

National Energy Technology Laboratory Accomplishments FY 2004





MESSAGE FROM THE DIRECTOR

It is my pleasure to present the National Energy Technology Laboratory's (NETL's) Accomplishments Report for fiscal year 2004. The report responds to the Government Performance and Results Act of 1993 by describing how NETL has spent taxpayer funds. It emphasizes the *results* of NETL's activities—not the activities themselves. It demonstrates that NETL has upheld the trust of the American taxpayer and has wisely used taxpayer funds to achieve meaningful results that benefit the country.

This laboratory has been evolving for nearly 100 years. What was once a small experimental laboratory near downtown Pittsburgh, is now a major research laboratory with facilities in four states—Alaska, Oklahoma, Pennsylvania, and West Virginia—and research and technology-development projects in nearly every state in the nation. Where it once narrowly focused on coal-mining safety equipment and practices, NETL's mission now is to conduct and implement wide-ranging research and technology development programs to ensure that fossil energy resources can meet increasing demand for affordable energy, without compromising the quality of life for future generations.

Innovative energy technologies are vital to fulfilling our mission. NETL is developing these new and improved technologies through onsite and contracted research focusing on the production, transmission, and utilization of fossil fuels—coal, oil, and natural gas. These resources provide 85 percent of our nation's energy supply today, and will continue to supply the bulk of the nation's energy needs for decades to come. Our work provides new, affordable ways to produce, transport, and use fossil fuels consistent with national environmental and energy security objectives.

With funding from the Department of Energy's Office of Fossil Energy, as well as other Department of Energy offices and federal agencies, NETL is speeding the development of energy *solutions*. We remain committed to turning taxpayer dollars into science and technology advances, and these advances into energy systems that improve the quality of life for all people.

Please take the time to browse through this accomplishments report. We believe our achievements speak for themselves.

A handwritten signature in black ink that reads "Carl O. Bauer". The signature is fluid and cursive, written in a professional style.

Carl O. Bauer

Acting Director
National Energy Technology Laboratory

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

CONTRIBUTING TO AMERICA'S ENERGY FUTURE: AN OVERVIEW

NETL—Who We Are, What We Do

The history of NETL dates back to 1910 when the Pittsburgh Experiment Station opened as part of the newly created Bureau of Mines. The station developed innovative coal-mining safety equipment and practices, and offered advanced training for coal operators and miners in its experimental coal mine. By the 1940s, the organizations that make up today's laboratory were devising processes to produce synthesis gas from coal, studying the thermodynamics of petroleum compounds, and developing synthetic liquid fuels. In the 1970s, the organizations began managing contracted research.

Today, NETL has four sites: in Fairbanks, AK; Morgantown, WV; Pittsburgh, PA; and Tulsa, OK. The four sites share the same organizational structure and the same mission: to resolve the environmental, supply, and reliability constraints of producing and using fossil resources.

NETL's Research Partners

NETL conducts its mission primarily through its work implementing coal, oil, and natural gas programs for DOE's Office of Fossil Energy, but the laboratory does work for other DOE offices as well, including the Office of Energy Efficiency and Renewable Energy and the Office of Energy Assurance.

NETL also works with other federal agencies—including the U.S. Environmental Protection Agency (EPA), the U.S. Forest Service, and the Departments of Defense, Homeland Security, and Transportation—and with various state groups, such as the California Energy Commission, the Ohio Coal Development Office, and the Interstate Oil and Gas Compact Commission. NETL's portfolio of projects includes activities with several Native American tribes and organizations.

NETL's research and development activities are conducted on- and offsite through partnerships, cooperative research and development agreements, financial assistance, and contractual arrangements. Nearly one-half of NETL's 1,400 research, development, and demonstration projects are carried out by private-sector organizations. This emphasis on the private sector is essential to NETL's mission. The laboratory's ultimate success comes when the advanced technologies emerging from NETL's research activities are commercialized by the private sector.

Our Research Focus

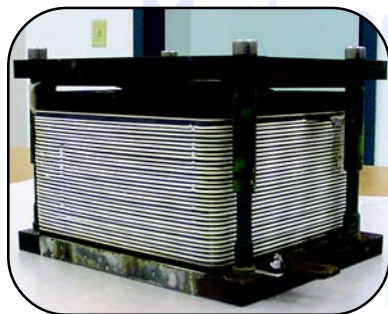
In choosing its portfolio of projects, NETL works closely with the DOE Office of Fossil Energy and other research partners to meet national goals in three key areas: clear skies, climate change, and energy security.

- **Clear Skies**—America has made dramatic progress reducing air emissions since the first Clean Air Act was passed in 1970. Legislation has now been proposed that would further cut power plant emissions of nitrogen oxides (NO_x) and sulfur dioxide (SO_2), and would, for the first time ever, restrict emissions of mercury from power plants. Developing technologies to control these emissions while enabling the continued use of our nation's abundant fossil resources will protect human health and help ensure an adequate supply of affordable energy to power our economy. NETL's research portfolio includes projects that will control these pollutants at existing plants today and in the power plants of tomorrow.
- **Climate Change**—President Bush has committed America to reducing greenhouse gas intensity—the ratio of greenhouse gas emissions to economic output—by 18 percent by 2012. This puts the nation on a path to slow the growth of greenhouse gas emissions and, as the science justifies, to stop and then reverse that growth. Carbon sequestration—the long-term storage of carbon in plants or in geologic formations such as depleted oil and gas reservoirs, unmineable coal seams, and saline formations—holds great promise for helping the nation meet this goal. NETL has spearheaded a number of projects to sequester carbon dioxide (CO_2) and slow the growth of greenhouse gas emissions.
- **Energy Security**—Energy security is a vital component of national security. Energy security is jeopardized by relying too much on any one energy resource or depending too heavily on energy supplies beyond our borders. It is also at risk when the nation's energy infrastructure is vulnerable. NETL has taken an active, two-pronged approach to energy security. On the one hand, NETL develops technologies to ensure that the nation has abundant and diverse supplies of clean energy from domestic resources. On the other hand, NETL supports the DOE Office of Energy Assurance, the Department of Homeland Security, and the Federal Emergency Management Agency, as well as local agencies, to evaluate and protect America's energy infrastructure.



Product Successes

Through NETL's onsite research and its various partnerships, a portfolio of product successes is already bolstering America's energy future:



- **Clean Coal**—Since the 1986 inception of the Clean Coal Technology Program, NETL has sponsored demonstration projects to advance clean coal power systems. That activity continues today through the Clean Coal Power Initiative. During fiscal year 2004, NETL made the first four awards under the new initiative and issued a solicitation for a second round of funding. Also this year, a project selected under Round II of the Clean Coal Technology Program surpassed \$1 million in repayments, demonstrating how a government-industry partnership can refund taxpayer investment while protecting the environment, creating and preserving jobs, and advancing technology.

- **Commercial Fuel Cell Plants**—Using molten carbonate fuel cell technology developed by FuelCell Energy with NETL support, the Los Angeles Department of Water and Power developed an internationally recognized distributed generation program demonstrating clean, efficient, and reliable onsite electric power generation. This and other successes date back to 1976 when DOE issued its first contract to begin fuel cell development. Fuel cells hold great promise for use in dense urban areas that need additional sources of power.

- **Clean Fuels from Coal and Gas**—As DOE continues to support the development of alternate sources of fuel, producing fuel from coal and gas provides yet another option to traditional fuels. In an NETL-supported project, a gas-to-liquids demonstration plant at the Port of Catoosa, near Tulsa, OK, is providing ultra-clean synthetic transportation fuel for three buses in the fleet at the pristine Denali National Park in Alaska.

- **Drilling Technology**—Advances in drilling technology facilitate access to hard-to-reach gas and oil and reduce costs associated with the drilling process. NETL-sponsored research has resulted in a commercially ready “bendable” drill pipe made from carbon fiber that can follow sharp curves underground without experiencing material fatigue. This new bendable pipe, used in conjunction with horizontal drilling technology, will revitalize old wells that were near their economic limit, or were plugged and abandoned.

- **Advanced Turbines**—NETL managed a number of advanced turbine project successes through DOE's former Advanced Turbine Systems Program. One of those projects, at the Baglan Bay Power Station, in Cardiff, Wales, UK, was selected by *Power Engineering* magazine as one of three 2003 “Projects of the Year”—an award given to projects that “demonstrate technical excellence and outstanding economic, social, and environmental benefits to power plant owners and their customers.” Emblematic of advances in turbine technology, GE's H Class turbine is the first gas turbine combined-cycle system capable of achieving 60 percent thermal efficiency.

2004

NETL's FY 2004 ACCOMPLISHMENTS

In a speech to Congress in 1824, Daniel Webster explained the value of invention by saying that “invention is the fruit of the human brain, industries grow in direct proportion to invention, and government must aid in progress by fostering the inventive genius of its citizens.” Although spoken more than 180 years ago, these words apply to NETL today.

Most of NETL's accomplishments are the result of partnerships created to foster the inventive genius of America's citizens and industries. While the end result of any one accomplishment may be unclear, the result of all of them is crystal: it is progress—toward energy security, an enhanced environment, and a robust economy. It is progress toward NETL's mission of resolving the environmental, supply, and reliability constraints of producing and using fossil resources.

Since fossil resources are the focus of NETL's mission, the bulk of NETL's FY 2004 accomplishments are grouped around these resources—coal, oil, and natural gas, which together provide 85 percent of America's energy supply. The first three of the six sections that list NETL's accomplishments are—

- Coal: America's Most Abundant Fossil Fuel
- Natural Gas: The World's Fastest Growing Energy Source
- Oil: Lifeblood of America's Economy

Each of these three sections has several subsections, and some of the subsections are further divided. With each division, an introduction has been included to explain program objectives and put individual accomplishments in context.

The last three of the six sections that list NETL's FY 2004 accomplishments are—

- Energy Efficiency and Renewable Energy
- Energy Information
- Awards and Recognition

NETL's goals in these areas are not lesser goals, but because these areas represent an extension of the laboratory's capabilities beyond its fossil-fuel focus, fewer resources are devoted to them. In fact, few resources are devoted to obtaining awards and recognition, but they are included in this report because they recognize accomplishments and speak to the value of NETL's work. These final sections also include introductions to put individual accomplishments in context.

Finally, please note that many accomplishments could have been listed in more than one place; for instance, an R&D 100 Award for a modeling advance could have been listed in the subsection for modeling as well as under Awards and Recognition. This has not been done. It is hoped, however, that the reader will understand the interconnectedness of NETL's work, and will see how NETL's accomplishments build on each other, moving us toward the progress so eloquently described by Congressman Webster.

“Invention is the fruit of the human brain, industries grow in direct proportion to invention, and government must aid in progress by fostering the inventive genius of its citizens.”

Daniel Webster
1824 speech to Congress



COAL: AMERICA'S MOST ABUNDANT FOSSIL FUEL

Coal is one of the true measures of America's energy strength. One quarter of the world's coal reserves are found within the United States, and the energy content of the nation's coal resources exceeds that of all the world's known recoverable oil. Coal is also the workhorse of the nation's electric power industry, supplying more than half of the electricity consumed by Americans. To preserve this economically vital energy foundation, the Office of Fossil Energy's Coal Program, implemented by NETL, is developing low-cost environmental compliance technologies, efficiency-boosting innovations, and technologies for future energy plants with near-zero carbon emission.

Technologies for Existing Coal-Fired Power Plants

NETL and its research partners are developing environmental control technologies for retrofitting existing power plants, with application to new plants as well. Key areas of research include controlling emissions of mercury, NO_x , SO_2 , and fine particulate matter; beneficial uses for coal utilization byproducts; and innovations to minimize the impact of fossil-fuel use on the nation's water resources.



Mercury

Coal-fired power plants are facing the first-ever caps on mercury emissions to reduce risks to human health. NETL research is intended to ensure timely development of cost-effective mercury-control technologies as emission limits are established. The program includes large-scale field testing, pilot-scale development of novel mercury-control concepts, and research to provide a fundamental understanding of mercury emissions, as well as the development of “co-control” technologies that reduce mercury emission while controlling other pollutants, such as NO_x and SO_2 .

NETL Licenses Mercury Removal Method—NETL has issued an exclusive license to Powerspan Corporation for a patented method to remove mercury from flue gas streams using irradiation with ultraviolet light. The license is limited to fossil-fueled power generation. The co-inventors of the mercury removal method—Evan Granite and Henry Pennline of NETL's Office of Science, Technology, and Analysis—each received a portion of the initial royalty fee. Powerspan intends to offer this technology in conjunction with its electrocatalytic oxidation technology and as a stand-alone product. The potential market for the licensed invention is estimated to be between \$3 billion and \$7.5 billion. NETL is pursuing opportunities to license the patent for applications in fields other than fossil-fueled power generation.

Results from Mercury Field Tests—To address critical questions related to the cost and efficiency of mercury-control technologies, NETL supports full-scale testing of mercury control technologies at power plants across the nation. The primary focus of the field-test program is testing of two advanced technologies: sorbent injection and enhanced wet scrubbing. The field-test program had the following accomplishments this fiscal year:

- In NETL-sponsored field tests completed at commercial facilities, investigators from ADA Environmental Solutions LLC of Littleton, CO, evaluated several approaches for controlling mercury emissions from coal-fired power plants. Standard activated carbon injected at the rate of 0.6 pounds per million cubic feet into the flue gas stream captured 87 percent of mercury at Unit 3 of Alabama Power Company's Gaston Plant, which burns a low-sulfur bituminous coal and controls particulate emissions with a hot-side electrostatic

precipitator in combination with a compact hybrid particulate collector baghouse. Injecting halogen-treated activated carbon for 30 days at a nominal concentration of 1.2 pounds per million cubic feet captured, on average, 91 percent of mercury from Sunflower Electric's Holcomb Station, which burns a Powder River Basin coal and is equipped with spray dryer adsorbers and fabric filters for air pollution control. Two other mercury control approaches were tested at Holcomb Station for shorter durations: blending a small amount of western bituminous coal with the Powder River Basin coal achieved mercury removal levels of almost 80 percent without the use of sorbent injection; and adding a proprietary chemical developed by ALSTOM Power enhanced the performance of standard activated carbon, resulting in 86 percent mercury removal at a carbon feed rate of 1.0 pounds per million cubic feet.

- During a month-long test at Basin Electric Power Cooperative's Leland Olds Plant in North Dakota, researchers from the University of North Dakota Energy and Environmental Research Center, working in cooperation with NETL, investigated the effect of chemical additives on mercury capture by activated carbon injection. Average mercury removal was 63 percent with the additives and less than 20 percent without. Additives that enhance the effectiveness of activated carbon could mean lower mercury-control costs for plants that burn lignite, which typically has low chlorine and high calcium concentrations that result in high levels of difficult-to-remove elemental mercury in flue gas.
- In a month-long test conducted in cooperation with NETL at Detroit Edison's St. Clair Plant in Michigan, researchers from Sorbent Technologies Corporation demonstrated 94 percent mercury removal from subbituminous coal by injecting brominated powdered activated carbon into the plant's flue gas stream at the rate of 3 pounds per million cubic feet. High levels of elemental mercury generated at the plant had made previous tests with other sorbents less successful.
- Mercury removals ranging from 83 to 99 percent were achieved with corn-char, bamboo, tire-derived, and carbon soot in power plants fired with either Powder River Basin subbituminous coal or a blend of low-sulfur bituminous coal with petroleum coke. The novel sorbents are expected to compete favorably with activated carbon and other commercially available materials. The tests were completed by Apogee Scientific Inc. at host facilities of We Energies and Midwest Generation LLC as part of an NETL-managed project.

Model Developed to Estimate Mercury Emissions from Coal in China—Because of concerns over the global mercury pool and the long-range transport of mercury emissions from China to the United States, NETL initiated a project to estimate total anthropogenic mercury emissions in China. To better understand both the chemical transformations of mercury in coal and the performance of downstream emission-control technology in China, NETL and Argonne National Laboratory developed a model capable of estimating mercury emissions as a function of the coal source, the boiler size and type, and any downstream emission-control technology. The work complements planned EPA efforts to monitor ambient mercury levels in China and will be refined when NETL collects emissions data from selected Chinese coal-fired power plants. Other project partners include the U.S. Geological Survey, Italy's Rendi Institute, and researchers at China's Zhejiang University.

Plume Measurements Show Partial Conversion of Mercury from Oxidized to Elemental Form—In cooperation with multiple industrial partners, NETL supported an innovative mercury measurement program at Southern Company's Plant Bowen in Georgia and We Energies' Pleasant Prairie Power Plant in Wisconsin. Specially instrumented aircraft were used to measure mercury concentrations and speciation within the power plant plumes at various distances downwind from the stacks at both plants. The data was compared with in-stack mercury concentrations and speciation. Preliminary analysis of the data suggests that a significant portion of the oxidized mercury emitted from the stacks at both plants was transformed to its relatively unreactive elemental form very rapidly upon release; between 15 and 66 percent of the initial oxidized mercury was converted to elemental mercury at 5 miles downwind. The results have policy implications because a regulatory approach allowing mercury emissions trading will be more environmentally acceptable if mercury from power plant emissions is mostly in the elemental form.

Potential Cobenefit of Mercury Removal Demonstrated—As part of DOE's Mercury Control Technology Program, CONSOL Energy Inc. completed an assessment of the effectiveness of selective catalytic reduction (SCR) and wet flue gas desulfurization (FGD) in capturing mercury at American Electric Power's Gavin Power Plant in Cheshire, OH. Results of measurements taken at the plant while burning an Ohio bituminous coal indicated that the combination of SCR and FGD resulted in

an 83–95 percent reduction in mercury emissions. SCR and FGD are used to control NO_x and SO₂ emissions, respectively, at the Gavin Station. The potential coremoval of mercury across SCR/FGD systems is an important component of the President's Clear Skies Initiative. The tests at the Gavin Plant were designed to provide greater understanding of the influence of factors such as coal type, catalyst degradation, and changes in load on the effectiveness of SCR in oxidizing elemental mercury.

Multipollutant Control Achieves 84 Percent Mercury Removal—Consol Energy obtained 84 percent mercury removal at a 650-megawatt West Virginia power plant fired with bituminous coal (4.7 percent sulfur) and equipped with a suite of postcombustion flue-gas-cleanup systems: a cold-side plate-type selective catalytic reduction system for NO_x control, an electrostatic precipitator for particulate control, and a forced-oxidation, wet lime flue gas desulfurization system for SO₂ control. While not conclusive for all power plant configurations, the finding has important implications for multipollutant control under the President's Clear Skies Initiative because it supports the hypothesis that elemental mercury can be oxidized by selective catalytic reduction systems, resulting in greater total mercury removal by downstream flue gas desulfurization scrubbers. Tests at other sites under the NETL-managed project will determine the role of coal type, the effect of selective catalytic reduction system modes of operation on mercury chemistry, and the efficacy of different flue gas desulfurization technologies for mercury capture.

Multipollutant Sorbent Successful in Test with Mercury—A field test at DTE Energy's 290-megawatt plant in River Rouge, MI, showed up to 80 percent total mercury removal and up to 97 percent removal of oxidized mercury from a blend of Powder River Basin subbituminous and eastern bituminous coals using postcombustion injection of a regenerative manganese-oxide-based sorbent. The technology, originally developed by EnviroScrub to control NO_x and SO₂, is effective in removing these pollutants at nearly 100 percent and greater than 95 percent, respectively. Conducted by the University of North Dakota Energy and Environmental Research Center in cooperation with NETL, the test showed that the EnviroScrub regenerative sorbent can remove mercury at a much lower injection rate than is typical with activated carbon, and the result is motivating more comprehensive tests with significant cost-sharing.

Membrane Collector Improves Cost-Effectiveness of Multipollutant Control via Wet Electrostatic Precipitators—NETL-sponsored testing at First Energy's Bruce Mansfield Plant confirmed that wet electrostatic precipitators can achieve highly efficient removal of a number of pollutants—fine particulates (96 percent), sulfuric acid mists (93 percent), and oxidized mercury (82 percent)—when placed after a flue gas desulfurization scrubber as a final polishing device. Moreover, these tests confirmed that inexpensive non-metallic membrane materials can be used for highly effective collection surfaces if properly designed. Membranes offer the potential for cost savings for retrofit and new installation in corrosive environments when compared to nickel-based alloys. By requiring significantly less water while providing more uniform coverage, the problems of wet-dry interfacing and mist-related field disruptions are reduced, leading to longer operating time between outages and improved collection. Wet membrane electrostatic precipitators thus offer an attractive option for plants seeking to control emissions of fine particulates, acid aerosols, and oxidized mercury.

Criteria Pollutants

NO_x, SO₂, and particulate matter are three of six "criteria pollutants" the EPA uses as indicators of air quality. Emissions of the three are currently regulated from coal-fired power plants, and emission limits may be further reduced in the future. NETL and its research partners are developing advanced low-cost technologies to address current and future limits on NO_x, SO₂, and particulates, including difficult-to-control "fine particulates"—also called PM_{2.5}—which are solid or liquid particles 2.5 micrometers or smaller in diameter.

NETL Investigates Source and Composition of Regional Ambient Particulate Matter—By correlating weather patterns with analyses of air samples, NETL scientists collaborating with investigators at Carnegie Mellon University have determined that the Ohio River Valley and, possibly, regions further west act as a significant source of fine particulates in the Pittsburgh area. Air samples were obtained during various periods from October 1999 through September 2004 from a variety of continuous and filter-based monitors located in the Pittsburgh area and sites in Ohio. Chemical analysis of the samples indicated that

high concentrations of ammonium sulfate, which is associated with stationary coal-fueled sources, accompanied transitions from high-pressure to low-pressure regimes in advance of approaching frontal systems. In contrast, fine particulate organic material, which is associated with mobile petroleum-fueled sources, appeared to be dominated by nearby sources. The investigation is part of the EPA's PM_{2.5} Supersite Program designed to obtain extremely detailed characterizations of ambient fine particulates in eight U.S. cities: Atlanta, New York, Pittsburgh, Baltimore, St. Louis, Houston, Fresno, and Los Angeles.

Experiments Investigate Toxicity of Coal Combustion

Emissions—NETL and the Electric Power Research Institute (EPRI) are collaborating on a program to examine the relative toxicity of particulate matter derived from coal combustion and mobile-source (gasoline and/or diesel engine) emissions. The NETL-sponsored portion of the study involves onsite sampling, dilution, and aging of coal combustion emissions at coal-fired power plants, followed by animal exposures incorporating a number of toxicological endpoints. The aging step transforms SO₂ in stack emissions to secondary sulfate particles, thereby simulating the atmospheric processing that occurs downwind of coal-fired power plants. Initial results suggest that short-term exposure to coal combustion emissions at realistic concentrations does not yield readily discernable changes in typical indices of cardiopulmonary health.

Novel Device Demonstrates Practical Measurement of Nitric Oxide—Under a University Coal Research Grant administered by NETL, Texas A&M University developed and demonstrated a diode-laser-based ultraviolet absorption sensor that measures nitric oxide concentration in the particle-laden exhaust stream of a laboratory-scale coal combustor. The device produced accurate measurements under real-world conditions, even when most (greater than 90 percent) of the ultraviolet beam was attenuated by particulate loading and optical window fouling. Planned modifications are expected to produce faster response times and greater sensitivity. Highly sensitive, non-intrusive real-time measurements of nitric oxide exhaust are essential for control systems that can minimize emissions while optimizing combustion process efficiency.

Commercial Contract Renewed for NETL-Developed Technology

—Northeast Generation Services operated Praxair's patent-pending oxygen-enhanced combustion system at the Mt. Tom Station in Holyoke, MA, during the 2004 ozone season. Throughout the 2003 ozone season, the system demonstrated NO_x emissions reductions at various loads and with a variety of coals—restoring unit capacity during hot days and providing enhanced flame stability, and reduced loss-on-ignition and carbon monoxide emission volatility. The system was developed in cooperation with NETL to help utilities meet near-term NO_x limits while enabling advanced combustion technologies that produce low pollutant emissions and facilitate CO₂ sequestration. The system is particularly suited for retrofitting older, space-constrained units with capacities of 300 megawatts or less. Such units represent 66 percent of boilers in the United States.

Training Completed Under U.S.–China Fossil Energy

Protocol—Nearly 200 Chinese engineers received training on U.S. practices for the design, specification, procurement, operation, and maintenance of flue gas desulfurization (FGD) equipment for coal-fired power plants. China has set a target of 2005 to reduce SO₂ emissions by 20 percent from 2000 levels, and has said that emissions reduction equipment must be installed in 137 key coal power plants to achieve this goal. Over the next 10 years, Asian utilities are expected to order about \$13 billion of flue gas desulfurization systems. The training was designed to familiarize Chinese utilities with U.S. practices and to help U.S. companies capture a larger share of the projected market. Flue gas desulfurization experts from the U.S. private sector delivered 2 weeks of training in China through NETL under Annex I: Advanced Power Systems of the Fossil Energy Protocol between DOE and China's Ministry of Science and Technology. The Chinese Electricity Council assisted with organizing the course.

NETL Organizes U.S.–China Industrial Boiler Workshop to Address Energy Efficient Pollution-Control

Technologies—With assistance from the U.S. EPA, DOE's National Renewable Energy Laboratory, China's National Development and Reform Commission, and Tsinghua University (China), NETL organized a June 2004 workshop in Beijing to review technologies that control SO₂, NO_x, mercury, fine particulate emissions, and CO₂ and other greenhouse gases. The workshop also facilitated business development opportunities for U.S. manufacturers, engineering companies, process control and other industry firms, and universities. The workshop allowed U.S. delegates to showcase products and

Coal-Fired Power Plants Utilization Byproducts

services to more than 80 organizations in China, and provided opportunities to interact with representatives of the U.S. Department of Commerce, United Nations, World Bank, and other key organizations involved in ongoing energy and environmental efforts, such as preparations for the 2008 Olympics in Beijing. The workshop was supported through an Interagency Agreement between NETL and the EPA on the Technology Cooperation Agreement Pilot Project, which is designed to help developing and transitioning countries attract investment in clean energy technologies. It followed a Chinese delegation's highly successful tour of U.S. facilities in 2002.

Coal Utilization Byproducts

Coal utilization byproducts are solid materials produced by the combustion or gasification of coal. In 2002, 129 million tons of solid byproducts were produced in the United States; about 35 percent of the total was recycled in beneficial ways, while 65 percent ended up in landfills or impoundments. To meet the DOE goal of increasing beneficial use to 50 percent by 2010, NETL supports the commercially viable and environmentally sound recycling of coal utilization byproducts through scientific research, development, and field testing.

Initial Results Show Minimal Mercury Leaching or Volatilization from Impounded Coal Utilization Byproducts—Results of applied industrial research conducted by NETL onsite researchers and NETL-funded investigators show that the potential for release of mercury from the byproducts of coal combustion or gasification (ash, slag, and scrubber sludge) is minimal with typical disposal or utilization procedures. Presented at the Combined Power Plant Air Pollutant Control Mega Symposium in Washington in September 2004, the preliminary results were based on analysis of coal utilization byproducts produced with and without the application of activated carbon injection or wet flue gas desulfurization—the most likely near-term approaches for removing mercury from coal plant flue gas. By diverting flue-gas-borne mercury into plant solids streams, such approaches could have posed an increased risk of releasing mercury to the environment through byproduct leaching or volatilization. However, the amount of mercury leached from byproduct samples was significantly lower than current standards for drinking water and protection of aquatic life, and volatilization at ambient temperatures was negligible.

Heavy Metals More Leachable from Integrated Gasification Combined-Cycle Fly Ash—Results of column leaching tests conducted at NETL show that most metal ions (cobalt, nickel, iron, lead, and zinc) in fly ash obtained from integrated gasification combined-cycle power plants are more soluble in acidic, alkaline, and neutral aqueous solutions than is the fly ash from conventional pulverized coal power plants, while the acid solubility of slag samples from both types of power plants is comparable. Since they are recirculated within the process, it is unlikely that fly ashes from integrated gasification combined-cycle plants would have a deleterious effect on the aquatic environment; however, the higher leachability of some heavy metals could lead to a buildup of these elements within the system, particularly in the recirculated “grey” water.

NETL Takes Lead on Interlaboratory Leaching Study—NETL's Byproduct Utilization Research Group initiated an interlaboratory comparison of four leaching methods that apply to granular materials such as coal utilization byproducts. The study is clarifying the environmental safety of using or disposing of these materials under various conditions, and will address whether data obtained by different leaching methods is comparable—an issue that is particularly important to environmental agencies. Other organizations participating in the study include the University of North Dakota Energy and Environmental Research Center, West Virginia University's West Virginia Water Research Institute, Virginia Polytechnic Institute and State University's Department of Crop and Soil Environmental Sciences, and the University of the Western Cape Department of Chemistry in Cape Town, South Africa.

Coal Ash Provides Low-Cost Option for Stable, Healthy Feedlot Soils—In cooperation with NETL, a project team led by researchers from the University of North Dakota Energy and Environmental Research Center successfully demonstrated the engineering, environmental, and technical feasibility of using fly ash to improve soils in animal feeding operations. In addition to improving the environmental stability of feedlot surfaces, reducing stress on animals caused by wet soil conditions, and increasing animal weight gain, the use of coal ash in livestock facilities decreases the need for landfill space and reduces the overall cost of electricity. Because of this research, four regional coal ashes were approved for use within pen areas at feedlot facilities regulated by the North Dakota Department of Health.

Coal-Fired Power Plants Water-Energy Interface

The Water-Energy Interface

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

Zebra Mussels Controlled Naturally—Results from research conducted at the New York State Museum's Field Research Laboratory in Cambridge, NY, in cooperation with NETL, show that bacterial cells containing a toxin specific only against zebra mussels can produce a kill rate close to 90 percent when fed to these mussels. This discovery suggests an alternative, potentially lower cost approach to removing this invasive species from power plant cooling water intakes. Dense colonization by these mussels requires regularly scheduled plant downtime for conventional treatments with chlorine. Inadvertently introduced into the United States and Canada in the late 1980s with ballast water from ships passing through the St. Lawrence Seaway, these mussels have cost the power industry nearly \$2 billion since 1990 in downtime and conventional treatments.

National Estimates of Water Needs for Projected Thermoelectric Power Capacity Additions Through 2025 Developed—Based on DOE Energy Information Administration projections for thermoelectric power capacity additions through 2025, and prior work on the water requirements for thermoelectric power generation, NETL has developed estimates of required water access for cooling applications. While it appears that sufficient quantities of water should be available to meet projected capacity additions on a national scale, the study showed that increased generating capacity in the western United States may be constrained by available water resources. Because of the prominence of water-related issues in the west, a more sophisticated regional analysis has been initiated. Results of these analyses are being used to support water-related activities at NETL through the Innovations for Existing Plants Program and through NETL's participation in the interlaboratory Energy-Water Nexus Initiative.

Technologies for Future Energy Plants

As NETL pursues innovations for today's power plants, the laboratory is also developing the technology base for the near-zero-emissions power plants of tomorrow. The centerpiece of these efforts is *FutureGen*, an initiative to build the world's first integrated sequestration and hydrogen production research power plant. When operational, the prototype power plant will coproduce electricity and hydrogen while preventing air pollutants and greenhouse gases from being released into the atmosphere. Technologies under development at NETL for future energy plants include coal gasification, combustion turbines, fuel cells, carbon capture and sequestration, hydrogen separation and storage, and advanced materials.



Future Energy Plants Coal Gasification

Coal Gasification

One of the cleanest and most versatile ways to extract energy from coal, coal gasification is likely to be a core technology for future power plants. Gasification-based systems provide high efficiency with near-zero pollutants and flexibility in the production of a wide range of products including electricity, fuels, chemicals, hydrogen, and steam. NETL is working to improve coal gasifier systems by lowering their cost and increasing their ability to process different fuels.

Testing Significantly Advances Transport Gasifier

Technology—More than 1,500 hours of transport gasifier tests at the power systems development facility (PSDF) in Wilsonville, AL, under air- and oxygen-blown conditions with three different coals (Illinois Basin bituminous, Powder River Basin subbituminous, and high-sodium Freedom Mine lignite) demonstrated an operating flexibility unmatched by most of today's commercial gasifiers. Numerous design improvements implemented by engineers and technicians from Southern Company Services Inc., which manages and operates the PSDF in cooperation with NETL, led to successful operation of the transport gasifier at the highest pressure (260 psig) and temperature (1,940 °F) to date.

Quality Synthesis Gas from Lignin—Results of bench-scale tests completed in cooperation with NETL at the University of North Dakota Energy and Environmental Research Center show that lignin can be gasified successfully in an air-blown continuous fluid-bed reactor, converting up to 90 percent of the carbon and producing fuel with heating values up to 144 Btu per standard cubic foot (higher heating value). Cofiring 20 percent lignin with subbituminous coal resulted in greater carbon conversion (up to 95 percent) and higher fuel heating value (up to 207 Btu per standard cubic foot). Gasifying lignin, a waste stream from the production of ethanol from switch grass, would partially satisfy the energy needs of ethanol production. Alternatively, cofiring lignin could lower the feed cost and partially offset CO₂ emissions for gasification processes that use subbituminous coal.

High-Efficiency Desulfurization of Synthesis Gas—

Working under a University Coal Research Grant administered by NETL, researchers at Louisiana State University in Baton Rouge developed a new high-temperature (600–800 °C) desulfurization sorbent that would reduce hydrogen sulfide levels from coal gasification process streams to less than 1 part per million. The cerium-zirconium sorbent can be easily regenerated, producing marketable sulfur in elemental form. This technology may also find application upstream of fuel cells and in certain synthesis gas conversion processes.

Lower Cost Membranes for Separating Oxygen from

Air—Working with NETL under the Fossil Energy Materials Program, scientists at Eltron Research Inc., a small business in Boulder, CO, have developed a novel, inexpensive way to synthesize membranes that separate oxygen from air. The membranes have provided stable performance over a period of 100 days, and will be assembled into a multistack configuration for scale-up to produce flows of commercial interest. Since air separation typically accounts for 12–15 percent of the capital cost of coal-based hydrogen production, the innovation could favorably impact overall costs of a FutureGen plant.

Pumping-Up Coal—Stamet Inc. successfully completed the first phase of its cooperative agreement with NETL by pumping dry pulverized coal from atmospheric pressure to 300 psig at a rate of 150 pounds per hour. The Stamet coal pump uses a simple rotary positive displacement principle that is more reliable and efficient than currently available dry-feed lock-hopper systems. Stamet's next pressure milestone is 500 psig. Success of this technology would allow reliable and accurate continuous feeding of dry coal to hydrogen-production processes and high-pressure advanced gasification and combustion systems, overcoming a major technical challenge.

Future Energy Plants Combustion Turbines

Combustion Turbines

Combustion turbines will be key components of future coal-based combined-cycle plants. NETL is developing new turbine technology to boost cycle efficiency, reduce capital cost, and improve environmental performance. The work includes studies on supporting technologies such as combustion instability, fuel versatility, and fluid and particle dynamics.

Development of Turbine Blade Online Monitor Makes Major Progress—For the first time anywhere, researchers at Siemens Westinghouse have produced high-speed infrared images of the first row of blades in a Westinghouse 501FD gas turbine under full operation. Once perfected, online monitoring will detect the integrity of thermal barrier coatings as they operate within the gas turbine. The ability to detect coating failure at the earliest stage would help operators identify problems and effect repairs before the failure becomes catastrophic. NETL is working with Siemens Westinghouse to develop this technology with an overall goal of reducing maintenance costs for more than 600 large utility gas turbines—a savings estimated to be about \$600 million.

Longer Life for High-Temperature Turbine Parts—Thermal barrier coatings are used to protect the blades in turbines operating at the high temperatures needed for better energy efficiency, power, and fuel economy. However, impurities such as vanadium and sulfur, increasingly found in lower cost opportunity fuels such as coal and petroleum coke, can destabilize the coatings and shorten turbine blade life. Through the NETL-managed Fossil Energy Materials Program, researchers at the University of Pittsburgh have devised a means to avoid the destabilization of thermal barrier coatings using special overlays applied by electron beam deposition. Materials research and development is helping to meet the challenges that future land-based turbine systems will face with respect to cycle configuration, firing temperature, duty cycle, and fuel type.

Novel Concept to Stabilize Low-Emission Flames Tested Successfully at NETL—NETL researchers have successfully tested a new concept that tunes the fuel delivery systems of low-emission combustors to allow turbine engines to operate with greater stability and unprecedented low NO_x emissions. Low-emission turbine

combustors are needed for future power plants that may use hydrogen or coal synthesis gas. At low-emission operating conditions, the heat release process in combustors can excite acoustic vibrations that damage the combustion and turbine hardware. The NETL concept involves adjusting the acoustic properties of the fuel injectors to avoid strong feedback among multiple flames. In tests conducted in a laboratory combustor, NETL researchers were able to produce wide variations in combustion-generated vibration amplitudes, consistent with theoretical predictions. NETL is working with Solar Turbines, under a cooperative research and development agreement, to determine if this new concept can be adapted to a practical engine.

Sensor Technology Successfully Tested—A combustor designed and fabricated by Woodward Industrial Controls to incorporate NETL's combustion control and diagnostics sensor (CCADS) was successfully tested during July 2004. The novel sensor monitors several key combustion parameters to identify abnormal operating conditions, such as flashback and lean blow-off, as well as the presence of large combustion oscillations that shorten the lifetime of power turbine components. Close control of the combustion process will be essential for reaching more stringent NO_x emissions targets with a wider range of fuel types, and doing so with greater reliability and lower electricity costs. CCADS technology development was initiated with an NETL patent on flashback detection, and it continued through a cooperative research and development agreement and a licensing agreement with Woodward, which resulted in three additional patent applications. Originally developed for monitoring combustion in natural gas power turbines, CCADS has also been demonstrated by NETL researchers for synthesis gas combustion systems.

First Commercial Deployment of NETL-Developed Gas Turbine Technology in North America—GE's H Class turbines, a new class of advanced gas turbines developed under DOE's former Advanced Turbine Systems Program, leapfrog existing technology with a demonstrated potential of 60 percent combined-cycle efficiency (when operating with natural gas), single-digit NO_x emissions, and 10 percent lower bus bar cost. Improvements embedded in H Class turbines are being applied to turbines used in coal-gasification systems. Deployment of H Class turbines helps accelerate this technology migration. GE Energy announced that two H Class gas turbines will be installed in a new 800-megawatt Hydro-Quebec facility to be built at Beauharnois, Quebec, for service in 2007. This will be the first launch of GE's H Class turbine technology in the 60-cycle configuration design for the North American power market.

Fuel Cells

Fuel cells are expected to play a major role in the nation's energy future by providing efficient, environmentally friendly electrical energy while extending the capacity of the nation's fossil-fuel supply. After helping to develop and introduce the first fuel cells into the market, NETL is now working on ways to dramatically lower their costs and expand their use in stationary power generation, military applications, and transportation.

Solid State Energy Conversion Alliance Progresses

Toward Program Goals—The Solid State Energy Conversion Alliance (SECA), managed by NETL in coordination with the Pacific Northwest National Laboratory, is a unique alliance among government, industry, and the scientific community. Its goal is to accelerate the commercialization of low-cost solid oxide fuel cells in the 3–10 kilowatt range as quickly as possible over the next decade. SECA is organized into industrial teams, which are developing prototype solid oxide fuel cell systems, and a core technology program, which provides focused research and development to overcome barriers identified by the industrial teams. Breakthroughs from the core technology program are made available to all industrial teams. The SECA program and SECA participants noted the following advances this fiscal year:

- The fuel cell designs of all SECA industrial teams achieved fuel utilization values exceeding the interim program goal of 60 percent. Fuel utilization is the fraction of fuel entering the cell that reacts electrochemically to produce electric power; higher fuel utilization relates directly to higher efficiency and leads to lower emissions. High fuel utilization is a key early performance milestone for reaching SECA's cost goal of \$400 per kilowatt and its system net-electrical-efficiency goal of 40–60 percent by 2010.
- GE Hybrid Power Generation Systems of Torrance, CA, exceeded its SECA Phase I cell module performance target for solid oxide fuel cell development. With modified electrode composition and microstructure, the fuel cell module achieved 404 milliwatts per square centimeter at 0.7 volts using a reformate composition with 64 percent hydrogen as fuel. This represents a 49 percent improvement over last year's best results under the same test conditions.
- SOFCo (McDermott International), a member of the SECA industrial team led by Cummins Power

Generation, achieved 2,000 hours of uninterrupted, steady-state operation while fueling a SECA fuel cell with natural gas. The achievement was enabled by a new catalytic partial-oxidation unit that prevents coking in the catalyst through control of the oxygen-to-carbon ratio rather than using water. The dry unit breaks down the natural gas into primarily hydrogen and carbon monoxide (a fuel for solid oxide fuel cells) with an efficiency of 68–70 percent.

- As part of a cooperative agreement with NETL under SECA, Delphi Automotive Systems LLC of Flint, MI, in partnership with Battelle Columbus Laboratories, successfully tested its 30-cell Generation 3 solid oxide fuel cell stack with a fuel that simulated hydrogen-rich gas derived from coal. The stack, which has half the volume of its predecessor, produced nearly 1 kilowatt of power at 21 volts. The test demonstrated the feasibility of building a well-sealed fuel cell module from thin metallic cassettes fabricated by high-volume manufacturing processes such as stamping, brazing, and laser welding used in the automotive industry.
- A residential-scale solid oxide fuel cell stack and reformer developed by Siemens Westinghouse and integrated by Fuel Cell Technologies under Fairbanks Natural Gas sponsorship reached 5,000 hours of operation in February 2004 and continued to perform satisfactorily at the University of Alaska through the fiscal year. Generating AC power from natural gas with a conversion efficiency of approximately 40 percent, the system demonstrated 100 percent reliability for the last 4,320 hours with no detectable power degradation—characteristics that are critical for remote distributed power applications.
- Thirty-nine scientists and engineers from industry, national laboratories, and universities received training on the state-of-the-art computational tools emerging from the SECA core technology program. The 4-day course included hands-on experience with computational fluid dynamics and finite element analysis codes that incorporate routines developed at NETL and Pacific Northwest National Laboratory. The training session transferred validated computer tools to SECA industry team designers and engineers who will use them to design reliable and optimized low-cost commercial solid oxide fuel cell systems.

Direct FuelCell® Technology Advances—FuelCell Energy of Danbury, CT, developed its patented Direct FuelCell® technology in a research partnership with DOE that began more than 25 years ago. While most fuel cells entering

commercial markets today are designed to use natural gas, Direct FuelCells internally generate hydrogen from fossil fuels and renewable sources. Although Direct FuelCells remain expensive compared to other power generation technologies, their use has mushroomed since the first commercial unit was delivered in 2003; by October 2004, more than 50 million kilowatt hours of electricity had been generated from power plants incorporating Direct FuelCell technology. With support from NETL, the technology advanced on several fronts this fiscal year:

- FuelCell Energy showcased the world's first fuel cell to operate on coal mine methane at a dedication ceremony in October 2003. The event at the Rose Valley coal mine methane test site in Hopedale, OH, marked the kickoff of a 6-month demonstration featuring a 200-kilowatt Direct FuelCell. Successful demonstration could pave the way for future use of fuel cells to mitigate coal mine methane emissions while producing power at high efficiency and very low emissions. Worldwide, coal mine methane could produce more than 1,000 megawatts of power.
- FuelCell Energy completed testing a first-of-a-kind power plant integrating a 250-kilowatt Direct FuelCell with a 60-kilowatt Capstone microturbine in late 2003. The results of these proof-of-concept tests will be used to optimize the design of a submegawatt-class hybrid power-generation unit to be demonstrated at the University of Montana. Ultimately, the NETL-managed project will design a megawatt-scale ultra-high-efficiency hybrid power plant that meets the hybrid module goals of DOE's FutureGen program.
- Governor John G. Rowland offered remarks in a December 2003 ceremony dedicating his state's first high-efficiency Direct FuelCell 300A power plant, which will provide heat and power to Yale University's Environmental Science Center near the Peabody Museum in New Haven, CT. The plant will supply approximately 25 percent of the building's electricity needs, along with heat to maintain tight temperature and humidity controls at the storage facility, where rare bones and artifacts are preserved.
- Arizona-based Salt River Project (SRP) will become the fifth municipal utility to own and operate a Direct FuelCell power plant provided and serviced by FuelCell Energy. SRP supplies electricity to nearly 800,000 retail customers in the Phoenix area. The 250-kilowatt unit will be the first SRP generator to provide clean, efficient, and reliable base-load electricity without the combustion of fuel.
- CSA International certified Direct FuelCell power plants as complying with the new ANSI/CSA America FC 1-2004 Standard covering the operation, construction, and performance of packaged stationary fuel cell power systems. The CSA certification applies to DFC300 and DFC1500 self-contained commercial-grade power plants that use natural gas to provide high-quality base-load electric power. The DFC300A power plant is also certified for grid interconnection with investor-owned electric utilities under California's "Rule 21" standard, and meets the California Air Resources Board's stringent distributed generation emissions standards for 2007. The certification will reduce the time, expense, and complexity of marketing clean and efficient U.S. products for distributed generation.
- FuelCell Energy will provide 16 additional 250-kilowatt Direct FuelCell power plants to Marubeni Corporation, one of Japan's leading general trading and marketing houses. Five Direct FuelCell power plants are currently operating at four customer sites in Japan. This latest order anticipates market stimulation by recently passed government support for additional wastewater treatment facilities throughout Japan. Wastewater treatment facilities consume large amounts of electricity and heat, but they also produce an excellent hydrogen-based fuel, "tailor made" for fuel cells, from anaerobic digestion processes. The current municipal and industrial wastewater treatment market in Japan represents more than 2,000 megawatts of potential electricity generation.
- FuelCell Energy announced it will provide four 250-kilowatt Direct FuelCell power plants to Sierra Nevada Brewing Company of Chico, CA, in 2005. The project qualifies for incentive funding—40 percent of project costs—offered by the California Public Utilities Commission under the Self-Generation Incentive Program. While gas-turbine power generation would have been less expensive, brewery officials opted to keep the facility as green as possible by using fuel cells. Moreover, the natural gas fuel supply for the fuel cells may be supplemented with brewery-generated anaerobic digester gas.

One-of-a-Kind Fuel-Cell/Turbine Hybrid System in Full Operation—NETL successfully completed shakedown of its hybrid performance (Hyper) facility in the spring of 2004. Combining fuel cells and turbines into hybrid power systems is being investigated as an approach to meet DOE's high-efficiency power generation targets. The Hyper facility will be used to develop and test the unique control strategies required to maintain harmonious operation of fuel cell and turbo-machinery under varying loads. The

facility is open to external partners who wish to participate in the advancement of this technology. Several industry and academic partnerships are now in place, including support from Woodward Governor Company, West Virginia University, Georgia Institute of Technology, and others.

Russia's First Commercial Fuel Cell Power Plant Begins Operation—With technical and logistical support from NETL and a U.S. Department of Defense (DoD) Climate Change Grant, a 200-kilowatt phosphoric acid fuel cell manufactured by UTC Fuel Cells Inc. of Windsor Locks, CT, began supplying power to an industrial site near Moscow in Russia. Demonstration of the upgraded fuel cell, originally purchased in 1996 by Gazprom, has developed significant market interest throughout Russia. Gazprom, the world's largest gas producer, is considering other potential applications for U.S. fuel cells, and the current demonstration provided a proof-of-concept foundation for Russia's first Targeted Initiative Program of the International Science and Technology Center. The project supports the Initiative for Proliferation Prevention, Nuclear Cities Initiative, and the Russian-American Fuel Cell Initiative.

HiTEC Program Develops Fuel Cell Curriculum—Graduate level courses in the science and engineering of high-temperature fuel cells are now being offered at Montana State University in conjunction with the university's High Temperature Electrochemistry Center (HiTEC) satellite center. HiTEC is a research collaboration focused on the scientific understanding and technical breakthroughs needed to realize DOE's vision for energy plants of the future. The collaborative effort is managed by NETL in coordination with Pacific Northwest National Laboratory.

West Virginia University Offers Graduate Course on Fuel Cell Technology—Collaboration with NETL in fuel cell education programs has produced the first graduate-level introduction to fuel cell technology offered at West Virginia University. Guest lecturers from NETL and fuel cell companies will support the syllabus, which includes principles of operation, electrochemistry, modeling and analysis, materials, fuel processing, design, and application. Students and faculty knowledgeable in the principles of fuel cell technology will form the next generation of engineers and technicians needed to design and build fossil-fuel-fired power plants that have maximum energy efficiency and minimum environmental impact.

Carbon Sequestration

“Carbon sequestration” describes a family of methods for capturing and permanently isolating gases that otherwise could contribute to global climate change. In its core research program, NETL is developing a portfolio of cost-effective, environmentally sound technology options that could ultimately lead to a reduction in greenhouse gas emissions. NETL also supports DOE's Regional Carbon Sequestration Partnerships—alliances of state agencies, universities, and private companies that form a national network to determine the most suitable technologies, regulations, and infrastructure for carbon sequestration in different areas of the country.

Regional Carbon Sequestration Partnerships Connected Through National Database—The seven Regional Carbon Sequestration Partnerships can now share information through the web-based, password-protected National Carbon Sequestration Database and Geographical Information System (NATCARB). The digital spatial database allows users to locate and estimate point sources of CO₂ (such as power plants and oil refineries) in relation to available terrestrial and geologic features (oil and gas fields, coalbeds, organic-rich shale, deep saline formations, etc.) that could be used as CO₂ reservoirs. Residing on a server operated by the Kansas Geological Survey, NATCARB provides national coverage by accessing data from the Regional Carbon Sequestration Partnerships, the Geological Survey Earth Resources Observation Systems Center, the Geography Network, the DOE Energy Information Administration, and the EPA. The system was developed as part of a cooperative agreement with NETL among the geological surveys of Illinois, Indiana, Kansas, Kentucky, and Ohio.

Public Scoping Meetings Completed for Carbon Sequestration Programmatic Environmental Impact Statement—In a series of public meetings held at strategic locations throughout the United States, stakeholders from industry, academia, environmental groups, and the general public provided input on a draft programmatic environmental impact statement for the Office of Fossil Energy's Carbon Sequestration Program, managed by NETL. Oral and written comments received at the meetings will be used to prepare the draft statement by mid-summer 2005, with public release of the final statement anticipated

for July 2006. The programmatic environmental impact statement will address potential environmental impacts of the program and will provide the framework for decisions regarding the implementation of field activities.

New Modular CO₂ Capture Facility Commissioned at NETL—The modular CO₂ capture facility, which will be used to test promising CO₂ capture technologies under a variety of operational parameters, began operation at NETL's Pittsburgh site in October 2003. The facility can operate on natural gas, coal, or a combination of both to simulate coal-fired combustion processes. Its inaugural campaign was designed to determine the durability and performance of a regenerable sorbent that removes CO₂ from a flue gas stream.

No Significant Technical Roadblocks to Integrating Carbon Capture with Oxygen-Fired Circulating Fluidized-Bed Technology—Based on tests results obtained at ALSTOM Power's 2.9-megawatt multiuse circulating fluid-bed facility, no significant technical hurdles are foreseen that would preclude successful integration of carbon capture and oxygen-fired circulating fluidized-bed technologies. No bed agglomeration problems occurred in the combustion furnace while burning either petroleum coke or an eastern bituminous coal at oxygen concentrations up to 70 percent; moreover, NO_x emissions were reduced nearly 50 percent compared to air-firing. The technology, being developed in cooperation with NETL, is expected to help reach the goals of the President's Clear Skies and Climate Change Initiatives by reducing emissions of SO₂, NO_x and other pollutants while providing a highly concentrated, sequestration-ready stream of CO₂ without costly separation.

NETL Research Takes Significant Step Toward Meeting Important Sequestration Technology Target—Researchers at NETL and The Pennsylvania State University collaborated on the development of a computer code for evaluating and ranking coal seams as potential sites for CO₂ sequestration. The code addresses one of DOE's major technology targets: to develop, by 2005, site-selection criteria and screening models for choosing unmineable coal seams for CO₂ sequestration projects. Site-selection criteria may include amounts of CO₂ sequestered, amounts of coalbed methane produced, breakthrough times for appearance of CO₂ at methane production wells, capital investment, risk, and return on investment. The work is highlighted in the September 2004 issue of the *Journal of Petroleum Technology*.

CO₂ Seismic Imaging Project Gains Visibility—An NETL-supported project revealed that CO₂ movement in thin, relatively shallow, mature carbonate reservoirs can be reliably detected using seismic techniques, a discovery that should increase ultimate oil recovery and help pave the way for CO₂ sequestration in geologic formations. Led by the Kansas Geological Survey, the ongoing project involves injecting CO₂ in the Lansing-Kansas City oil reservoir in central Kansas to assist in recovering more oil, and then using seismic techniques to monitor the movement of the CO₂. High-resolution seismic images acquired before and during the CO₂ flood have highlighted changes consistent with CO₂ movement; the movement has been further substantiated based on production data, fluid-injection volumetrics, and reservoir simulations. Monitoring the fate of CO₂ belowground is essential to ensuring the permanence of CO₂ sequestration in depleted oil and gas reservoirs or brine aquifers. Refinements to three-dimensional high-resolution reflection imaging resulting from this study could make seismic data a useful tool for monitoring geologically sequestered CO₂. In addition to the Kansas Geological Survey and NETL, project partners include the Kansas Department of Commerce, and Kansas oil companies John O. Farmer Inc. and Murfin Drilling Company.

Weyburn Project Demonstrates Safety and Permanence of Sequestration—A multinational project that includes NETL has injected more than 110 billion cubic feet of 95 percent pure CO₂ into the Weyburn oilfield in Saskatchewan, near the North Dakota border, producing more than 6 million barrels of oil. The effort, known as the Weyburn Project, is expected to store about 22 million tons of CO₂ and produce 130 million barrels of oil over 20 years. Data from the project, combined with the well's historical data, is providing specific insights on which a sound economic model of current and future sequestration efforts of this type can be based. This and similar efforts are expected to illustrate that combined enhanced oil recovery and sequestration projects provide a viable and environmentally safe way of storing CO₂ while producing oil that is difficult and expensive to extract through traditional methods. Since its launch in 1999 by the Petroleum Technology Research Centre in Regina, Saskatchewan, and EnCana Resources of Calgary, Alberta, the project has become a model of international cooperation by attracting 15 sponsors from government and industry—including DOE, Natural Resources Canada, Alberta Energy Research Institute, Saskatchewan Industry and Resources, and the European Community—and 10 industrial sponsors in Canada, the United States, and Japan.

Columbia River Basalt Formation Could Store 20 Years' Worth of U.S. Coal-Related CO₂

—Based on supercomputer modeling, scientists at Pacific Northwest National Laboratory, working in cooperation with NETL, estimate that more than 100 gigatons of CO₂—equivalent to 20 years of domestic coal-related CO₂ emissions—could be stored in the Columbia River Basalt Group. Basalt formations have a unique chemical makeup that could potentially convert injected CO₂ to a solid mineral form, thus isolating it from the atmosphere permanently. If successful, project results will expand CO₂ sequestration options domestically and in developing countries such as India and China, where major basalt formations exist.

Eighteen-Month Study of Geologic Sequestration Completed

—Representatives of the British Broadcasting Company (BBC) visited American Electric Power's Mountaineer Plant near New Haven, WV, to get a first-hand look at a DOE-sponsored field test assessing the potential of deep geologic formations for storing CO₂. In the NETL-managed test, an injection well was drilled 9,200 feet deep to evaluate several geologic formations that may have the storage capacity needed to sequester CO₂ emitted by the large power plant on the Ohio River. Test results will be used in a related DOE-sponsored project conducted by researchers at Battelle Laboratories who are evaluating the regional potential of the Ohio River Valley for geologic storage of CO₂. The concept of geological sequestration has great potential in the United States where various deep geological features, such as saline formations, unmineable coal seams, and depleted oil and gas reservoirs, may be suitable for storing large the volumes of CO₂ that result from power production.

First U.S. Effort to Evaluate CO₂ Sequestration in Deep Saline Formation

—In cooperation with NETL and multiple industrial and academic partners, the University of Texas at Austin Bureau of Economic Geology drilled an injection well into the Frio Formation, a deep saline reservoir near Houston, as part of a feasibility study to evaluate the potential of geologically sequestering large quantities of CO₂ collected from chemical, refinery, and industrial sources in the Gulf Coast region. The Texas Bureau of Environmental Quality approved drilling the 5,000-foot-deep well, which will be used to inject 3,000 tons of CO₂ into the formation. NETL scientists will conduct soil-gas sampling and near-surface monitoring for CO₂, CO₂ tracers, and methane, and will model wellbore leakage. Scientists at Lawrence Berkeley National Laboratory will assist by modeling how the CO₂ disperses within the reservoir and any impacts it may have on reservoir characteristics and features.

Interagency Collaboration Produces Comprehensive Model for Terrestrial Carbon Sequestration

—In cooperation with NETL, researchers at Stephen F. Austin University in Nacogdoches, TX, collaborated with personnel from the U.S. Department of Agriculture Forest Service to develop the Forest Management Optimizer (FORMOP), a dynamic software program that analyzes millions of thinning and harvesting combinations for maximum financial returns from carbon sequestration credits, saw timber, and pulpwood. FORMOP could be used to determine the physical, biological, and economic potential for sequestering carbon in any ecosystem in North America. Over the next 2 years, the researchers will model the major commercial tree species in the United States to determine the optimum management practices for a range of carbon prices.

Terrestrial Carbon Sequestration Imagery Completed

—Working under a cooperative agreement with NETL, The Nature Conservancy and Winrock International have completed a multispectral three-dimensional aerial digital imagery survey of the Delta National Forest in the Lower Mississippi Alluvial Valley. The technology is being developed to reduce the time and cost of measuring carbon in terrestrial systems. The digital imagery will be correlated with available carbon storage data from the range of forest classes of various ages contained in the Delta National Forest. A significant benefit of the technology is the creation of a historical record of the inventory survey. These historical records can be reevaluated as the science of determining carbon content from imagery improves, which is currently not possible with manual forest inventories.

NETL-Supported Technology to Help Explore Mars

—Laser-based spectrometry developed through an NETL-managed project at Los Alamos National Laboratory will play a role in NASA's Mars Rover Mission scheduled for 2009. Developed under the Office of Fossil Energy's Carbon Sequestration Program, managed by NETL, the technology represents a leap forward for rapid and accurate determination of elements in soil. Los Alamos National Laboratory won a 2003 R&D 100 Award for a rugged, low-cost, lightweight, and compact field instrument that employs the technology to measure organic and inorganic carbon in soil, and can be used to verify and monitor the effectiveness of terrestrial carbon sequestration projects.

Patent Application Filed for Novel Methane Upgrading Process

—Velocys Inc. filed a provisional patent application focusing on system configurations for modular microchannel process technology, designed to upgrade methane streams from coal mines, landfills, and other

subquality sources. The revolutionary approach, which would enable compact, economic systems for upgrading methane streams to pipeline quality, is being developed in cooperation with NETL under the Office of Fossil Energy's Carbon Sequestration Program. Separation and purification systems based on microchannel process technology have the potential to reduce U.S. annual greenhouse gas emissions by 23.5 billion kilograms of CO₂ equivalent, and to enable the cost-effective annual recovery of 3.5 trillion cubic feet of natural gas. The technology employs small process channels that greatly enhance heat and mass transfer, reducing to seconds the cycle times that typically last hours with conventional upgrading systems.

Hydrogen

Hydrogen is seen by many as the energy carrier of the future, a clean and efficient fuel for use in transportation and stationary power. NETL research is hastening a future in which hydrogen is used to power our cars, trucks, homes, and businesses with no pollution or greenhouse gases. Areas of NETL research include hydrogen separation membranes to produce hydrogen at lower cost, and technologies to address the challenges related to hydrogen storage and distribution.

NETL Researchers Demonstrate Enhanced Hydrogen Production—Researchers at NETL experimentally validated their model predictions of enhanced hydrogen production from the non-catalyzed water gas shift reaction at gasification conditions. The reaction is important because it produces additional hydrogen from carbon monoxide and water, components of the synthesis gas produced in a gasifier. Process modeling conducted at NETL indicated that the economics of hydrogen production could be improved by including a hydrogen-permeable membrane as part of the reactor system; the membrane would remove the hydrogen from the reactor as it formed, shifting the equilibrium and causing more hydrogen to be produced along with sequestration-ready CO₂. NETL researchers developed a novel membrane reactor—consisting of a 3-foot length of thin-walled tube coiled into a helix to maximize surface area—to conduct validation tests. In experiments using the membrane reactor, hydrogen production rates greater than equilibrium were observed. When applied to a gasifier, this concept has the potential to reduce operating costs by eliminating the need for catalysts and gas pre-cooling of existing processes.

New Hydrogen Separation Membrane Demonstrates Record Performance—Working under a cooperative agreement with NETL, investigators at Eltron Research Inc. have replicated several times the stable performance and record hydrogen transport rate produced by its layered composite membrane. The hydrogen transport rate exceeds that reported for polymeric, inorganic porous, and proton-conducting membranes by over an order of magnitude, and that for palladium membranes by a factor of four. The hydrogen product is essentially 100 percent pure, and a preliminary cost estimate of \$100–\$120 per cubic foot of membrane attests to the commercial viability of producing hydrogen and sequestration-ready CO₂ from coal as envisioned in DOE's FutureGen program. The production rate reduces by 50 percent the capital cost of a membrane-based hydrogen-separation device, and reduces the overall separation-plant cost by approximately 3 percent. Moreover, the higher hydrogen flux reduces process equipment sealing and fabrication complexities, allows process intensification via smaller plant footprint, and can accelerate the timeframe for engineering-scale demonstration of hydrogen production technology, making the success a significant milestone toward a fossil-fuel-based hydrogen economy.

Minority Institution Makes Advances in Membrane Science—Researchers at North Carolina Agricultural and Technical State University, a historically black institution located in Greensboro, NC, prepared palladium membranes on porous stainless steel supports that produced a high flux of pure hydrogen from coal-derived synthesis gas. The preparation process for the highly selective, high temperature, high strength, lower cost, novel composite will be optimized to improve the fabrication rate for commercial application. In addition to investigating a way to provide hydrogen for FutureGen applications, the NETL-managed project is providing minority students with hands-on experience conducting energy research.

New Material Shows Promise for Hydrogen Storage—NETL scientists have determined that a novel crystalline material synthesized at Rutgers University has a higher volumetric hydrogen storage density than other formulations in the family known as microporous metal organics materials. The new material was designed with micropores that more closely match the dimensions of the hydrogen molecule so that the interaction energy between the pore walls and the adsorbed gas is maximized. Further exploitation of this newly developed family of materials is underway in pursuit of the programmatic targets for onboard hydrogen storage in fuel-cell-powered automobiles.

Patent Pending for NETL-Supported Hydrogen

Separation Method—Researchers at ITN Energy Systems of Littleton, CO, a small business working in cooperation with NETL, are patenting a novel method for separating hydrogen from coal- or natural gas-derived synthesis gas. The patent application describes a composite material, one side of which dissociates hydrogen into protons and electrons for diffusion through an intermediate electrolyte layer, and the other side of which recombines them into neutral hydrogen molecules. Novel proton-conducting materials within the electrolyte are also claimed in the application. The technology significantly advances the state of the art for producing high-purity hydrogen from coal, natural gas, and certain opportunity feed stocks. Used with gasification-based systems, the technology could become a major source of low-cost hydrogen for use in transportation and clean electricity production.

Novel Concept in Hydrogen Separation Membranes

—Researchers at Media & Process Technology Inc., a small business in Pittsburgh, have developed a carbon molecular sieve membrane that provides high hydrogen flux while meeting a cost target of \$100 per square foot. Unlike palladium-based membranes, the material is inert to most industrial gases, including sulfur compounds, making it particularly well suited for hydrogen production from coal-derived gas. Results of the investigation, completed under the Office of Fossil Energy's Hydrogen and Syngas Program, managed by NETL, were presented at the 21st Annual International Pittsburgh Coal Conference held in Osaka, Japan, in September 2004.

Economical Fabrication of Hydrogen-Producing

Membranes—Working with the Office of Fossil Energy's Hydrogen and Syngas Program, managed by NETL, Media & Process Technology Inc. has developed a method for depositing defect-free hydrogen-selective inorganic membranes on porous metallic supports made by Pall Corporation. Inorganic membranes provide superior thermal and chemical stability compared to commercially available organic membranes, and find widespread use in fossil energy systems, including hydrogen production from coal. The advance will help overcome scale-up barriers associated with production of hydrogen-selective membranes. During the coming year, the project team will use the new technique to fabricate a membrane reactor that will enhance hydrogen production via the water-gas shift reaction.

Materials

Future power plants and energy systems will require new materials that can withstand increasingly higher temperatures and corrosive environments. The goal of the Fossil Energy Materials Program, managed by NETL, is to ensure the success of these systems by providing the needed materials technology base. Current research is focused on developing high-temperature corrosion-resistant structural ceramic composites and alloys, and materials that perform specific functions in advanced fossil energy systems.

Materials Program Seeks to Extend Boiler Component Life

—Working in cooperation with the Fossil Energy Materials Program, managed by NETL, a consortium of four prominent boiler makers—ALSTOM Power, Babcock & Wilcox, Foster Wheeler, and Riley Power—is evaluating and developing advanced materials to allow the use of advanced steam cycles in coal-based power plants. In contrast to European and Japanese programs that target an operating temperature of 1,300 °F, the U.S. consortium aims to extend the operating temperature of future coal-fired boilers to 1,400 °F. The higher operating temperature will increase boiler efficiencies from a current domestic fleet average of about 35 percent to approximately 47 percent while reducing CO₂ and other fuel-related emissions by nearly 25 percent. The consortium is also supported by Energy Industries of Ohio, the Electric Power Research Institute, and Oak Ridge National Laboratory. The consortium's accomplishments this year include the following:

- Investigators at Babcock & Wilcox have found that carbon, boron, and chromium play a consistent and significant role in the steamside oxidation behavior of ferritic steels used in boiler components. The discovery could lead to improved alloys for advanced boilers operating in temperature regimes where oxidation is accelerated and the likelihood of failure from metal wastage is increased.
- Steam loops made of several candidate high-temperature alloys were installed at Dairyland Power Cooperative's John P. Magett Generating Station in Alma, WI. The loops were tested at temperatures up to 1,400 °F in a low-sulfur coal unit. The test complemented another test underway in a high-sulfur coal unit at the Reliant Energy power plant in Niles, OH. In the near term, results of steam-loop tests are expected to guide retrofit decisions made by operators of existing plants affected by fireside corrosion.

- University of Cincinnati researchers have found that examination of microstructures after heat treatment provides the insight needed to optimize the mechanical strength of nickel-based super alloys. Results of their investigation, completed in cooperation with NETL under the Fossil Energy Materials Program, were presented to the U.S. boilermakers consortium at a meeting in Oak Ridge, TN, in March and April 2004.
- The boilermakers consortium successfully developed welding procedures that do not compromise the material properties of new alloys being considered for high-temperature applications. The consortium is considering the new alloys for coal-fired boilers capable of operating at much higher efficiencies than the current generation of supercritical plants. The procedures will be validated through tests under actual utility boiler conditions. Test results should improve estimates of fabrication and construction costs associated with the new alloys, and aid ongoing conceptual design and economic studies of advanced coal-fired plants.
- In tests conducted by Babcock & Wilcox in conjunction with NETL, a new alloy developed at Japan's National Institute for Materials Science showed steam oxidation resistance nearly 10 times superior to other ferritic steels. The Japanese alloy steel will be further evaluated for use in supercritical high-efficiency coal-fired power plants designed to operate at higher pressure and temperature than conventional plants, thus emitting significantly less CO₂. The collaboration could reduce the overall costs and duration of similar research and development efforts in both countries.
- Babcock & Wilcox investigators have, for the first time, welded 3-inch-thick plates of a super alloy known as Haynes 230. The technique could make possible application of nickel-based alloys for high-temperature coal-fired supercritical steam power-generation cycles with significantly higher efficiencies and lower CO₂ emissions than current plants. Extensive tests will be performed to compare the mechanical strength of the welded section to the parent material.
- Officials of First Energy, Cinergy, and Xcel Energy agreed to host corrosion tests to be conducted under the NETL-managed Fossil Energy Materials Program. Corrosion probes made of various new alloys, coatings, and weld overlays will be installed at selected power plants fired by a range of domestic coals for long-term exposure to temperatures typical for the reheater/superheater of advanced plants.

- The consortium developed new cylinder design rules to remove some of the over-conservatism in current design codes, permitting the specification of thinner wall thicknesses and/or use of materials with lower stress tolerances. Adoption of the new formula in a standard supercritical boiler design represents a 12.5 percent savings in material costs. The savings amount to more than \$600,000 for a 600-megawatt 1,050 °F boiler. The group will address questions arising from the new design formula and will present a proposed revision of code language to the American Society of Mechanical Engineers.

Significant Discovery Reported in Materials Program—

In an NETL-managed project, researchers at West Virginia University have shown that spinel particles significantly improve the mechanical properties of moly-silicide, a class of materials that, with increased toughness and ductility, could be applied at service temperatures near 2,700 °F. The higher service temperatures would enable fossil energy systems to operate with thermodynamic efficiency significantly greater than can be achieved with nickel-based super alloys, which are limited to approximately 1,900 °F.

Innovative Steam Turbine Blades Ready for Testing—

In an NETL-funded project, GE Energy has designed and fabricated a prototype full-scale steel-hybrid last-stage "bucket" (blade) with an advanced three-dimensional aerodynamic shape. The 33.5-inch prototype is an intermediate step in designing ultra-long full-speed last-stage buckets that will improve overall Rankine cycle efficiency up to 0.5 percent, reduce fuel consumption by 1 percent, and avoid the generation of 2 million tons per year of CO₂ for the next generation of low-pressure steam turbines. Results from tests in August 2004 showed that the bucket could be lightened by the removal of metal and backfilled with low-density material to maintain the aerodynamics. When fully tested, the prototype design will be introduced with the next generation of GE low-pressure steam turbines, while development of 54-inch steel-hybrid and 62-inch titanium-hybrid last-stage bucket design continues.

Clean Coal Demonstration Projects

Clean coal demonstration projects showcase new energy processes that sharply reduce air emissions and other pollutants compared to older coal-burning systems. DOE's commitment to clean coal demonstration projects dates back to 1986, when the first of five rounds of the Clean Coal Technology Program was initiated to combat emissions of NO_x and SO_2 , which contribute to acid rain. DOE's commitment has continued through the 2001 Power Plant Improvement Initiative and today's Clean Coal Power Initiative, with its expanded focus on emissions of mercury, fine particulates, and greenhouse gases.

First Clean Coal Power Initiative Projects Awarded—

Since the first rounds of the Clean Coal Technology Program in the 1980s, environmental concerns surrounding the use of coal have expanded to include the potential health impacts of trace emissions of mercury, the effects of microscopic particles on persons with respiratory problems, and the potential for greenhouse gases to alter the global climate. These concerns have spurred the new Clean Coal Power Initiative, which targets today's most pressing environmental challenges. Four awards, totaling more than \$300 million, were made during fiscal year 2004 under the first round of the Clean Coal Power Initiative:

- Great River Energy and its research partners at the Coal Creek Station in Underwood, ND, will demonstrate the Lignite Fuel Enhancement System, a technology that uses so-called "waste" heat from power plants to dry coal before it is fed into the power plant boiler. After developing a prototype to dry about one-sixth of the coal fed to a 546-megawatt unit at the Coal Creek Station, Great River Energy will design, construct, and perform full-scale long-term operational testing on a complete set of dryer modules for full power operation at one of the 546-megawatt units. The coal will be dried to several different moisture levels to measure the effects of coal drying on plant performance, and to determine optimum operating conditions. Successful commercial application of this technology could boost the generating capacity and efficiency of power plants that burn high-moisture coal, thereby reducing emissions of air pollutants and greenhouse gases.
- NeuCo Inc., the nation's leading provider of optimization software for electric power producers, will design and demonstrate integrated online optimization systems at Dynegy Midwest Generation's Baldwin Energy Complex located in Baldwin, IL, which has three 600-megawatt coal-fired units. Two of the units are cyclone-fired boilers with selective catalytic reduction (SCR) and the third is a tangentially fired boiler. The optimization modules to be developed will include combustion, soot blowing, SCR operations, overall unit thermal performance, and plant-wide profit optimization at all three of the generating units. The system is built on NeuCo's ProcessLink® technology platform, which uses neural networks, genetic algorithms, and fuzzy logic techniques. Anticipated benefits of the \$19-million, cost-shared, 4-year project are reduced NO_x emissions, improved reliability, and increased fuel efficiency, which will provide commensurate reductions in greenhouse gases, mercury, and particulates.



- We Energies of Milwaukee will design, install, operate, and evaluate the Electric Power Research Institute's patented TOXECON™ multipollutant control process at its Presque Isle Power Plant near Marquette, MI. By injecting sorbents such as powdered activated carbon upstream of a pulse-jet baghouse, but downstream of existing particulate control devices, TOXECON is an integrated approach to controlling emissions of mercury, particulate matter, SO₂, and NO_x. The process is potentially a low-cost retrofit option for achieving high levels of mercury control at coal-fired power plants. When completed in 2009, the \$52.9 million, cost-shared demonstration is expected to reduce mercury emissions by 90 percent from three units of the nine-unit Presque Isle plant. The multipollutant control strategy could also reduce the already low SO₂ and NO_x emissions at the plant by an additional 70 percent and 30 percent, respectively. In addition, release of particulate matter would be reduced to 0.01 pounds per million Btu.
- Western Greenbrier Cogeneration LLC will build a demonstration plant in West Virginia that will use a fluidized-bed combustor to coproduce industrial heat and electricity enough to power 85,000 homes. The power plant will use nearby waste coal to generate electric power with ultra-low emissions of pollutants, while concurrently producing combustion ash byproducts and heat to support industrial activities. The plant will serve as an anchor tenant for a new "eco-park" site in Rainelle, WV, where low-grade waste heat from the plant will heat greenhouses and fish ponds. The plant will use a novel ALSTOM inverted-cyclone separator for the capture and recirculation of solids. The design has the potential to reduce boiler construction time by up to 10 percent, and the boiler footprint by up to 40 percent. It should also reduce construction costs compared to existing circulating fluidized-bed systems.

Solicitation for Second Round of Clean Coal Power Initiative Issued

NETL issued a solicitation for the second round of proposals under the Clean Coal Power Initiative in February 2004. The solicitation provided approximately \$280 million in federal matching funds for demonstrating barrier-breaking technologies that sharply reduce, and ultimately eliminate pollution in coal-based power plants. The call for proposals required that prospective projects use coal for at least 75 percent of the

fuel energy input to the process, while electricity is at least 50 percent of the energy-equivalent output from the technology demonstrated. Additionally, proposals had to show the potential for rapid market penetration upon successful demonstration of the technology. Priorities for the second round of competition were advancements for gasification-based electricity production, advanced mercury control, and sequestration and sequestration-readiness. NETL received proposals offering projects valued at nearly \$6 billion by the June 2004 submission deadline.

Clean Coal Demonstration Projects Continue to Reap Benefits

The 35 projects selected under the Clean Coal Technology Program and the eight selected under the Power Plant Improvement Initiative continue to demonstrate coal's potential as a clean, abundant, and affordable energy source. The projects are improving power plant efficiencies, reducing emissions, lowering fuel costs, and preserving jobs. Information about the projects is available on an NETL-managed website that is accessed hundreds of thousands of times each year.

- Results from tests at Tampa Electric Company's Power Plant Improvement Initiative demonstration project, conducted in cooperation with NETL, show that coal-fired boiler efficiency can be increased 0.5–1 percentage point and NO_x levels reduced 10–20 percent by integrating neural-network-based technology with state-of-the-art controls on soot blowers used to keep heat transfer surfaces clean. Widespread commercial application of this technology in the United States could reduce NO_x by almost 200,000 tons, SO₂ by 30,000 tons, CO₂ by 6 million tons, particulate matter by 1,500 tons, and fuel costs by about \$67 million each year.
- Results from Bethlehem Steel Corporation's Blast Furnace Granular-Coal Injection System Demonstration Project—selected under Round III of the DOE Clean Coal Technology Program, managed by NETL—were published in the January–March 2004 issue of the prestigious peer-reviewed journal, *Mineral Processing and Extractive Metallurgy Review*. The manuscript, coauthored by NETL, Science Applications International Corporation, and International Steel Group, discusses the blast furnace granular-coal injection technology demonstrated on furnaces at Bethlehem Steel's Burns Harbor Plant in Indiana. Developed by British Steel/CPC-Macawber, the process

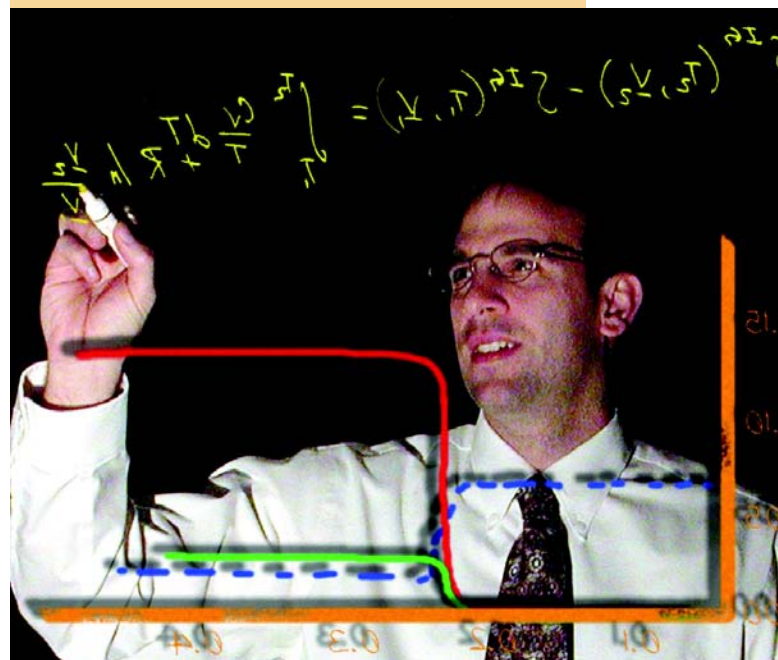
utilizes granular coal as a fuel supplement to decrease coke requirements. Replacing coke with coal realizes a concomitant reduction in emissions from coke production. Using granular rather than pulverized coal saves further on the capital cost of grinding equipment and approximately 60 percent in grinding energy.

- The Advanced Flue Gas Desulfurization Demonstration Project, selected under Round II of the DOE Clean Coal Technology (CCT) Program, managed by NETL, and completed in 1996 by Pure Air on the Lake L.P., is the first CCT project to accumulate over \$1 million in repayments. The project won national achievement awards from *POWER* magazine and the National Society of Professional Engineers, and helped to modify both utility scrubber specifications and vendor guarantees for compliance with the Clean Air Act Amendments of 1990. Repayment derives mainly from the sale of gypsum produced as a byproduct of the project's advanced desulfurization unit, and represents more than half of all repayment funds collected under the CCT program. The unit continues to operate commercially, scrubbing approximately 70,000 tons of SO₂ annually at the Northern Indiana Public Service Company's Bailly Generating Station near Chesterton, IN. The less-expensive advanced flue gas desulfurization byproduct also preserved 200 jobs by reducing production costs at the nearby USG wallboard plant, which otherwise would have been closed.
- Demonstrating the popularity and usefulness of the NETL-managed Clean Coal Technology Compendium website, users from more than 130 countries accessed the site an average of 16,000 times a month during 2003. The website offers data from DOE Clean Coal Technology Programs, the President's Clean Coal Power Initiative, and related clean coal information, and it provides access to clean coal program documents even before hard copies might be available. The most frequently visited document during 2003 was The Electric Utility Engineer's Manual on Flue Gas Desulfurization Process Design, while the most accessed technology category was integrated gasification combined-cycle.

Modeling

Computational modeling and simulation are among the most significant developments in the practice of scientific inquiry in the twenty-first century.

Scientific computing is particularly important in solving problems that are insoluble by traditional approaches, are hazardous to study in the laboratory, or are time-consuming or expensive to solve by traditional means. NETL uses modeling and simulation to assist the development of power plant components and subsystems, and to analyze the overall performance and cost of advanced energy systems.



Understanding How Hydrogen Transport Membranes Function—Working under DOE's Advanced Research Program, managed by NETL, University of Cincinnati researchers developed a physics-based theory to explain how hydrogen permeates through certain members of a family of ceramic materials known as perovskites, of which strontium-cerium-oxide is an example. The group is using the theory to synthesize new materials with improved hydrogen permeance in support of affordable coal-based hydrogen production.

New Computer Modeling Center for SECA—The SECA industry teams now have a powerful computational platform on which to design and optimize solid oxide fuel cell systems: a Silicon Graphics computer located at Pacific Northwest National Laboratory, where some of the most advanced solid oxide fuel cell software packages are developed under the SECA Core Technology Program. Negotiations are underway with software developer Fluent Inc. to place software developed in collaboration with NETL on the new system. The modeling center will facilitate the efficient analysis and modification of existing cell and stack designs to enhance both performance and reliability. In addition, these tools may be used to define precisely the safe operation envelope needed in planning an effective system control strategy.

NETL-Developed Heat Transfer Simulation Attracts Industry Interest—In an NETL-supported project, researchers at Virginia Polytechnic Institute and State University have developed and verified computational approaches for turbine blade cooling designs that are more accurate and less expensive than previous methods. The greater accuracy allows designers to specify more precise cooling airflow paths and quantities, cutting both aerodynamic losses and improving turbine performance. Improved computer predictions for high rotational speeds will also eliminate expensive testing and shorten product development time. The development has caught the eye of U.S. turbine manufacturers GE Energy, Siemens Westinghouse, Pratt & Whitney, and Solar, who recognize the outstanding progress and value achieved under DOE's University Turbine Systems Research Program. The turbine manufacturers are members of the Industrial Review Board for the University Turbine Systems Research Program, a government-industry-academia collaboration managed by the South Carolina Institute for Energy Studies at Clemson University under a cooperative agreement with NETL.

NETL Model Significant for CO₂ Sequestration—A model developed by NETL researchers can be used to describe coal's effectiveness in adsorbing CO₂. This is

particularly important for sequestration in coal seams where high pressures of CO₂ will be used. Previous attempts to describe high-pressure CO₂ adsorption isotherm data using conventional adsorption equations to model coal behavior have been only partially successful.

Virtual Power Plant Performance Models a Reality—Computational scientists at NETL developed the advanced process engineering cosimulator (APECS) for seamlessly integrating scientifically accurate models of devices such as gasifiers, reformers, and fuel cells together with balance-of-plant simulators for advanced fossil energy systems. Such integration, combined with advanced visualization and high-performance computing, is a necessary step in the development of "virtual" models that will enable design engineers and other users to better understand and optimize the fluid mechanics, heat and mass transfer, and chemical reactions that drive overall power plant performance and efficiency. The capability should speed technology development by reducing pilot- and demo-scale facility design time and operating campaigns, thereby lowering the cost and technical risk in realizing high-efficiency, near-zero-emission power plants.

New Strategy for Producing Hydrogen from Coal—Computer simulations completed under the Office of Fossil Energy's Transportation Fuels and Chemicals Program, managed by NETL, show that a membrane reactor operating at mild temperatures (200–250 °C) could produce hydrogen from coal-derived gas through the water-gas shift reaction taken to completion. Similar results usually require two reactors operating in a much more energy-intensive process scheme. Moreover, the new strategy would permit collection of concentrated, sequestration-ready CO₂ with minimum or no parasitic energy consumption. Collaborators at the University of Southern California and Media & Process Technology Inc. conducted the simulations.

Coal Power with Sequestration Yields Lower Lifecycle Greenhouse Gas Emissions than Photovoltaic System—NETL analysts published results of a study showing that integrated gasification combined-cycle with CO₂ capture gives lower lifecycle greenhouse gas emissions than a prominent renewable technology. The article, published in the peer-reviewed *Journal of Infrastructure Systems*, describes two approaches for computing lifecycle assessments: a traditional process-based approach and one based on economic input-output analysis. These environmental lifecycle assessments were used to compare the greenhouse gas implications of various electricity generation technologies. It was shown that the lowest

lifecycle emissions are achieved with hydropower and wind farms, while an integrated coal-gasification combined-cycle plant with 90 percent CO₂ capture has lower lifecycle greenhouse gas emissions than natural-gas combined-cycle and solar photovoltaic systems.

Carbon Sequestration Model Now Publicly Available—

The Integrated Environmental Control Model—Carbon Sequestration Edition (IECM_{cs}) is available for public download at www.iecm-online.com. IECM_{cs} is a powerful analytical tool developed by Carnegie Mellon University in cooperation with NETL to rapidly characterize and evaluate the impact of carbon capture and storage technologies on the emissions, cost, and performance of pulverized coal, natural-gas combined-cycle, or integrated gasification combined-cycle power plants. Subsequent updates will incorporate new information on multipollutant control options, advancements in capture technology, and power systems with near-zero emissions. IECM_{cs} is free to utilities, state governments, and other decisionmaking stakeholders to encourage the voluntary reduction in carbon intensity called for by the President's Global Climate Change Initiative.

Integrated Gasification Combined-Cycle Plant

Improvements Identified—NETL analysts completed process modeling studies of a novel concept that combines two advanced technologies being developed for use in integrated gasification combined-cycle processes for generating electricity from coal: ceramic membranes for oxygen separation from air, and the advanced transport reactor, a high-efficiency gasifier. The concept involves placing the membrane inside the reactor. This *in situ* placement increases efficiency by using process heat instead of synthesis gas to bring the membrane to its operating temperature; capital costs are also reduced because the oxygen is delivered directly to the reaction zone. Five cases—employing various gasifier types, oxygen preparation technology, and process configurations—were modeled. The *in situ* configuration was calculated to offer the highest thermal efficiency: nearly 44 percent on a higher heating value basis.

NETL-Developed Technology Improves Integrated Gasification Combined-Cycle Competitiveness—A study by ChevronTexaco shows that an advanced gas-cleaning technology developed by RTI International through an NETL-managed project would reduce the capital cost of an integrated gasification combined-cycle plant by at least half of the \$200 per kilowatt needed to make these plants competitive in today's power generation market. By operating at mild process temperatures (500–700 °F), the

advanced sorbent-based technology would reduce the capital cost of an integrated gasification combined-cycle plant by approximately \$125 per kilowatt (assuming all the benefits are realized), increase plant efficiency 1–2.5 percentage points, and achieve an order of magnitude reduction in sulfur emissions compared to a base-case plant with conventional cold gas-cleanup technology.

Advanced Coal-Based Power Systems May Have Cost Advantage—

A preliminary analysis completed by a consortium of U.S. boilermakers working in cooperation with NETL under the Fossil Energy Materials Program shows that advanced coal-fired power plants could generate electricity at competitive rates while reducing CO₂ and other fuel-related emissions by nearly 25 percent. Although extensive use of nickel-based super alloys would increase capital costs for an ultra-supercritical boiler by 28 percent, its elevated operating temperatures would increase energy conversion efficiency from 35 percent (the current domestic fleet average) to about 47 percent. Additional analyses will be performed to determine if fabrication and erection costs with the new super alloy materials would alter initial conclusions.

Coal-Fired Steam Plants an Attractive Future Option—

A techno-economic study commissioned by NETL concludes that significant improvements in steam cycle efficiency, cost, and emissions can be achieved to make coal-fired steam plants an attractive future energy option. The study was conducted by ALSTOM Power, Parsons Energy and Chemical Group, and American Electric Power. Three configurations were compared—pulverized coal, circulating fluid-bed, and circulating moving bed—each with the higher steam cycle temperatures and pressures needed to boost energy conversion efficiency upward from the current domestic fleet average of about 35 percent. All configurations were found capable of achieving the low levels of pollutants contemplated for 2010, and the study found that a significant reduction in the cost of electricity can be expected with newer technologies. Technologies are available today to construct higher efficiency pulverized-coal-based cycles. Circulating fluid-bed steam cycles, which are especially attractive for high-sulfur coals, are likely to require another 3–5 years for commercialization. Ultra-supercritical circulating moving bed technology, now under development, is expected to reach the highest efficiency (48 percent) in 10–15 years. These highly efficient technologies, in combination with advanced tail-end CO₂ capture, may also offer an alternative approach for near-zero-emission coal-fired power plants.



NATURAL GAS: THE WORLD'S FASTEST GROWING ENERGY SOURCE

Clean-burning natural gas is one of the nation's principal sources of energy. It supplies nearly a quarter of U.S. primary energy and is the world's fastest growing energy source. Its worldwide abundance, coupled with its environmental soundness and multiple applications, means that natural gas will play an increasingly important role in meeting U.S. energy demand. To ensure an adequate supply of reasonably priced natural gas for the American consumer, NETL conducts research in four broad areas: gas exploration and production; methane hydrate; gas transmission, distribution, and storage; and gas environmental solutions

Gas Exploration and Production

NETL's gas exploration and production activities help expand domestic natural gas supply to fuel the nation's economy while protecting the environment. New supplies of natural gas must come from sources that are more complex, very remote, and much deeper—resulting in higher natural gas prices if new technologies are not developed. The program strives to produce a balanced portfolio of projects that address a wide range of near- and long-term gas-supply issues while decreasing the impact to the environment.

Intellipipe™ System Successful in Commercial Test—A revolutionary high-speed, downhole communications network developed by Novatek Engineering Inc. of Provo, UT, and Grant Prideco Inc. of Houston through a cooperative agreement with NETL, was successfully tested for the first time in a full-scale commercial well. Approximately 6,400 feet of Intellipipe™ was deployed in the Oklahoma well during 500 drilling hours. Except for the lower two modules where conditions exceeded the temperature rating of the electronics, all modules established high-rate data communications links with aboveground receivers during the test. The high-speed communications link will allow operators five orders of magnitude more data transmission than commonly available technology, enabling real-time downhole sensor data to more accurately control the drilling operation, increasing drilling efficiency, and leading to safer, more productive wells.

First Commercial Order Received for Composite Drill Pipe—Integrated Directional Resources Inc. ordered 300 feet of a new type of flexible, lightweight drill pipe made from space-age carbon fiber composites. Advanced Composite Products and Technology Inc., a small business in Huntington Beach, CA, whose major customers have been the aerospace and automotive industries, developed the 2½-inch composite drill pipe in cooperation with NETL. Because it can remain bent for extended periods without suffering fatigue damage, composite pipe is particularly suited to horizontal drilling, which allows production from geologically complex formations, where much of the nation's oil and gas remains. Short-radius horizontal drilling is especially useful in accessing these formations from old wells, avoiding the environmental impacts of drilling new ones. A 5½-inch pipe under development will include an electric wire embedded in the composite material to support “smart drilling” systems.

Stripper Well Consortium Technologies

Commercialized—The Stripper Well Consortium offers small, independent oil and gas operators—who account for 8 percent of the total natural gas and 27 percent of the oil produced in the contiguous United States—the opportunity to work with technology developers and researchers to solve production problems. Managed by The Pennsylvania State University, the consortium has more than 60 members, and receives funding from NETL and the New York State Energy Research and Development Authority. Two technologies developed with funding from the Stripper Well Consortium were offered commercially in fiscal year 2004:



- A line of electrical submersible pumps that can handle solids- and gas-contaminated fluids, from heavy oil to water, were offered by Smith Lift LLC, a subsidiary of Smith International Inc. Developed by Pumping Solutions Inc., now part of Smith Lift LLC, the lightweight pumps can produce 50–400 barrels of fluid per day using a third of the power required to drive a conventional rod or centrifugal pump. Lower capital and operating costs and higher production rates will allow the pumps to extend the economic life of marginally productive wells, particularly low-pressure gas wells, horizontal or deviated wells, heavy oil wells, and wells located in environmentally sensitive areas.
- Brandywine Energy and Development Company offered its gas-operated automatic lift (GOAL) PetroPump for sale to interested well owners and operators. The pump uses the natural downhole pressure within well casings to automatically lift fluids to the surface. The system is unique in that it operates automatically using an on-tool pressure-activated valve preset to retrieve and deliver a fixed volume of fluid each run and return additional fluid to the wellbore when required. The low-maintenance pump is inexpensive to operate, as it requires no external energy source and limited manpower.

Study Shows How to Increase Gas Production—

A 5-year study completed by the New Mexico Institute of Mining and Technology in cooperation with NETL shows that changing the well placement pattern used in naturally fractured, tight gas reservoirs of the San Juan Basin could increase gas recovery 23–46 percent, depending on reservoir conditions. The new pattern departs from the normal square pattern that assumes a well is draining gas radially. As a result of the study, Burlington Resources and British Petroleum were granted permission by the New Mexico Oil and Gas Conservation Commission to site wells using the new pattern with closer well spacing. Extrapolation of the results across the Mesaverde producing area suggests that an additional 7.8 trillion cubic feet of natural gas could be recovered by the new drilling practice. The study has demonstrated a new methodology and analytical procedures that will assist industry in producing gas from tight reservoirs. Several independent operators have already contacted the project team to conduct similar work, without federal funding, in tight gas sand basins of the Rocky Mountain area.

Technology Reduces Natural Gas Exploration and Production Investment Risk—

In an NETL-managed project, Innovative Discovery Technologies LLC, of Laramie, WY, constructed a basin-wide, three-dimensional model that helps gas operators select optimum drilling and completion sites in low-permeability formations of the Wind River Basin. The technology decreases dry hole rates and increases production from low-permeability formations by offering operators a general sense of where to find gas-charged compartments, and specifying targets worth a closer look. The same methodology can be applied to other tight gas basins. The technology is one reason why Wyoming has been able to maintain positive gas production while all other contiguous states and provinces of Canada have been unable to do so.

New Method for Finding Gas Proves Successful—

Using an innovative method of predicting sweet spots in tight gas formations, three test wells drilled in the San Juan Basin of New Mexico during fiscal year 2004 came on line with very strong initial production rates, and all continue to be good producers. The new methodology, developed through an NETL-managed project by Geospectrum Inc. of Midland, TX, combines seismic attributes with petrophysical data and production history to detect and quantify areas of high natural-fracture density that are likely to produce gas without artificial wellbore enhancements. A fourth well, drilled in a location where not all of the seismic attributes were favorable, had low initial production, and lower current production. The success of the first three wells, and the lower production rate of the fourth, appear to validate the predictive capability of the seismic methodology. Successful application of the methodology should significantly increase gas reserves in the San Juan Basin and other Dakota sandstone reservoirs by bringing more high-end producing wells on line.

Stripper Well Technology Gets to the Heart of the Matter—

A spherical pump developed under a contract with the Stripper Well Consortium to increase the efficiency and economics of pumps in the oil and gas industry, was called “ingenious” by Dr. Bud Frazier, Chief of Cardiopulmonary Transplantation at the Texas Heart Institute, who asked the pump’s designers to fabricate a prototype for use as a human heart pump. The pump displaces almost its entire liquid or gas intake in one revolution, making it the most efficient pump ever created, and it can even function in reverse as a fluid motor. If successful, the model being fabricated for the Texas Heart Institute will reduce fatalities from heart disease.

Improved Measure-While-Drilling Telemetry

Successfully Tested—A novel electromagnetic telemetry receiver developed by E-Spectrum Technologies of San Antonio in cooperation with NETL was successfully field-tested at the Halliburton Energy Services north test well in Carrollton, TX. The unique receiver is designed primarily for recovering very weak ultra-low-frequency signals from measure-while-drilling sensors downhole near the drill bit or from wireless well logging, even with the high ambient electromagnetic noise associated with well drilling. The innovative receiver combines the incoming electromagnetic wave information from multiple receiver inputs, and applies proprietary algorithms to reconstruct the original, uncorrupted signal. When fully developed, the “through-the-earth” telemetry system will provide relatively low-cost data of an order of magnitude better quality without the need for a special drill pipe.

Advanced Drill Bit Project Yields Significant Results

A field test completed at the Gas Technology Institute’s Catoosa test well shows that a hard rock drill-bit design containing specially processed ENDURUS™ cutters, developed by Technology International Inc. in cooperation with NETL, successfully drilled hard and abrasive rock without significant cutter wear. Controlled tests performed at the TerraTek Drilling Laboratory in Salt Lake City to simulate deeper drilling conditions (about 13,000 feet) have shown the new bit design, with ENDURUS thermally stable cutters, drilled at double the rate of penetration of a roller cone bit. The improved cutters will increase drilling rate and bit life in hard rock drilling applications, thereby improving the economic development of these resources.

High-Speed Drilling System Tested—Results from the first full-scale test of high-pressure jet-assisted drilling show that the technique can penetrate various lithologies of limestone and sandstone approximately three to seven times faster than conventional drilling systems. The technique uses high-pressure water to cut slots into rock, forming ledges that are then removed by mechanical cutters. Maurer Technologies of Houston conducted the test in cooperation with NETL using a drilling rig modified to safely deliver water at approximately 200 gallons per minute and 10,000 pounds per square inch to the vicinity of the drill bit.

Advanced Technology Could Produce More Gas and Revenue—An analysis completed for NETL by Advanced Resources International estimates that multiseam completion technology could increase economically

recoverable coalbed methane in the Powder River Basin by 125 percent—providing an incremental 21.5 trillion cubic feet of natural gas, and augmenting federal, state and local revenues up to \$8 billion. Unlike the current practice of single zone completions, multiseam completion uses a single well to recover methane from multiple coal seams, improving production efficiency and economic performance. The technology may become a necessity in the future as development moves to the central and northern portions of the basin where the coal seams are deeper and thinner, respectively. Coalbed methane contributes roughly 8 percent to the domestic supply of natural gas and represents 10 percent of the U.S. proved reserves. Nearly 1 billion cubic feet per day is produced from the more than 12,000 wells in the Powder River Basin of Montana and Wyoming.

Study: Hydraulic Fracturing Fluids No Threat to Drinking Water

—The EPA made public a final report summarizing a multiyear evaluation of the potential threat to drinking water from the use of hydraulic fracturing fluids for enhanced production of coalbed methane. In the hydraulic fracturing process, fluids are injected into the ground to break up rock or coal formations, forcing the release of methane. The report concludes that use of the predominant water-based fracturing fluids poses little or no threat to underground sources of drinking water, and that additional study is not warranted at this time. Concurrently, EPA secured a memorandum of agreement with the three service companies that perform the vast majority of the hydraulic fracturing projects in the United States to ensure that fracturing fluids contain no diesel fuel. During the study period, the Office of Fossil Energy advised EPA on coalbed methane basins and production, reviewed multiple documents, and participated in public dialogs and forums; NETL produced white papers related to hydraulic fracturing, one of which is appended to the final report. Departmental involvement was essential for achieving the positive outcome: continued development of needed energy supplies while affording the environment additional protection without more regulation.

Gas Upgrading Technology Successfully

Demonstrated at Full Scale—Approximately 90 billion cubic feet of sour gas has been processed with no solvent-related problems using Morphysorb® solvent technology at the Kwoen Plant, a new gas-processing facility owned by Duke Energy Gas Transmission Company near Chetwynd, British Columbia. Morphysorb's development was cosponsored by NETL and the Gas Technology Institute, which jointly owns the process with Uhde GmbH, an international engineering firm. Morphysorb removes 25 percent more hydrogen sulfide and CO₂—impurities that degrade the heating value of natural gas and can adversely impact distribution operations—than competing processes. The improved process efficiency provides the Kwoen Plant with a 50 percent capacity increase in acid gas removal—the equivalent of a plant expansion worth (U.S.) \$25–\$40 million.

NETL-Developed Technology Commercialized

TDA Research Inc. of Wheat Ridge, CO, signed an exclusive commercialization agreement with SulfaTreat for its new direct oxidation technology that removes sulfur from natural, landfill, and synthesis gas. SulfaTreat, a business unit of M-I LLC, is the market leader in hydrogen sulfide scavenging. M-I publicly announced the commercialization agreement in a January 2004 news release. An independent economic analysis shows that the process, developed under an NETL-managed Small Business Innovation Research Grant, offers significant cost savings over conventional sulfur-recovery processes, particularly at the scale of 1–50 tons per day of sulfur, and in combination with a tail gas treatment would provide greater than 99 percent sulfur recovery for the process.

Methane Hydrate

Methane hydrate—molecules of natural gas trapped in ice crystals—is a mixed blessing. Occurring naturally in marine sediments and polar regions, methane hydrate is a potentially vast energy source, but it is also a threat to deep-water drilling that passes through overlying marine hydrate deposits. NETL works in both areas. NETL is developing the knowledge and technology base to enable commercial production of methane from domestic hydrate deposits, and it is working to ensure the safety of deep-water drilling operations that pass through methane hydrate.



Large-Volume, High-Pressure View Cell Helps Fill Gaps in Understanding Methane Hydrate Behavior—NETL constructed and installed a 15-liter high-pressure view cell able to replicate the diverse physical conditions that encompass naturally occurring hydrate formations. With this capability, NETL researchers can study the dissociation of naturally occurring hydrates and investigate the physical properties of pure methane hydrate and hydrates from ocean or permafrost environments. The size of the new view cell—one of the largest in the world—allows core samples to be placed within it for study. This ability is important because developing technologies to produce methane from hydrates and accurately estimating producible gas from various reservoirs will require data from actual hydrate deposits.

Progress Toward Methane Hydrate Production—Results of NETL-supported production tests conducted at the Mallik well site in Northwest Territories, Canada, conclusively demonstrated the technical feasibility of producing methane from gas hydrates. The tests used a simple process of thermal stimulation through the circulation of hot water. Additional work at the site continues to be discussed, including more extensive testing of alternative production strategies and well designs.

First Methane Hydrate Prospects Defined—In the Prudhoe Bay area of Alaska's North Slope, a team consisting of BP Exploration (Alaska), the University of Alaska Fairbanks, the University of Arizona, the U.S. Geological Survey, and NETL reviewed existing well and seismic data to delineate the first drillable hydrate prospects in the United States. More than a dozen prospects were identified and characterized. Both reservoir- and economic modeling indicate that several of the prospects are capable of producing methane in economically viable quantities with known production methods. The work is a key step in bringing the ultimate resource potential of hydrates into clearer focus.

Hydrate Modeling Capabilities Advance—Two NETL-sponsored projects significantly advanced the capability to conduct numerical simulations on methane hydrates in natural environments. DOE's Lawrence Berkeley National Laboratory released the beta version of its Tough-Fx/Hydrate Code, which provides a rigorous analysis of hydrate dissociation and resulting product flows from all currently conceivable production mechanisms. A team working in conjunction with the BP Exploration (Alaska)

project on Alaska's North Slope successfully conducted simulation of hydrate production using a modified version of the Canadian Modeling Group's STARS simulator. These tools will be an indispensable part of both the analyses of data gathered in the field and the prioritization of the remaining gaps in hydrate knowledge.

Alaskan Hydrate Well Produces Wealth of Information—The "Hot Ice No. 1" well didn't encounter methane hydrate as expected, but it did produce a wealth of geological and geophysical information that should help to overcome the technical obstacles to the eventual commercial production of methane from hydrate. The well was drilled in 2003 and 2004 as part of a 2-year cost-shared partnership among NETL, Anadarko Petroleum Corp., Maurer Technology Inc., and Noble Engineering and Development. The well was expected to encounter a methane hydrate accumulation suitable for production testing; instead, researchers found free gas and water in the target interval. The project successfully developed and demonstrated for the first time a number of innovative technologies, including Anadarko's Arctic Drilling Platform, a mobile hydrate core analysis laboratory, and a new application of a continuous coring rig. The research team also acquired a three-dimensional vertical seismic profile at the well, which resulted in very high resolution images of the subsurface and possible indications of hydrate updip and east of the well site. Analyses of the core, log, and seismic data from the well indicate that the hydrate in this region occurs in patchy deposits and may require a high methane flux from the subsurface in order to form more continuous drilling prospects.

New Reservoir Mapping Technology Applied to Methane Hydrate—A newly developed seismic signal detector-processor was used to complete a three-dimensional vertical profile on Alaska's North Slope. The technology, developed in cooperation with NETL by Paulsson Geophysical Services Inc., consists of closely spaced, high-frequency geophones lowered into existing boreholes to acquire and record data from reflected seismic energy. Data conversion to visual representation provides images that have a resolution three- to fourfold greater than currently available technology, and should reveal thin beds within the hydrate stability zone. The technology is designed to lower exploration and production costs by reducing the investment in data acquisition, the number of wells drilled, and the percentage of dry holes.

Gas Transmission, Distribution, and Storage

Delivering natural gas is an enormous enterprise. The majority of natural gas consumed in the United States is produced at remote sites and moved to consumers through a vast system of reservoirs, compressors, and more than 1.4 million miles of transmission and distribution pipelines—all of which must be efficient and reliable. The Office of Fossil Energy's Natural Gas Program, implemented by NETL, includes research and technology development to solve the technical challenges associated with efficient and reliable gas transmission, distribution, and storage.

Bishop Process Meets Critical Milestone—A full-scale test of the energy-efficient heat exchanger critical to the Bishop Process™ was initiated in April 2004 at the AGL Resources liquefied natural gas (LNG) peak shaving facility located near Canton, GA. Over several days, the heat exchanger flawlessly processed LNG at a design flow rate equivalent to 4 billion cubic feet per day. The process, a novel method for unloading and regasifying LNG directly from ocean tankers for storage in underground salt caverns, is being developed in cooperation with NETL by Conversion Gas Imports L.P. with 25 industry partners. The salt-cavern-based design has the potential to revolutionize the gas industry by providing LNG imports faster, cheaper, and possibly more securely than conventional facilities.

New Offshore Mooring and Receiving Technology Completes Subscale Tests—Bluewater Offshore Production Systems tested the “Big Sweep” offshore mooring and product transfer concept, one of four concepts considered as a terminal option for the Bishop Process™, which would allow rapid unloading and regasifying of liquefied natural gas (LNG) directly from ocean tankers for storage in underground salt caverns. Tests were completed in April 2004 as part of a cooperative agreement with NETL using a model basin (1:40 scale) located at the Oceanic Consulting Corporation facility in St. John's, Newfoundland, Canada. The model basin tests were designed to verify system operation with an LNG carrier under normal conditions and under extreme (hurricane) conditions without a carrier. The offshore terminal systems being investigated by project leader Conversion Gas Imports L.P. would allow all LNG receiving, transfer, and storage activity to occur offshore, diversifying LNG receiving capabilities in the United States.



First Application of Bishop Process—HNG Storage Company, an experienced developer, owner, and operator of salt-cavern storage facilities, announced the Freedom LNG Terminal project, an offshore, salt-cavern-based receiving terminal for liquefied natural gas (LNG). The project will use the Bishop Process™ for unloading and regasifying LNG directly from ocean tankers for storage in underground salt caverns. This is the first announced application of the Bishop Process for which a full-scale design was field-tested under an NETL cooperative agreement. By eliminating aboveground cryogenic storage tanks and replacing them with salt-cavern storage of regasified LNG, the technology improves the scalability, economics, and security of LNG receiving terminals in the United States. The project will be designed to deliver up to 2 billion cubic feet per day of LNG with the capability of doubling that amount through expansion. The terminal will be located off the coast of Louisiana and is planned for operation in 2008.

Innovative Process Holds Promise for Developing Gas Storage Capacity—A feasibility study completed by Clemson University researchers in cooperation with NETL shows that gas storage caverns can be created by dissolving carbonate rock with acid. The spent acid “waste” stream can be used beneficially so there is no adverse environmental impact. The novel process is economically competitive with other methods of creating storage, avoids the problem of brine disposal associated with salt caverns, and could be applied in modular fashion by adding capacity as needed. Strategically placed gas storage facilities would help reduce price spikes during periods of peak demand.

Innovation for Improved Gas Delivery Reliability Successfully Field-Tested—Colorado State University researchers, working in cooperation with NETL, have demonstrated an improved method for engine ignition on a commercial natural gas pipeline compressor. The work was performed in a field test conducted at the El Paso Window Rock Compressor Station in Window Rock, AZ, using a full-scale (2,500 horsepower) compressor fueled with natural gas. The new ignition method employs small amounts of distillate diesel fuel injected into the engine to initiate combustion instead of using spark ignition. The innovation may save fuel, improve engine performance, and reduce emission of pollutants. The technology has significant implications for the U.S. natural gas pipeline industry, in which similarly designed compressors represent a critical part of the natural gas delivery infrastructure.

Improved Gas Delivery Infrastructure—As part of a cooperative agreement with NETL, Southwest Research Institute completed development of a “conformable array” corrosion-evaluation system. By automating a process currently performed manually, the system offers a faster, cheaper, more accurate way of determining pipe strength. The system will encourage widespread pipeline inspections, allow on-the-spot repair/replace decisions to be made, and ultimately produce a safer and more reliable gas pipeline delivery system. The system uses an array of sensors configured on a flexible substrate that conforms to pipe shape to efficiently and effectively map and evaluate the extent of corrosion with only limited surface preparation. Clockspring Inc., a pipeline services company and cofunder of the project, expressed strong interest in commercializing the technology for incorporation in its service program, and the company officially requested that Southwest Research Institute provide the first commercial prototype of the system.

Pipeline Leak Detection Technologies Tested—Six new technologies for the remote detection of natural gas pipeline leaks were demonstrated in September 2004 in a real-world environment. The participating technologies included four developed with NETL funding and one funded by the U.S. Department of Transportation’s Office of Pipeline Safety. Testing and demonstration were carried out at the Rocky Mountain Oilfield Testing Center in Casper, WY, over a 7½-mile-long test course with multiple leak sites capable of variable leak rates. The event—which was attended by Senator Craig Thomas (R-WY) and representatives for Senator Michael Enzi (R-WY) and Representative Barbara Cubin (R-WY)—included the testing and demonstration of remote leak-detection technologies carried on aircraft, satellite, unmanned aerial vehicles, and mobile ground-vehicle-based platforms. These new technologies will enhance the reliability of the nation’s 1.3 million miles of natural gas pipelines, increase safety, and lessen the environmental impacts of undetected leaks.

Patent Issued for Natural Gas Delivery Reliability System—A U.S. patent was issued to Automatika Inc. for the data communications method at the heart of the Gasline Sensor Network System (GASNET). GASNET is being developed in cooperation with NETL by Automatika in partnership with Northeast Gas Association and associated utilities. The wireless system is designed to transmit real-time radio-frequency-encoded data (flow, pressure, moisture, etc.) from sensors distributed throughout an entire network to a central control and monitoring station. The system eliminates the need for costly communications infrastructure, and significantly improves response time to changes in supply and demand.

NETL-Developed System Detects Buried Plastic Pipe—As part of a cooperative agreement with NETL, the Gas Technology Institute completed prototype development of a compact and inexpensive sensor that can be placed on the ground to image objects embedded in the soil. The capacitive tomography system is not hindered by wet soils, can be produced at a lower cost than ground-penetrating radar, and provides a much more intuitive image that is easy to interpret without extensive operator training. The Gas Technology Institute is planning to take this technology from proof-of-concept to a prototype more suitable for commercial production. A compact, low-cost, widely available sensor that can image objects through soil would avoid costs associated with inappropriate excavations and inadvertent pipe breakage.

Gas Storage Technology Consortium Adopts Constitution, Initiates Research Program—Following its formal launch in March 2004, when approximately 30 prospective members met in Houston to ratify a constitution, the Gas Storage Technology Consortium initiated a 5-year collaborative research program valued at \$6 million with the release of its first request for proposals in April 2004. The consortium's mission is to assist in the development, demonstration, and commercialization of technologies that improve the integrity, flexibility, deliverability, and cost-effectiveness of the nation's underground natural gas storage facilities. Led by The Pennsylvania State University, in cooperation with NETL, the consortium helps ensure a safe and reliable supply of natural gas to meet domestic demand.

Gas Environmental Solutions

While many, if not most, of NETL's natural gas research activities improve the environmental performance of natural gas, the projects in the Gas Environmental Solutions Program have regulatory compliance and improved environmental protection at their heart. The goal of the program is to provide low-cost technologies to overcome the environmental barriers that limit domestic gas production.

NETL Surveys Produced Water in Wyoming—As part of an assessment of the fate of produced water associated with coalbed methane production, NETL arranged with Fugro Inc. to fly an airborne electromagnetic survey of four separate areas of the Powder River Basin, including two that had been over-flown previously. NETL staff also collected geophysical and hydrologic data to correlate with the airborne data. The surveys have proven valuable in establishing baseline information and identifying potential problem areas related to water management. The NETL team is also coordinating a hydro-geologic investigation within one of the flight areas with the U.S. Geological Survey and the U.S. Bureau of Land Management.

Western Governors Release Best Management Practices Handbook—A best management practices handbook for the production of coalbed methane that relies heavily on NETL-sponsored work was released by the Western Governors' Association in April 2004. Announced at the North American Energy Summit in Albuquerque, the handbook focuses on coalbed methane production in Colorado, Montana, New Mexico, Utah, and Wyoming. It highlights issues and public perceptions surrounding coalbed methane development, and it discusses the best methods and technologies for minimizing the amount of water produced along with coalbed methane and solving produced-water problems. The handbook builds on work that NETL sponsored to develop best practices for coalbed methane production in the Powder River Basin.





OIL: LIFEBLOOD OF AMERICA'S ECONOMY

Oil supplies 40 percent of America's total energy needs and more than 99 percent of the fuel we use in our cars and trucks. Directly or indirectly, oil makes possible the functioning of nearly every component of the U.S. economy. With two thirds of America's discovered oil still in the ground, innovative new technologies are needed to economically access this vital resource. The Office of Fossil Energy's Oil Program, implemented by NETL, works to resolve the environmental, supply, and reliability constraints of producing and using oil by investing in research with clear and tangible public benefits.

Oil Exploration and Production

DOE's role in oil exploration and production is to facilitate the development of critical technologies where a federal presence is needed to achieve national energy goals. Through shared research with its industry partners, NETL develops technologies to increase domestic oil production and coordinates the rapid transfer of innovations to commercial use.

Kansas CO₂ Field Demonstration Produces First Incremental Oil

—An NETL-supported project to demonstrate the efficacy of CO₂ flooding in a mature, nearly abandoned oilfield produced its first incremental oil shortly after CO₂ injection began in December 2003; as of September 1, 2004, 550 barrels of oil had been produced, and incremental oil production was expected to rise significantly as the CO₂-rich oil bank neared the production well. The location for this ongoing demonstration with the University of Kansas is the Hall-Gurney Field near Russell, KS. The site had produced several million barrels of oil from primary and water-flood recovery since its discovery in the 1930s, but for several years it was considered completely depleted. This field was chosen because it is typical of the thousands of nearly depleted and soon-to-be-abandoned oilfields throughout Kansas. The first 2 years of the project were spent preparing the field for the CO₂ flood and performing reservoir engineering studies to optimize CO₂ injection and oil production. Injection of CO₂ will continue until CO₂ production is excessive; then it will convert to WAG (water alternating gas) injection. This is the first use of CO₂ for enhanced oil recovery in Kansas. If the technology is proven technologically and economically feasible, the estimated incremental oil production in the state of Kansas is 100–160 million barrels over 20 years.

NETL Project Results in More Oil, Better Environment

—By reprocessing historic seismic data with modern computer software and fracture analysis technology developed at the University of Southern California, Venoco Inc. enhanced existing maps detailing the South Ellwood Field off the coast of Santa Barbara, CA. The result: significantly greater oil production and the discovery of 80 million barrels of additional new oil reserves. Before the NETL-supported project started in 2000, only 5 percent of the 1-billion-barrel reservoir had been recovered because of high water influx and well siting difficulty. New technology has been successfully applied to cut water influx in half and increase oil production by 800 barrels per day from existing offshore Holly platform oil wells. The new maps also located large open fractures from which natural gas has been seeping for millions of years. During the late 1980s, an early attempt to collect some of the escaping methane gas using submerged concrete pyramid-shaped seep tents was successful; work to clean up the rest of the gas seep is under review. All of the oil and gas produced, plus the natural gas collected, has worked toward stemming the flow of the greenhouse gas, significantly reduced the sheen previously evident on the water surface, reduced the amount of oil washed up on area beaches, and, according to the nearby Marine Mammal Institute, allowed local marine life to flourish.



Native American Project Finds 9 Million Barrels of Economically Recoverable Oil—Seismic and aeromagnetic research completed by Advanced Resources International in cooperation with NETL identified 11 specific leads for petroleum exploration under Lake Sakakawea on the Fort Berthold Indian Reservation in Montana. The previously unexplored area represents the largest contiguous acreage block, about 50,000 acres, under control of the Arikara, Mandan, and Hidatsa Tribes, which have united to form the Three Affiliated Tribes. The reservation is located approximately 15 miles east of the center of the Williston Basin, and to the southeast of a major structural feature and petroleum-producing province, the Nesson anticline. The Three Affiliated Tribes are marketing the leads—which have expected recoveries ranging from 283,000 to 1.7 million barrels of oil each (18.7 million barrels of oil total)—to independent operators. Finding and development cost estimates range from \$6 to \$15 per barrel.

Horizontal Drilling Technology Finds More Oil—Using horizontal drilling technology in conjunction with Intelligent Computing System (ICS) software, Luff Exploration Company of Denver, CO, has increased proven oil reserves in the Williston Basin of North Dakota by 6 million barrels and produced nearly 1 million barrels of incremental oil. The technologies revitalized wells that were near their economic limit or were plugged and abandoned, and could produce similar results in known oilfields throughout the United States. Developed through a cooperative agreement with NETL, ICS is a set of internet-based, downloadable software tools with tutorials that aid petroleum professionals in reservoir characterization and risk assessment. The software uses geologic, seismic, drilling, and production data to create a suite of maps that can predict the production rates and remaining oil and gas in any part of the reservoir, identifying drilling sites and approaches that would maximize hydrocarbon recovery.

Nitrogen Injection Yields 30 Percent Increase in Production from Oklahoma Oilfield—Using a flood of cryogenically produced nitrogen and improved techniques for injection and completion, Binger Operations LLC of Cody, WY, increased oil production from each of six new wells in the Marchand C tight sand reservoir in western Oklahoma to 900–1,000 barrels per day. Only 10 percent of the reservoir's 104 million barrels of oil-in-place has been

recovered over more than 30 years of development. An arrangement with a local power generator to exchange natural gas for electricity makes the nitrogen injection cost-effective. Conducted in cooperation with NETL, the project demonstrates that improved nitrogen injection could be an economically viable option for independent operators in areas where CO₂ is not readily available.

Enhanced Oil Recovery from Low-Permeability Bartlesville Sandstone—Results of a study to test horizontal water-flooding in the shallow Bartlesville sandstone in Osage County, OK, were reported in September 2004 issue of *The American Oil & Gas Reporter*. The article summarized the goals and results of the NETL-supported project, which was funded as a Native American Initiative Grant. Mineral rights to the Bartlesville reservoir in Osage County belong to the Osage Tribe, which will benefit from the increased oil production. Project objectives were to demonstrate the technical and economic feasibility of horizontal water-flooding, to test the viability of open-hole completions, and to demonstrate that short-radius rotary steerable technology can drill horizontal wells at low cost and without reservoir damage. Simulation results and economic evaluation indicate that the horizontal water-flood using 23-acre spacing will generate \$2.9 million over 6 years compared to \$1.4 million over 30 years for a typical five-spot pattern.

Increased Oil Recovery in Wyoming—Correlations Company of Socorro, NM, found that combining neural network analysis with data from laboratory imbibition tests provides a valuable way to predict whether surfactant stimulation will be beneficial in a particular oilfield, and even for specific wells within a field. The method can also be used to determine the optimal amount of surfactant to inject. Applying the method to 23 wells in the Cottonwood Creek Field resulted in an average oil production increase of 15 percent from 6 months of surfactant injection. The work was completed through a Small Business Innovation Research Grant administered at NETL.

New Well Completion Device Successful in Field Test—

In an NETL-managed project, Completion Concepts of Katy, TX, successfully field-tested a new approach to well completions for formations with limited stability or integrity. The new technology consists of telescoping perforations (teleperfs) arrayed around the outside of a well-casing liner. When pressurized from within the liner, the teleperfs project into the formation face, securing the liner in place and providing entry ports for the formation fluids. The devices include a sand exclusion medium to limit entrainment of formation material and debris. The new approach represents an alternative to jet perfs that are “exploded” into place at the risk of reducing reservoir permeability, and to gravel packs that require an oversize wellbore and are often ineffective for controlling sand entrainment. This device will increase well productivity and sharply enhance well economics. As a result of a successful field test in Bossier City, LA, British Petroleum plans to employ the new approach for an injection well in Alaska in 2005.

New Method for Direct Detection of Hydrocarbons Developed—

In an NETL-managed project, Houston-based Rock Solid Images developed a greatly improved method of predicting and quantifying oil and gas saturation distributions by interpreting seismic attributes such as velocity and impedance in terms of inelastic rock properties. The technology is expected to provide more accurate reservoir simulations, resulting in fewer dry holes and lower production costs. Two U.S. patent applications were filed covering various aspects of the technology.

NETL Study on Alaska’s North Slope Garners Media Attention—

The first scientifically based study to determine when oil companies can transport equipment over the Arctic tundra without damaging the fragile ecosystem received a considerable amount of favorable media coverage in 2004. The new ecological model is a major improvement over the current 30-year-old *ad hoc* standard that limits oil exploration and ice road construction to times when there is a minimum of 12 inches of frozen ground and 6 inches of snow on the tundra. In addition to snow depth and ground hardness, the model accounts for interactions between vegetation and soil that protect the tundra from being compacted or deformed. The scientific approach allows work to start earlier, and extends the number of workdays without harming the environment.

Model Predicts Chemical Nature of Hydrocarbons Within Geologic Basins—

The California Institute of Technology made public an advanced chemistry basin model that can determine the source and migration pathways of hydrocarbons within a geologic basin, thereby reducing the risk of drilling dry holes. Produced with Cornell University and GeoGroup Inc. in cooperation with NETL, the new software tool is a user-friendly, graphically intuitive basin model that includes an oil maturity indicator and maturation kinetic data set, and a Microsoft Excel-compatible oil chemistry and flash calculation tool. The software operates on a personal computer, and simulates hydrocarbon generation and migration, and the chemical changes that can occur during migration, such as phase separation and gas washing.

Energy Bill Safety Net Proposal Presented to U.S. Bureau of Land Management Incentives Team—

As part of the U.S. Bureau of Land Management Incentives Team, NETL has applied analytical modeling tools to evaluate a series of potential safety net incentives that can be put in place on federal lands to encourage oil and gas production when product prices are low. Seven scenarios were analyzed for comparison to the current effective royalty as well as to a flat 12.5 percent royalty on each of the 16,515 federal leases active in 2003. Results of the analysis were presented at a spring 2004 meeting with other team members—representing the Bureau of Land Management, and U.S. Minerals Management Service, the Office of Fossil Energy, and the States of California, Wyoming, New Mexico, and Oklahoma—and resulted in a revised energy bill safety net incentive. The Bureau of Land Management is considering replacing the current heavy oil incentive and the stripper well incentive with some form of the safety net incentive, so the analysis must determine the base price for the new incentives as well as the price indexing mechanism for current incentives, should they be reinstated.

Improved Resolution for Porosity Maps Made Possible with New Inversion Algorithms—

Researchers at the University of Texas at Austin successfully completed a 3-year, NETL-funded project to improve the efficiency of inversion algorithms and to develop algorithms for direct estimation of petrophysical parameters. Researchers integrated seismic data, well data, and reservoir production data using Bayesian Stochastic Inversion. A full-waveform inversion algorithm of elastic properties was developed and tested successfully, tremendously improving horizontal resolution of porosity maps.

Algorithms for Discriminating Lithology from Sonic Data—In an NETL-supported project, Southwest Research Institute created, processed, and tested algorithms to extract wave attenuation and dispersion attributes from seismic data. The procedure automatically corrects the data for scattering, geometrical spreading, and borehole effects. The algorithms have been tested and verified, and can be used to process new and existing monopole full-waveform sonic data. The borehole application demonstrated that results can discriminate lithology and provide information on pore structure when integrated with cores and logs. In highly permeable formations, pore structure can be related to fluid flow between the pore matrix and vugs.

Reservoir Modeling Identifies Infill Drilling as Best Approach to Increase Oil Recovery—With assistance from NETL, the Kansas Geological Survey and American Energies Corporation demonstrated the application of low-cost tools and techniques to build a reservoir geomodel for the Wellington West Field in south-central Kansas. The work included the integration of petrophysical logs, cores from analogous reservoirs, production histories, and well tests. A spreadsheet-based log-analysis tool called PFEFFER, developed at the Kansas Geological Survey, was used to analyze well logs. Spreadsheet-based decline analysis and material balance calculations were used to refine the model, which formed the basis of reservoir stimulation study. Permeability distribution and residual saturation maps of the field were developed to select an optimum field-management plan. The reservoir stimulation study concluded that, because of permeability and heterogeneity considerations, coupled with a strong bottom-water drive, a water-flood in the field would not be effective. However, evidence from the study led to the strong support of infill drilling to recover oil in an area of relatively high oil saturation.

Technology Transfer Project Supports Domestic Oil and Gas Industry—Through a contract with NETL, the Texas-based Houston Advanced Research Center identified and catalogued the first 20 of possibly 800 technologies developed by the U.S. Navy that are suitable for supporting maritime operations of the offshore oil and gas industry. The Houston Advanced Research Center is a non-profit organization cooperating with universities, industry, and government agencies to address regional ecological issues. The technologies identified would complement those under development by NETL to improve domestic oil and gas supply. The center plans to make the information widely available.

Popular Handheld PC Program for Oil and Gas Operators Receives Upgrade—After receiving high marks from oil and gas operators, an electronic tally sheet program for Pocket PCs was upgraded and improved to make it even more user friendly. The “Tally II” Pipe Tally Sheet for Pocket PC allows users to conveniently build an inventory or tally sheet for tubular products and downhole tools. Developed by Maurer Technology Inc. with assistance from NETL, the program saves time while improving recordkeeping accuracy. Interest in the first version of the program was very high, and feedback received from users led to the current upgrades and improvements. The Tally II software can be downloaded for free from the Maurer Engineering and NETL websites.

Digital Play Portfolio for the Permian Basin Publicly Available—A team of researchers at the University of Texas at Austin Bureau of Economic Geology and the New Mexico Bureau of Geology and Mineral Resources released a new digital oil-play portfolio of the prolific Permian Basin of west Texas and southeast New Mexico. The portfolio includes a reservoir database, sorted by plays, of all reservoirs in the Permian Basin that have produced more than 1 million barrels of oil through 2000; maps in geographic information system (GIS) format of each play, showing the location of reservoirs in the play and the play boundaries; and written summaries of each play and figures illustrating the nature of the geologic heterogeneities that characterize the play. The project was completed in cooperation with NETL under DOE’s Preferred Upstream Management Practices program to find new, more cost effective ways to locate and recover oil remaining in carbonate reservoirs in the Permian Basin and elsewhere in the United States. The Permian Basin has produced oil for

more than 80 years, and it is still one of the largest petroleum-producing basins in the United States. It contains an estimated 22 percent of proved oil reserves in the United States, and it has the biggest potential for additional oil production in the country, containing 29 percent of estimated future oil reserve growth.

Artificial Network Approach to Reservoir

Characterization for Independents—A study conducted by Advanced Resources International with assistance from ChevronTexaco and NETL found that using clustering analysis to interpret porosity and permeability trends is an effective low-cost decision making tool when time, manpower, and economics preclude a full-scale, core-based reservoir characterization of an oilfield. The goal of the study was to determine the best way to use existing data-acquisition capabilities to improve vertical resolution and reduce uncertainty in reservoir characterization. Performance forecasting technologies using artificial intelligence and clustering proved to be the most cost-effective way to improve reservoir predictions. This information should prove useful to small independent operators.

Oil Well Stability Studies Lower Well Construction

Costs—Insight from oil well stability studies being conducted by NETL and Sandia National Laboratories has already saved millions of dollars in well construction costs in the Gulf of Mexico. In a \$3-million, 4-year project, researchers at the laboratories are using sophisticated computer models to determine how oil wells in the 1,000-mile-wide Gulf can be stabilized while drilling in slabs of salt thousands of feet thick. The research helps industry determine stable locations where drilling can take place through or near salt formations, and it provides essential guidance to optimize well trajectories and casing designs. Results of the work have been applied to the Thunder Horse North and Mad Dog Fields, two of the five largest oilfields in the Gulf of Mexico. The more aggressive well-casing design implemented in the Thunder Horse North Field resulted in estimated well construction cost reductions of more than \$30 million.

Cable-Suspended Submersible Pumps Reduce Production Costs, Increase Ultimate Oil Recovery—

Enerdyne LLC, a small independent oil and gas producer, and Pumping Solutions Inc., developer of a low-volume electric submersible pump, re-established marginal oil production from the Red Mountain Field in the San Juan Basin in New Mexico by installing cable-suspended electric submersible pumps in 17 existing wells. Objectives of the NETL-supported project were to resume oil production in the Red Mountain Reservoir by using the pumping system; to determine if the system can reduce lift costs, making it a cost-effective production system for similar oilfields within the region; and, if warranted, to drill additional wells to improve the economics. The average Red Mountain well made eight barrels of fluid per day in the first 4 weeks of production, with the pump operating 2 hours per day; the average oil cut was calculated at 15 percent. Potential oil production is estimated at 15–20 barrels of oil per day once all 17 wells are allowed to produce on a regular extended schedule.

Low-Cost Well-Monitoring Device Promises to Optimize Production—

A new, ultra-low-cost device for monitoring marginal oil wells was successfully field-tested by Vaquero Energy in the Edison Field near Bakersfield, CA. Developed with support from NETL, the Marginal Expense Oilwell Wireless Surveillance (MEOWS) system helps improve the efficiency of rod-pumped oil wells and promises to help rescue thousands of U.S. wells from an early demise. The system allows daily, remote monitoring of wells in real time at a significantly reduced cost, while providing information that helps the operator improve the efficiency of rod pumps controlled by timers. As a result of the field test, preliminary patent searches on the new device and application were initiated, followed by additional patent-related investigations and discussions with patent attorneys. The preliminary patent search was satisfactory, and the project team anticipates successful application of the low-cost device on pumping oil wells.

Fuels

To ensure a diverse and secure domestic supply of energy and lessen America's dependence on imported oil, NETL works with its industry partners to develop advanced alternative fuels.

Promising technologies include processes to convert natural gas into a liquid and innovations to improve refinery efficiency, thereby improving the economics of upgrading heavy oils to desired light oil quality.

NETL-Developed Technology Yields Heavy Oil Upgrading Process—Western Research Institute of Laramie, WY, developed a process to convert bitumen (heavy oil, oil sands, etc.) into a residuum-free stock that meets or exceeds pipeline specifications for density and viscosity. The Western Research Institute Thermal Enhancement (WRITE) process, which involves no addition of diluents, would save approximately \$2–\$3 per barrel over current practice. The WRITE process—an offshoot of the Western Research Institute's patented TaBoRR (tank bottom recovery and remediation) process, which was developed in cooperation with NETL for recovering salable petroleum products from oilfield sludge—is ready for pilot-scale testing and field deployment.

Tests Confirm Performance of Reactor System for Early-Entrance Coproduction Plant—ChevronTexaco completed tests confirming the design basis for the Fischer-Tropsch bubble column reactor central to ChevronTexaco's concept for an early-entrance plant to coproduce electric power, clean diesel fuel, and steam from petroleum coke, a low-cost byproduct of oil refining. The tests also validated proposed techniques for online catalyst withdrawal and addition, catalyst rejuvenation, and catalyst regeneration. The project, undertaken in cooperation with NETL, will provide the necessary technical, economic, and environmental information needed by industry to move the concept forward to detailed design, construction, and operation.

Field Test and Evaluation of Ultra-Clean Diesel Fuel in Denali National Park Buses Gears Up to Full Scale—In an NETL-supported project, a gas-to-liquids demonstration plant at the Port of Catoosa, near Tulsa, OK, is providing ultra-clean synthetic transportation fuel for three buses in the fleet at Denali National Park in Alaska. Researchers from West Virginia University are comparing emissions from six Denali buses—three using the ultra-clean fuel and three others using the park's normal fuel. This demonstration project marks the first time that buses are operating on Syntroleum's Fischer-Tropsch fuel, and it is happening in one of the most pristine places in the world. The test vehicles will demonstrate that the fuel can be used in diesel engines without excess wear, and there will be lower emissions using this fuel. The synthetic fuel is produced at the Port of Catoosa plant and provided to the park under a cost-shared cooperative agreement between NETL and Integrated Concepts and Research Corporation (ICRC); Syntroleum is a subcontractor to ICRC. Using Syntroleum's advanced Fischer-Tropsch process, the plant will, at full capacity, convert approximately 1 million cubic feet per day of natural gas into 70 barrels per day of diesel fuel containing virtually no sulfur, aromatic hydrocarbons, or metals.



Oil Environmental Solutions

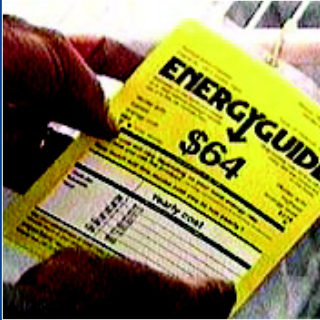
Just as most of NETL's natural gas research activities improve the environmental performance of natural gas, most of NETL's oil research activities improve the environmental performance of oil. And just as the projects in the Gas Environmental Solutions Program have regulatory compliance and improved environmental protection at their heart, so it is with the projects in the Oil Environmental Solutions Program. In both cases, the program goal is to provide low-cost technologies to overcome the environmental barriers that limit domestic production of America's fossil resources.

NETL-Supported Project Demonstrates Soil Restoration at Tallgrass Prairie Preserve—With support from NETL, the University of Tulsa is developing models and strategies to reduce the likelihood of an accidental oil or brine release during oil production and minimize ecosystem damage should one occur. The work is being conducted in the Tallgrass Prairie Preserve in Oklahoma, where more than 100 wells produce an average of 15–20 barrels per day of crude oil, and as much as 10 times that volume of brine. The infrastructure in the preserve is aging and requires maintenance, increasing the risk of environmental damage in the ecologically sensitive setting should an equipment failure occur. The project employs risk assessment techniques to gauge the probability of damage to soil ecosystems from spills of produced fluids such as oil and brine, to identify spill causes, and to determine appropriate clean-up standards. The project will enable better environmental protection with the limited resources typical of operators of marginally producing wells.

Drilling Waste Management Information System

Published—The Drilling Waste Management Information System (DWMIS) developed for DOE by Argonne National Laboratory was highlighted in the August 2004 issue of *Oil & Gas Journal*. Drilling waste management practices vary throughout the world and are subject to legal requirements to protect human health and the environment. With assistance from NETL and industry partners Chevron-Texaco and Marathon Oil, Argonne developed an interactive DWMIS website, which provides comprehensive information of drilling-waste management and summarizes applicable technologies and regulatory information for individual states and federal agencies. DWMIS will benefit operators by providing easy access to U.S. regulations and waste management options. This information will allow operators to select the options with the most environmental and economic benefits. The journal article provides a background description of drilling waste, the purpose of sound environmental management, and the design and use of the DWMIS module, which went on line in June 2004.



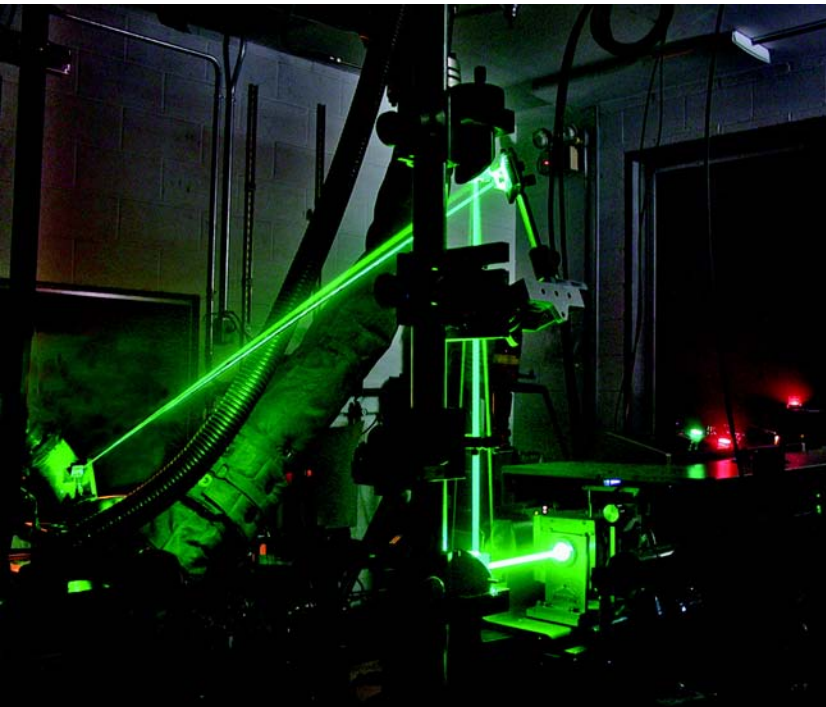


ENERGY EFFICIENCY AND RENEWABLE ENERGY

NETL is the lead research and development center for the Office of Fossil Energy, but it shares its wide-ranging expertise with other offices and departments within the federal government. NETL supports the DOE Office of Energy Efficiency and Renewable Energy (EERE) in its mission to enhance energy efficiency and productivity by conducting relevant research on site and managing external research and development projects for various EERE programs.

Laser Ignition Lowers Engine NO_x—Studies conducted at NETL have suggested a way to improve reciprocating engine performance to meet more demanding emissions limits. Using a laser-spark ignition system, NETL researchers increased the total operating margin (defined as the interval between the knock and misfire regimes) of an engine by 46 percent compared to conventional spark plug ignition systems. The wider margin afforded by the laser system permitted NO_x reduction of 50 percent relative to the spark plug system, with greater ignition system durability and no degradation in thermal efficiency or combustion stability. This technology was developed under the Office of Energy Efficiency and Renewable Energy's Distributed Energy Program.

NETL-Supported Project Produces Power from Waste—In a project funded by NETL under the Office of Energy Efficiency and Renewable Energy's Biomass Program, the Port of Tillamook Bay, OR, is converting animal waste from an environmental liability into a significant source of energy and profit. Anaerobic digestion of cow manure allows the port to heat water, produce grid-quality electricity, and recover fertilizer and other marketable products while protecting approximately 100 jobs in the local dairy industry. Attendant profits are making the project self-perpetuating by financing additional digester installations throughout Tillamook County.



Black Liquor Gasifier Commissioning Begins—Commissioning of a black liquor gasifier being integrated into Georgia-Pacific's 100-year-old containerboard mill in Big Island, VA, as part of an NETL-supported demonstration project began in March 2004 with the first injection of black liquor into the gasifier. Gasification of black liquor, a papermaking byproduct that also serves as a fuel for pulp and paper mills, transforms the byproduct into value-added chemicals and synthesis gas, and it is a promising alternative to the recovery boilers traditionally used in paper manufacturing. Funded by the Office of Energy Efficiency and Renewable Energy's Biomass Program, the commercial-scale demonstration project is illustrating the viability of black liquor gasification in the forest products industry.

Commercial Building Market Study Completed—

Innovologie LLC, formerly TecMRKT Works, has found that great gains could be made in improving the energy efficiency of commercial buildings by targeting the relatively few major players in each of seven submarkets (office, retail, food sales and service, lodging, healthcare, warehouses, and education). Relying on data from the DOE Energy Information Administration, the Commercial Building Energy Conservation Survey, and other sources, the study describes for each building submarket such characteristics as building size, energy use, and ownership; it also examines corporate, social, and cultural influences on building design, construction, and renovation. The study was completed for the Office of Energy Efficiency and Renewable Energy's Building Technologies Program in cooperation with NETL to help develop research programs and technology implementation strategies based on a scientific analysis of the needs and operation of the commercial new construction market.

Record-Setting Lighting Panel Developed, Delivered, Displayed—

By incorporating a number of innovative technical advances, General Electric produced a 2-foot-square lighting panel that set a world record for light output using organic light-emitting diode (OLED) technology. Similar in appearance and function to a fluorescent lighting fixture, the lighting panel produced 1,200 lumens, about the same light output as an ordinary 100-watt incandescent lamp. OLED technology employs ultra-thin films of organic molecules that can be spread out over a large surface, causing the entire surface to emit light when the molecules are excited by an electric current. The demonstration panel was delivered for display at DOE's Forrestal Building headquarters in February 2004 at the conclusion of a 3-year, NETL-managed project aimed at reducing the technical risks that are keeping the lighting industry from embracing and developing this potentially energy-saving technology. The project was funded by the Office of Energy Efficiency and Renewable Energy's Building Technologies Program.

High-Efficiency Condensing Gas Water Heater Ready for Market—

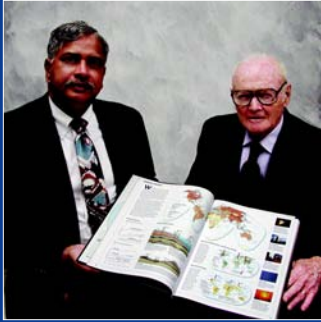
The A. O. Smith Corporation, a leading manufacturer of residential and commercial water heaters, has set mid-2005 for the rollout of a high-efficiency condensing gas water heater developed by TIAX under an agreement with NETL. Final testing of the newly designed water heater, which has a thermal efficiency greater than 90 percent, is being conducted by TIAX, A. O. Smith, and the Gas Research Institute. A. O. Smith is re-tooling its manufacturing facility and developing a marketing campaign to target residential users and light-duty commercial applications. The water heater was developed with funding from the Office of Energy Efficiency and Renewable Energy's Building Technologies Program.

Advanced Microturbine Surpasses 2,000 Hours of Testing—

Capstone Turbine Corporation's 200-kilowatt microturbine surpassed 2,000 hours of pre-production testing at the National Fuel Cell Research Center and Combustion Lab at the University of California, Irvine. The C200 microturbine was installed and commissioned, and began continuous, full-load operation in May 2004. Efficiency of the C200 averaged over 33 percent on a lower heating value (LHV) basis; commercially available microturbines operate well below 30 percent LHV efficiency. The natural-gas-fueled microturbine was developed with funding from the Office of Energy Efficiency and Renewable Energy's Distributed Energy Program.

Operating Framework Developed for Project Management Center—

A full year of planning and implementation led to the October 2004 opening of the Office of Energy Efficiency and Renewable Energy (EERE) Project Management Center. Consisting of nine field implementation organizations—EERE's Golden Field Office, EERE's six Regional Offices, NETL, and the State Technologies Advancement Collaborative—the Project Management Center is a virtual organization that manages formula grants, research and development projects, and projects funded from a variety of state and federal programs. The center takes advantage of the resources and capabilities of its members to manage projects using common business practices, and it affords EERE the flexibility to deal with uneven workflows.



ENERGY INFORMATION

Shared knowledge is the enabler of scientific progress. Recognizing this, DOE aims to be the definitive source of energy-related information and forecasts in the United States. NETL contributes by sharing its expertise within DOE and outside the federal government, in the United States and around the world.

NETL Experts Contribute to Encyclopedia of Energy—

Guided by an international team of editors, approximately 400 authors participated in producing the “Encyclopedia of Energy” released by Elsevier publishers in March 2004. NETL experts contributed seven sections to the six-volume set, including articles on the formation of coal resources, the chemical and physical properties of coal, coal transportation and storage, coal conversion, clean coal technology, fuel and non-fuel uses of coal, and coal mine reclamation and remediation. The publication has been lauded as “an invaluable reference guide” by Faith Birol, Chief Economist at the International Energy Agency, and a “most thorough and up-to-date work” by T. Nejat Veziroglu, President of the International Association for Hydrogen Energy. Gerald Doucet, Secretary General of the World Energy Council, noted that the publication contained “authoritative articles from leading experts in all aspects of energy.” The encyclopedia is expected to be internationally referenced for decisionmaking and policy development.

NETL Provides Hurricane Assistance—During and in the aftermath of Hurricanes Charley, Frances, Ivan, and Jeanne, six NETL employees were deployed to field locations to provide around-the-clock technical support to the Department of Homeland Security’s Federal Emergency Management Agency (FEMA). During federal emergencies, DOE coordinates the provision of emergency power and transportation fuels to support response operations, and it coordinates the restoration of normal electrical power and other energy supplies to the affected areas. In support of the former DOE Office of Energy Assurance, NETL staff were deployed to FEMA headquarters in Washington, FEMA’s regional office in Atlanta, and state emergency operations centers in Florida and Texas. Their primary responsibility was to collect and share information on the status of energy infrastructure, allowing FEMA to better coordinate emergency response to the affected areas. In addition, the NETL Energy Infrastructure and Security Research Group played a vital role in providing deployed NETL staff with accurate analytical and geospatial visualizations of possible energy impacts and maps of after-hurricane energy-restoration status.

European Union Seeks NETL Expertise—Most mine drainage problems are associated with mine voids rather than mine waste, and with abandoned mines rather than active operations, NETL’s Dr. Robert Kleinmann told a group of mine water engineers from six European countries, and representatives from three European Union agencies, at a November 2003 meeting in Brussels. Kleinmann discussed how remote sensing being developed by NETL could be used to rapidly inventory problems

caused by abandoned mine sites, and illustrated how technology has made it possible to remediate many problem sites that could not be dealt with a decade ago. Giving examples of how such efforts are being addressed elsewhere, Kleinmann highlighted Pennsylvania’s innovative approach of funding volunteer watershed organizations to coordinate and conduct site remediation, and how alkaline waste materials, such as coal combustion byproducts, can be utilized. The group of engineers was funded by the European Union to provide advice on needed regulatory and policy changes. Dr. Kleinmann was asked to attend the meeting to provide an independent perspective on the issue and the experts’ recommendations.

NETL Technology Manager Invited Speaker at Major International Conferences in Japan—

In support of the DOE-initiated International Partnership for the Hydrogen Economy, Dr. Mark C. Williams, NETL’s Technology Manager for Distributed Generation, delivered invited lectures at the 56th Dokiya Memorial International Symposium on Solid Oxide Fuel Cells in Tokyo, and the 15th World Hydrogen Energy Conference in Yokohama, Japan. Dr. Williams discussed the latest developments in hydrogen- and fuel-cell-based energy technologies; assessed related research, development, and demonstration progress and policy development in other countries; and identified opportunities for collaboration, particularly the export and demonstration of U.S. fuel cell technology abroad.

NETL Invited to Speak at Society of Petroleum Engineers’ Advanced Technology Workshop—

NETL was invited to give a presentation on its Microhole Technologies Program at the Society of Petroleum Engineer’s Advanced Technology Workshop on “Leading Edge Rigs” at Stateline, NV, in August 2004. The workshop was attended by both operators and service companies involved in construction of state-of-art drilling rigs for both offshore and onshore operations. Although NETL is not actually building such a rig, NETL’s microhole technology concept supports rig developers, especially those involved in drilling in environmentally sensitive areas. The “designer seismic” concept made possible by microhole technology was recognized as an enabling technology for pad and platform drilling. The potential of the concept for use in developing environmentally sensitive areas was especially apparent in the presentation by Anadarko on its DOE-funded project for methane hydrate exploration and development in environmentally sensitive Arctic areas. Successes such as the Anadarko work are key milestones to future oil and gas development in sensitive areas.

NETL Researcher Participates in National Research Council Review—Dr. Geo Richards, a researcher and Focus Area Leader in NETL's Office of Science, Technology, and Analysis, was invited to participate in a National Research Council review panel. The National Research Council is widely recognized for providing technical opinion and reviews of the highest technical caliber, and panels are formed from the nation's leading scientists and engineers. Dr. Richards served as an evaluator for proposed research in NASA's Intelligent Propulsion Systems Foundation Technology. The proposed research covers the use of advanced sensors and controls to operate high-efficiency propulsion turbines. The review was conducted in Washington in August 2004.

NETL Shares Oil and Gas Data with DOE Energy Information Administration—Under the terms of an agreement with NRG Associates Inc., NETL shares data with DOE's Energy Information Administration about virtually all known recoverable petroleum resources in the United States. NRG databases allow NETL and the Energy Information Administration to support a broad variety of oil and gas analyses, including petroleum resource assessment, production forecasting, basin and play evaluations, acquisition studies, and upstream technology reviews. These analyses are critical to DOE in developing and reaching realistic goals and milestones in its oil and gas program, and in evaluating the impact and benefits of related research and development.

NETL Updates National Energy Modeling System Costing Algorithm—A general costing algorithm for estimating refinery capital and operating costs has been developed by NETL analysts for the petroleum marketing module of the DOE Energy Information Administration's National Energy Modeling System. The new algorithm is similar to the algorithm used in the petroleum marketing module for the 2004 Annual Energy Outlook, but it has been updated and expanded to reflect the Energy Information Administration's current and future needs. In addition, a number of changes have been made to make the new algorithm conform to standard costing practices. Capital and operating costs are used within the petroleum marketing module to determine whether the capacity of refinery processing units considered in the model should be expanded in forecast years. The capital cost of an individual refinery unit includes all inside battery-limit equipment and installation. It is used to estimate total project capital investment, which also includes outside battery-limit and other one-time capital costs. A capital recovery factor is then applied to calculate an annual charge for the total unit investment less a tax credit for

depreciation. Non-labor-related fixed costs are also estimated from the capital investment. Operating labor costs are used in a similar fashion to estimate total labor-related fixed costs. Variable operating costs are calculated separately within the petroleum marketing module for each process unit. The updated costing algorithm will provide a more accurate representation of the current U.S. refining industry.

NETL Staff Briefs White House Task Force—A January 2004 presentation on three-dimensional watershed profiling technology was well received by the White House Task Force on Energy Project Streamlining. The airborne electromagnetic technology, which has a theoretical capability of mapping groundwater as deep as 1,500 feet below the earth's surface, has been used to map the shallow subsurface (approximately 75 feet) of Wyoming's Powder River Basin to determine the impact of produced waters resulting from coalbed methane operations on groundwater, streams, and irrigation systems. The project is part of DOE's effort to increase the nation's energy supplies while protecting and improving the environment.

DOE Joins U.S. Department of State in Training Foreign Service Officers—For the fifth consecutive year, NETL organized and conducted a weeklong course in coal and power technologies for Foreign Service Officers in the summer of 2004. The training covered—

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

Participants included 19 representatives from the U.S. Department of State, the U.S. Department of Commerce, and NETL, with Foreign Service officers from posts in Abu Dhabi, Bulgaria, China, Kazakhstan, Kosovo, Japan, and Mexico. The Foreign Service identifies free market opportunities abroad, and collaborates with international institutions on global issues such as the environment. By briefing the Foreign Service on capabilities and key contacts within U.S. industry, the annual course supports a number of National Energy Policy objectives.



AWARDS AND RECOGNITION

NETL's technologies, programs, projects, and people received awards and recognition from a wide variety of stakeholders in fiscal year 2004. External recognition affirms the value of NETL's work, and acknowledges NETL's contribution to solving America's energy and environmental challenges.

Awards and Recognition

NETL-Funded Technologies Win R&D 100 Awards—

Seven technologies developed by NETL researchers, or with support from NETL, received prestigious R&D 100 Awards from *R&D Magazine* in 2004. The R&D 100 Awards—sometimes called “the Oscars of Invention”—are given to the 100 most technologically significant products and processes of the year. Recognized by industry, government, and academia, an R&D 100 Award provides an important boost to new products just entering the marketplace.

- **Aspen Plus-FLUENT Integration Toolkit**—The Aspen Plus-FLUENT Integration Toolkit couples Aspen Plus process simulation software with FLUENT computational fluid dynamics models using CAPE-OPEN interfaces, the process industry standard. The toolkit provides, for the first time, the level of detail and accuracy needed for virtual power plant simulation. NETL researchers developed the toolkit in cooperation with computational scientists and engineers at Fluent Inc., ALSTOM Power, Aspen Technology Inc., and West Virginia University. Enductive Solutions sold the first license and training agreement for its use to a major chemical company in 2004.
- **T-2749 Fluidized-Bed Desulfurization Sorbent**—Developed by RTI International with assistance and funding from NETL, the effective, attrition-resistant, regenerable zinc-based sorbent is used in fast fluidized-bed reactors to remove gaseous sulfur contaminants from the high-temperature synthesis gas generated during coal gasification. Its invention may also allow other feed stocks—including petroleum coke, a waste product of the petrochemical industry; black liquor, a waste product of the paper-pulping industry; and municipal waste—to become viable sources of clean energy. The technology may reduce the capital costs of coal-based integrated gasification combined-cycle plants by \$60–\$80 per kilowatt, and should improve the thermal efficiency of the system by up to 2 percentage points. The sorbent will also achieve reductions in sulfur levels by over an order of magnitude compared to conventional amine systems.
- **Hydrogen Transport Membrane**—A hydrogen-selective membrane, developed at Argonne National Laboratory in partnership with NETL, separates pure hydrogen from gas mixtures generated by such processes as the gasification of carbon-based feed stocks and methane reforming. Because it can operate at elevated temperatures and pressures without becoming embrittled by hydrogen or poisoned by sulfur, the dense-ceramic membrane could enable direct production of hydrogen fuel from coal.
- **Optical Fiber Sensor Technology**—The Center for Photonics Technology at Virginia Polytechnic Institute and State University was honored for a fiber optic sensor developed under an NETL grant. Designed to operate under hostile downhole conditions, the sensor allows efficient and economic recovery of petroleum by providing reliable, cost-effective, real-time measurement and monitoring of key physical wellbore parameters such as pressure, temperature, flow, and acoustic wave patterns. The technology was successfully field-tested by ChevronTexaco, and licensed to Tubel Technologies for commercial development.
- **SmartScreensSystems™**—QRDC Inc. was recognized for its SmartScreensSystems mining technology, which uses a patented energy flow control system to transfer energy from “smart motors” directly to the screening medium, rather than to an entire vibrating screen machine. Developed with support from NETL under DOE’s Industrial Technologies Program, the system dramatically reduces energy requirements and equipment maintenance, as well as noise and vibration.
- **Radio Imaging Method System 4 (RIM-IV)**—Stolar Research Corporation was honored for its RIM-IV radio frequency device, which generates high-resolution tomographic images of features below the surface of the ground. Locating geologic anomalies and hazards ahead of mining operations improves mine planning, lowers operating costs, and reduces the risk of intersecting abandoned, potentially flooded mines. Mining companies, construction firms, and the military already have used the technology worldwide as a safe and effective means of subsurface exploration and extraction. The technology was developed with support from NETL under DOE’s Industrial Technologies Program

- SageGlass® Smart Window Glazing—Developed by SAGE Electrochromics Inc. with support from NETL under DOE’s Building Technologies Program, SageGlass technology provides important economic and functional benefits, including thermal comfort, elimination of glare on computer and television screens, protection of interior furnishings and fabrics from fading, enhanced security, and energy savings. Moreover, extensive testing indicates service lifetimes in excess of 20 years for SageGlass all-ceramic thin films.

NETL Project Helps Win “Top Plant” Recognition—

NETL provided technical assistance to a consortium of private-sector Indian organizations to help establish and commercialize a first-of-its-kind fuel management system. The system, installed at the Dahanu Thermal Power Station on India’s west coast, was instrumental in *POWER* magazine listing this 500-megawatt power plant as one of its “Top Plants of 2004.” India plans to double its installed electrical generation capacity to more than 200,000 megawatts in the near future. The efficient operation of the Dahanu plant demonstrates that advanced technologies can meet high environmental standards. This is important in the Indian market because it allows electricity to be generated near cities, minimizing transmission and distribution losses, which are currently higher than 30 percent in some regions of the country. NETL provided the technical assistance through a Participating Agency Service Agreement with the U.S. Agency for International Development.

“Projects of the Year” Award Goes to NETL

Technology—Development of H Class gas turbine technology under DOE’s former Advanced Turbine Systems Program, managed by NETL, culminated in the installation and successful startup of a 400-megawatt natural-gas-fired combined-cycle power plant in Baglan Bay, Cardiff, Wales, UK. The plant received one of three 2003 “Projects of the Year” Awards from *Power Engineering* magazine during the POWER-GEN International convention in December 2003. This new class of advanced gas turbines is manufactured by General Electric in Greenville, SC. Low emissions with high efficiency support the President’s Clear Skies and Climate Change Initiatives, and will reduce consumption of natural gas.

NETL-Sponsored Project Wins Award for Innovation—

A new insulation material that will help make low-cost solid oxide fuel cell power generation systems a reality received the Stoel Rives “Utah Innovation Award.” The nano-ceramic material, named CERCANAM, was developed by Ceramatec Inc. of Salt Lake City with support from a Small Business Innovation Research Grant administered at NETL. A key advantage of this castable, high-temperature, chemically stable material is that insulation components for solid oxide fuel cell stacks can be formed with a high degree of dimensional accuracy and stability, minimizing costly machining operations. Moreover, the material contains minimal silica, which could react with the high-temperature fuel stream entering the stack and have an adverse effect on performance. While the material represents a significant advance toward the SECA goal of developing cost-competitive, modular, 3- to 10-kilowatt solid oxide fuel cell systems by 2010, it can also be used in a broad range of other applications, including optical connectors and fire-retardant building materials.

NETL-Supported Fuel Cell Technology Receives EPA

Award—The Los Angeles Department of Water and Power, the nation’s largest municipal utility, received the 2004 Environmental Achievement Award from the EPA for leadership in environmental protection shown by the utility’s Fuel Cell Demonstration Program. Using molten carbonate fuel cell technology developed by FuelCell Energy with NETL support, the Los Angeles Department of Water and Power developed an internationally recognized distributed generation program demonstrating clean, efficient, and reliable onsite electric power generation. The EPA Region 9 Environmental Awards acknowledge individuals and organizations that contribute significantly to environmental protection in California, Arizona, Nevada, Hawaii, Guam, and tribal lands.

NETL-Supported Project Receives California’s Highest Environmental Honor—

At a ceremony held in Sacramento in December 2003, California Governor Arnold Schwarzenegger awarded the prestigious Governor’s Environmental and Economic Leadership Award to Inland Empire Utilities Agency (IEUA) for deploying energy-conserving innovations in a new 66,000-square-foot headquarters complex in Chino, CA. IEUA serves more than 700,000 people in a 242-square-mile area, distributing imported water and providing municipal and industrial wastewater collection and treatment. The award-winning innovations include utilization of methane gas generated from anaerobic digestion processes, a technology

developed and installed at the complex in partnership with NETL under the Office of Energy Efficiency and Renewable Energy's Biomass Program. IEUA expects the complex to become 100 percent energy self-sufficient within 2 years, saving more than \$800,000 per year in energy costs alone, and demonstrating that such smart project designs can save ratepayers money while improving air and water quality.

Microdrilling Technology Reaches *World Oil Magazine* Award Finals

—A novel microdrilling technology developed by researchers at Los Alamos National Laboratory with support from NETL was selected as a finalist for *World Oil* magazine's 2004 New Horizons Idea Award, which recognizes breakthrough thinking that will help guide the next generation of oil industry professionals. The miniaturization technology, which deploys a drill motor and bit on the end of conventional coiled tubing, could lead to rigless small-footprint drilling systems that can be lifted into remote areas by helicopter, significantly reducing environmental and visibility impacts. The technology was featured in the November 2004 issue of the *Journal of Petroleum Technology*, the flagship publication of the Society of Petroleum Engineers, and it continues to enjoy strong industry support as a lower cost approach to shallow drilling and less environmentally risky exploration.

NETL Environmental Management System Receives Enviro Star Award

—The Allegheny County Health Department in Pennsylvania recognized with a three-star award the voluntary pollution prevention practices being implemented through the environmental management system at NETL. The award, the highest under the department's Enviro Star Program, was made in April 2004, as part of Earth Day celebrations in Pittsburgh. The NETL environmental management system covers onsite research and development, site operations, and administrative support activities, and it conforms to International Standards Organization Standard 14001 requirements. Built upon DOE's Integrated Safety Management System, the system has yielded many improvements in pollution prevention, regulatory compliance, waste minimization, and quality assurance/control activities. NETL received a certificate signed by the Allegheny County Chief Executive and the Director of the Allegheny County Health Department, and a placard signifying NETL's role as a good neighbor and model for the community in implementing sound pollution prevention practices and programs.

NETL Earns Safety Awards—For the eighth consecutive year, NETL was recognized for outstanding performance in occupational safety and accident prevention. NETL received the 2003 "Quality" Safety Performance Award from the Western Pennsylvania Safety Council, a chapter of the National Safety Council, at the 79th Annual Safety and Health Conference in May 2004. In addition, NETL site-support contractors received the Outstanding Achievement Award for a twelfth consecutive year. The awards were made to organizations in western Pennsylvania that maintained the lowest U.S. Occupational Safety and Health Administration "lost workday case rates." Having worked 579,107 person-hours, employees at the NETL Pittsburgh site recorded a rate of only 0.34.

Patents Awarded for NETL Inventions—NETL scientists and engineers received or shared patents for seven new technologies during fiscal year 2004. Details about these and other NETL patents are available in the "Business" section of the NETL website:

- Process to Accomplish Autothermal or Steam Reforming Via a Reciprocating Compression Device
- Low Temperature Sorbents for Removal of Sulfur Compounds from Fluid Feed Streams
- Device and Method for Separating Minerals, Carbon, and Cement Additives from Fly Ash
- Transpiration-Purged Optical Probe
- Gas Sampling System for a Mass Spectrometer
- Planar Solid Oxide Fuel Cell with Staged Indirect-Internal Air and Fuel Preheating and Reformation
- Method to Remove Ammonia Using a Proton-Conducting Ceramic Membrane

NETL Associate Director Receives Fuel Cell Award

—Citing his "vision, leadership, and guidance of SECA, a new model for joint government and private industry technology research and development," the American Society of Materials International presented Dr. Joseph P. Strakey, Associate Director at NETL, with a Resolution of Appreciation. Dr. Strakey received the award at a special dinner held in his honor during ASM International's Materials Solutions 2003 conference held in Pittsburgh in October. The citation also acknowledges the SECA program as "a leader in the development and implementation of fuel cell technology."

NETL Technology Manager Receives Pathfinder Award—The Pathfinder Award, to be presented annually to people outside the fuel cell industry who have contributed significantly to the commercialization of fuel cells in the United States, was inaugurated by the U.S. Fuel Cell Council during the 2003 Fuel Cell Seminar in Miami Beach, FL. Dr. Mark C. Williams, NETL's Technology Manager for Distributed Generation, was one of the first four recipients of the award, and was recognized for 18 years of dedicated government leadership to the fuel cell industry. The U.S. Fuel Cell Council is an industry association of the world's leading fuel cell developers, manufacturers, suppliers, government agencies, and customers. It offers technical advice and networking opportunities, issues reports on the industry and industry segments, promotes public awareness of fuel cells and their potential, and establishes links among comparable activities around the globe.

NETL-Supported Researcher Wins Lester C. Uren Award—Dr. Alkil Datta-Gupta, Associate Professor of Petroleum Engineering at Texas A&M University, received the 2003 Lester C. Uren Award from the Society of Petroleum Engineers for his research in reservoir characterization and streamline-based flow simulation. Dr. Datta-Gupta has been the principal investigator on several research projects funded by DOE, the National Science Foundation, and various oil companies. Presented at the Annual Technical Conference and Exhibition of the Society of Petroleum Engineers, the award recognizes distinguished achievement in petroleum engineering technology by a society member under the age of 45.

NETL Scientist Receives Mining and Reclamation Award—The American Society for Mining and Reclamation presented its most prestigious award, the William T. Plass Award, to NETL's Dr. Robert Kleinmann for significant lifetime achievements and dedication to the advancement of mine land reclamation science and technology. Dr. Kleinmann, a division director in NETL's Office of Science, Technology and Analysis, developed technology used to retard acid mine drainage formation in coal mine refuse, and led pioneering research for predicting and avoiding acid generation, and for treating acid mine water less expensively. Active in the society for more than 20 years, he organized the society's largest and most successful conferences, and continues to serve as a technical division chairperson, and as Editor-in-Chief of the journal *Mine Water and the Environment*.

NETL Employee Honored as West Virginia's Outstanding Older Worker for 2004—Hugh D. Guthrie, a Senior Management and Technical Advisor at NETL, was selected as the 2004 Outstanding Older Worker for the State of West Virginia by Experience Works, the nation's oldest and largest provider of older-worker training and employment. Guthrie and the 51 other recipients of the award—one for each state, Puerto Rico, and the District of Columbia—were chosen for their leadership, learning, mentoring, community service, and contribution to their employers, following an extensive grassroots nomination effort. With 41 years of technical and management experience in private industry and 20 years in the federal government—including 3 years as the Director of Oil and Gas for the Ford Administration—85-year-old Guthrie has been variously described as “the world's leading technical expert on oil shale,” “a walking encyclopedia,” and “the Energizer Bunny®.” In endorsing his nomination as West Virginia's Outstanding Older Worker, NETL Director Rita A. Bajura noted his “continuing significant contributions to the laboratory's mission,” and said Guthrie is “a true gentleman—both in his professional and personal life.” The award winners were honored during a week of high-visibility events, including awards ceremonies and legislative hearings on issues important to seniors, in Washington.

NETL Researchers Receive Best Paper Award at International Gas Turbines Conference—A technical paper coauthored by researchers at NETL and Woodward Industrial Controls was selected as the best paper in controls, diagnostics, and instrumentation at the American Society of Mechanical Engineers TURBO EXPO 2003 conference. Entitled “Flame Ionization Sensor Integrated into a Gas Turbine Fuel Nozzle,” the paper describes the development and testing of the combustion control and diagnostics sensor (CCADS), invented at NETL and licensed to Woodward Industrial Controls. CCADS is incorporated into the fuel nozzle of a turbine combustor, and is used to monitor flashback, lean blow out, combustion dynamics, and equivalence ratio. This technology has been recognized by the international turbines community as a significant technical advance in real-time monitoring and diagnostics of turbine combustor operation. CCADS offers the potential for improving reliability, reducing emissions, and reducing the cost of power generation. Representatives from Woodward Industrial Controls and NETL attended the official presentation and accepted the Best Paper Award at the TURBO EXPO 2004 conference in June.

NETL Research on Methane Hydrate Inspires Award-Winning Student Theses—Phil Tsunemori and Namit Jaiswal of the University of Alaska at Fairbanks won first place and third place, respectively, from the Society of Petroleum Engineers for outstanding research in connection with the BP Alaska Methane Hydrate Project. BP Alaska, the University of Alaska at Fairbanks, and other partners are investigating the commercial viability and recoverability of methane hydrate and associated free-gas resources from Alaska's North Slope. Students at the university are providing laboratory analysis and reservoir- and economic-modeling support for the DOE-funded effort. The students' success demonstrates the important role that DOE will play in the future of the oil and gas industry, where it is estimated that 50 percent of all professionals will retire over the next 5 years.

Leading Trade Magazine Features DOE's University Turbine Systems Research Fellows Program—The June/July 2004 issue of *Gas Turbine World* featured an article on the highly successful University Turbine Systems Research Fellows Program, which provides undergraduate and graduate engineering students a sense of the real world of gas turbine engineering. Companies participating in the program, which is administered by the South Carolina Institute for Energy Studies in cooperation with NETL, sponsor 10–12 week internships with leading gas turbine manufacturing and service companies. Placing approximately 15 interns each year, roughly 80 percent of whom ultimately accept full-time positions with turbine-related companies, the program contributes significantly to the knowledge and skill base of the U.S. turbine industry.

NETL-Managed Project Featured in *Industrial Heating Magazine*—Technological advances in the production of very-fine-diameter silicon carbide fibrils achieved under the NETL-managed Fossil Energy Materials Program were reported in *Industrial Heating* magazine. Investigators at ReMaxCo Technologies Inc. developed an innovative process that greatly reduces the hazards associated with fibril manufacture and could slash product costs from nearly \$2,000 per pound to \$300 per pound. Used to reinforce high-temperature metals and ceramics, the fibrils may help meet materials challenges facing next-generation energy systems by improving the creep strength of combustion-chamber refractory tiles, producing high-temperature filter media for combustion gases, and improving the toughness of refractory metals.

NETL Project Highlighted in Professional Journal—Results of NETL's project with the Utah Geological Survey were reported in the October 2003 issue of the Rocky Mountain Association of Geologists' quarterly magazine, *The Mountain Geologist*. The Utah Geological Survey led a 4-year study of the lower and middle members of the Eocene Green River Formation, a highly oil-productive formation consisting of open- and marginal-lacustrine rocks deposited in and around Lake Uinta. The objectives of the study were to increase both primary and secondary hydrocarbon recovery through improved characterization of the reservoirs, thereby preventing the premature abandonment of producing wells. The project established an alphanumeric, log-based correlation scheme and nomenclature that reflect, as near as possible, time-correlative depositional cycles of the lower and middle members of the Green River Formation. The cycles are easily recognizable on geophysical well logs and can be correlated throughout most of the central Uinta Basin. Five intervals, each with distinct reservoir properties, were identified.



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