2010 NETL Accomplishments

U.S. DEPARTMENT OF ENERGY | the ENERGY lab
NATIONAL ENERGY TECHNOLOGY LABORATORY

Our Mission

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

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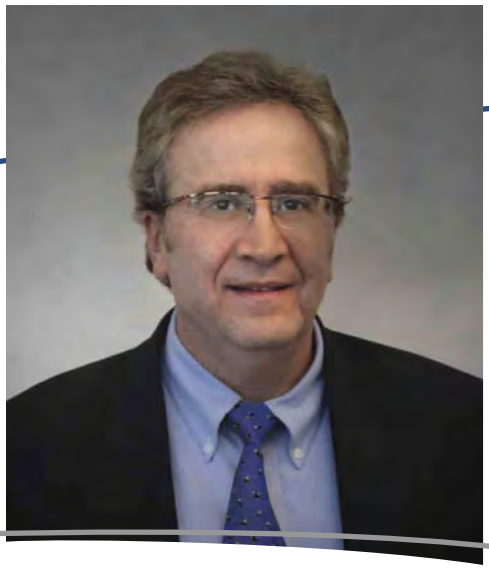

Anthony V. Cugini, Director

Innovative Solutions for Complex Energy Challenges

It is my pleasure to present the NETL (National Energy Technology Laboratory) 2010 accomplishments report. The achievements compiled in this report are the result of long-term efforts championed by many talented people. Our success is driven through onsite research, the work of our dedicated contractors, and our collaborations with fellow national laboratories, other government agencies, industry, and university partners.

As a national laboratory, NETL is unique in that we are actively engaged in all aspects of the U.S. Department of Energy mission to ensure America's energy future. We serve as a broad-based technical resource providing guidance on many strategic energy initiatives that address complex energy and environmental challenges. NETL is further distinguished by its strategic focus on applied research programs that are directly linked to our mission of technology deployment to the marketplace.

As you will learn from this report, we have achieved significant advances in our core program areas. For example, an innovative coal-drying technology that extracts more energy from high-moisture coal at less cost, while at the same time reducing potentially harmful emissions, was named Power Engineering magazine's 2010 Coal-Fired Project of the Year. The project, managed by NETL, was conducted with funding from the Clean Coal Power Initiative and was implemented at Great River Energy's Coal Creek Station. This technology proved so successful that full-scale dryer modules were constructed for the entire Coal Creek Station. Now ready for commercial deployment, this technology will be important to America's energy consumers since nearly one third of the electric power generated by coal comes from plants that burn high-moisture coal, making this technology a breakthrough development for efficient coal-fired power production.

A significant milestone was met by the Solid State Energy Conversion Alliance when its 2010 cost goal for solid oxide fuel cells was achieved: $700 per kilowatt for high-volume production. This cost baseline is comparable to existing central power generation technologies and reflects an 88 percent reduction in production cost. The application of cost-effective fuel cell technology will enhance industry adoption while increasing power plant efficiency and reducing pollutant emissions.

In addition, NETL's long-standing leadership in horizontal drilling and hydraulic fracturing, and their impact on natural gas recovery from hard-to-reach shale gas plays, has been widely recognized. Three decades of research by NETL and our partners helped drive shale gas production to account for nearly 14 percent of the dry natural gas produced in the United States, a number that is projected to

reach 45 percent by 2035. We are now making technological advancements in remediating flowback water produced during hydraulic fracturing and reducing other environmental impacts of shale gas drilling.

I am particularly pleased to report that NETL researchers received recognition from the U.S. Geological Survey for exemplary service to the nation. During the Deepwater Horizon oil spill in the Gulf of Mexico, a team of NETL scientists used advanced image analyses and fluid flow modeling, under extreme time constraints, to help provide accurate estimates of oil leakage rates and plume formation. The data provided by NETL researchers was used by Unified Command to set level of response. As an organization, we are extremely proud that our technical expertise was able to assist our nation in a time of extreme crisis.

I think you will agree that these achievements and the others presented in this year's report illustrate NETL's commitment to advancing energy technologies into the public arena where they will have a direct impact on Americans' prosperity by facilitating affordable, reliable, and environmentally responsible energy. NETL continues to judiciously invest U.S. taxpayer dollars in applied research programs that yield high rates of return, while ensuring environmental conservation.

NETL's successes in 2010 serve as another step in building and securing America's energy future. We have a long and successful history of providing innovative solutions to complex energy challenges, and I am honored to be a part of such an outstanding organization. The innovative, translational work conducted by NETL and its partners will continue to touch America's future.

Anthony V. Cugini, Director
National Energy Technology Laboratory

NETL Powers the Future of Energy

Affordable, reliable, and secure energy played a major role in powering the 20th century, but what about the coming decades? Can we harness our nation's vast fossil fuel resources without sacrificing clean air, clean water, and affordable power? Can we mitigate our dependence on fossil fuels through the use of alternate energy sources? Can we find new domestic sources of energy?

In 2010, as part of an effort to secure America's energy future, scientists and engineers working at NETL continued to address these vital questions. The *2010 NETL Accomplishments* report showcases NETL's cutting-edge research on coal-based power generation, natural gas and oil production, energy efficiency, power grid management, and more.

Coal is America's most abundant fossil fuel. In fact, coal-fired power plants provide nearly 45 percent of the electricity generated in the United States, despite accounting for only 30 percent of our power-generation capacity.

NETL is developing technologies to demonstrate a virtually pollution-free coal plant in time for the next wave of power plant construction. For example, NETL is leading national efforts to develop technologies for the safe, economical storage of carbon dioxide (CO_2). We are improving the ability to capture CO_2, inject it underground, and track its movement in deep geologic reservoirs. Similarly, we are helping the coal-power industry eliminate mercury and other pollutant emissions, reduce water use, and turn coal waste into marketable by-products.

Another important fossil fuel is petroleum. In 2010, NETL continued to demonstrate that, when traditional oil recovery is exhausted, enhanced recovery can coax even more petroleum from mature wells. As part of our carbon management effort, NETL is advancing CO_2 injection for enhanced oil recovery coupled with CO_2 storage. DOE studies indicate that we can produce another 40–45 billion barrels of oil from America's mature oilfields if we successfully divert a portion of the CO_2 emitted from burning fossil fuels to CO_2 injection. With improvements in technology, we are projected to double that number.

Natural gas, or methane, is a clean and convenient heating fuel. Though not as abundant as coal, the United States has significant natural gas resources, especially in unconventional plays. For decades, NETL scientists and engineers have made meaningful contributions to increasing production of coalbed methane and shale gas. In 2010, NETL turned its attention to protecting aquifers and improving ways to dispose of waste water during shale gas recovery.

NETL is also investigating another unconventional natural gas resource, methane hydrates. Trillions of cubic feet

Albany, OR. NETL's Albany site has been a premier center of energy research, particularly materials science research, since it was established in 1943 as the Northwest Electro-development Laboratory.

of methane hydrates lie under continental shelves around the world, but only now are we fully learning its characteristics and potential. Commercial production of methane hydrates may be decades away, but NETL researchers are pioneering approaches that will allow us to utilize this enormous energy resource in the future.

While NETL's focus is on fossil fuels, our research cuts across energy applications and industries. For example, NETL works closely with state energy programs and weatherization projects to support high-efficiency building and vehicle technologies. Our particle-flow simulation tools are used in hospitals, and we have demonstrated the potential of using fuel cells as auxiliary power units in the trucking industry.

To build on our success and launch the next generation of energy research, NETL enlists the brightest minds in academia and industry through partnerships such as the Power Systems Energy Research Center, Regional Carbon Sequestration Partnerships, and the newly launched NETL-Regional University Alliance. Together we are pursuing advanced power systems, carbon management, smart-grid technologies, and other future energy solutions.

Finally, NETL is committed to answering the public's questions about energy issues and promoting science, technology, engineering, and mathematics in our nation's schools. In 2010, NETL dedicated the Energy Challenge, a permanent educational exhibit at Pittsburgh's Carnegie Science Center, and we continued support of programs like the JASON Project and the DOE National Science Bowl. The reason for this is simple: the young students inspired by these efforts will become the scientists who solve the energy challenges of tomorrow.

The *2010 NETL Accomplishments* presents many important projects. It also details the impact NETL has on our country realizing low-cost energy, a safe environment, job creation, and long-term prosperity. Most energy experts agree that, as global energy demands accelerate, we must maximize the output of every energy resource. These solutions are likely to come from the world of research, and when it comes to research, NETL is the ENERGY lab.

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Fossil resources supply approximately 85 percent of our nation's energy, and experts project that they will remain the world's dominant energy resource through 2035. NETL supports research partnerships aimed at using fossil fuels in the most efficient, economic, and environmentally sound way possible.

Advanced Power Systems

Low-Impact, Cost-Effective Energy

NETL's advanced research projects aim to provide measurable benefits to coal and power system technologies, including improved efficiencies, lower costs, new materials, and new processes.

Why invest in advanced power generation technology?

Today's advanced power systems enable America to use its most abundant energy resource, coal, while reducing its environmental impact. Through enhanced efficiency and pollution control, NETL's clean coal technologies, such as coal gasification with CO_2 capture, and alternative energy sources, like fuel cells that run on synthesis gas, offer America a broad energy portfolio for enhanced energy security. Investments in the innovations that make these technologies possible can spur new commercial opportunities to improve cost, reliability, security, and environmental impact. NETL's cutting-edge research is pioneering a global clean energy future.

Advanced Power Systems

Low-Impact, Cost-Effective Energy

Gasification

NETL's research is advancing IGCC (integrated gasification combined cycle) technologies to meet U.S. energy needs while maintaining the highest environmental standards. By producing clean-burning syngas (synthesis gas) to fuel advanced turbines and fuel cells, IGCC offers many advantages over conventional coal combustion: greater energy efficiency, feedstock flexibility, and the potential to create multiple products, including hydrogen. NETL is supporting development of gasification technologies that will enhance competitiveness and increase the commercial acceptance of coal gasification both nationally and abroad. The success of these efforts will help position advanced gasification as the preferred technology to fulfill the nation's growing demand for clean energy.

Simulating the Future of Power Generation

AVESTAR™—NETL's Advanced Virtual Energy Simulation Training and Research simulator—is designed to train engineers and power plant operators to safely and efficiently operate IGCC plants. By providing comprehensive simulator-based training, AVESTAR is poised to develop a workforce prepared to operate these next-generation systems capable of 90 percent CO_2 capture.

In 2010, the AVESTAR team demonstrated the simulator's functionality by achieving a virtual IGCC plant start-up and shutdown, setting the stage for a 2011 unveiling of state-of-the-art facilities at NETL and West Virginia University's National Research Center for Coal and Energy. At the AVESTAR center, engineers and operators will interact with a highly realistic dynamic simulation of a coal-fired IGCC plant. Wearing a stereoscopic headset or eyewear, trainees will also be able to enter a 3-D virtual environment, moving freely through a simulated facility to learn operation, control, and safety.

NETL's Collaboratory for Process and Dynamics Systems Research group developed AVESTAR in close collaboration with West Virginia University, Fossil Consulting Services, Enginomix, the Electric Power Research Institute, and Invensys Operations Management.

What is APECS?

APECS, NETL's Advanced Process Engineering Co-simulator, is a first-of-its-kind process-equipment co-simulation software toolkit that aids engineers in improving the design and performance of power plants. APECS provides the high-level accuracy and detail needed to model and optimize fluid flow, heat and mass transfer, and chemical reactions that drive overall plant performance.

NETL-Developed Instrument Used to Optimize Circulating Fluidized-Bed Operation—NETL researchers have invented a relatively nonintrusive method for measuring the flow of solids (mass flux) within a circulating fluidized-bed reactor. The new NETL measuring instrument uses pressure transducers that respond to the impact of particles in the flow stream. Interpretation of the transducer signal allows mass flux to be determined even for dense flow conditions without the physical samples of the flow stream that are normally required. This approach is superior to traditional methods and offers a viable and economic way to determine local mass flux. Modification of this parameter will allow for system adjustments to ensure proper spatial and temporal location of reactants to enhance system performance for energy output and removal of environmental contaminates. Additionally, this instrument will be an important aid in validating computational models for energy systems. The device was tested at NETL's cold-flow circulating fluidized bed facility and the results published in *Powder Technology* (Vol. 203, No. 1, 2010).

Cost Estimation Module Developed for Coal-Fired Power Plant Simulations—NETL, in collaboration with researchers at Carnegie Mellon University, has developed a cost estimation module for use in simulations of conventional pulverized coal plants and IGCC systems. This standardized, systematic approach to cost estimation reduces project risks with better cost accuracy. Economic decision making occurs earlier in the design process, ensuring energy plant projects are completed much faster and at significant savings. The module uses Carnegie Mellon University's integrated environmental-control model to calculate plant capital cost, operating and maintenance cost, and the total cost of electricity produced, based on the Electric Power Research Institute's technical assessment guide methodology. The cost estimation module is compliant with the CAPE OPEN software standard and can be used in the CAPE OPEN–compliant Aspen Plus steady-state process simulator and the NETL Advanced Process Engineering Co-simulator.

New APECS Release Reduces Time and Cost of Energy Process Innovations—The newest release of NETL's award-winning APECS (Advanced Process Engineering Co-simulator) has been integrated with FLUENT 13.0 software capabilities to provide an improved engineering tool suite to co-simulate power generation processes. APECS version 2.04 further reduces the time and cost needed to foster energy plant innovations by seamlessly integrating process simulation with high-fidelity device-scale simulations built using FLUENT computational fluid dynamics software. The advanced technology behind APECS version 2.04 includes many new features that make it easier, faster, and cheaper for users to optimize existing and future plant designs with a high degree of confidence that predicted results will be realized. The APECS software was developed by a collaborative team that includes NETL, ANSYS, and Aspen Technology. In addition, ALSTOM Power has been a valuable industrial partner applying APECS co-simulations to a wide variety of energy applications, including conventional pulverized coal combustion, oxy-combustion, IGCC, chemical-looping combustion, and gasification.

Advanced Power Systems

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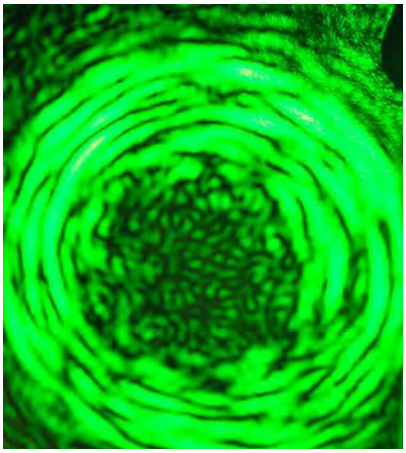
Gasification



NETL scientists are constructing extremely fast and accurate Raman gas sensors for measuring hydrocarbon gases and other mixtures of scientific interest.

Raman Gas Sensing Technique Approaches Real Time—NETL researchers and collaborators at the University of Pittsburgh have devised an extremely fast and accurate approach for sensing hydrocarbon gases and other mixtures of scientific interest. The sensor system builds on the improved modeling of light transmission through metal-lined capillaries. With inner diameters as small as 250 microns, these mirror-lined gas-sampling tubes greatly enhance signal collection from laser Raman scattering used to analyze fuel gas composition. The technique can achieve complete multispecies gas characterization in less than a second with concentration accuracies better than 0.1 percent for most common gases. By treating the light-transmitting capillaries as waveguides rather than optical fibers, the improved model produced results that matched the performance of an experimental system within the error limits of the equipment. The unprecedented detection speed and accuracy of Raman gas-sensing instruments would improve control of gas turbines, fuel cells, and reciprocating engines, particularly in applications where the fuel composition could change rapidly, such as when switching from coal-derived syngas to biogas or natural gas. The results of this work are described in the *Journal of the Optical Society of America B* (Vol. 27, No.12, 2010).

NETL Develops Rapid Gas Analysis Technique—NETL researchers have developed a technique that can measure trace metals present in liquid- and gas-phase process streams at concentrations below 1 part per billion. The technique uses a modified GC-ICP-MS (gas chromatograph-inductively coupled plasma-mass spectrometer) to produce results 50 times faster than established methods. Testing at the National Carbon Capture Center at Wilsonville, AL, showed that at a temperature of 250 °C, the GC-ICP-MS detected trace levels of nickel and selenium, and 5–8 parts per billion of mercury in a raw syngas stream. This new approach dramatically reduces the response time for measuring trace components in coal syngas or flue gas, which is important for assessing cleanup requirements for advanced coal power production systems, including integrated gasification and fuel cell technology.

Significant Milestone Reached Toward Commercialization of Ion-Transport-Membrane Oxygen Technology—Working in cooperation with NETL, engineers at Ceramatec, Inc., of Salt Lake City, UT, have exceeded production targets for a prototype manufacturing line that will produce commercial-size membrane wafers of the ion transport membrane called "ITM Oxygen." The wafer manufacturing line, when completed, will have the capability to produce membrane components required for a process that can separate 100 tons per day of oxygen. The achievement results from optimizing more than 20 key process-control parameters and represents a critical step toward realizing the superb cost-reduction potential of the ITM Oxygen technology over previous oxygen-separation technologies. The benefits of the efficiency of ITM-produced oxygen could help partially offset carbon capture costs for IGCC and oxy-combustion boilers. System

The National Carbon Capture Center is furthering national efforts in reducing greenhouse gas emissions, such as CO_2.

studies predict that this novel air-separation technology may reduce costs of advanced IGCC applications when integrated with standard and custom turbo-machinery.

Novel Pre-combustion Carbon Capture Membrane Tested at National Carbon Capture Center—Researchers at Membrane Technology and Research, Inc., working in collaboration with NETL have developed a new polymer membrane for CO_2 capture. In field tests conducted at the National Carbon Capture Center, the Proteus™ membrane was evaluated continuously for 3 weeks using a shifted coal-derived syngas containing sulfur components (780 parts per million of hydrogen sulfide). Preliminary analysis shows that these membranes can capture 90 percent of the CO_2 from an IGCC plant while increasing the levelized cost of electricity by approximately 15 percent. Conventional absorption technologies are associated with increases in the levelized cost of electricity of 25–30 percent for the same capture performance.

NETL Researchers Illuminate Catalytic Activity of Iron Oxide Catalyst Particles—NETL scientists completed a series of experiments at Lawrence Berkeley National Laboratory's ALS (Advanced Light Source) facility to learn more about how particle size, shape, structure, and defect differences affect the WGS (water-gas shift) activity of iron oxide catalyst particles. Using a specialized technique, NETL researchers determined the reaction mechanisms of iron-based WGS catalysts, the electronic structure changes required to activate them, and the molecular intermediates involved. Findings showed that defects residing at the edges of a catalyst's crystalline lattice, and to some extent the interactions of these defects with underlying support material, seem to be critical features governing WGS activity. Access to the ALS—a $99 million user facility that provides extremely intense soft x-ray light for electronic structure measurements, crystallography, and x-ray microscopy—is based on a highly competitive, peer-reviewed proposal process. Results of the NETL studies were published in the *Journal of Physical Chemistry C* (Vol. 114, No. 51, 2010) and could help guide the production of cheaper and more efficient WGS catalysts for use in transforming gasified coal into useful fuels.

What is produced water?

Produced water is the water extracted with oil and natural gas during their recovery. Historically, about 90 percent of this water, which may contain salts, oil, and various inorganic compounds, has been injected into disposal wells. Today, NETL and others are devising ways to creatively reuse and clean up produced water.

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Fuel Cells

Alternative energy sources play an important role in our national strategy to reduce U.S. dependency on petroleum. SOFCs (solid oxide fuel cells) not only produce electricity from a variety of fuels, including coal, they do so with great efficiency. Advanced coal-fueled integrated gasification–fuel cell (IG-FC) systems are ultimately projected to achieve at least 99 percent CO_2 capture, up to 60 percent efficiency, and near-zero emissions of criteria pollutants while consuming significantly less water and producing electricity at a commercially competitive cost.

"My favorite part of my job is seeing development occur. I began in fuel cell technology about 10 years ago, and since that time, there's been about an order of magnitude improvement in the ability of that technology to convert fuel to electrical energy. So, it's a serious advancement, and I'd like to see that keep on growing."

Randall Gemmen
NETL reseacher

Model Helps NETL Examine Hybrid System Response to Power Demand Changes—There is significant interest in using the heat generated from the operation of an SOFC to supplant the normal combustion process of gas turbine systems. Because the turbine uses heat produced by an SOFC to produce work, the hybrid system is capable of an overall system efficiency that greatly exceeds those of either system alone. One of the most critical problems that must be addressed in gas turbine–fuel cell hybrid technology is temperature control. A hybrid system designed to operate efficiently for a given base load may not be easily extended to accommodate peak loads. Using ASPEN PLUS® simulation software with special modules to calculate fuel cell performance, NETL scientists have modeled a simple hybrid system configuration consisting of a standard SOFC and a single compressor-turbine pair. The simulation model was used to determine the effects of key configuration parameters on system temperature. To explore the limitations of the system, the configuration model was then scaled over a range of fuel input and power output parameters. Results of this work were published in the *Journal of Fuel Cell Science and Technology* (Vol. 7, No. 1, 2010).

NETL Pyrochlore Catalyst Reforms Liquid Fuels for SOFC Use—An NETL-developed catalyst exhibited stable near-equilibrium performance while reforming biodiesel throughout a 100-hour test. Liquid biodiesel fuel reacting with air and steam across the monolithic-structured pyrochlore-based catalyst produced hydrogen-rich syngas (synthesis gas) that powered a fuel cell in the NETL fuel cell test facility. The catalyst was also successful in reforming commercial diesel fuel during more than 1,000 hours of continuous testing at NETL, and kerosene-based military logistics fuel (JP8) during a 100-hour test in collaboration with West Virginia University. The technology will help make SOFC-based auxiliary and distributed power units practical and economic for military and civilian uses.

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Solid Oxide Fuel Cells

SOFCs can use a wide range of fuels, including coal synthesis gas, natural gas, diesel, biogas, and hydrogen. They are also inherently modular, and the technology is readily scalable.

Solid State Energy Conversion Alliance—In partnership with industry, university, and national laboratory members participating in SECA (Solid State Energy Conversion Alliance), NETL aims to develop a low-cost, high-performance, robust SOFC technology suitable for large (greater than 100 megawatt) coal-fueled central generation applications. The SECA Industry Teams are assisted by participants in the NETL-supported SECA Core Technology Program, who develop the science and technologies for overcoming specific technical challenges and barriers to meeting SOFC system cost reduction and performance improvement goals. In addition to those offered here, other significant accomplishments are reported in the 2010 SECA Accomplishments Summary available at the NETL website.

SECA Team on Target to Surpass Goal—The SECA Industry Team led by FuelCell Energy, Inc., forecasts a cost of approximately $650 per kilowatt for producing the power block of an IG-FC plant, surpassing the FY 2010 SECA goal of $700 per kilowatt (in 2007 dollars). The estimate is based on the realized performance of the team's fuel cell designs, IG-FC performance and cost models, and conventional ceramic manufacturing processes.

Fuel Cell Design Exceeds Goal—The improved fourth-generation fuel cell design developed by SECA member Delphi Automotive Systems achieved a power density that exceeded SECA 2011 goals with performance of 0.81 volts per cell using fuel consisting of 48 percent hydrogen, 48 percent nitrogen, and 3 percent moisture. A 25-cell stack based on the design produces power in excess of 5 kilowatts and is being used as the basis for a proof-of-concept power plant being developed by SECA Industry Team leader, UTC Power.

SECA Team Demonstrates Power Density Progress—The SECA Industry Team led by Rolls-Royce Fuel Cell Systems has demonstrated a 36 percent increase in power density for its integrated planar SOFC. Higher power density allows smaller overall fuel cell systems for a given power rating, which translates to lower capital cost for the power plant and lower cost of electricity.

NETL Analyzes IG-FC Performance—NETL completed an analysis of multiple IG-FC plant configurations for both atmospheric and elevated-pressure fuel cell operating conditions using different levels of technology maturity. The analysis projects future cost and performance benefits resulting from SOFC technology development, provides DOE with a basis for selecting the most appropriate technology development pathway, helps prioritize research and development, and measures programmatic success. The pathway study, available at the NETL website, includes findings such as these: near-zero emissions, including greater than 99 percent carbon capture (greater than 97 percent for pressurized SOFCs), may be achieved; significant performance and cost advantages of IG-FC systems with either a commercial or advanced gasifier may be realized over today's IGCC (integrated gasification combined cycle) and pulverized coal systems technology when considering CCUS (carbon capture, utlization, and storage); advanced IG-FC efficiency without CCUS is significantly better than that of IGCC (approximately 57 percent versus 40–42 percent), and with CCUS is comparable in cost to today's IGCC without CCUS (approximately $65 per megawatt-hour versus $60 per megawatt-hour); water consumption for IG-FC is about half that of natural gas combined cycle and about a third of IGCC.

New Infiltration Technique Shows Promise—Researchers at NETL and West Virginia University have successfully infiltrated SDC (samaria-doped ceria) into a conventional SOFC cathode composed of strontium-doped lanthanum manganite. The SDC is applied as a liquid, but subsequent thermal processing deposits a homogeneously distributed array of sintered nanoparticles onto the surface of the cathode backbone. Experimental results show that polarization resistance of the infiltrated cathodes can be reduced significantly compared to un-infiltrated cathodes, and the portion of the cathode that is active toward oxygen reduction is increased at least threefold. The investigation is discussed in the Elsevier *Journal of Power Sources* (Vol. 196, No. 5, 2010).

New Alloy May Lower Costs—Collaborators at NETL, ATI Allegheny Ludlum Corporation, and Pacific Northwest National Laboratory have successfully modified the metallic alloy AISI 441 and taken an important step toward achieving the SOFC electrical interconnect lifetime target of 40,000 hours or more. The suitability of AISI 441—an inexpensive, commercially available ferritic stainless steel—would mean lower manufacturing and sunk costs compared with producing state-of-the-art high-temperature metal alloys for SOFC electrical interconnect service.

Ceramic Coatings Protect Fuel Cell Components—Product developers at NexTech Materials have demonstrated impressive corrosion resistance for metallic components in an SOFC stack that are protected by ceramic coatings applied by the low cost, easily-scaled ASD (aerosol spray deposition) process. The cost for ASD-coating large interconnects is projected to be within DOE targets.

Advanced Power Systems

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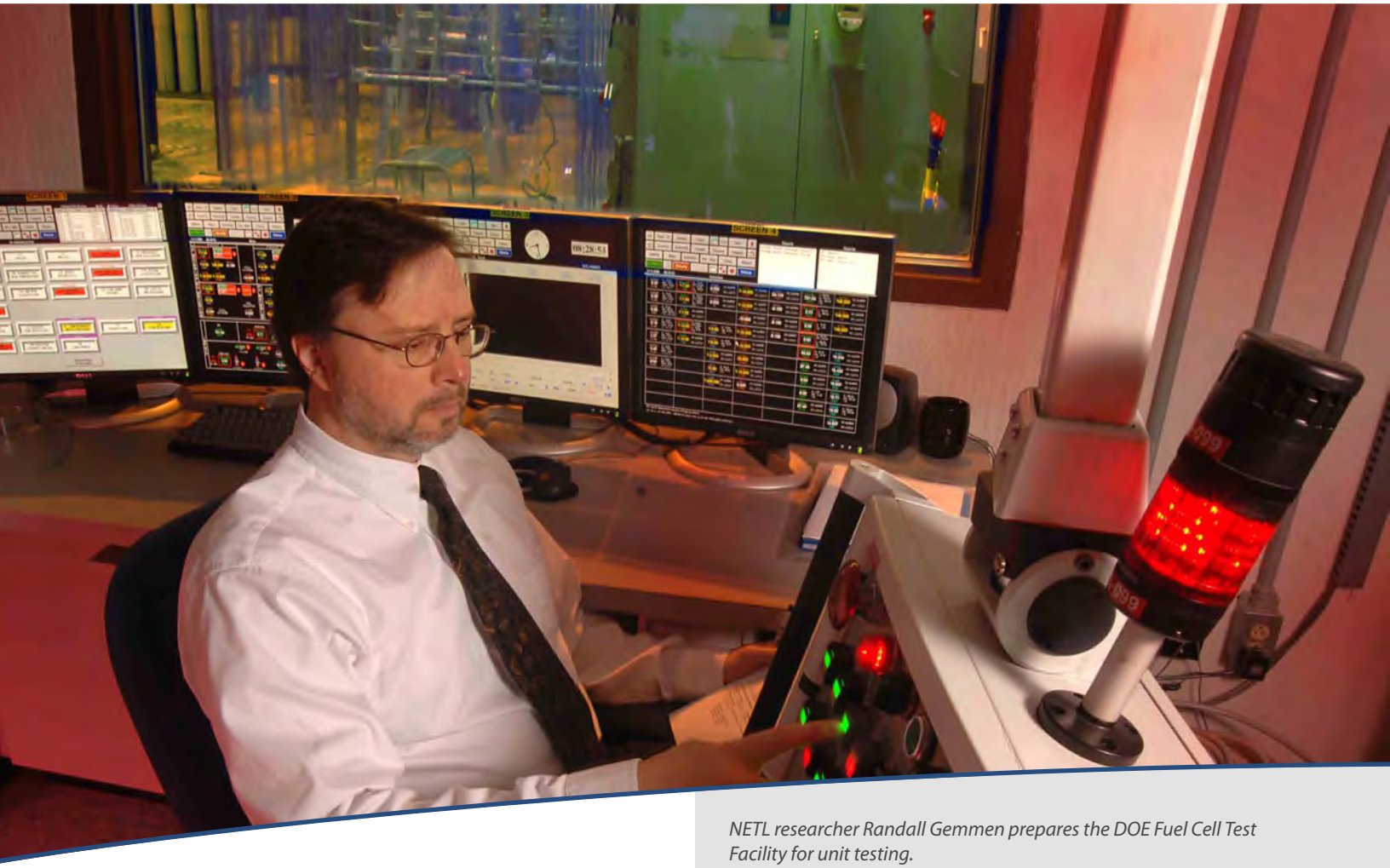


NETL researcher Randall Gemmen prepares the DOE Fuel Cell Test Facility for unit testing.

SECA Reaches 2010 Program Goal

Fuel cell technology has traditionally been too expensive for broad penetration into commercial markets. To be practical for widespread use, fuel cell systems need to be mass produced and they need to generate affordable power. NETL's SECA (Solid State Energy Conversion Alliance) program achieved its 2010 power block cost goal of $700 per kilowatt for high-volume production, which is comparable to cost baselines for existing stationary power generation. SECA's achievement reflects an 88 percent reduction in cost over the course of the program, supported by a four- to fivefold improvement in stack power density, a fivefold increase in cell size, and a twenty-fivefold increase in stack size. Based on this exciting progress, DOE projects that SOFC (solid oxide fuel cell) technology could be a cost-effective power generation technology by 2020.

Since 1999, SECA, a collaborative effort between NETL and our research partners, has been devoted to the development of low-cost, modular, fuel-flexible SOFC technology. SECA's Core Technology Program has supported dozens of innovative fuel cell projects from leading universities, national laboratories, and businesses. These projects provide vital research and development, as well as

Research Highlight

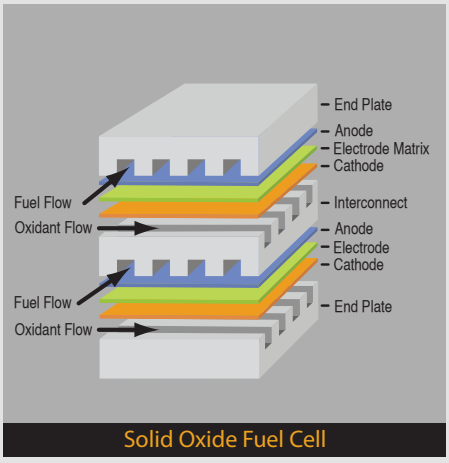
How do we reduce the CO_2 that is released into the atmosphere from coal-powered plants? SECA's research may provide an answer.

testing support to SECA Industry Teams, who leverage the collective ingenuity of the Core Technology Program to pursue innovations.

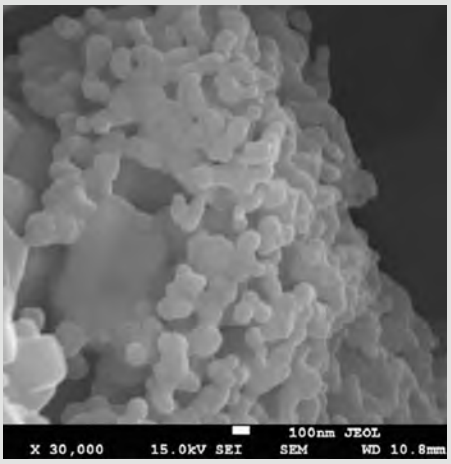
SECA's primary goal is to deploy fuel cells in high-efficiency, near zero-emission IG-FC (integrated gasification-fuel cell) systems. The application of SOFC technology in gasification-based power plants increases the efficiency of the plants. Pollutant emissions are also significantly reduced, and SOFC-based IG-FCs appear well suited for use in power plants that use CO_2 capture technologies.

SOFC-based power generation systems are very efficient compared to combustion-based technologies and result in decreased emissions, particularly NO_x (nitrogen oxides). Further, SOFCs, which are capable of using a wide range of fuels, can lower CO_2 emissions and increase CO_2 capture capabilities because fuel and air do not mix in an SOFC system. Isolation of the fuel stream permits 99 percent CO_2 capture and easy recovery of process water, resulting in considerably lower water consumption compared to commercial technologies. Systems containing improved fuel cell technology, in combination with heat recovery subsystems and commercial CO_2 capture, can easily surpass Office of Fossil Energy goals that include 45–50 percent efficiency, less than 2 parts per million NO_x, and at least 90 percent carbon capture.

It's easy to see how SECA technologies now in development could make future coal-based power systems dramatically more efficient and cleaner while keeping electricity affordable. It is also worth noting that fuel cells are a modular, scalable technology, meaning they can be manufactured commercially and installed in a variety of industrial applications. Successful demonstrations of SECA fuel cell technology in auxiliary power units for the trucking industry and as potential power sources for unmanned underwater vehicles for the U.S. Navy speak to the flexibility of SECA fuel cell technology. By providing America with a cleaner, more affordable way to generate energy, fuel cell technology can help us secure a better future.



Much like a battery, a fuel cell uses an anode, a cathode, and an electrolyte to generate electricty directly from the chemical energy of the fuel.



Scanning electron microscope image of an infiltrated cathode. The newly formed nanoscale material shown here enhances oxygen reduction, creating less CO_2.

Advanced Power Systems

Low-Impact, Cost-Effective Energy

Turbines

Turbine research at NETL is advancing technologies that will enable the development of turbine-based systems that use coal more cleanly, efficiently, and at lower cost. Our research is developing high-temperature systems with stronger and more efficient components and minimal emissions. Through our own onsite research, collaborations with U.S. universities, national laboratories, and partnerships with turbine manufacturers, NETL is making great strides in advancing more efficient and lower-cost power plants with CO_2 capture. These advanced power plants are made possible—and economic and energy security are enhanced—by retaining U.S. technology leadership in high-performance gas turbines.

NETL-Designed Hydrogen Fuel Injector Demonstrates Stable Operation—NETL researchers have completed testing a novel low-emission hydrogen-diffusion flame injector for gas turbine application. The injector design features a dense array of small-diameter jets that allow high-velocity, nitrogen-diluted hydrogen fuel to flow to the combustor at realistic firing rates. The multiple discrete, compact, highly strained diffusion "flamelets" produced with this design enable fast quenching of combustion temperatures to reduce formation of the pollutant NO_x (nitrogen oxide).

NETL-Regional University Alliance Team Advances Cooling Technology Critical for Advanced Turbines—Researchers at NETL, and Regional University Alliance partners at the University of Pittsburgh and Virginia Tech, have demonstrated significant internal, double-wall, skin-cooling enhancement using novel pin-fin arrays. In bench-scale tests, the arrays improved heat transfer by nearly a factor of 4.5 over smooth-channel architectures—an outstanding technological achievement for single-phase forced convection enhancement for turbine airfoil cooling. Other geometric changes, detailed in NETL's *FY 2010 Turbine Annual Report*, led to significant increases in the effectiveness of external airfoil film cooling and could be applied to future gas turbine engines where inlet operating temperatures may exceed 1,400 °C.

NETL Collaborations Enhance Performance of Turbine Thermal Barrier Coatings—Researchers at NETL, along with university and industrial research partners, have made outstanding progress in developing protective coatings that have potential to extend the life of turbines operating at extreme temperatures:

- Working in conjunction with commercial metal and coating suppliers, researchers at NETL and Coatings for Industry, Inc., demonstrated at bench scale a newly developed, low-cost, diffusion bond-coat system that exhibited extended oxidation resistance and excellent high-temperature life compared to current state-of-the-art materials.
- In conjunction with the University of Pittsburgh, NETL conducted bench-scale cyclic tests showing that high-purity, low-density thermal barrier coatings exceeded the thermal stability of conventional yttria-stabilized zirconia thermal barrier coatings.
- The University of Pittsburgh-NETL team also demonstrated that diffusion barrier coatings could reduce elemental inter-diffusion while retaining high-temperature oxidation resistance.
- The NETL-University of Pittsburgh team evaluated existing and potentially new coating compositions and determined appropriate thicknesses of extreme-temperature overcoat layers that may be used in advanced high-temperature land-based engines.

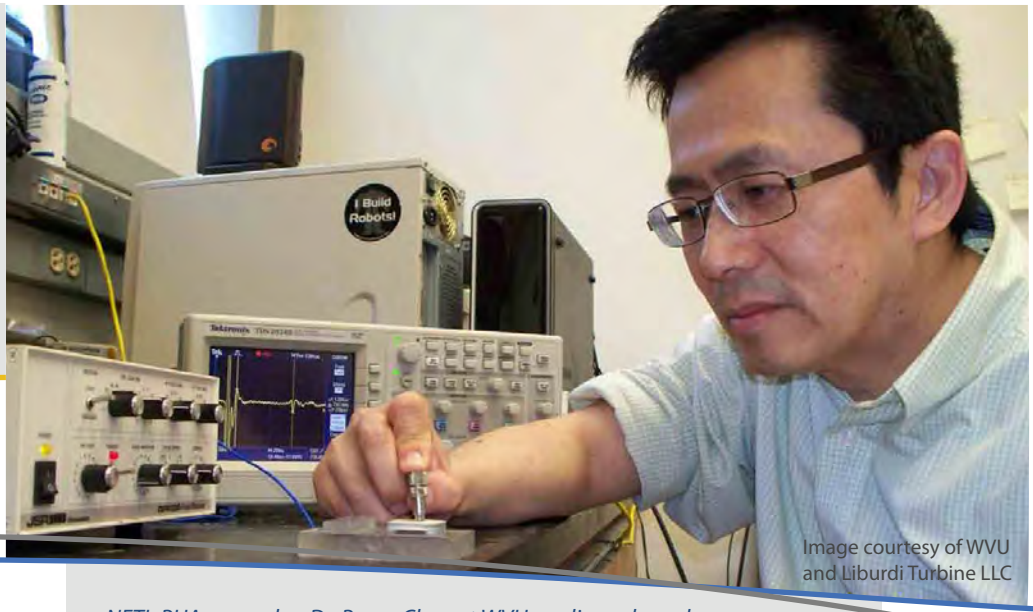


Image courtesy of WVU and Liburdi Turbine LLC

NETL-RUA researcher Dr. Roger Chen at WVU applies pulse-echo techniques to thermal barrier coating combustion liners.

New Non-destructive Evaluation Techniques Detect Onset of Thermal Barrier Coating Failure

As part of the NETL-Regional University Alliance, NETL researchers and their partners at WVU (West Virginia University) have developed two techniques to predict early failure in thermal barrier coatings of advanced gas turbine engines.

Thermal barrier coatings provide corrosion protection in engines operating at high temperatures. Failure of these coatings can expose an engine to costly heat damage, causing component failures, which require expensive maintenance, or lead to power outages.

In bench-scale tests, the NETL–WVU team demonstrated that their new techniques could prevent such failures by detecting coating damage before any external signs become obvious. The novel approaches examine variations in average surface stiffness (measured by micro-indentation techniques), as well as wave reflection amplitude and travel time (observed by pulse-echo non-destructive evaluation techniques). Both novel approaches are projected to be cost-effective, time-efficient evaluation tools.

Notably, the NETL–WVU technique has already been used in industrial applications. In response to the pulse-echo technique's success, a field-service supplier provided researchers with an in-service combustor liner and requested identification where refurbishment may be needed.

Advanced Power Systems

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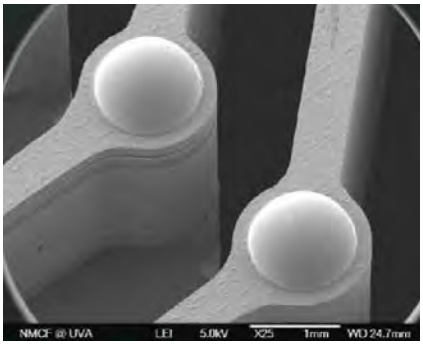
Turbines



For generations, turbines have been the world's energy workhorses. Today's power generation systems continue to rely on turbines to provide secure U.S. electric power production. The image above shows the advanced trailing edge feature (ceramic core) on gas turbine blades.

Novel Ceramic-Core Casting Technology Enhances Heat Transfer and Performance of Gas Turbine Blades—The next generation of gas turbine engines must run hotter to provide improved performance, greater efficiency, and reduced emissions. To meet these goals, new turbine blade designs are needed that have improved internal cooling passages to allow the blades to withstand higher operating temperatures. With assistance from an NETL-managed DOE Phase I Small Business Innovation Research award, Mikro Systems, Inc., has developed a unique ceramic-core casting technology that permits the intricate design and casting of enhanced heat-transfer features on gas turbine blades. This method allows new cooling surface features to be created that would not be possible with current casting processes. Further, this improved core casting technology will seamlessly integrate into existing multimillion dollar casting processes used by the industry and quickly revolutionize the industry's ability to enhance both existing and future turbines with new blade designs. Improved heat transfer within gas turbine blades will result in increased performance, lower manufacturing cost, and reduced emissions.

Innovative Micro-mixing Fuel Injectors Demonstrate Superior Performance and Ultralow NO_x Emissions—Working under an NETL-sponsored project, researchers at Parker Hannifin have demonstrated enhanced combustion performance with ultralow NO_x emissions by using novel micro-mixing turbine fuel injectors powered by high-hydrogen fuels. These scalable, high-performing, multi-point injectors utilize multiple small mixing cups in place of a single conventional large-scale premixer. The small size enables fuel and air to mix rapidly within the cups, thereby providing well-premixed reactants to the flame front, which minimizes NO_x emissions. The manufacturing process enables flexibility in the design, yielding injectors with superior mixing and combustion capabilities. Additionally, the micro-mixing fuel injectors are scalable to all engine sizes, are very economical, and are able to burn a wide range of fuels, from natural gas to synthesis gas to high-hydrogen fuels. The excellent emissions and performance results demonstrate the utility of micro-mixing fuel injectors for challenging high-hydrogen fuels. The newly developed technology is easily adaptable to large-scale engines, and future work is planned to integrate this technology into larger combustion engines.

NETL Facility Gaining International Recognition—Several modeling groups in the United States and Europe—including Siemens, Lawrence Berkeley National Laboratory, the Technical University of Eindhoven (Netherlands), and the Italian Research Agency on New Technologies, Energy, and Environment—have started using the experimental data generated in NETL's SimVal (Simulation Validation) combustor to validate their computational fluid dynamics codes for modeling advanced combustion processes. The SimVal combustor is being

used to better understand combustion and emissions issues related to variations in the properties of different fuels, such as natural gas and hydrogen-based fuels. SimVal provides the capability to directly observe high-pressure combustion processes at realistic gas turbine conditions. The system is uniquely suited to provide combustion data that will improve the fundamental understanding of key processes in turbulent combustion and may promote the development of novel, ultralow emissions, fuel-flexible combustors.

NETL's Unique Turbine Program Focuses on Industry Needs — The UTSR (University Turbine Systems Research) Program supports scientific research to develop advanced turbines and turbine-based systems that will operate cleanly and efficiently when fueled with coal-derived syngas (synthesis gas), hydrogen fuels, and other fossil fuels. Funded and managed by NETL, research projects focus on combustion, aerodynamics, heat transfer, and materials in support of DOE's Office of Fossil Energy's Advanced Turbine Program goals. UTSR is unique in that it provides a dynamic interaction among government, industry, and universities with a focus on applied research projects that directly address turbine industry needs. It is anticipated that the deployment of research results will have a direct, positive impact on turbine performance. Current targets for UTSR participants include the following:

- A key goal for the University of Texas at Austin is to create a simulation that models the deposits that form on gas turbine components operating on coal-derived syngas so that designs can be created to improve turbine efficiency. University researchers developed a process in which molten wax particles of the appropriate size and temperature are used to simulate contaminants in a laboratory test facility. Simulations of depositions to turbine components were verified by industry partners to be representative of those occurring in operating turbine engines.

- Virginia Tech is investigating the dynamics of syngas ash deposits on the edge of a turbine vane by using large-eddy simulations. They have developed detailed deposition profiles that model surface ash deposition—the first such comprehensive model of its type that can be used for calculating ash deposition.

- Using experimental data, researchers at the Georgia Institute of Technology have developed a physics-based model for predicting turbulent flame speed in turbines. These results and models are being used to develop a combustion technology that allows gas turbines to operate with low emissions when using high-hydrogen fuels.

What is syngas?

Synthesis gas, or syngas, is a mixture of carbon monoxide and hydrogen, which can be generated by reforming carbonaceous fuels such as natural gas, biomass, or coal. Syngas is valuable for many chemical processes, such as producing synthetic fuel, plastics, fertilizer, and other products, and it can be directly used to produce electricity in a solid oxide fuel cell.

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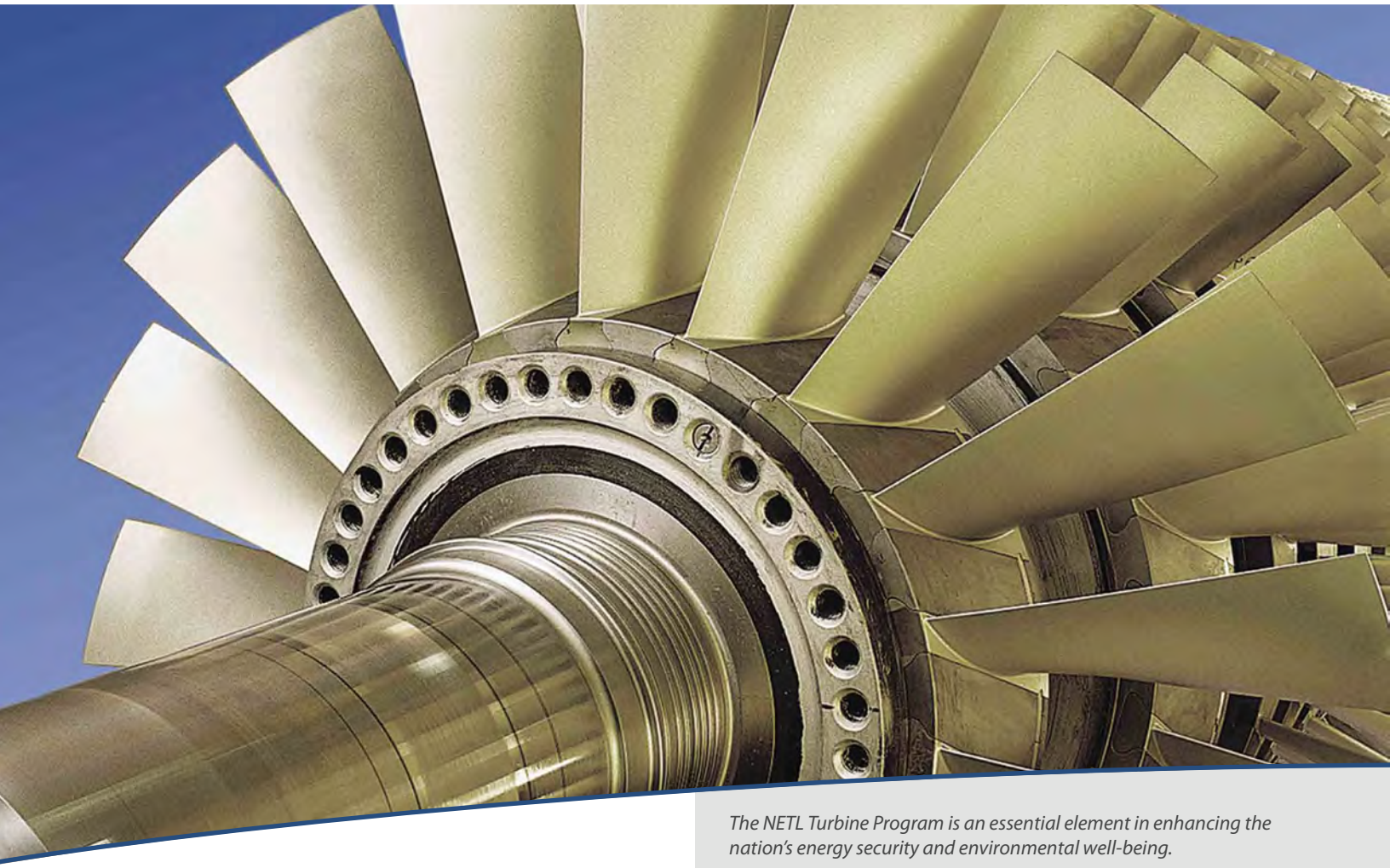


The NETL Turbine Program is an essential element in enhancing the nation's energy security and environmental well-being.

Turbine Program Develops Prototypes for Reducing Emissions

Ever since Hero of Alexandria invented a steam turbine toy 2,000 years ago, innovative thinkers have worked to improve turbine efficiency and expand its use to a variety of applications, from powering trains and ships to the production of electricity. Today, the cutting edge of turbine research is represented by NETL and its partners. Working with companies like GE Energy and Siemens Energy, we are making advancements that will offset much of the costs associated with CCUS (carbon capture, utilization, and storage), while simultaneously improving the emissions performance of coal-based power production.

The inherent costs associated with CCUS are driving NETL turbine research, which addresses key technology developments required to achieve DOE performance goals for emissions reduction, efficiency, and costs. In an IGCC (integrated gasification combined cycle) power plant, syngas (synthesis gas) produced from coal is cleanly burned in a heavy-duty gas turbine. With pre-combustion CO_2 capture, the resulting fuel burned in the gas turbine is hydrogen. Future IGCC plants using pre-combustion CO_2 will produce a high hydrogen content fuel for the gas turbine; the fuel will then be combusted in the turbine, and the CO_2 will be permanently stored in deep underground formations.

In 2010, NETL researchers overcame many of the challenges associated with this approach to hydrogen combustion. Most importantly, three independent tests (one by NETL, one by GE Energy, and one by Siemens Energy) confirmed that the most recent model for IGCC with hydrogen gas would recover all the cost and performance penalties incurred from carbon capture.

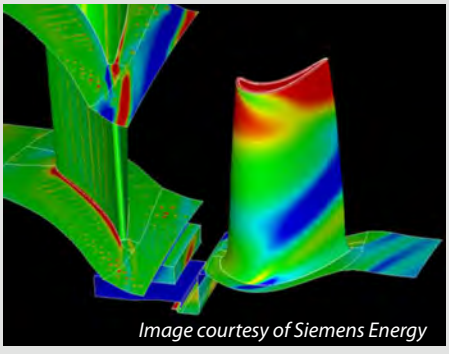
During 2010, NETL and its research partners successfully lowered the NO_x (nitrogen oxide) levels produced under advanced gas turbine operation conditions with high-hydrogen fuel by nearly 25 percent. The team lowered NO_x levels produced at the operating conditions proposed for the 2012 prototype machine to a level approaching the 2 parts per million program target. At the same time, operability in bench tests with high-hydrogen fuels has improved. These advancements represent significant progress.

NETL and its partners also developed new manufacturing methods that allow for operation in the high-temperature, high-pressure environment required for advanced turbines. Combustion development also continued, with a focus on high-pressure testing and refined computational fluid dynamics calculations. In addition, intermediate goals were met in the development of a high-temperature- capable thermal barrier coating.

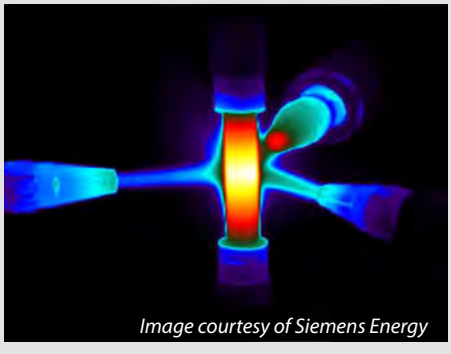
Our oxy-fuel turbine development effort scored an early milestone when Clean Energy Systems, Inc., (CES) of Rancho Cordova, CA, signed a purchase order for a used Siemens SGT-900 B12 gas turbine. The machine will be refurbished and converted for oxy-fuel application, then tested in 2014 at the CES Kimberlina Power Plant facility.

These technologies are considered key components of FutureGen-type plants, which will use NETL-developed technology to build and operate the world's first near-zero-emissions power plant. The successful prototype will be a model for other cost-efficient, near-zero-emission coal plants. To facilitate the development of near-zero emission coal-based power systems, NETL is developing oxygen-fired turbines and combustors that provide high efficiency through the use of ultra-high-temperature power cycles. Meanwhile, our academic partners are researching advanced turbine combustion, aerodynamics and heat transfer, and materials.

Near-term goals for the NETL Turbine Program include development of a hydrogen-fueled turbine that facilitates integration with coal-based IGCC power plants designed for CCUS; demonstration of fuel flexibility capabilities that allow turbine operation on conventional syngas or 100 percent hydrogen; development of emissions control technology capable of reducing NO_x emissions to near zero; and development of oxy- fuel turbine and combustor technologies for highly efficient, near-zero-emissions, coal-based power systems.



NETL and its partners conduct computational fluid dynamics research to determine optimum blade designs for turbines.



Testing a Siemens high-heat flux rig. NETL tests the impact of extreme and normal operational conditions for turbines operating under high-heat flux conditions.

Advanced Power Systems

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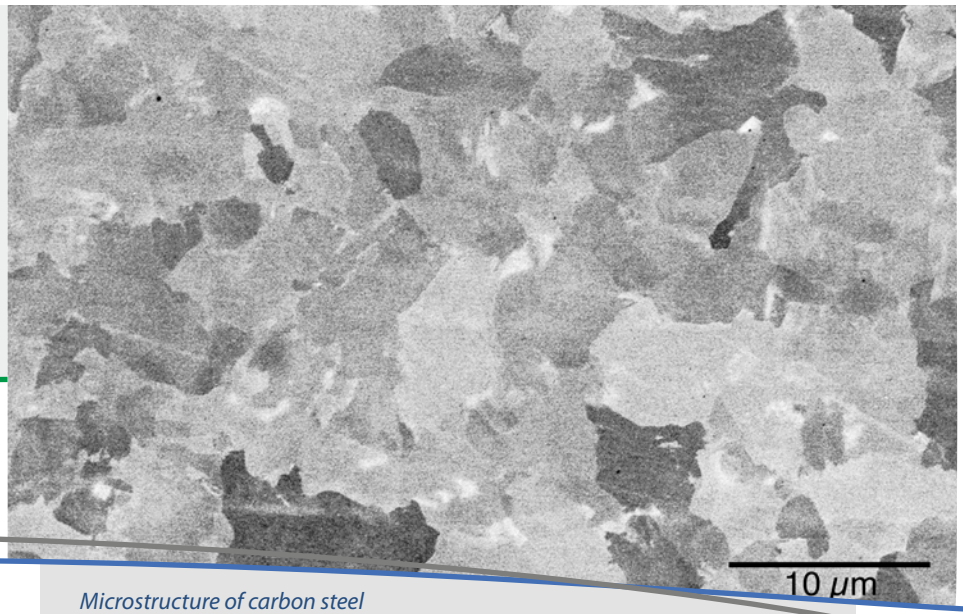
Materials

NETL researchers are developing new materials for advanced power-generation technologies, such as advanced gasification, advanced turbines, and advanced oxy-fuel and ultra-supercritical steam combustion systems. These systems will require materials that can withstand the harsh operating environments characterized by high temperatures, high pressures, and corrosive conditions—operating conditions that increase efficiency and reduce pollutant emissions. Through fundamental studies, laboratory experiments that simulate real-world conditions, and field trials, NETL is working to create materials that can perform effectively in these extreme environments and ensure that America continues to enjoy clean, sustainable energy.

Thermodynamic Modeling Identifies Lower-Cost, High-Temperature Alloys for Advanced Power Plants—NETL researchers are working to eliminate sources of microstructural instability typically found in the alloys currently used in most coal-fired power plants. Using ThermoCalc software, researchers modeled 19 iron-based alloy compositions and identified three new and unique compositions that have the potential to outperform currently available alloys. The new tempered martensitic ferritic alloys show potential to withstand temperatures to 650 °C, which would enable them to be used in ultra-supercritical coal-fired power plants—plants that operate with greater heat and efficiency, with a smaller carbon footprint, and at lower cost than today's more conventional power plants. Additionally, the new compositions would be much less expensive than the austenitic iron- and nickel-based alloys and superalloys currently used in such applications, leading to significant cost savings.

Research Illuminates Beneficial Effect of Rare Earth Additions to Iron-Chrome Alloys—As part of a fundamental investigation aimed at improving the performance of relatively inexpensive alloys for use in harsh operating environments, NETL scientists examined the surface oxidation process of iron alloys containing 22 percent by weight of chromium, with and without the rare earth elements lanthanum and cerium. The process was imaged in situ through a confocal scanning laser microscope, and the results were correlated with post-experiment characterization through scanning-electron, focus-ion beam, and electron-beam microscopy. Results demonstrated that the addition of rare earth elements reduced scale ridge formation and improved the oxidative resistance of iron-chromium alloys. Incorporating these elements into SOFC interconnect materials will allow for the use of less expensive alloys while maintaining electrical conductivity at lower operating temperatures. Results of this study were published in the *Journal of the Electrochemical Society* (Vol. 157, No. 5, 2010).

University Coal Research Team Devises Novel Coating Method for Advanced Boiler Materials—Working under an NETL-administered University Coal Research grant, collaborators at the University of Utah have demonstrated a novel process for depositing intermetallic coatings on steel or nickel-based alloy substrates. In the process, the coating is formed by an in situ reaction between the metal substrate and aluminum powder (iron aluminide or nickel aluminide) fed through a plasma transferred arc. The resultant coatings are free of defects and capable of completely protecting the underlying surface. These coatings exhibited excellent high-temperature corrosion resistance under environments simulating the steam side and fire side of coal-fired boilers. In principle, the process could be applied to other intermetallic coatings and alloys, providing for enhanced corrosive resistance and operating efficiencies. By coating relatively inexpensive metal substrates with thin layers of corrosion-resistant materials, energy systems can be designed to operate at higher temperatures and pressures with only a modest increase in capital cost.



Microstructure of carbon steel meeting Americian Petroleum Institute (API) 5L pipe standards as viewed by a scanning electron microscope.

Advanced Electrochemical Approach Assesses Pipeline Corrosion in Supercritical CO_2 Fluids

To transport CO_2 from a power plant to a sequestration site, operators compress the gas into a supercritical liquid state and send it via steel pipeline. While pure supercritical CO_2 fluid is not corrosive, impurities commonly present in real fluid—water, sulfur dioxide, and oxygen—are.

To help identify materials that can be used safely in pipeline walls, NETL researchers and NETL-Regional University Alliance collaborators at Penn State University have successfully demonstrated a time-efficient electrochemical method for investigating the corrosion performance of carbon steels when they are exposed to contaminated supercritical CO_2. The method would enable engineers to quickly learn how the low-cost steel alloys currently used in pipelines respond to different levels of impurity.

For example, in one experiment, results showed that a non-protective film forms on the steel surface when it comes in contact with supercritical CO_2 containing water. A precise understanding of how impurities affect steel alloys is important to evaluating pipeline corrosion and will help optimize the safety and economy of CO_2 transportation via pipeline.

Advanced Power Systems

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Materials

"Coal is a modern energy resource in the United States. My job is to use this energy resource very efficiently without hurting the environment, so we don't have to depend on foreign energy resources."

Ranjani Siriwardane
NETL researcher

Aluminide Coatings Developed for Oxidation Protection in Ultra-supercritical Boilers—Working in cooperation with NETL, researchers at Tennessee Technological University developed an aluminizing procedure that provided tempered martensitic ferritic alloys with excellent oxidation resistance in humid air at 650 °C for more than 14 months of testing. The coatings also exhibited good oxidation protection at 700 °C for 6,000–8,000 hours. Applied at lower temperatures than that of conventional aluminizing processes, the procedure offers protection from steam-side oxidation for boiler components exposed to ultra-supercritical steam conditions without undermining key substrate mechanical properties, such as high-temperature strength and creep resistance. Advanced boilers operating at ultra-supercritical steam temperature and pressure are expected to produce power from coal with greater efficiency and lower emissions than conventional power plants.

Supplier Assists Advanced Ultra-supercritical Turbine Consortium—In an NETL-supported project, Houston-based Wyman-Gordon, a manufacturer of components for the power generation industry, has undertaken compression testing of nickel-based alloys (Nimonic 105 and Haynes 282) to better understand the effects of strain rate and temperature on final grain size (re-crystallization). The alloys were identified by the Advanced Ultra-supercritical Steam Turbine Consortium—a team of scientists and engineers from NETL, industry, and academia—as candidate materials for service at advanced ultra-supercritical steam conditions (1,400 °F and 5,000 pounds per square inch). The study will help materials scientists determine the processing window and processing issues that might arise when forging large components from the alloys. Supplier collaboration with the consortium, which is led by Energy Industries of Ohio, Inc., in cooperation with NETL, is crucial to ensuring the availability of materials and components that will enable advanced coal-fired power plants to generate electricity with greater efficiency and lower fuel-related emissions, including CO_2.

Why simulations?

Science-based computer simulations save time and money by reducing the number of experiments required to develop a technology and by improving the quality of experiments actually conducted.

Novel Material Joins Dissimilar Metals—Using data from a number of different weldability tests, researchers working in cooperation with NETL have shown that EPRI P87 is an acceptable filler material for making welds in various combinations of creep-strength-enhanced ferritic steels with traditional and advanced austenitic stainless steels. Weld metals and joint designs that help minimize the use of austenitic materials would greatly reduce the cost of high-efficiency coal-fired boilers operating at advanced ultra-supercritical steam conditions. The work is part of a collaboration led by Energy Industries of Ohio in cooperation with NETL—and with participation by major U.S. boiler manufacturers, the Electric Power Research Institute, and Oak Ridge National Laboratory — to develop the materials technology necessary for construction and operation of advanced supercritical boilers.

Simulation Evaluates Effects of Oxy-firing on Fireside Corrosion—Foster Wheeler engineers are performing a 3-D computational fluid dynamics simulation of a 750 megawatt oxy-fired pulverized coal plant operating at advanced ultra-supercritical steam conditions. The effort utilizes data obtained from an earlier computational fluid dynamics study that characterized the chemical composition and distribution of gases representing the oxy-combustion of high-sulfur, eastern bituminous coal (Illinois 6), and low-sulfur western (Eagle Butte) coal in retrofitted air-fired furnaces, as well as in new, significantly smaller units specifically designed for oxy-combustion. The work is part of a collaboration led by Energy Industries of Ohio in cooperation with NETL—with participation by major U.S. boiler manufacturers, the Electric Power Research Institute, and Oak Ridge National Laboratory—that is developing the materials technology necessary for construction and operation of higher efficiency coal-fired boilers operating at advanced ultra-supercritical steam conditions. In addition to the higher efficiency obtained at those conditions, the oxy-combustion process would discharge a sequestration-ready stream of CO_2.

Clean Energy

The Science of Sustainability

Fossil fuels are considered to be the most dependable, cost-effective energy source in the world. The availability of these fuels to provide clean energy will be essential for domestic and global prosperity and security well into the 21st century.

Can we use fossil-based energy without harming the environment?

NETL scientists and engineers are discovering and developing ways to find, supply, and deliver ever cleaner and more economic energy for our nation. Building upon work done in the past of developing methods to capture air pollutants, like mercury and NO_x, and practical uses of by-products of coal, our researchers are developing innovative methods to capture and use greenhouse gases, such as CO_2. They are focused on finding ways to increase energy efficiency in our industries, our homes, and our power grid. And, they are protecting our water supply by seeking ways to limit and reuse the water required by power plants and industrial processes.

Clean Energy

The Science of Sustainability

Carbon Capture

Climate change concerns could require reducing CO_2 and other greenhouse gas emissions from industrial sources. NETL researchers are developing novel CO_2 capture concepts to effectively remove carbon from stationary source emissions. This work will reduce costs associated with carbon capture by decreasing capital costs of capture equipment and processes and by reducing the amount of energy required to operate CO_2 capture systems. Through in-house and external research, we are approaching DOE's target of developing technologies that achieve 90 percent carbon capture—with less than 35 percent increase in cost of electricity—that will be ready for commercial demonstration by 2020.

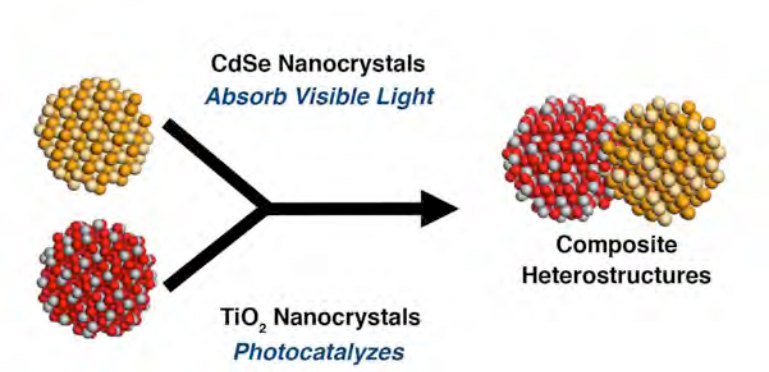

Photo-excited cadmium selenide transfers electrons to titanium dioxide, allowing titanium dioxide to convert CO_2 into other compounds.

Light-Activated Catalyst Converts CO_2 for Reuse

NETL scientists have developed a new light-activated catalyst, or photocatalyst, for converting CO_2 and water from power plant emissions into methane, methanol, and other chemicals. The novel material is believed to be the first titania-based photocatalyst capable of reacting to visible light, which means that it can use natural light to produce energy—and then the energy to initiate the chemical reaction between CO_2 and water. This improves the catalyst's carbon-management efficiency and permits revenue from sales of the resulting chemicals to offset costs associated with carbon capture.

This significant advance in the development of technologies for CO_2 capture and reuse is detailed in the inaugural issue of the *Journal of Physical Chemistry Letters* (Vol. 1) published by the American Chemical Society.

NETL Researchers Develop New Ionic Liquids for Carbon Capture—NETL researchers have devised a robust method for CO_2 capture by the synthesis of triazolium cations to create new ionic capture liquids. Important not only as capture solvents, ionic liquids are key to the potential use of membranes, which do not require regeneration as do solvent and sorbent technologies. This new method allows a wide range of functional groups to be easily placed on the triazole ($C_2H_3N_3$) ring. The resulting triazolium cation can then be coupled with various anions to form unique ionic liquids with distinct properties. The inherent flexibility in this synthesis method makes it a powerful tool for creating ionic liquids tailored to particular capture applications. Several new ionic liquids have been synthesized and tested as solvents and supported ionic liquid membranes for CO_2 capture.

NETL Testing Shows Electrochemical Reuse of CO_2—NETL researchers have electrochemically reduced CO_2 to ethylene at ambient temperature and pressure. The electrochemical reduction of CO_2 was studied at lab scale using halide anions (potassium chloride, potassium bromide, or potassium iodide) as the electrolytes. Results of the work, described in *Electrochimica Acta* (Vol. 56, No. 1, 2010), suggest that the stronger the adsorption of these halide anions to the electrode, the more strongly CO_2 is restrained, resulting in a higher CO_2 reduction current and a higher CO_2 conversion rate. Moreover, adsorption of halide anions onto the working electrode may impede hydrogen evolution—a competing reaction—by suppressing the adsorption of protons, promoting greater CO_2 electrochemical reduction. This technique could be utilized as an alternative to geologic storage of CO_2, with potential application in industrial and power plants. The resulting ethylene is a valuable product, widely used in many industries to create other chemical compounds.

NETL Process Makes Beneficial Use of CO_2—Researchers at NETL have incorporated CO_2 into polymeric materials similar to epoxy. Like epoxy, these materials are made by mixing two liquid components: a multifunctional cyclic carbonate and a multifunctional amine. Using novel chemistry, CO_2 is incorporated into these materials, and the two liquid components react to form a cross-linked polymer (hydroxyurethane) that is strong and adheres well to aluminum and glass surfaces. In addition to their use as adhesives, these materials have potential application as sealants and binders for composites such as fiberglass and plywood. By developing technology that utilizes CO_2 as a chemical feedstock in the preparation of useful products, NETL is working to reduce the quantity of greenhouse gases that must be geologically stored, as well as providing industry a means to partially offset storage costs through product sales.

Clean Energy

The Science of Sustainability

Carbon Capture

An NETL breakthrough oxy-combustion concept under development is the chemical-looping combustion process. Chemical looping splits combustion into separate oxidation and reduction reactions. A metal (e.g., iron, nickel, copper, or manganese) oxide is used as an oxygen carrier, which then releases the oxygen in a reducing atmosphere, and the oxygen reacts with the fuel.

NETL Discovery Could Produce Sequestration-Ready CO_2 from Low-Temperature Combustion—Recent studies in chemical-looping combustion have considered the difficulty of reacting solid fuels (e.g., coal, waste streams) directly with solid metal oxides. To proceed at a practical rate, such solid-to-solid reactions were assumed to require temperatures high enough to gasify the solid fuel or decompose the metal oxide. Now, NETL researchers have demonstrated that solid-to-solid reactions between copper oxide and carbon-rich fuels can be completed at much lower temperatures, with comparable rates, as long as adequate fuel-to-metal oxide contact is maintained. Theoretical analysis, flow reactor studies, and data from thermogravimetric and various spectroscopic analyses indicate that carbon induces the copper oxide bond to break, initiating combustion of carbon at temperatures significantly lower than required for spontaneous decomposition. This lower temperature of combustion may allow for reduced bed sintering tendencies and more reliable plant operation. A paper presenting evidence of this novel reaction mechanism for combustion of fossil fuels using oxygen from metal oxides for the production of sequestration-ready CO_2 appears in the Elsevier publication *Combustion and Flame Journal* (Vol. 157, No. 11, 2010).

Oxy-combustion Tests Completed at Pilot Scale—A multi-campaign test program using a modified Siemens oxy-combustion research burner was completed in the 1.2-megawatt thermal pilot-scale boiler facility at the University of Utah in Salt Lake City. The test campaigns are part of a research effort involving multiple partners led by Reaction Engineering International in cooperation with NETL to characterize and predict the impacts of CO_2 flue gas recycle and burner feed design on corrosion, fouling, slagging, heat transfer, emissions, and other flame characteristics when oxy-combustion systems are retrofitted to existing coal-fired boilers. The research is providing key data for commercialization of oxy-combustion processes, which could prevent emissions of many pollutants while providing a highly concentrated stream of CO_2 for permanent storage or enhanced oil recovery without costly gas separation.

Test Confirms Effectiveness of Oxy-combustion Retrofit Technology—Working with NETL, engineers at Alstom Power completed the third in a series of test campaigns designed to evaluate oxy-combustion using the 15-megawatt thermal, tangentially fired boiler simulation facility in Windsor, CT. Conducted with high-sulfur coal obtained through the Illinois Clean Coal Institute, the general operation and combustion

performance of the unit with flue gas recycle presented no significant technical issues and attained all desired test points and combustion conditions. A dry flue gas desulfurization unit controlled the amount of sulfur in the flue gas recycle. The testing complements prior tests with West Virginia bituminous and Powder River Basin coals. Data from this research are valuable for commercialization of oxy-combustion processes. Along with preventing pollutant emissions, these oxy-combustion processes could circumvent the cost of gas separation and provide a highly concentrated stream of CO_2 for permanent storage or enhanced oil recovery.

Follow-On Test Campaign Supports Initial Oxy-combustion Flue Gas Processing Unit Results—Working with NETL, APCI (Air Products and Chemicals, Inc.) investigators successfully completed a second test run of the APCI oxy-combustion purification and compression unit. The APCI PDU (process development unit), which provides flue gas cooling, compression, and acid gas removal, processed a slipstream of flue gas from the oxy-combustion of Illinois high-sulfur bituminous coal in the Alstom 15-megawatt thermal boiler simulation facility in Windsor, CT. While the first test campaign used low-sulfur West Virginia bituminous coal, the second campaign more rigorously tested the PDU's sulfur-removal feature needed to operate Alstom's oxy-combustion unit with recycled flue gas. Data from the test campaigns will help finalize a reaction model of the PDU system. The APCI technology may enable oxy-combustion systems to capture CO_2 with the purity requirements for permanent storage, enhanced oil recovery, and other beneficial uses.

Leading Metal Organic Framework for CO_2 Capture Identified—In cooperation with NETL, a project team led by UOP LLC discovered that favorable CO_2 adsorption at flue gas conditions is dominated by one particular structure type of MOF (metal organic framework) called M/DOBDC, where "M" is a metal such as zinc, cobalt, nickel, or magnesium and the "DOBDC" refers to the form of organic linker in the resultant MOF structure, dioxybenzenedicarboxylate. The magnesium/DOBDC has outperformed all MOF and zeolite materials evaluated to date, capturing approximately 25 percent by weight of CO_2 at flue gas conditions. A technical and economic analysis suggests that an MOF-based vacuum-pressure swing adsorption process could be less expensive than using amines to capture CO_2.

Image courtesy of Sandia National Laboratory

FYi

Oxy-fuel Combustion

Pulverized coal oxy-fuel combustion burns fossil fuels in a mixture of recirculated flue gas and oxygen, rather than air. The products of oxy-fuel combustion are just CO_2 and water. The water is easily separated, producing a stream of CO_2 ready for sequestration. The above image shows single particle oxy-combustion measurements being taken.

Clean Energy

The Science of Sustainability

Carbon Storage

Once CO_2 has been captured, it is injected deep underground in areas, such as depleted oil fields, unminable coal seams, and saline water-bearing geologic formations, for safe and effective storage. NETL leads the nation in innovating technologies for permanently storing CO_2, with many pioneering developments on the horizon. We are also developing technologies to monitor CO_2 storage sites to ensure the gas is permanently confined in deep geologic formations. Projects currently underway are stationed across the United States as NETL partners with multiple organizations to advance safe and permanent storage technologies.

As part of NETL's diverse carbon sequestration research, scientists are studying chemical reactions in the reservoir. Shown here, the flow path of an acidic fluid through a fracture in cement is discolored by chemical reactions.

NETL Successfully Simulates Coal Seam Carbon Storage—NETL has developed a new model to determine the geologic and mechanical responses of coal-seam systems to CO_2 storage. The new model has improved the ability of simulating coal permeability so it agrees with field data obtained from the Allison field in northwest New Mexico—the site of the world's first enhanced coalbed methane-carbon storage field project. In addition to permeability, the model yields a better description of the roles of coal shrinkage and swelling, coal's elastic properties, and porosity of fractures in the coal seam. The simulation also gives better estimates for geophysical parameters that are difficult to measure in the laboratory. Results of the study appear in a special section on CO_2 storage in the journal *The Leading Edge* (Vol. 29, No. 2, 2010), published by the Society of Exploration Geophysicists.

NETL's Seismic Surveys Track CO_2 Movement Underground—NETL researchers and collaborators at the University of Pittsburgh have developed a correlation between acoustic wave velocity and relative CO_2 saturation that can be used to calibrate and refine the interpretation of 3-D seismic reflection surveys. Discussed in a special section on CO_2 storage in *The Leading Edge* (Vol. 29, No. 2, 2010), the lab-scale study, conducted with actual reservoir rocks, shows the procedure could be employed to effectively track the movements of CO_2 after injection for carbon storage or enhanced oil recovery. Tracking injected CO_2 will help determine if a site is effective in keeping CO_2 trapped underground, preventing it from being released into the atmosphere.

Study of Offshore Geologic Storage Publicized by American Association of Petroleum Geologists—An article in the September 2010 issue of *The Explorer* describes a first-of-a-kind study to investigate the potential for underground storage of CO_2 in offshore U.S. geologic formations. Launched in cooperation with NETL by researchers at the Bureau of Economic Geology, the project will evaluate new and historic data to identify at least one injection site within an

area of Texas offshore state lands that could be suitable for the safe and permanent storage of CO_2 from commercial CCUS (carbon capture, utilization, and storage) operations. Using a cable, researchers send high-energy sound waves into the shallow marine sediments. When they bounce back, the sound waves are converted into high-resolution images, much like a sonogram, to determine potential storage sites. Submerged state lands of the northern Gulf of Mexico offer geologic storage advantages, such as existing oil and gas infrastructure, available sources of industrial CO_2, reduced environmental risks to underground sources of drinking water (as compared to storage beneath land onshore), and state land ownership extending 12 nautical miles offshore—compared to 3 miles for all other states except Florida.

Canada and United States Renew Investment in Leading Carbon Capture and Storage Project—DOE Secretary Steven Chu and Canada's Minister of Natural Resources Christian Paradis announced a total of $5.2 million in new funding for the Weyburn-Midale CO_2 Monitoring and Storage project. To date, a record 18 million metric tons of CO_2 have been sequestered in the Weyburn and Midale oil fields in southern Saskatchewan as part of EOR (enhanced oil recovery) operations. EOR operations are expected to yield 215 million additional barrels of oil by 2035, while storing 40 million metric tons of CO_2—the equivalent of taking nearly 9 million cars off the road for an entire year. NETL represents DOE's interest in this largest-ever full-scale CCUS field study to determine permanency and best practices of geologic sequestration in conjunction with EOR. Recognized as part of President Obama and Prime Minister Stephen Harper's 2009 United States-Canada Clean Energy Dialogue, the research project is conducted by the Petroleum Technology Research Centre with sponsorship from the DOE Office of Fossil Energy, Natural Resources Canada, and 14 other international government and industry sponsors from Canada, Europe, Japan, the Middle East, and the United States.

A key goal of NETL's carbon sequestration research program is at least 99 percent retention of CO_2 in underground reservoirs over a 100-year period. Pictured here, an injection well head at a sequestration test site near Natchez, MS.

Clean Energy

The Science of Sustainability

Perfluorocarbon tracers in a syringe pump are added to CO_2 as it is injected underground at the Lower Michigan Basin saline aquifer sequestration test site near Gaylord, MI.

Perfluorocarbon Tracers Go with the Flow

A big part of keeping energy clean is preventing by-products like CO_2 from being released into the atmosphere. We can remove CO_2 from power plant emissions, but what can be done with it once we have it? If we store it, can we be sure it will not leak out and add to the greenhouse gas burden in our air?

To answer these questions, NETL is researching the permanent storage of CO_2 in geologic reservoirs that have already stored fluids and gases for millions of years. Carbon sequestration involves capturing CO_2 emissions at their source, compressing the CO_2 into a liquid, and injecting it deep underground in rock formations that act as reservoirs. CO_2 can be injected into confined rock reservoirs where it won't escape, as well as depleted oil or natural gas fields to enhance resource recovery. In addition to capture and storage aspects, the success of carbon sequestration also depends on monitoring techniques, such as PFTs (perfluorocarbon tracers) used by NETL scientists, that ensure carbon sequestration is permanent and leak-free.

When examining reservoirs as potential CO_2 storage targets, researchers seek out the ideal porosity, permeability, storage space, and seal to trap the liquid CO_2. Rock is often not as solid as it appears. On the microscopic level, rock can appear like a jar of marbles. The "marbles" represent grains in the rock or coal, while the open

spaces between the marbles are referred to as pores. Cracks also appear as spaces between the marbles. The way those grains are positioned defines the way the pores connect to determine a rock's permeability. A rock with very connected pores, or lots of open spaces, is highly permeable. Injected CO_2 will move into these pores, so high permeability is highly desirable for a reservoir. The opposite holds true for the caprock seal that keeps the CO_2 trapped. Because liquid CO_2 tends to rise, a caprock seal with very low permeability is needed so fluids will not pass through. This caprock must also cover a reservoir that has enough volume to store millions of tons of liquid CO_2.

Once researchers have located an ideal site, the next critical step is to actualize technology that will monitor sequestration sites for leakage. PFTs are an effective way to monitor injected CO_2. PFTs are non-toxic, clear, colorless liquids injected with CO_2 to easily track its migration, making them appealing for NETL to use in research. PFTs do not occur in nature and can be detected at extremely low concentrations, so they are easy to identify and track.

Once the PFT and CO_2 are injected, researchers can tell if the CO_2 plume is moving, and where, by testing gas samples from monitoring wells surrounding the injection site. A range of PFTs are available commercially, so researchers can use a different type in each injection well within an injection field, tailoring their efforts to specific wells. Tracking the PFTs helps researchers build an image of the reservoir, which can be used to predict how well CO_2 will remain sequestered in a particular reservoir, estimate the potential for leakage, and quantify the reservoir's storage capacity.

Increased interest in carbon sequestration has led to NETL's small-scale and near-industrial-scale pilot CO_2 injection projects for greenhouse gas mitigation, many of which are now including PFTs to study plume flow. Tracer measurements at an injection site in the San Juan Basin in New Mexico showed subsurface migration of the plume—lateral movement underground, away from the injection field. In another case, the plume was expected to migrate in one direction, but PFTs were detected

Depth profile sampling at the San Juan Basin sequestration test site. A sorbent tube at the bottom of each pipe detects perfluorocarbon tracers in the strata below or the atmosphere above.

at a well in the opposite direction, alerting researchers to the inconsistency. PFTs can also be used to distinguish between naturally occurring CO_2 and CO_2 that has been injected, thus eliminating confusion if CO_2 is detected at the surface.

As technologies for carbon storage mature, more tools for monitoring, such as PFTs, will become essential, ensuring that human health and safety and the host ecosystem are not adversely affected by sequestration projects. At NETL, researchers continue to embrace and develop new carbon storage technologies, with the constant goal of finding solutions for tomorrow's energy challenges.

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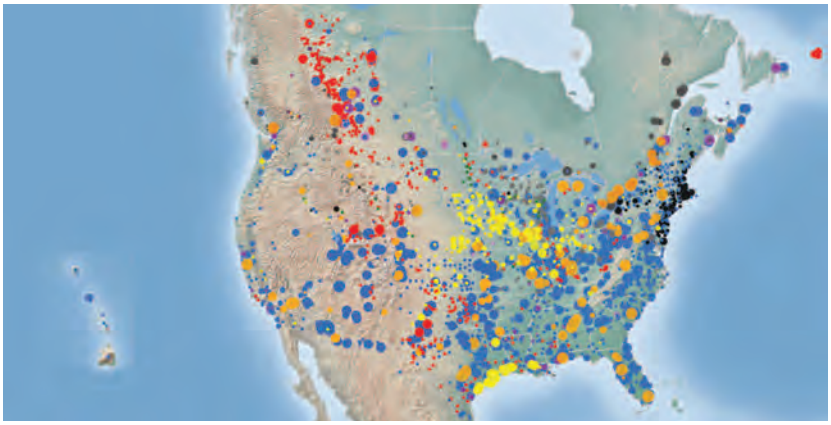
The Science of Sustainability

Carbon Sequestration Partnerships

Over 400 state agencies, universities, and private companies in 43 states and 4 Canadian provinces belong to the RCSP (Regional Carbon Sequestration Partnership) program. The RCSP program is developing effective CO_2 transport and storage solutions, as well as advancing public understanding of the process and tailoring these efforts to the needs and resources of its seven regions. NETL leads the Partnerships through management and funding, working groups, technical oversight, and conferences. Currently, CO_2 injection testing is underway for Phases II and III of the program. The RCSP program remains the centerpiece of national efforts to commercialize carbon capture and storage technologies.



Atlas III *map of North America identifying stationary CO_2 sources.*

Third Edition of *Carbon Sequestration Atlas of the United States and Canada* Released

In November, the Office of Fossil Energy released a new edition of its *Carbon Sequestration Atlas of the United States and Canada,* called *Atlas III*. The updated version describes current activities of the seven NETL-managed Regional Carbon Sequestration Partnerships, including details about commercialization opportunities for carbon capture, utilization, and storage technologies from each region.

Produced in cooperation with carbon sequestration experts from local, state, and federal agencies, as well as industry and academia, *Atlas III* contains updated information on stationary CO_2 emission sources, as well as the locations and CO_2 storage potential of geologic formations across the United States and portions of Canada. Estimates suggest that these formations could store up to 5,900 years of CO_2 emissions.

In addition, *Atlas III* outlines DOE's Carbon Sequestration Program, international carbon capture and sequestration collaborations, projects, and regulatory issues.

Atlas III is available in hard copy from NETL. It can also be accessed online from NATCARB (National Carbon Sequestration Database and Geographic Information System)—a tool that provides a view of carbon capture and storage potential in the United States and Canada. NATCARB is updated every 3 months, while the hard copy of the Atlas is updated every 2 years.

Midwest Geologic Sequestration Consortium Regional Partnership Proceeds to Injection Phase of Large-Scale Demonstration—

NETL approved continuation of the development phase of the MGSC (Midwest Geologic Sequestration Consortium) Regional Partnership's effort to inject and monitor 1,000 metric tons of CO_2 per day at a depth of 7,000 feet into the Mount Simon sandstone formation of the Illinois Basin. More than 1 million metric tons of CO_2 from a nearby Archer Daniels Midland ethanol facility in Decatur, IL, will be compressed, piped, and injected into the bottom 400 feet of the 1,300-foot thick formation over a 3-year period beginning in early 2011. MGSC is led by the Illinois State Geological Survey.

Southeast Regional Carbon Sequestration Partnership Reaches CO_2 Injection Milestone—

More than 2.5 million metric tons of CO_2 have been injected at depths greater than 10,000 feet into the lower Tuscaloosa Formation near Natchez, MS, as part of a project by the SECARB (Southeast Regional Carbon Sequestration) Partnership. Beginning with EOR (enhanced oil recovery) operations conducted at the Cranfield site by Denbury Resources, Inc., the SECARB project proceeded to demonstrate the feasibility of injecting CO_2 from Jackson Dome, near Jackson, MS, into a regionally significant, deep brine-bearing formation along with the use of multiple tools to monitor subsurface movement of the injected CO_2. The project will help determine whether the immediate commercial benefit of EOR can offset infrastructure development costs for follow-on, large volume, long-term storage of CO_2 in underlying saline formations. SECARB is a public-private partnership led by the Southern States Energy Board, which represents 11 southeastern states.

SECARB Completes Phase II CO_2 Injections—

The last SECARB Phase II injection has been completed: injection operations for the Black Warrior Basin Coal Seam project located near Tuscaloosa, AL, have concluded. An existing coalbed methane well was converted for the CO_2 injection, and three wells were drilled to monitor reservoir pressure, gas composition, and the CO_2 plume. A total of 277 tons of CO_2 were injected into coal seams of the Pratt, Mary Lee, and Black Creek coal groups within the upper Pottsville Formation. The targeted seams range from 940 to 1,800 feet deep and from 6 inches to 6 feet thick. Coal in the Black Warrior Basin—an area of about 23,000 square miles in northwestern Alabama and northeastern Mississippi—has the potential to sequester 1–2 gigatons of CO_2—approximately the amount that Alabama coal-fired power plants emit in two decades—and CO_2-enhanced coalbed methane recovery could extract another 1.5 trillion cubic feet of natural gas from the reservoirs.

Permit Issued to Big Sky Carbon Sequestration Partnership for World's First CO_2 Injection into Continental Basalt Formation—

The Washington State Department of Ecology issued a permit—the world's first for a continental flood basalt sequestration project—for the pilot-scale injection of CO_2 near Wallula, WA. The BSCSP (Big Sky Carbon Sequestration Partnership), a public-private partnership led by Montana State University, plans to inject 1,000 metric tons of CO_2 over 14 days into a candidate injection test zone, between 2,716 and 2,870 feet deep. The maximum working pressure at 2,720 feet will not exceed 1,893 pounds per square inch, and the radius of the injected supercritical CO_2 is not expected to extend beyond 180 feet per year after injection begins. Simulations predict no CO_2 migration into the overlying Slack Canyon flow interior, even after a year.

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Carbon Sequestration Partnerships

Initial drilling at the launch of a geologic sequestration project that plans to deposit one million metric tons of CO_2 into the ground by 2012.

Drilling Completed for Observation Well at Midwest CO_2 Storage Site—Drilling operations organized by MGSC are complete for a 7,264 foot-deep observation well that will be used to monitor injection of 1 million metric tons of compressed CO_2 piped from the Archer Daniels Midland ethanol facility in Decatur, IL, over a 3-year period. The CO_2 will be injected into the Mount Simon sandstone formation—a potentially vast CO_2 storage reservoir within the Illinois Basin. In conjunction with drilling operations, core samples were taken from the bottom 400-foot injection zone of the formation, as well as from top- and mid-regions to evaluate permeability variation. The core data will improve the accuracy of computational models used to predict migration pathways of the CO_2 plume during and following injection. Core samples of the overlying 500 foot-thick Eau Claire Shale formation and other cap rock formations were also recovered to characterize their sealing properties. MGSC is led by the Illinois State Geological Survey.

Best Practices Manual for Carbon Capture and Storage Public Outreach and Education Published—The RSCP program has released a new manual to recommend best practices for public outreach and education for CO_2 storage projects. The recommendations are based on lessons learned by the seven members of the RCSP during the first 6 years of the partnership program. The new publication, titled *Best Practices for Public Outreach and Education for Carbon Storage Projects*, is intended to assist project developers in understanding and applying best outreach practices for siting and operating CO_2 storage projects. The manual provides practical, experience-based guidance on designing and conducting effective public outreach activities. The best practices highlighted in the new manual take into account the social context within which projects are deployed, addressing the critical social implications of implementing CO_2 storage projects across a variety of U.S. geologic and cultural settings. Conducting effective public outreach will not necessarily ensure project success, but underestimating its importance can contribute to significant delays, increased costs, and lack of community acceptance.

Terrestrial CO_2 Storage Practices Demonstrated in Great Plains Region of the United States and Canada—A field test demonstrating the best approaches for terrestrial CO_2 storage in the heartland of North America has been successfully completed by one of the RCSPs. The PCOR (Plains CO_2 Reduction) Partnership, a collaboration of over 80 U.S. and Canadian stakeholders, conducted the field test at sites in the Prairie Pothole region. The area contains thousands of shallow wetlands called "potholes"

that were formed by retreating glaciers approximately 10,000 years ago. Terrestrial carbon storage involves removal of CO_2 from the atmosphere using photosynthesis of plants, resulting in storage of the carbon in biomass and soils. Participating PCOR Partnership organizations—including Ducks Unlimited, Inc., the U.S. Geological Survey Northern Prairie Wildlife Research Center, and North Dakota State University—collected soil and gas samples from restored grasslands, native prairie, cropland, and wetlands throughout Montana, North and South Dakota, Minnesota, and Iowa. In addition to carbon uptake and storage measurements, methane and nitrous oxide gas levels were also measured to estimate the net change in greenhouse gas levels.

Test Demonstrates Viability of Simultaneous CO_2 Storage and Enhanced Oil Recovery in Carbonate Reservoirs—A field test conducted by a PCOR Partnership team of regional partners has demonstrated that using CO_2 in an EOR method dubbed "huff-and-puff" can help assess the carbon storage potential of geologic formations while tapping America's valuable oil resources. The PCOR Partnership collaborated with Eagle Operating, Inc., to complete the test in the Northwest McGregor Oil Field in Williams County, ND. The huff-and-puff method of EOR proceeds in three phases: injection (the huff stage), "soaking" for a short period of time, and production (the puff stage). Compared to other huff-and-puff operations, the PCOR Partnership test was unique because the depth (approximately 8,050 feet) was among the deepest, pressure (3,000 pounds per square inch) and temperature (180 °F) were among the highest, and the formation was a carbonate rather than clastic reservoir. The test also determined that two Schlumberger technologies—a reservoir saturation tool and vertical seismic profiling—may be effective tools for detecting and monitoring small-volume CO_2 plumes in deep carbonate reservoirs to ensure safe and permanent storage. Project outcomes may be applicable to many other sites in the PCOR Partnership region and in similar settings globally.

NETL Releases CO_2 Storage Best Practices Manual—A best practices manual developed by NETL, *Site Screening, Site Selection, and Initial Characterization for Storage of CO_2 in Deep Geologic Formations*, focuses on the most promising methods for assessing potential CO_2 geologic storage sites. This resource intended for future project developers and CO_2 producers and transporters can also be used to apprise government agencies of best practices for exploring potential CO_2 geologic storage sites and to inform the general public about the rigorous analyses conducted for potential storage sites. Developing reliable and consistent standards and operational characteristics for CO_2 collection, injection, and storage provides the basis for legal and regulatory framework and encourages widespread global carbon capture, utilization, and storage (CCUS) deployment. This newest manual, the fourth in a series, communicates rigorous analyses and guidelines for paring down potential subregions into qualified sites for geologic storage. It provides a framework for reporting resources and will be instrumental in developing consistent industry-standard terminology and guidelines for communicating storage resources and storage capacity estimates, including project risk, to stakeholders. It can be found on NETL's website along with other documents and reference materials related to CCUS.

Carbon Sequestration Partnerships

The DOE/NETL Carbon Dioxide Capture and Storage RD&D Roadmap *was prepared by NETL's Innovations for Existing Plants and Carbon Sequestration Programs.*

New Roadmap Updates Carbon Capture and Storage Project Status—An overview of RD&D (research, development, and demonstration) efforts to supply cost-effective, advanced CCUS technologies for coal-based power systems is the focus of a new roadmap published by DOE. Prepared by NETL, the latest *DOE/NETL Carbon Dioxide Capture and Storage RD&D Roadmap* outlines the program's efforts to develop advanced CCUS technology. CCUS is considered by many experts as a strategic component in reducing greenhouse gas emissions and mitigating climate change. As outlined in the roadmap, DOE's Clean Coal Research Program integrates advances and lessons learned from fundamental research, technology development, and large-scale demonstration.

Study Confirms NETL Research on Monitoring of Carbon Capture and Storage Sites—In another step toward improved scientific understanding of potential geologic CO_2 storage impacts, a DOE-sponsored study has confirmed previous NETL research showing that proper site selection and monitoring is essential for helping anticipate and mitigate possible risks. "Potential Impacts of Leakage from Deep CO_2 Geosequestration on Overlying Freshwater Aquifers," published in the October 26, 2010, edition of *Environmental Science & Technology*, presents the results of a year-long study investigating the impact of CO_2 injection into different geologic formations and the possible dissolution of metals from specific rocks that naturally contain high concentrations of these metals. The researchers incubated core samples from a variety of freshwater aquifers with CO_2 for more than 300 days and found increased acidity and metal concentrations in water surrounding the samples. They concluded that "the relative severity of the impact of leaks on overlying drinking water aquifers should be considered in the selection of CO_2 sequestration sites." This confirms earlier research conducted by NETL, several other DOE national laboratories, the U.S. Geological Survey, and others indicating that carbon storage sites must be carefully selected and monitored.

Field Test Finds Potential for Permanent Storage of CO_2 in Lignite Seams—A field test sponsored by DOE has demonstrated that opportunities to permanently store carbon in unminable seams of lignite may be more widespread than previously documented. The PCOR Partnership collaborated with Eagle Operating, Inc., to complete the field test in Burke County, ND. Testing demonstrated that the injected CO_2 did not significantly move away from the wellbore and was contained within the coal seam for the duration of a 3-month monitoring period. The partnership also evaluated a variety of carbon storage operation conditions to determine their

applicability to similar coal seams. While the results did not change the initial regional storage capacity estimates, they do suggest that suitable lignite seams are potential targets for carbon storage. The study also investigated the feasibility of combining CO_2 storage with enhanced methane production. When CO_2 comes in contact with coal, including low-rank coals like lignite, the CO_2 molecules physically attach to the coal. In many cases, the CO_2 displaces methane, the primary component of natural gas, making it easier to recover. This combination potentially offers both a near-term economic return and a long-term environmental benefit.

Manual Studies 11 Major CO_2 Geologic Storage Formations—A manual developed by NETL contains a comprehensive study of 11 geologic formations suitable for permanent underground CO_2 storage. With data from the Regional Carbon Sequestration Partnerships and other sponsored research activities, the manual provides a better understanding of characteristics of geologic formations that could be used for carbon storage. The manual investigates 11 major classes of geologic reservoirs for formations that can store large volumes of CO_2, receive CO_2 at an efficient and economic rate of injection, and safely retain the CO_2 over long time periods. It builds on lessons learned from CO_2 behavior in geologic reservoirs during earlier investigations. NETL evaluated the geology and depositional environments of each of the sponsored projects to determine if additional efforts are needed. The resulting manual allows carbon storage participants to better understand depositional environments and predict the behavior of CO_2 within those environments. With this information, government agencies and their project partners and private investors can optimize their storage efforts, saving time and funds.

Study Shows "Sour" Gas Streams Safe for Carbon Storage—Gas streams containing high levels of both CO_2 and hydrogen sulfide can be safely used for CCUS operations, according to results from a field test completed by the PCOR Partnership. PCOR's test also demonstrated that carbon sequestration using "sour" gas streams can be combined successfully with EOR and hydrogen sulfide disposal. Some of these same geologic formations may also be fit for large-scale storage of CO_2 streams containing significant quantities of hydrogen sulfide, a toxic and flammable sour gas that smells like rotten eggs. Results from the Zama field test in Alberta, Canada, will help in determining the technical and economic viability of CO_2 and sour gas storage and support the ultimate deployment of commercial-scale projects. About 33,500 tons of sour gas were injected, simultaneously storing CO_2, disposing of hydrogen sulfide, and increasing oil recovery by reducing the viscosity of the crude oil and pushing it toward the production well. Apache Canada, Ltd., undertook the injection and hydrocarbon recovery processes, while the PCOR Partnership conducted monitoring, verification, and accounting activities to verify and validate the containment integrity of the reservoir.

Clean Energy

The Science of Sustainability

Demand-Side Efficiency

In supporting the DOE Office of Energy Efficiency and Renewable Energy (DOE-EERE), project management expertise at NETL has been instrumental in promoting the use of alternative fuels, helping consumers conserve energy, and advancing the state of the art in high-efficiency lighting. Annual energy savings from solid-state lighting by 2030 could be approximately 190 terawatt-hours, or the equivalent annual electrical output of about 24 large (1,000 megawatt) power plants.

Weatherization Assistance Program Awards Federal Grants

Typically, 17 percent of the total annual income for a low-income household is spent on energy, compared to 4 percent for other households. Through DOE's WAP (Weatherization Assistance Program), NETL and the DOE-EERE's Golden Field Office collaborate with state and local agencies to help these homes become more energy efficient, reducing their annual gas heating consumption by 32 percent. Each dollar invested through WAP leverages $1.54 in other federal, state, utility, and private resources, and returns $2.73 in economic and environmental benefits. Weatherization measures reduce CO_2 emissions by 1 metric ton per weatherized home, or one-third the average emissions of an automobile.

The Weatherization Assistance Program enables low-income families to permanently reduce their energy bills by making their homes more energy efficient.

Recovery Act Milestone: 300,000 Homes Weatherized

In January of 2011, U.S. Department of Energy Secretary Steven Chu announced that states and territories across the country have weatherized more than 300,000 low-income homes under the Recovery Act, a major milestone in the Department's efforts to reduce home energy bills for families.

The weatherization program, which NETL helps manage, is helping families save money on their energy bills by improving home energy efficiency with upgrades like insulation, air-sealing, and more efficient heating and cooling systems. The program has also trained a new generation of clean energy workers and currently employs more than 15,000 people.

"Through the weatherization program," said Secretary Chu, "we are laying the groundwork for a broader efficiency industry in the United States that will help grow our economy while saving money for American families."

Weatherization assistance reduces energy consumption for low-income families 35 percent on average, saving families about $400 on their heating and cooling bills in the first year alone. Nationwide, the weatherization of 300,000 homes is estimated to save $161 million in energy costs in just the first year.

Image courtesy of Pulte Homes

Energy-saving houses built as part of the NETL-managed Villa Trieste project.

NETL-Supported Project Lowers Homeowner Power Bills

For residents of Pulte Homes' Villa Trieste, "green" means more than just a healthier environment. It also means lower power bills.

Pulte Homes'185-unit green community was developed in partnership with Nevada Energy and the University of Nevada and aided by an NETL-managed grant through the DOE Office of Electricity Delivery and Energy Reliability. Each home in the community is designed to minimize energy use, especially during "peak" hours—periods of time each day during which electricity prices are highest.

Solar panels are installed on roofs, a community battery stores power for use during peak hours, and interactive smart meters—intelligent computer agents—help homeowners individually reduce their electricity use. They will also help evaluate homeowner participation during the project. In addition, developers used "Environments for Living" methods to build the community's structures. Energy-conserving features such as high-efficiency lighting, low-e (low-emissivity) windows, and airtight construction have earned the buildings Leadership in Energy and Environmental Design, or LEED, certification. Each home is also equipped with high-efficiency toilets, low-flow faucets, and ENERGY STAR appliances.

Saving homeowners money, conserving power, and protecting the environment—these goals are being realized at Villa Trieste today.

Demand-Side Efficiency

LEDs use tiny inorganic semiconductors to create an intense point source of light. OLEDs are made of organic polymers and emit a soft diffuse light over a relatively large area. Both promise to be 10 times more efficient than incandescent lighting.

NETL-Managed Projects Improve Lighting Systems—NETL supports DOE-EERE with project management expertise that has been instrumental in advancing the state of the art in high-efficiency lighting. By 2030, annual energy savings from solid-state lighting could be approximately 190 terawatt-hours, or the equivalent annual electrical output of about 24 large (1,000 megawatt) power plants.

- Researchers at DuPont Displays have demonstrated the application of low-cost solution deposition techniques for manufacturing large-area OLEDs (organic light emitting diodes). Produced at the DuPont Displays pilot-line located in Santa Barbara, CA, the 4-inch diagonal, square lighting panels mounted in two light boxes were attached to a controller that allowed the light to be color-tuned by individually adjusting the output of red, green, and blue pixels.

- Osram Sylvania has demonstrated a down light luminaire that achieves 1,256 lumens at an efficacy of 68 lumens per watt—very close to the project goal of 1,300 lumens at 70 lumens per watt. The white light is generated by an array of blue LEDs (light emitting diodes) covered by a phosphor-coated glass disk. Osram expects to reach its goal by improving the phosphor, optical, electronic, and thermal systems of the luminaire.

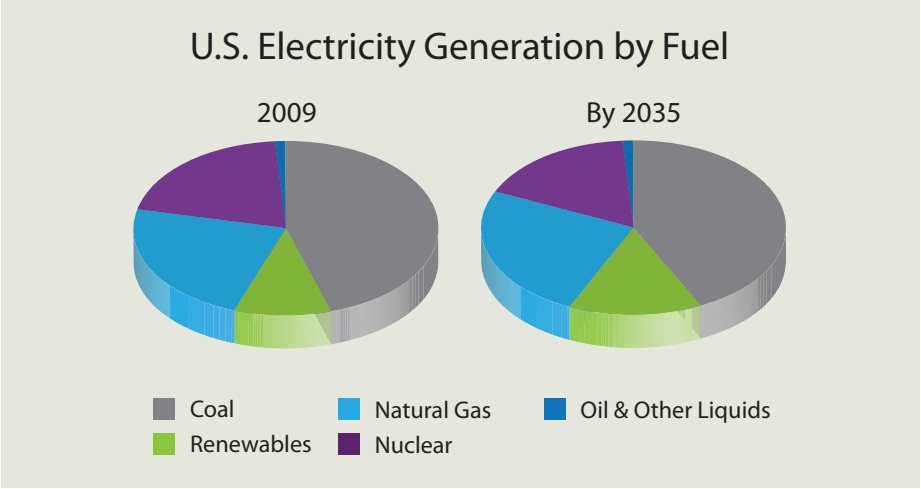
- Philips Lumileds Lighting Company has demonstrated an LED-based source that produces a light output of 811 lumens with an efficacy of 99 lumens per watt—very near the project goal of 800 lumens of warm white-light output at100 lumens per watt. The 2 x 2 array of 1-mm^2 LEDs exhibits a correlated color temperature of 3307 Kelvin.

- Delivering more than 400 lumens with an efficacy of 69 lumens per watt, new LED components developed at Cree, Inc., are smaller, brighter, and more efficient than previous products. Conventional 20-watt halogen MR16 products deliver up to 350 lumens, but with an efficacy of less than 20 lumens per watt. Other LED MR16 products can reach 50 lumens per watt, but CALiPER (Commercially Available LED Product Evaluation and Reporting) tests show they typically deliver less than half the light of conventional products. An LED-based MR16 replacement lamp could eventually deliver as much light as a conventional lamp but with three times the efficiency.

Why fuel cells?

Fuel cells have unique characteristics that make them robust and efficient electricity providers. Integrated solid oxide fuel cell system designs are nearly twice as efficient as conventional power systems fueled with pulverized coal. These systems also generate almost half the CO_2 and a fraction of the nitrogen and sulfur oxides.

Clean Cities Initiative Wins Golden Bullet Award—DOE's CCI (Clean Cities Initiative) received the Golden Bullet Award for speed and success in deploying alternative fuel and advanced technology vehicles through the American Recovery and Reinvestment Act. Established in 1993, CCI is part of the Vehicle Technology Program within EERE. CCI projects coordinated through NETL are designed to reduce petroleum consumption in the transportation sector by advancing the use of alternative fuel vehicles, idle reduction technologies, hybrid electric vehicles, fuel blends, and fuel economy. CCI is responsible for managing $300 million in Recovery Act funding to support the investments made by transit authorities and state and local governments in clean vehicles and alternative fuel infrastructure. Twenty-five cost-shared projects will put more than 9,000 alternative-fuel and energy-efficient vehicles on the road, establish 542 refueling locations, and install more than 1,000 electric charging stations nationwide. These projects, which support local coalitions that promote the growth of alternative fuels and energy efficient vehicles, include the use of natural and renewable gas, propane, ethanol, biodiesel, electricity, and hybrid technologies and will displace 38 million gallons of petroleum annually.



Clean Energy

The Science of Sustainability

Air, Water, Land

NETL's scientists and engineers have a mandate to protect and conserve our air, water, and land resources while ensuring we have economic, abundant, and secure energy supplies to meet the needs of the nation. In this pursuit, NETL is dedicated to developing innovative or improved technologies for capturing air pollutants such as mercury and NO_x (nitrogen oxides); treating and reclaiming water used in the production of oil, gas, and coal; responsibly using water in the production of electrical power; and remediating soil that was contaminated by historical, energy-related activities. NETL's work yields technologies that will make our country—and our world—a cleaner place.

The Centribaric centrifuge can recover tons of waste coal for energy use.

Image courtesy of Decanter Machine, Inc.

NETL-Supported Centribaric™ Centrifuge Turns Waste Coal into Energy Resource

Every year, U.S. coal producers discard up to 2 billion tons of moisture-laden fines (very fine, wet coal particles) as slurry in containment ponds or impoundments because the moisture left over in fines processed through conventional dewatering systems leaves them unmarketable.

Now, an exciting new technology is available that can turn this waste coal into a viable energy resource. The Centribaric™ centrifuge, developed by Virginia Tech with support from NETL's Hydrogen and Clean Fuels Program, takes the wet sludge and wrings dry coal fines from it, working much like the spin cycle of a washing machine with the addition of compressed air. The centrifuge can enable the reclamation and profitable use of billions of tons of what is now considered waste coal, including 70–90 million tons of coal fines that are currently added to slurry impoundments each year.

The Centribaric centrifuge also offers the possibility of creating jobs in the recovery industry while reducing the volume of waste impoundments in the environment without the expense and emissions of conventional thermal drying.

Canadian Tests Show Effectiveness of NETL Mercury-Removal Process—CanmetENERGY, the Canadian leader in clean energy research and technology development, extensively tested the ability of NETL's patented photochemical oxidation process (originally called the GP-254 Process) at lab scale, with flue gas slipstreams from a vertical combustor burning Saskatchewan lignite, and from a mini-circulating fluidized-bed combustor burning subbituminous Powder River Basin coal. Available for license, the process utilizes ultraviolet light to convert elemental mercury in flue gas to a more readily captured oxidized form. Obtaining as much as 91 percent oxidation of mercury at lab scale and 66 percent oxidation of mercury in the slipstream tests, the Canmet researchers concluded the method merits further development.

NETL-Developed NO_x Management Technology Patented—Fossil Energy Research Corporation of Laguna Hills, CA, received a U.S. patent for technology developed under the Office of Fossil Energy's Innovations for Existing Plants Program. The nonintrusive monitoring system provides a real-time view of catalyst deactivation within SCR (selective catalytic reduction) units used to control NO_x released from the combustion of coal. Developed in collaboration between NETL, Southern Company, and the Electric Power Research Institute, the Knoxcheck Online Catalyst Activity Test system enables optimized catalyst management for year-round SCR operation by predicting remaining catalyst life and evaluating catalyst replacement options without requiring a costly unit outage to obtain and analyze catalyst samples. Fossil Energy Research Corporation recently received the first commercial purchase order for the catalyst.

Report Cites Coal Plant Wastewater's Total Maximum Daily Loads—Argonne National Laboratory researchers, working under the Office of Fossil Energy's Existing Plants Research and Development program implemented by NETL, produced a report on the impact of state-regulated TMDLs (total maximum daily loads) on coal-fired power station wastewater operations—including cooling water, flue gas desulfurization, and ash handling, as well as coal-pile and other storm-water runoff. Each point and nonpoint source discharging to a water body is allocated a fraction of the TMDL allowed for a pollutant, with some allocation held in reserve as a margin of safety. The report examines three rivers serving coal-fired power plants: the Roanoke River (VA, NC), the Monongahela River (PA, WV), and the Susquehanna River, which is the largest source of water for the Chesapeake Bay (NY, PA, MD). Over 175 TMDLs are operative along the more than 6,000 impaired watershed segments on these rivers. As new TMDLs are developed and existing ones become more stringent, the most likely pollutants to affect the power industry are metals (mercury and other heavy metals), nitrogen, excessive heat and temperature changes, PCBs, phosphorus, storm water sediment, pollutants associated with acid mine drainage (aluminum, iron, manganese, and acidity), and pollutants associated with salinity (total dissolved solids and chlorides).

Novel Sorbents Stabilize Metals in Coal-Fired Power Plant Wastewater—Working under an NETL-administered grant funded through the Office of Fossil Energy's University Coal Research Program, researchers at Texas A&M University have found that micro- and nano-sized iron sulfide and disulfide sorbents have the ability to remove arsenic, mercury, and selenium from ash and scrubber-pond effluent by producing solid phases of the pollutants that are stable when disposed in landfills. Stability after disposal is important to ensure that removal of these compounds from wastewaters will not result in contamination of soils and groundwater. Methods for producing these inexpensive sorbent materials reliably and economically could improve the environmental performance of coal-fired power plants.

Report Assesses Impact of Water Shortages on Power Plant Operations—In a report titled *Water Vulnerabilities for Existing Coal-Fired Power Plants,* Argonne National Laboratory researchers working under the Office of Fossil Energy's Existing Plants Research and Development program implemented by NETL have identified 347 coal-fired plants that are vulnerable to water demand and supply concerns. The study uses GIS (geographical information system) and plant-specific data for more than 500 plants in the NETL Coal Power Plant Database. Moreover, the GIS-based study provides an overview of the general proximity of vulnerable plants to locations of nontraditional water sources, which the Office of Fossil Energy's Research and Development program is evaluating as substitutes for a portion of freshwater used in power plants. The identification of vulnerable power plants, as well as the location of available alternative water sources, will help avert power outages caused by water shortages.

Clean Energy

The Science of Sustainability

Air, Water, Land

"My favorite part of my job is solving problems that people can't seem to be able to solve or that have simple solutions and they just look past them."

Bill Ayers
NETL researcher

Mine Pool Water Is an Environmentally Friendly Alternative for Power Plant Cooling—Working in cooperation with NETL, West Virginia University researchers have evaluated the potential economic and environmental benefits of using mine water as an alternative to traditional freshwater supplies when operating a 320-megawatt power generation facility fired by waste coal left from mining operations. The facility is to be located in Washington County, PA. The study shows that, in addition to lower water acquisition and delivery costs, using the colder mine water from the five mines adjacent to the proposed Beech Hollow Plant would increase operating efficiency by lowering turbine backpressure. Greater efficiency means more electricity can be generated from less fuel while yielding environmental benefits in the form of reduced emissions. The study provides a framework for systematically evaluating the hydrologic, chemical, engineering, and environmental factors that need to be considered in using mine water as an alternative to traditional freshwater supplies.

Flue Gas Water-Capture Technology Tests Completed—Working with NETL and industrial partners, investigators at the University of North Dakota's Energy & Environmental Research Center have completed pilot-scale tests aimed at the recovery of water from flue gas using an aqueous solution of calcium chloride as a drying agent. The LDDS (liquid desiccant dehumidification system) recycles the desiccant solution between an absorber tower (packed bed or spray) and a vacuum flash vaporization-and-condensation stage for recovering water and re-strengthening the solution. Testing was performed with flue gas produced from the oxy-combustion of coal. The gas was cleaned of sulfur oxide and particulates and scrubbed of CO_2 with an amine-based process. Although the low heat recovered from a condensing flue gas heat exchanger precluded auto-thermal operation, and chemical treatment was needed to adjust the desiccant solution's pH, novel integration strategies to distribute the capital expenses and energy requirements among several power plant functions could make the LDDS concept attractive.

Marcellus Shale Frac Water Treatment Initiated—A project team led by Altela, Inc., working with NETL, has installed a frac flow-back water treatment system at a well site in Indiana County, PA. Frac water is produced during hydraulic fracturing, a method used to fracture rock in the production of natural gas or oil. The project team, consisting of Altela, CWM Environmental, Inc., and BLX, Inc., has successfully deployed Altela's patented mobile desalination system to

treat frac flow-back and produced water directly at the wellhead in the Marcellus Shale. The Altela water treatment system removes all contaminates from the frac flow-back water generated from hydraulic fracturing and natural gas production. To date, approximately 275,000 gallons of Marcellus Shale frac flow-back water have been treated and purified at the well site, resulting in the production of approximately 182,380 gallons of clean distilled water. This successful NETL-funded demonstration project has permitted Altela to accelerate its commercialization efforts with development and deployment of the recently released AltelaRain® 600 Module that can treat 600 barrels (25,300 gallons) of fluid per day.

NETL Method Measures Subsurface Water Interaction with Coal Utilization By-Product—Using strontium isotopes, NETL scientists quantified the extent to which mine water interacts with grout containing coal utilization by-products. The grout, consisting of 98 percent fluidized-bed combustion ash and fly ash with 2 percent Portland cement, is used in remediation at the inactive Omega Coal Mine in West Virginia. The ratio of strontium isotopes in the mine water clearly distinguished discharges from grouted and non-grouted areas, whereas conventional chemical analysis could not. Based on results of the study, water that interacted with the grout received 30–40 percent of its strontium from the grout mixture, suggesting the grout is chemically eroding at a rate of approximately 0.04 percent per year. The same approach is now being used to study the interaction of subsurface CO_2-laden waters with geologic media at carbon storage sites. The February 2010 issue of the Elsevier journal *Applied Geochemistry* (Vol. 25, No. 2, 2010) describes the study.

Industry Shows Interest in NETL Pipeline Inspection Sensor—NETL researchers are continuing discussions with interested commercial companies who, at the recent American Gas Association Conference, learned of NETL's novel capacitance sensor technique for detecting changes in the dielectric properties of plastic pipe material. Changes in capacitance have been successfully used to identify discontinuities, which would indicate potential trouble spots or leak points in plastic pipeline. The researchers are also looking at similar applications such as pre-installation inspection of plastic pipe fusion joints to ensure pipeline integrity. The amount of plastic pipeline used in the natural gas transmission and distribution network across the United States continues to increase as new capacity is added and aging metal pipes are replaced with polyethylene pipe.

NETL-Developed Toxicology Technique Validated—Results from five independent laboratories completing a round-robin study of the SPME (solid phase micro-extraction) method of detecting PAHs (polycyclic aromatic hydrocarbons) were accepted by the technical committee at ASTM International, an organization that develops international standards for materials, products, systems, and services used in construction, manufacturing, and transportation. By measuring the concentration of PAHs in pore water rather than in sediment, SPME predicts more accurately PAH bioavailability and environmental effects than does current practice. Developed in cooperation with NETL at the University of North Dakota's Energy & Environmental Research Center, the method has been provisionally accepted as ASTM Standard Test Method D7363-07, and the round robin test results now warrant full acceptance. Because PAH bioavailability decreases over time, the approach promises to reduce to a small fraction the quantity of soil or sediment requiring remediation to fully protect the environment.

What are CUBs?

CUBs (coal utilization by-products) are the solid materials, such as ash, slag, and desulfurization gypsum, formed during the combustion or gasification of coal for electric power generation. Instead of depositing CUBs in ash ponds or landfills, NETL and others are working on ways to turn CUBs into safe and useful commodities.

A Century of Science

NETL's Century of Science Commemorated at Carnegie Science Center

NETL's Energy Challenge exhibit at the Carnegie Science Center in Pittsburgh, PA, was dedicated during NETL's centennial commemoration.

U.S. Representatives Tim Murphy and Mike Doyle present NETL's Anthony Cugini and Cynthia Powell with a Congressional proclamation, "In recognition of the 100th Anniversary of the National Energy Technology Laboratory."

NETL launched our second exciting century of scientific advancement with an event at Pittsburgh's Carnegie Science Center on October 13, *A Century of Science: NETL Launches the Next 100 Years of Energy Innovation*. In conjunction with this event, NETL highlighted our NETL-Regional University Alliance (NETL-RUA)—a collaborative partnership with URS Corporation and five regional universities—and dedicated a new science exhibit, the Energy Challenge, which will remain on display at the Carnegie Science Center for the next several years.

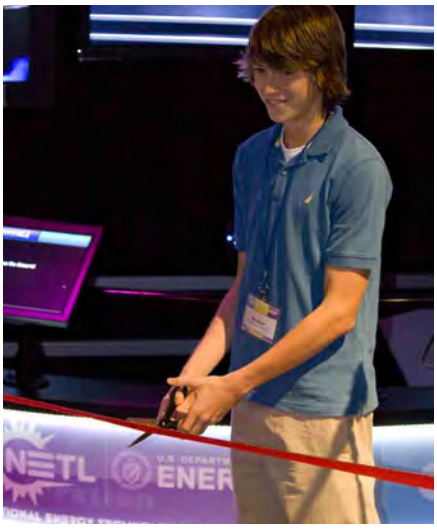
During the event's opening ceremonies, Dr. Anthony Cugini, Director of NETL, spoke enthusiastically of the "Shared Laboratories, Shared Intellect, Shared Resources" concept of NETL-RUA, saying that "it promises advanced energy technologies and growth in our regional and national economies, high-tech jobs for our nation's engineers and scientists, and the education of a new generation of researchers and entrepreneurs who are passionate about pursuing sustainable energy sources for our children and our children's children."

Dr. James Markowsky, DOE's then Assistant Secretary for Fossil Energy, also praised the project, stating that "NETL-RUA will certainly benefit from NETL's expertise in the laboratory, its project management experience, and its understanding of demonstration and technology transfer and commercialization."

A panel discussion on "The Role of NETL and Its Collaborations in Developing Innovative Technology and Promoting Economic Development" gave the heads of the five universities, Cugini, Markowsky, and others an opportunity to talk energy—past, present, and future—and how to best ensure secure, reliable, and affordable energy supplies for the coming decades.

NETL welcomed several special guests to *A Century of Science*, many of whom congratulated NETL on the recent celebration of its 100-year anniversary. U.S. Representatives Mike Doyle and Tim Murphy presented NETL with a special Congressional proclamation, "In recognition of the 100th Anniversary of the National Energy Technology Laboratory." Congressman Doyle praised the partnership, adding his hope that it will "not only strengthen our region but also address the critical energy and environmental challenges that will face our nation for years to come." Congressman Murphy also commended NETL's "100 great years of research," adding that it will quickly compound with the addition of "NETL-RUA's tremendous universities. We look forward to great things coming from this partnership."

The celebration culminated with the dedication of the Energy Challenge. The energy quiz game is a new, permanent exhibit at the Carnegie Science Center and a first for Pittsburgh, one that will help children think early on about careers in energy science and engineering. NETL's Deputy Director Scott Klara dedicated the exhibit with help from the Marshall Middle School Science Bowl team of Wexford, PA, who won the 2010 Southwestern Pennsylvania Science Bowl middle school competition and kicked off the Energy Challenge as the game's first contestants.



Mike Becich from Marshall Middle School cuts the ribbon for NETL's Energy Challenge.

The Energy Challenge teaches Science Center visitors about the importance of energy in our daily lives, how energy works, and how we can conserve and reduce our energy use. It also illustrates the unique collaboration among the region's academic, government, business, and nonprofit organizations in addressing the challenges posed by energy use.

NETL greatly appreciates the work put forth by the Carnegie Science Center in hosting *A Century of Science*. Through the event, NETL entered our next 100 years of technology development and commercialization. With our scientific, engineering, and administrative talent, we will continue to conduct the research, implement the partnerships, and manage the programs that will help provide clean, affordable, reliable energy in the 21st century.

A recording of the full *A Century of Science* event can be seen on YouTube. For more information about NETL-RUA, please visit http://www.netl.doe.gov/rua.

NETL Director Anthony Cugini welcomes guests to A Century of Science, *including (pictured left to right) former ASFE James Markowsky, WVU President James Clements, CMU Vice President of Research Richard McCullough, University of Pittsburgh Chancellor Mark Nordenberg, Penn State President Graham Spanier, and Virginia Tech President Charles Steger.*

Reliable Supply

Abundant, Secure, Affordable

Image courtesy of DMSP & NASA

Securing America's energy supply is a central part of NETL's mission. Our research is dedicated to innovating solutions that will continue to provide clean, affordable, and reliable energy to meet our country's growing demands.

How does NETL help ensure Americans' energy security?

NETL supports and directly conducts research and development activities to secure America's domestic energy supply and recover that supply efficiently and with minimal environmental impact. NETL's long-term research in natural gas and oil recovery is returning economic and energy security benefits today and is projected to do so for decades to come. In addition, the infrastructure technologies pursued by NETL have dramatically improved how we deliver our power. Through continued innovations related to environmental sustainability and improved safety of next-generation enhanced oil recovery, tapping non-conventional sources like methane hydrates, and the development of smart grid technologies, NETL is helping to ensure the clean, cost-competitive recovery of our nation's remaining energy resources.

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Energy Infrastructure

Modernizing our nation's aging energy infrastructure is critical to improving how we use and distribute energy. Energy stoppages can disrupt lives, harm our economy, and cause cascading impacts to other critical infrastructures. NETL's strategic partnership with DOE-OE (DOE's Office of Electricity Delivery and Energy Reliability) is developing advanced technologies for electricity transmission and distribution and improving the ability of the energy sector to prevent, prepare for, and respond to threats and supply disruptions. In addition, NETL staff supports DOE-OE during exercises and emergencies involving energy infrastructure, security, and restoration of services.

PSERC research indicates plug-in hybrid electric vehicles will have a negligible impact on America's electricity distribution systems.

Power Systems Engineering Research Center Studies Future Technology Impacts

Researchers at PSERC (Power Systems Engineering Research Center) have identified a method for improving the reliability of electricity distribution systems and concluded that the impact of plug-in hybrid electric vehicles on America's electricity distribution systems is likely to be negligible.

PSERC researchers at Texas A&M University found that the reliability of electricity distribution can be dramatically improved when intelligent electronic devices are preloaded with non-operational system characterization data, such as the wear on a circuit breaker. The devices can then more accurately monitor grid conditions, helping reduce the frequency and duration of outages.

In another study, PSERC collaborators at the University of Illinois and the Georgia Institute of Technology examined the collective impact of plug-in hybrids, which are expected to become more prevalent in our nation's vehicle fleet. The study forecasts no adverse impact on electricity distribution systems, energy resources, or grid security if vehicles use an optimal power mix (62 percent battery, 38 percent internal combustion) and the national fleet includes 10 percent plug-in hybrids. The study also predicts that emission standards would be met, power demand would increase by only 3.3 percent, and household capacity for battery recharging would be adequate for typical driving needs.

Participation of the 13 universities in PSERC is led by Arizona State University in cooperation with NETL. The group also receives substantial input from the Consortium for Electricity Reliability Technology Solutions.

New Tool Finds Cost Targets for Superconducting Power Equipment—A framework has been developed to enable planning engineers at electric utilities to evaluate HTS (high-temperature superconductivity) applications against traditional T&D (transmission and distribution) solutions, while taking into account unique value drivers of the HTS applications, such as cost. For example, one of the "bottom line" outputs of the analysis is the installation costs of HTS equipment that the utility could pay and still achieve parity with a conventional T&D solution. Navigant Consulting, Inc., built the macro-driven Excel spreadsheet, and NETL is implementing this and other superconductivity-related projects on behalf of DOE-OE. The project supports DOE goals to accelerate the modernization of the nation's electric delivery system through the application of HTS technology.

Fuel Pretreatment Reduces Nitrogen Oxide Generated by Large Reciprocating Engines—Researchers working with NETL have reduced generation of NO_x (nitrogen oxide) by more than 50 percent in large-bore, natural gas-fueled, two-stroke engine tests. More than 6,000 existing natural gas pipeline pump engines could be retrofitted with the technology, which would reduce NO_x emissions some 25,000 tons per year with only 25 percent market penetration. Reduction of NO_x is accomplished by extending lean-combustion limits through the injection of small amounts of syngas (synthesis gas). This Congressionally directed project was managed by NETL for DOE-OE and was performed by researchers from Rolls-Royce Fuel Cell Systems (U.S.), Inc., and collaborators at Colorado State University. The technology developers are now pursuing private partnership agreements to demonstrate a combined engine-syngas generator in the field.

Cyber Security Solutions Debut at DistribuTECH—Several devices and tools developed in cooperation with NETL through funding by DOE-OE were demonstrated March 23–25, 2010, at Pennwell Corporation's 20th DistribuTECH Conference and Exhibition—industry's leading grid event. The products help protect the energy infrastructure from cyber attacks and diminish the risks of energy disruptions because of cyber-related incidents. Organizations displaying the outcome of their projects included Schweitzer Engineering Laboratories, Inc., EnerNex Corporation, Digital Bond, Inc., Siemens Corporate Research, SRI International, and Sandia National Laboratory. Developed rapidly from concept to commercialization, the showcased products resulted from industry-driven initiatives that involve successful partnerships between vendors, asset owners, end users, and national laboratories.

Microgrid Concept for Distributed Energy Sources Successfully Tested—Under a cooperative agreement with NETL, PSERC (Power Systems Engineering Research Center)—a collaboration of 13 universities organized to support research for a reliable grid—performed a series of tests designed to help demonstrate the ease of integrating distributed energy sources into a microgrid. Conducted at the CERTS (Consortium for Electric Reliability Technology Solutions) Microgrid Laboratory, the tests demonstrated stable behavior at critical operations points, the flexibility of control concepts, and the ability to island and reconnect to the grid in an autonomous manner. All tests were performed as expected, demonstrating the robustness of the coupled microgrid concept. Successful connection of numerous microgrids in a distribution system would contribute to achieving a truly "smart" grid with greater reliability, high penetration of renewable sources, self-healing characteristics, distributed control, and improved generation efficiencies. CERTS membership draws from the utility industry, national laboratories, universities, and government agencies in researching, developing, and disseminating new methods, tools, and technologies to protect and enhance the reliability of the U.S. electric power system and the efficiency of competitive electricity markets.

Reliable Supply

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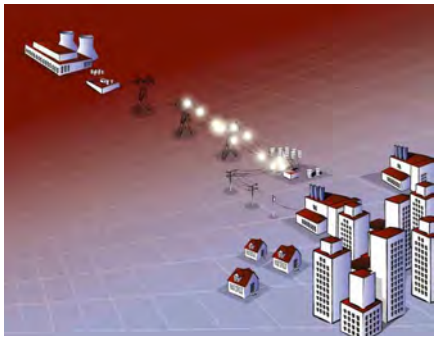
Energy Infrastructure



Why Smart Grid? Our country's outdated power grid is vulnerable to sabotage and breakdowns, which can lead to dangerous blackouts. "Smartening up" our power grid by replacing the old parts with new, innovative equipment and, most importantly, installing much-needed computer controls and software will guard us against power outages and provide higher reliability, greater national security, lower costs, and reduced foreign dependency.

Research Helps Ensure Reliable Inter-regional Flow of Electricity—Working in collaboration with NETL, researchers at Cornell University and the University of California at Berkeley can now simulate and analyze the likelihood of electricity flow disruptions caused by such things as bad weather, high demand, or equipment outages. The approach helps planners anticipate where the infrastructure should be fortified in order to preserve the economically preferred direction of flow, i.e., from low-cost to high-cost regions. The study confirmed the hypothesis that electricity transport costs can blunt the advantage of introducing arbitrage across boundaries of electricity-control areas. It also confirmed the high likelihood of significant electricity price reductions if theoretical analysis of spatial competition were practiced as the basis for planning new facilities. The researchers are PSERC participants led by Arizona State University in cooperation with NETL, with funding from DOE-OE.

U.S. Grid Health Study Completed—Under a cooperative agreement with NETL, researchers at Washington State University have shown that the analysis and communication of electrical waveform data (phasor measurements) would streamline the assessment of grid health if shared inter-regionally with state estimators. As part of a PSERC study, researchers also developed an algorithm to determine the optimal selection of conventional measurements in the external system—that is, external to the system in which the state estimator resides. The study frames an approach for managing data from interconnection-wide monitoring centers, which will become mandatory to avoid cascading blackouts similar to the one that occurred in August 2003.

New Techniques Could Enhance Power System Situational Awareness—University of Illinois at Urbana-Champaign researchers with collaborators at the University of Wisconsin-Madison have identified several techniques for extracting useful information from the voluminous data contained in electrical waveforms (phasor measurements). The techniques, presented in "Using PMU Data to Increase Situational Awareness," can allow operators to look beyond direct control center display of phasor measurement unit data and reach critical understanding quickly, avoiding cascading blackouts similar to the one that occurred in August 2003. The researchers are PSERC participants led by Arizona State University in cooperation with NETL, with funding from DOE-OE.

Improved Fault Reliability Index Could Significantly Reduce Blackouts—Researchers participating in PSERC have developed an improved reliability index by integrating a database for transmission-system equipment asset management with an outage management database. Together, the two databases

blend business data with technical field data and include equipment rating and system models, outage trouble calls, operational records, and data stored in equipment devices. The integration results in an improved business process that correlates outage management with risk-based management of equipment assets, allowing optimized equipment maintenance practices while minimizing the risk of outages. Through a cooperative agreement with NETL, PSERC is funded by DOE-OE and led by Arizona State University.

Variability of Renewable Power Has Cost Impact—Research conducted at Cornell University has found that the need for additional standby conventional generating capacity will increase as the nation's energy grid derives more electricity from variable wind and solar power sources. Associated costs could be mitigated by regulatory practices or by offering end users incentives to invest in more controllable loads and storage capacity. Such incentives ensure traditional electricity transmission and delivery standards are maintained on networks with a high permeation of energy generation from renewable sources. Cornell University is conducting the research as a participant in PSERC, led by Arizona State University in cooperation with NETL with funding from DOE-OE.

Technology May Accommodate Variability of Wind Power—Collaborators at Iowa State University and the University of Illinois at Urbana-Champaign have found that special DFIG (double-fed induction generation) wind turbine controls may help alleviate problems of transient frequency dip. DFIG controls trim turbine blades commensurate with wind force to produce more uniform electricity output, whereas traditional wind turbine designs maximize blade inertia for greater power output. Within limited market penetration (up to 8 percent), the technology could improve grid frequency control, assuming its cost benefit outweighs penalties attributable to "spilling" wind. The researchers are participants in PSERC, led by Arizona State University in cooperation with NETL with funding from DOE-OE.

Improved Infrastructure Permits Full Staffing of Mississippi Toyota Plant—The City of New Albany, MS, has extended electrical services to support the new Toyota Automobile Assembly Plant at Blue Springs, MS. Completed on budget and ahead of schedule, the infrastructure improvement allows the plant to begin ramping up to full operation by the fall of 2011 with full employment levels expected to top 2,000 people. This Congressionally directed project is funded by DOE-OE and managed by NETL.

Electric Infrastructure Design Supports World's Most Advanced Microchip Fabrication Plant—The NETL-managed construction of the electrical infrastructure design for GLOBALFOUNDRIES Fabrication Facility 8 in Saratoga County, NY, is complete and the infrastructure itself is largely in place. The facility, when complete, will be the most advanced semiconductor manufacturing plant in the world. Nearly 1,500 high-tech workers will be employed when mass production begins in 2012. Funding from DOE-OE supported the design of the electrical infrastructure for this $4.2 billion project. The money represents the only federal dollars contributed under Congressional direction to develop the shovel-ready Luther Forest Technology Campus site in New York's Tech Valley. Worldwide nanotech industries will benefit from the scale, operational efficiency, and technology leadership of the Fab 8 plant and will give upstate New York a world class facility.

Reliable Supply

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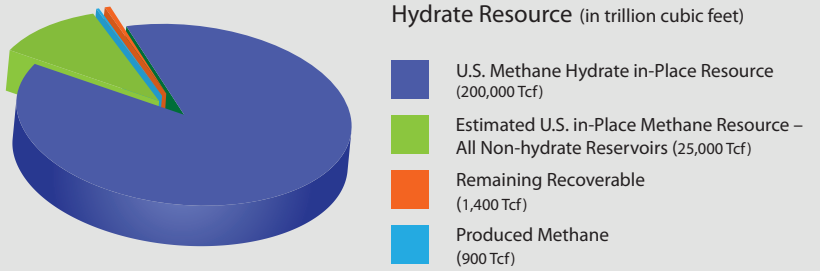
Methane Hydrates

One of the most promising unconventional energy sources under investigation by NETL is the planet's vast store of gas hydrate deposits, in particular methane hydrates. The science and technology to find and produce gas from hydrates could boost U.S. and international economies and energy security by providing new supply options to address future demand. On the other hand, methane derived from gas hydrates may play a key role in the process of climate change. NETL has also been leading the effort to ensure that an accurate understanding of gas hydrate occurrence and behavior is incorporated into leading climate models.

Methane hydrate, "ice that burns."



NETL Develops Method for Near-Instantaneous Hydrate Formation

NETL researchers have engineered a new "rapid formation" process that could economize the use of domestic natural gas resources by reducing production, transportation, and storage costs.

Conventionally, natural gas is cooled and compressed into liquid form to reduce its volume for transport over long distances—a process that is neither energy efficient nor cost effective. Additionally, some of the gas is lost to vaporization during transport and storage. NETL's novel process creates synthetic hydrates of natural gas in seconds with just water and methane, using much less energy and time than is required to liquefy it.

Using Raman spectroscopy, NETL researchers verified that rapid formation produces Type 1 methane hydrates, the same type found in nature. As part of their experiments, researchers also developed nozzle technologies that produce the exact mix of water and methane required to economically form the synthetic hydrates. NETL researchers designed, machined, and assembled a variety of nozzles before selecting one that performed optimally, resulting in the near instantaneous and continuous formation of a snow-like synthetic hydrate.

The successful new process has the potential to significantly reduce costs associated with production, transportation, and storage, while enhancing the efficient use of natural gas from remote or stranded resources.

Initial Results of DOE-Funded Gulf of Mexico Gas Hydrate Expedition Made Public—NETL has released comprehensive initial scientific reports from the most recent gas hydrate expedition in the Gulf of Mexico through the NETL website. The series of 13 reports details initial findings obtained during the 22-day expedition, during which gas hydrates were discovered at high concentrations in sand reservoirs. NETL provided direct geologic expertise for drill site selection and an NETL scientist to serve as science co-chief for the expedition. Obtained as part of the Chevron-led Gulf of Mexico Gas Hydrates Joint Industry project, the findings are critical to evaluating whether gas hydrate accumulations exist in sufficient quantity and quality to become a significant energy supply source—a major goal of the DOE-led National Methane Hydrate R&D Program. NETL contributed further by reporting these results via a special session at the 2010 Offshore Technology Conference and also in several invited presentations, including the Gordon Research Conference and the Goldschmidt Conference.

NETL Assesses Alaska North Slope Gas Hydrate Production Testing Opportunities—NETL scientists have collaborated with the U.S. Geological Survey and BP Exploration (Alaska) to identify two viable gas hydrate production test sites from an established production pad in the Prudhoe Bay area of the Alaska North Slope. NETL geologists conducted extensive mapping of the detailed subsurface environment and utilized numerical simulation to identify areas in which a test could be conducted that would not impact existing or future planned well bores and also would not encounter areas in which the in situ gas hydrates may have been impacted by the prior drilling operations from the pad. This work was instrumental in gaining industry partner approval for forward production testing operations in the area.

First Detailed Results of Methane Production Simulator Published—NETL researchers have successfully applied HRS (HydrateResSim) to predict the amount of methane produced from a laboratory-scale hydrate reservoir. Originally developed for NETL at Lawrence Berkeley National Laboratory, HRS is the sole open-source code available for simulating complex physical, chemical, and thermodynamic processes. NETL researchers employed HRS to compare two dissociation theories: kinetic and pure equilibrium. Generally, the kinetic model revealed a dissociation rate lower than that of the equilibrium model. Hydrate dissociation patterns differed significantly when the thermal boundary condition shifted from adiabatic to constant temperature, and the deviation between the two models increased with decreasing surface area. The work appears in the peer-reviewed journal *Industrial and Engineering Chemistry Research* (Vol. 49, No.11, 2010).

NETL Helps U.S. Geological Survey Expedite Hydrates Research—An automated controls configuration developed by NETL has enabled U.S. Geological Survey researchers to bring a new experimental system online quickly and collect data efficiently in real time. Used to guide a bank of syringe pumps through a highly specialized routine for performing natural gas hydrate formation and dissociation tests under in situ conditions, the automated procedure provides improved control of experimental parameters and enables a single operator to obtain immediate feedback while recording data.

NETL Provides Key Support for International Gas Hydrate Programs—At the invitation of gas hydrate programs in India and Korea, NETL scientists served on expert advisory panels to aid in the planning for future gas hydrate programs. NETL geochemists also served as shipboard scientists for a second natural gas hydrate expedition organized by the government of South Korea. NETL scientists served as senior science advisors to the project and were significantly involved in the planning, logistics, and training related to geochemical evaluations during the expedition. NETL's international collaborations support DOE international agreements and are key to maintaining the program's leadership position in global gas hydrate research and development.

"The punctuation point of the impact of hydrates research here at NETL—and particularly for me as a geologist—has to do with its multifaceted aspects: it has an energy component, it has a climate component, it has a seafloor stability component, and all of these are large, critical issues that are facing not just the United States, but populations worldwide."

Kelly Rose
NETL researcher

Reliable Supply

Abundant, Secure, Affordable

Natural Gas and Oil Production

NETL has a long history of characterizing shale resources, matching technology to geology, and leading the development of enabling technologies for shale gas development. Innovations in fracturing, drilling, motors, downhole tools, and fracture mapping have all resulted from NETL research—technologies that today's oilfield service industry uses for shale development with high research and development cost benefits. NETL's progressive research in gas shales, "tight gas," coalbeds, EOR (enhanced oil recovery), and ultra-deep drilling give rise to technologies that help America's producers, especially small independent companies with limited research capital, economically tap our domestic oil and natural gas resources while also protecting our environment.

Inorganic Nanoparticles Could Make Better Drilling Mud—Collaborating researchers at NETL, Carnegie Mellon University, and West Virginia University have developed a novel application of "nanoparticle haloing" to stabilize drilling-mud formulations. Nanoparticle haloing involves adding highly charged nanoparticles to a suspension of neutrally charged particles to form a stable colloidal mixture. Tests showed the mechanism worked when applied to barite, a real drilling mud constituent. The approach should be applicable for many drilling fluids and could help in developing stable polymer and organic-free drilling fluids.

NETL Develops Smart Drilling Fluids—Researchers at NETL and the University of Pittsburgh have developed hybrids of clays and iron oxide nanoparticles that can be used as rheological additives in drilling fluids. Rheological qualities are those having to do with the flow or deformation of materials. The hybrids possess unique magnetic properties unattainable in individual clay or iron oxide particles. Adding nanoparticles allows the rheology of water- or oil-based fluids to be finely tuned using an external magnetic field. The innovation could not only increase the efficiency of drilling operations and the longevity of drilling tools, but could also find a wide range of applications in mechanical, electronic, and biomedical systems.

Enhanced Oil Recovery with CO_2 Injection Initiated in Alabama Formation—A university-industry project team working in cooperation with NETL and led by the University of Alabama at Birmingham has successfully initiated CO_2 injection as part of a pilot study of CO_2 used for EOR in the highly heterogeneous sandstone reservoirs of the Citronelle oilfield in southwest Alabama. The Citronelle field is Alabama's largest producer and is an ideal candidate for a CO_2 flood because the field's structure and lack of faulting are well-suited for CO_2 storage. The 5-month, 7,500-ton injection and incremental oil-recovery effort produced 60 percent more oil than conventional secondary EOR by water flood. Full-scale CO_2 EOR in the Citronelle field meets the programmatic goal of introducing the technology in areas where it has not previously been deployed.

Seismic Project Helps Identify Untapped Oil—Using technologies developed with funding from NETL, a Kansas drilling company has discovered an untapped 10-foot-thick oil zone in an already developed reservoir. Mull Drilling Company of Wichita, KS, discovered the untapped zone near Cheyenne Wells, CO, using seismic technology designed to detect hydrocarbons. The project improves our understanding of karst reservoirs, which are characterized by low permeability, fluid-control problems, and low recovery rates. These reservoir systems account for 30–50 percent of the hydrocarbon production in the U.S. mid-continent region. The project can help incrementally increase oil and natural gas production, and extend the productive life of mature fields.

Innovative Telemetry System Will Help Tap Hard-to-Reach Natural Gas Resources—The commercialization of an innovative telemetry communications system developed through an NETL research program will help U.S. producers tap previously hard-to-reach natural gas resources deep underground, resulting in access to additional supplies that will help enhance national energy security. Using novel technologies normally associated

with interplanetary deep-space navigation and missile-guidance systems, the patented, proprietary measurement-while-drilling electromagnetic telemetry system is designed to transmit data to and from downhole equipment in real time, enable surface processing of downhole sensor data, and control downhole tools directly from the surface. The technology allows the system to successfully operate at greater depths than other electromagnetic systems and to propagate signals through formations that typically weaken electromagnetic waves.

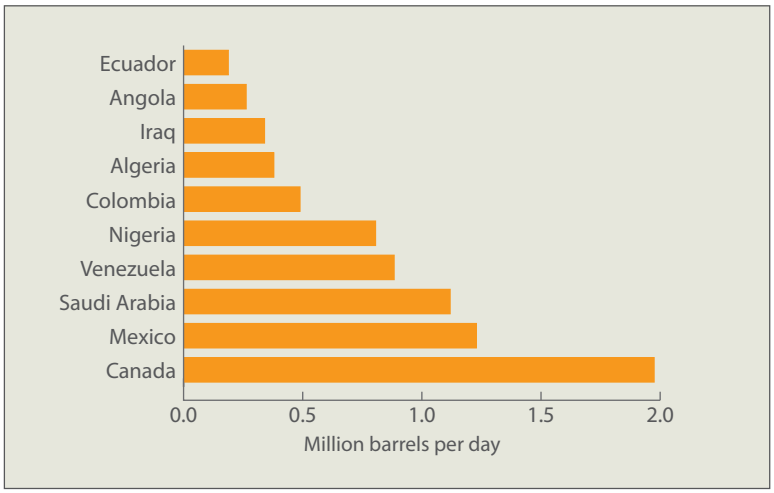
Rugged Reconfigurable Processor Developed—Through a cooperative agreement with NETL, Honeywell International, Inc., has developed an RPDA (reconfigurable processor for data acquisition)—a reprogrammable, multifunctional device tailored to downhole applications in terms of physical dimensions, wide operating temperature ranges, and the ability to withstand high-shock and -vibration environments. Honeywell's RPDA utilizes highly reliable, co-fired ceramic multichip modules similar to an electronic circuit board implanted in a single, solid piece of ceramic material. The RPDA addresses a unique, previously unfilled need for flexible, reprogrammable digital electronics that can operate in extreme downhole oil and natural gas drilling, exploration, and production environments.

NETL Studies Environmental Effects of Producing Marcellus Shale Gas—NETL scientists are investigating the connection between shale geology and gas productivity and preparing to monitor the environmental impacts of shale gas drilling and production at several well sites in Pennsylvania. With the cooperation of a major gas production company, the researchers will obtain onsite baseline values for environmental parameters within air, water, habitat, soils, and ecosystems during the year preceding drilling operations. Monitoring will continue throughout the drilling and production life cycle. Results are expected to help industry improve management practices to lessen environmental impacts, allow regulators to focus on monitoring the most sensitive environmental indicators, and help inform the environmental debate over shale gas development. The American Geophysical Union weekly, *Eos* (Vol. 91, No. 32, 2010), describes the effort.

Unique Ultra-deep Drilling Simulator Sets Operational Record—The NETL UDS (ultra-deep drilling simulator) reached a major milestone by successfully operating at pressures of 10,000 and 15,000 pounds per square inch while drilling a fine-grained limestone specimen. The performance demonstrates a capability superior to currently available test platforms. Designed and assembled at TerraTek, Inc., a Schlumberger company, the UDS is a one-of-a-kind research instrument that physically simulates the bottom-hole conditions of ultra-deep wells. When fully commissioned, the UDS will routinely operate at pressures up to 30,000 pounds per square inch and temperatures up to 250 °C, allowing the Extreme Drilling Laboratory team at NETL to conduct fundamental studies of rock-cutter-fluid interactions under extreme conditions.

Study Allows Better Evaluation of Mesaverde Sandstone—In cooperation with NETL, scientists at the University of Kansas Center for Research have completed a study of Mesaverde sandstones in six basins of the western United States. These tight-gas sandstones represent a significant portion of the U.S. unconventional natural gas resource base. More than 9 gigabytes of Web-based data are available to provide improved algorithm tools for wire-line log analysis and petrophysical formation evaluation of important reservoir properties. The detailed and accurate assessment of moveable gas-in-place resources is most critical in marginal gas plays. Results from this project have provided improvements to the quantitative tools used to determine water saturation as well as gas production.

U.S. Crude Import Sources 2010



Reliable Supply

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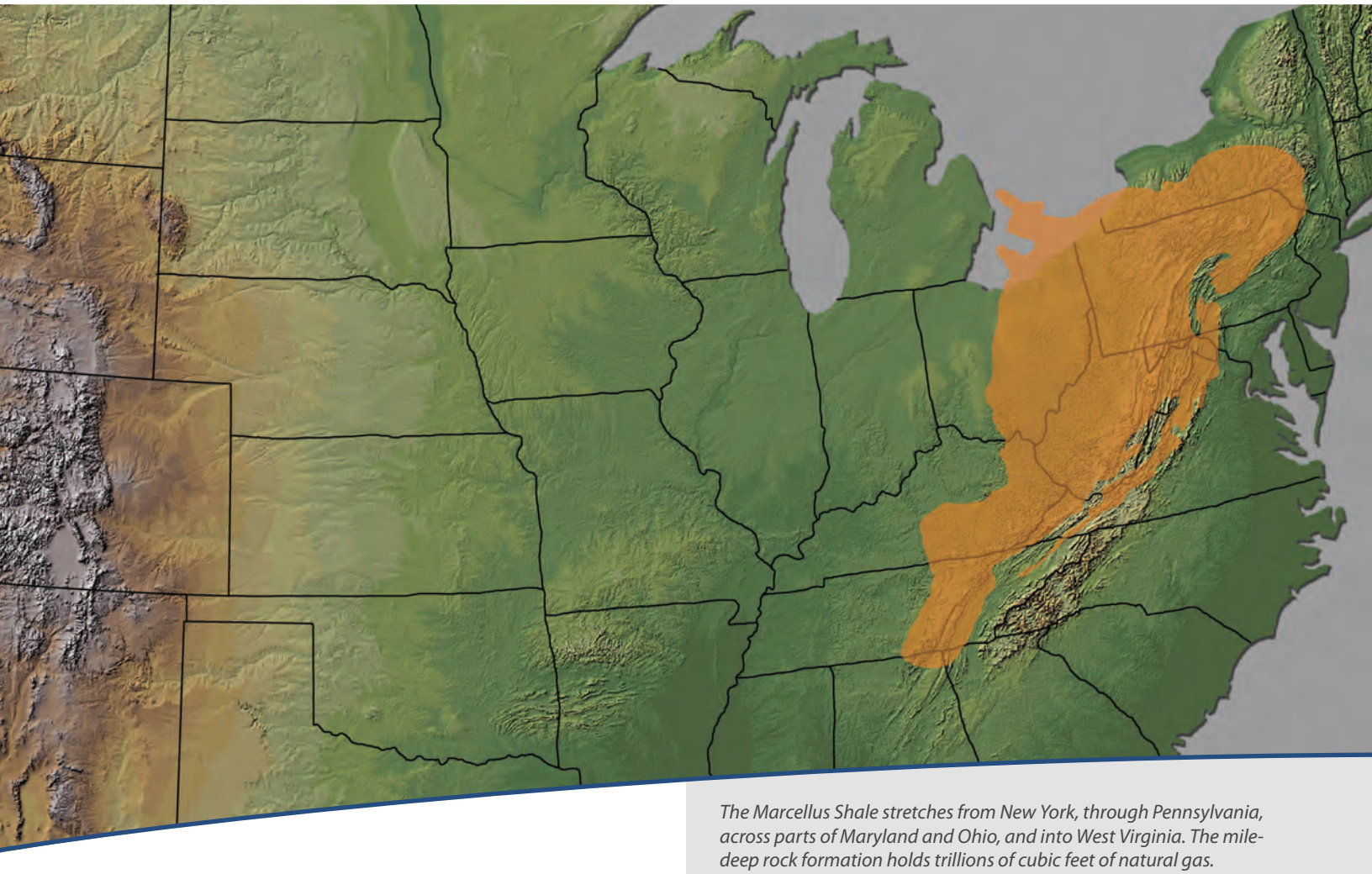
Image courtesy of USGS



The Marcellus Shale stretches from New York, through Pennsylvania, across parts of Maryland and Ohio, and into West Virginia. The mile-deep rock formation holds trillions of cubic feet of natural gas.

Turning Shale into Fuel: NETL Leads Natural Gas Breakthroughs

The Marcellus Shale gas play represents an enormous energy resource, but if the gas has been trapped in the shale for millions of years, why has it taken so long to tap its potential? The answer is a clear indicator of the positive impact of NETL's long-term research projects.

A $92 million DOE research investment begun in the 1970s is widely credited with pioneering key technologies that have stimulated natural gas production from the Marcellus Shale. The result: more U.S. jobs, increased energy security, and higher revenues for states and the federal government.

The Marcellus Shale is a vast, mile-deep, natural gas-bearing rock formation stretching from southern New York through Pennsylvania, western Maryland, eastern Ohio, and West Virginia. According to the U.S. Geological Survey, the shale holds trillions of cubic feet of natural gas. Because it burns more cleanly than coal, shale gas is a potential bridge between fossil fuels and a greener energy future. The United States is already the world's largest producer of natural gas, and recent increases in shale gas production may allow the country to become a net exporter, enhancing our energy security while helping stabilize domestic natural gas prices.

Before the development of advanced drilling techniques, many of which were

pioneered by NETL, the commercial natural gas industry did not have the advanced technology necessary to profitably extract natural gas from deep shales like the Marcellus. Beginning around 2008, however, NETL-developed advanced drilling techniques began to be applied to new gas wells.

These techniques had been developed across three decades, as NETL collaborated with industry to improve horizontal drilling and develop high-efficiency tools, such as electromagnetic measurement-while-drilling, advanced hydraulic fracturing, shale well simulation, and fracture mapping—a technique that uses sound waves to map fractures. Applied originally to the Devonian Shale, these technologies also included multistage fracturing and slick-water fracturing—two additional advances that are currently being adapted for use with Marcellus Shale.

Today, NETL is widely recognized for having contributed directly to the growth of U.S. shale gas production. Because we can now tap rich stores of gas from these once out-of-reach formations, shale gas amounts to nearly 14 percent of the dry natural gas produced in the United States. That share could reach 45 percent by 2035.

NETL continues to partner with industry to examine the environmental impact of advanced drilling, with 27 active shale gas projects across all program areas.

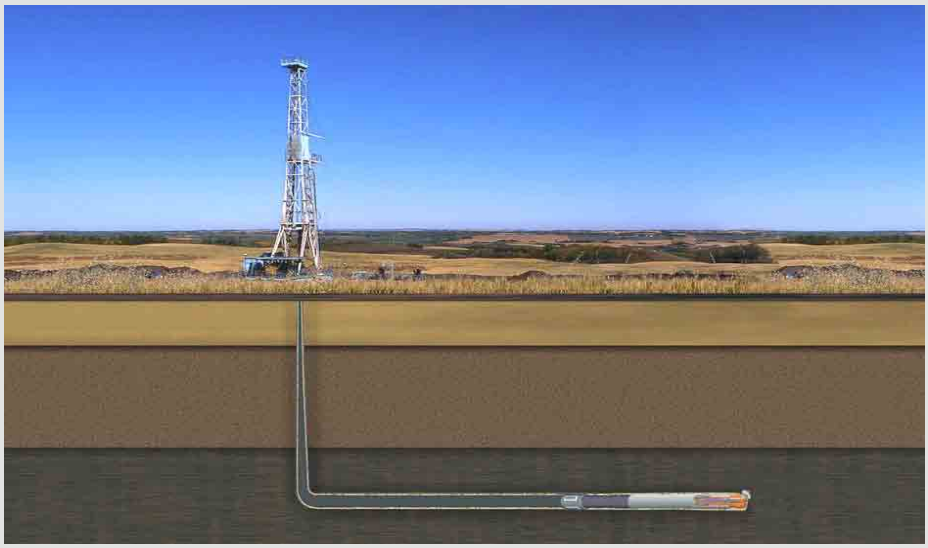
In 2010, NETL began a collaborative effort with Range Resources, one of the largest companies drilling in the Marcellus Shale, to monitor well sites. The resulting data are expected to drive management practices by industry, as well as provide government policy makers and environmental scientists with data on how advanced drilling activities impact the area around the sites.

NETL is at the forefront of shale gas water management research. These projects aim to provide solutions to some of the most vexing shale gas challenges, such as how to cleanly dispose of water used in hydraulic fracturing. NETL also conducts research to monitor air emissions from shale gas wells and determine the environmental impact of constructing access roads and drill pads. Related NETL projects focus on improving the characterization of shale gas, determining the weathering products of shale drill cuttings, and assessing depleted gas shale reservoirs for their potential to store CO_2.

The success of our natural gas shale research in 2010, and across the previous three decades, has been recognized by industry and academia, and it has supported real returns. Developing domestic natural gas resources means additional jobs. Larger volumes of domestic natural gas translate into lower fuel and feedstock prices for industries that use natural gas to process or manufacture products. Increased domestic natural gas production improves national energy security and results in higher tax revenues to states and the federal government. Each of these benefits represents a high-value return on NETL's long-term research projects.

Research Highlight

According to Dr. Terry Engelder, Professor of Geosciences at Penn State University, DOE's Eastern Gas Shales Research Program, initiated in the 1970s, "helped expand the limits of gas shale production and increased understanding of production mechanisms.... It is one of the great examples of value-added work led by the DOE."



NETL contributions to advanced drilling techniques, such as horizontal drilling, have helped make possible the profitable extraction of natural gas from deep shales like the Marcellus.

Science & Technology Leadership

Communication, Collaboration, Commercialization

NETL partnerships and collaborations transfer knowledge and technologies that improve energy production and pave the way for future generations to maintain a lead in the energy industry. From left, Scott Klara (NETL), Congjun Wang (URS Corporation), and Jonathan Lekse and Kristi Kauffman (Oak Ridge Institute for Science and Education).

How does NETL's research make the leap from laboratory to real life?

NETL conducts research to solve our nation's energy challenges, and it is our responsibility to maximize returns to the American people by transferring technologies from our lab to individual households. To achieve this, we pursue regional, national, and international partnerships to lead our discoveries into the marketplace. Our researchers, scientists, and engineers also double as educators and authors who transfer their knowledge and lessons learned to tomorrow's scientific workforce, ensuring that we continue to improve on yesterday's accomplishments. With research as the backbone to our energy solutions, NETL will continue to lead the way to a secure energy future.

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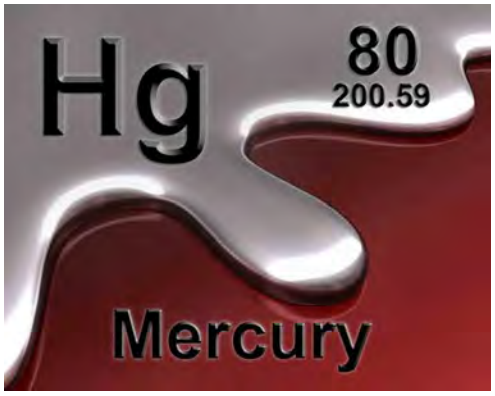
Technology Transfer

The greatest ideas, developments, and discoveries cannot become solutions to energy challenges without being placed in the hands of those who can use them. That's why NETL's technology transfer is key; we must ensure that advances travel from the laboratory to the public domain. In pursuit of this, we partner with commercial, educational, not-for-profit, and government entities to maximize returns to America and to support international causes such as limiting greenhouse gas emissions. Through partnerships, patents, licensing, publications, and policy discussions, NETL is ensuring that our accomplishments profit the nation—and the world.



NETL Patents Novel Catalyst That Makes Elemental Mercury Easier to Capture

NETL's Evan Granite and Henry Pennline have created and patented a catalyst combination that can assist in controlling problematic elemental mercury from the flue gas of power plants. Elemental mercury is extremely difficult to control since it is not soluble in water and, thus, eludes capture by the wet scrubbers that eliminate acid gases in today's power plants.

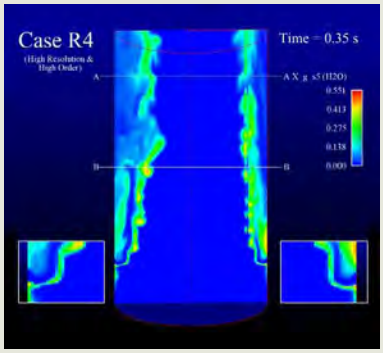
With new mercury laws coming into effect in the next few years, restricting mercury output from power plants, which contribute a third of the mercury released each year, has become more urgent. Mercury released into the air contaminates our lakes, rivers, and streams, making it necessary to set limits on how much fish humans may safely consume from certain waters to avoid mercury poisoning.

Using corrosion-resistant and regenerable iridium and platinum, the new catalysts bring together oxidizing agents that change the mercury into an easily captured and water-soluble species that current scrubbing solutions—or NETL's previously patented Thief carbons—can eliminate. The new catalysts are more temperature- and corrosion-resistant than those currently available, while the Thief catalyst is far less expensive than many used previously.

NETL Launches World's Most Comprehensive Benchmarking of Fluid Dynamic Models—NETL scientists and their collaborators at PSRI (Particulate Solid Research, Inc.) posted the third CFD (Computational Fluid Dynamics) Challenge Problem Package on the MFIX webpage at the NETL public website on May 9, 2010. The international commercial and academic CFD community was thus challenged to model the behavior of selected bed materials in the NETL circulating fluidized bed and the PSRI bubbling fluid bed based on detailed descriptions of those facilities as well as information on the four different bed materials being tested. The comparisons will identify strengths and weaknesses associated with the different modeling approaches, allowing shortcomings to be targeted for future development and improvement.

NETL Research Resolves Scientific Debate on Gas Absorption in Ionic Liquids—NETL scientists applied an ensemble of classical molecular dynamics and Monte Carlo simulations to calculate the self-diffusivity and solubility of pure and mixed CO_2, hydrogen, and argon gases adsorbed in a popular ionic liquid. Supported ionic liquid membranes represent a promising method for CO_2 capture in precombustion processes. Results of the investigation indicate that only one of several experimental studies available in the scientific literature presents accurate data for the ionic liquid examined. Carefully designed measurements corroborate the investigators' theoretical findings. The study also yields the important conclusion that ionic liquids with smaller molar volumes that interact strongly with CO_2 will perform best for separation of CO_2 and hydrogen. Presented in the *Journal of Physical Chemistry B* (Vol. 114, No.19, 2010), the work demonstrates the increased accuracy provided by computational chemistry in describing thermochemical and transport properties of ionic liquids, and it shows how scientific disputes among different experimental groups can be resolved by complementary use of theoretical and experimental methods.

NETL Licenses Patented Technology to International Instrument Manufacturer—Officials at NETL and Zolo Technologies, Inc., have signed a memorandum of understanding for the licensing and use of the NETL-patented transpiration probe. The probe can stay cool and maintain clean optical surfaces while allowing optical access to high-temperature, hazardous, and dirty environments for extended periods. Zolo Technologies plans to incorporate the technology into laser-based ZoloBOSS sensors, which can see through flame, dust, and ash to measure multiple constituents in the harshest environments, including coal-fired combustion processes.



What are fluid dynamics?

"Fluid dynamics" is the technical term for the natural flow of liquids and gases and the effect of forces on their motion. NETL uses computational modeling of fluid dynamics to improve operation, prevent risk, and reduce cost in turbines, solid oxide fuel cell systems, CO_2 management devices, gasifiers, and related technologies.

Science & Technology Leadership

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Technology Transfer

NETL researchers Yee Soong, Sheila Hedges, and Robert Dilmore are inventors of a novel process to separate CO_2 from utility emissions streams.

Active Combustion Throttle Valve Improves Gas Turbine Performance—Collaborators at NETL and the University of Pittsburgh have filed a provisional patent application for a valve design that fine-tunes the control of advanced lean-premixed gas turbines. With the ability to modulate flow around a nominal set point, a turbine-control circuit can tune or balance multiple injectors to achieve greater efficiency and lower emissions by reducing hot spots that may otherwise result from uneven distribution of fuel. Designed for high-pressure and high-temperature gas turbine fuel inlet conditions, the novel high-frequency electromagnetic valve can rapidly modulate fuel flow to counteract the onset of combustion dynamics that can accelerate aging and cause expensive damage to gas turbine components.

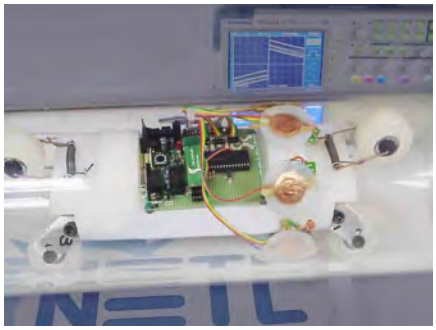
NETL Patents Novel Carbon Capture Concept—An innovative NETL process to separate CO_2 from utility emissions streams (U.S. Patent Number 7,842,126) has proven effective as an alternative to current practice using "monoethanolamine scrubbing." In the NETL process, CO_2 from combustion flue gas dissolves into an aqueous solution of amine and soluble sodium or potassium carbonate. The dissolved carbonate rapidly reacts with amine-associated carbamate and water to form a bicarbonate precipitate. The precipitating reaction serves to separate CO_2 as solid bicarbonate while regenerating the amine solution by removing carbamate. The separated bicarbonate can then be treated thermally to release concentrated CO_2 gas, regenerating the carbonate for recycling with the regenerated amine solution. In an alternate configuration, the CO_2-loaded amine solutions can be used to promote rapid carbonation of solid streams that have significant carbonation potential (e.g., waste cement, calcium oxide-bearing fly ash, and other industrial by-product streams). Through carbonation, CO_2 can be sequestered as a stable mineral carbonate, and the CO_2 capture capacity of the amine solution can be chemically regenerated.

NETL Patents Probe That Detects Anomalies in Non-metallic Plastic Pipe—Since the 1970s, a large portion of gas distribution lines have been fabricated from polyethylene. A special investigative report issued by the National Transportation Safety Board indicates that hundreds of thousands of miles of plastic pipe installed from the 1960s through the early 1980s may be vulnerable to a phenomenon called "brittle-like cracking." Failures from brittle-like cracking may represent the second most frequent failure for older plastic piping, exceeded only by excavation damage. During the 1980s, standards were changed, and the phenomenon of brittle-like cracking was eliminated; however, no satisfactory technique exists for the inspection of older, buried plastic pipelines.

To overcome this problem, scientists at NETL developed a device and method that can detect flaws in buried plastic pipelines (U.S. Patent Number 7,839,282). The probe uses a sensor that measures changes in electrical properties of the plastic to evaluate structural integrity. Using this device will allow for the inspection and replacement of older polyethylene gas lines and prevent disruption in gas distribution service.

New Patented Regenerable Sorbent Removes Hydrogen Chloride and Hydrogen Sulfide from High-Temperature Gas Streams—A number of components in coal and other carbon-based fuels form corrosive and toxic compounds during the gasification process. If gasification processes are to be successful, all contaminants in gas streams must be removed. Hydrogen chloride and hydrogen sulfide are two of the most significant corrosive compounds that need to be removed from coal gas streams. This NETL invention (U.S. Patent Number 7,767,000) addresses an industry need by providing a reusable multifunctional sorbent for the simultaneous removal of hydrogen chloride and hydrogen sulfide. Using a multifunctional sorbent will minimize the number of steps involved in the treatment process and contribute to lower power plant operating costs. The regenerable sorbent is more environmentally friendly than other methods of hydrogen chloride and hydrogen sulfide capture because it eliminates waste disposal problems.

Thermal Barrier Coatings Patented by NETL Will Protect Turbine Components—Higher operating temperatures increase turbine efficiencies for gas turbine engines, but to achieve these increased efficiencies, the gas turbine systems must operate under extreme temperatures and in harsh environments. Significant advances in high-temperature capabilities of turbine components have been achieved through the formulation of nickel- and cobalt-based superalloys, but the use of alloys alone is inadequate to maintain the mechanical and material properties of gas turbines. For this reason, turbine components are often protected using thermal barrier coating systems. Work done by NETL has resulted in the development of novel metallic-ceramic overlay coating materials that protect gas turbine blades and engine components from high temperatures and corrosive gases (U.S. Patent Number 7,740,948). The coating material provides enhanced oxidation resistance to the underlying superalloy. Thermal barrier coatings can be applied using low-cost commercial spraying techniques and low-temperature curing. The use of these coatings will allow turbine systems to operate at higher temperatures with increased efficiency.



This NETL-patented probe uses a sensor to measure changes in the electrical properties of plastic pipe to evaluate structural integrity.

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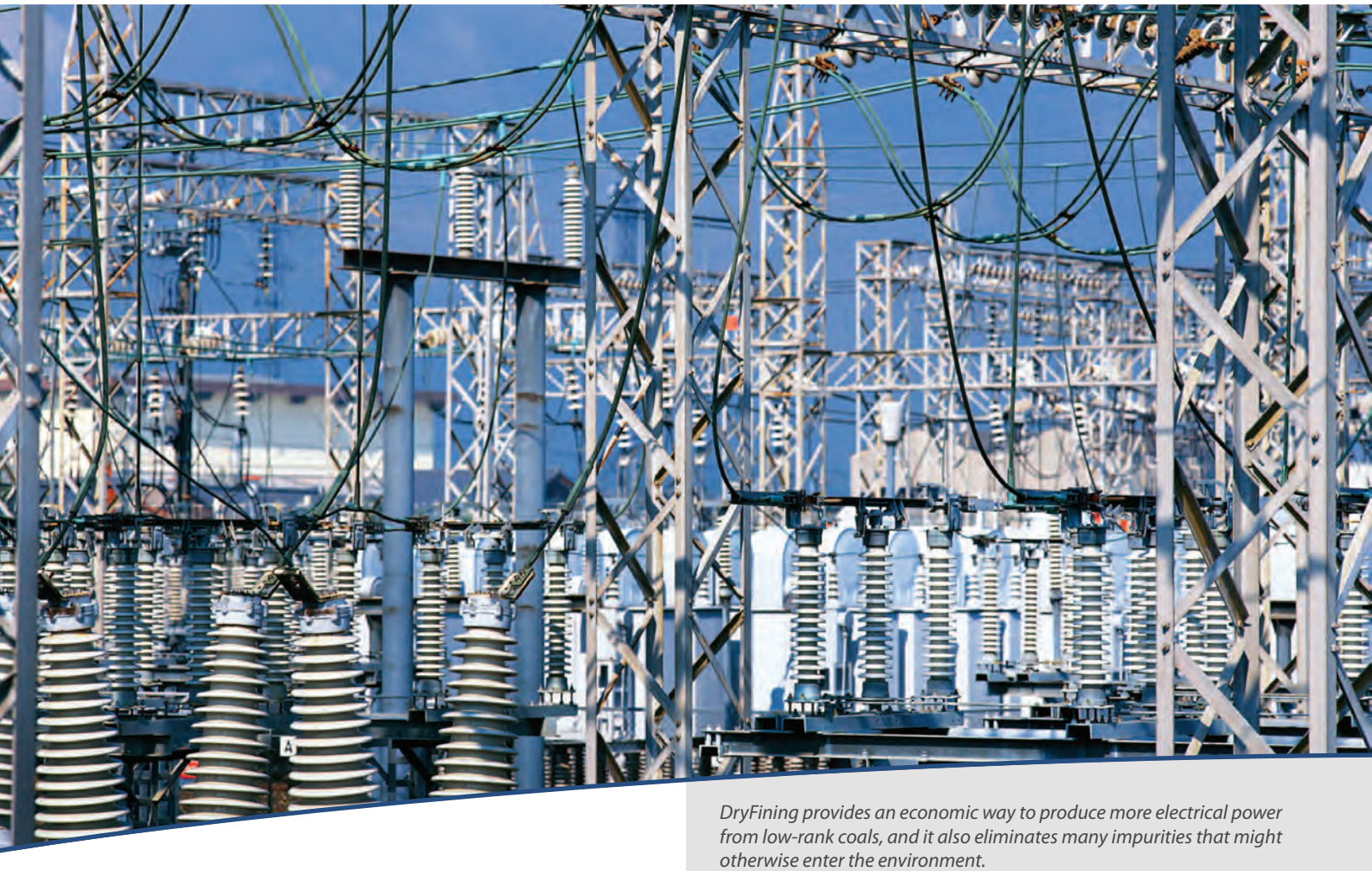

DryFining provides an economic way to produce more electrical power from low-rank coals, and it also eliminates many impurities that might otherwise enter the environment.

"Project of the Year" Awarded to NETL-Managed Technology

DryFining™, a major breakthrough solution in coal-fired energy production, earned the title "2010 Project of the Year" in the category "Best Coal-Fired Project" from the editors of the prestigious *Power Engineering* magazine. DryFining was developed by GRE (Great River Energy) and NETL under the CCPI (Clean Coal Power Initiative) of DOE's Office of Fossil Energy.

DryFining provides an economic way to produce more electrical power from low-rank coals, and it also eliminates many impurities that might otherwise enter the environment. Since 280 U.S. power stations burn low-rank coal, discovering an economic and cleaner way of raising the power output of this coal is truly a major advance.

Coal comes in four broad categories according to hardness and energy content. Anthracite is the hardest, followed in order by bituminous, subbituminous, and lignite. The low-rank coals, subbituminous and lignite, have less density, are higher in moisture and pollutants, and produce the lowest amount of energy when burned (measured in Btus). These low-rank coals together make up 51 percent of coal mined in the United States today, with lignite, a high-moisture, "brown" coal, making up about 7 percent. More than 100 gigawatts of power are produced in the United States today by burning subbituminous and lignite coals.

The high moisture content in low-rank coals causes a less efficient conversion to electricity, the same way that wet wood does not burn as efficiently as dry wood. Lignite

may contain up to 40 percent moisture and subbituminous up to 30 percent. When used to produce power, these low-rank coals must first expend some of their energy burning off water. Further, the high moisture creates a tendency for the pulverized coal to cake and jam in the handling, lowers the heat rate, and causes a higher number of maintenance problems compared to higher quality coal.

DryFining addresses the moisture content in these low-rank coals by partially drying it with the power plant's own waste heat. About 50 percent of a plant's heat is lost from the plant's condenser and stack—heat that ordinarily cannot be harnessed to produce energy. But, with DryFining, that heat is used to pre-dry the coal so that when it is fed to boilers, more power is generated from less coal.

The DryFining method also reduces potentially harmful emissions by segregating the coal particles according to density. Since particles containing mercury and sulfur are heavier than the all-coal particles, they are easily separated out. DryFining has reduced sulfur dioxide and mercury emissions by more than 40 percent, nitrogen oxide by more than 20 percent, and—by increasing unit efficiency—also reduced CO_2 emissions. The dryer, cleaner coal thus produces more energy than an equal amount of untreated coal—and with less environmental penalty.

Years of effort went into this elegant technology. Beginning in 2004, NETL partnered with GRE to develop the DryFining technology. In July of that year, the collaborators began working on a 115-ton prototype dryer design at GRE's 546-megawatt Unit 2 located at their lignite-fueled Coal Creek Station. The prototype started operation in March 2006, and it became apparent almost immediately that this dryer design was working well. In fact, DryFining increased the energy content of the lignite from 6,200 to 7,100 Btu per pound, the same amount of coal producing more heat, which translates into more power.

This significant improvement in plant performance led GRE to begin construction of full-sized dryers at their Coal Creek Unit 2 in September 2007. In fact, GRE was so impressed with the success of DryFining that they simultaneously began full-scale dryer modules for Unit 1 at their own expense. Full-scale dryer operation on both units started in December 2009. The DOE CCPI project was concluded in March 2010.

GRE is now in a formal agreement with WorleyParsons to begin licensing the technology. Already, more than 50 U.S. and international utilities have expressed interest in DryFining technology and have signed confidentiality agreements.

NETL is proud of the significant award won by DryFining and proud of their position at the forefront of discovering, developing, and introducing this effective clean coal technology. NETL's leadership in fossil energy—energy that today produces the great majority of our nation's electricity—profits us all.

Great River Energy's Coal Creek Station, Underwood, ND.
Image courtesy of Great River Energy

Science & Technology Leadership

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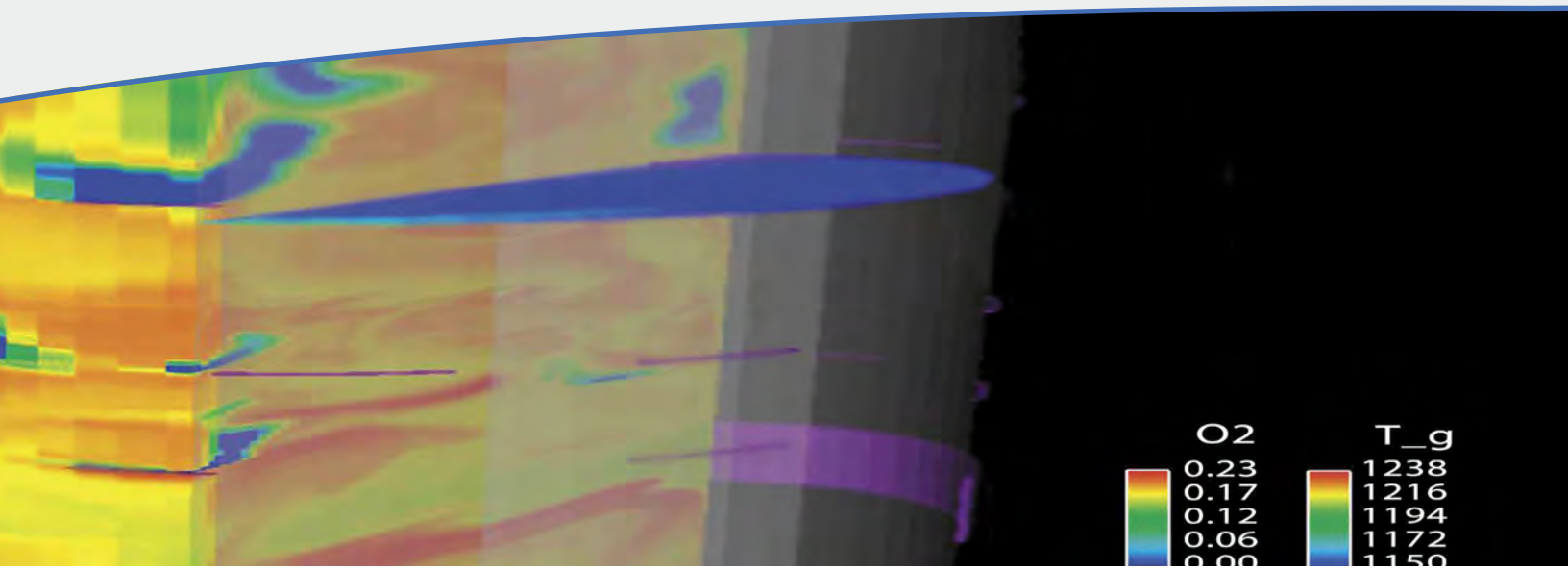
Noteworthy Publications

Ideas, innovation, and invention have the farthest-reaching benefit when they are made available for others to build on. Making our discoveries available to the public is crucial to NETL's mission. To encourage access to our results and lessons learned, NETL scientists and engineers offer their research findings through books, scientific journals, and other media. By disseminating this information, these publications are helping accelerate the development of energy technologies to boost efficiencies, drive down costs, and protect public health and shared resources.



NETL's MFIX software simulates a gasification system.

NETL Shares Gasification Resources with the Nation

Gasification is an exciting and desirable technology for future power plants. Using gasification to convert coal into hydrogen, and then using the hydrogen to make power, results in a truly clean way to convert coal into electricity. Gasification is more efficient than conventional means of producing power, and it produces a CO_2 stream ready for capture and storage. Further, gasification can be used to produce fuels and chemicals from coal, petroleum coke, and biomass.

To educate the public about this technology and its benefits, the Gasification Technology Program, which operates under NETL's Office of Coal and Power Research and Development, has made available two new gasification resources on the NETL website.

The first, called "Gasifipedia," is a comprehensive collection of resources that gives both an introductory and an in-depth understanding of gasification technology and its benefits. The second, the "World of Gasification Database," documents gasification's worldwide growth, plant data, current world industry, and planned near-term capacity additions. It reveals that the worldwide gasification capacity has continued to grow for the past several decades and is now at 70,817 megawatts thermal of synthesis gas output at 144 operating plants with a total of 412 gasifiers.

NETL Researchers Contribute to New John Wiley & Sons Geosciences Volume—NETL researchers Dustin Crandall, Grant Bromhal, and Dustin McIntyre found a new approach to couple experimental and numerical information that is described in *Advances in Computed Tomography for Geomaterials*, edited by Khalid A. Alshibli and Allen H. Reed. By employing digital information obtained from CT (computational tomography) scans of core fractures as input to computational fluid dynamics codes, the researchers can obtain high-resolution data that allow simulation of fluid flow through fractures to be more precise with minimal loss of intrinsic roughness information. Data re-sampling of the CT-scanned fracture produces more efficient numerical simulations, which would otherwise be time consuming and computationally costly to achieve with equivalent resolution.

NETL Researchers Serve as Guest Editors for Special Elsevier Issue—NETL researchers Dushyant Shekhawat, Henry Pennline, Evan Granite, and David Berry co-edited a special issue on advanced fossil energy utilization for the journal *Fuel* (Vol. 89, No. 6, 2010). The special issue contains a selection of papers presented at a symposium the researchers organized for the 2009 American Institute of Chemical Engineers Spring National Meeting in Tampa, FL, April 26–30, 2009. Nineteen refereed articles by authors in government research laboratories, academia, and industries of Austria, Belarus, Canada, China, Germany, Greece, Ireland, Russia, Spain, and the United States present informative and thought-provoking research on hydrogen production and separation for fuel cell applications, carbon capture and separation for power generation systems, and mercury and other trace elements removal from coal-derived gas.

NETL Contributes to New Book on Natural Gas Hydrates—NETL's methane hydrates technology manager Ray Boswell served as co-editor for a new publication released by the AAPG (American Association of Petroleum Geologists) titled *Natural Gas Hydrates—Energy Resource Potential and Associated Geologic Hazards*, Memoir 89 in the AAPG Memoir series. The book also contains chapters authored by NETL's Ray Boswell, Yongkoo Seol, Charles Taylor, and Robert Warzinski where they provide an overview of the National Methane Hydrates R&D Program and report on their research, simulation, and modeling activities. The book also contains reports from other research organizations participating in the NETL-managed program. The publication, an outcome of the 2004 AAPG Hedberg Research Conference in Vancouver, British Columbia, is a comprehensive treatment of the geology of gas hydrates that is of value to the gas hydrate research community, as well as exploration and development geologists working in arctic and deep marine environments.

NETL Scientist Co-authors Chapter in New Gas Hydrates Publication—Ray Boswell co-authored "Motivations for the Geophysical Investigation of Gas Hydrates," NETL's contribution to *Geophysical Characterization of Gas Hydrates*, published by the Society of Exploration Geophysicists. *Geophysical Characterization of Gas Hydrates* is the first book to document geophysical approaches used in detecting and mapping gas hydrates. The book's comprehensive treatment of the geology of gas hydrates is of value to both the gas hydrate research community and exploration and development geologists working in arctic and deep marine environments.

NETL Researcher Serves as Guest Editor for Special Elsevier Issue—NETL's Ronald Breault was invited to be guest editor of a special issue of *Powder Technology* (Vol. 203, No. 1, 2010). The special issue contains a selection of papers presented at NETL's 2009 Workshop on Multiphase Flow Science, as well as the 3rd CFD (Computational Fluid Dynamics) Challenge Problem, which encouraged the international commercial and academic CFD community to meet modeling challenges in granular-fluid hydrodynamics. The feedback on predictions of competing models, as compared to actual experimental results, identified strengths and weaknesses associated with different modeling approaches. The continued development and improvement of CFD models will make multiphase science-based computer simulations accessible by 2015 for the design, operation, and troubleshooting of energy conversion processes. This new CFD technology will be applied in gasifiers, coal combustion systems, carbon capture, clean coal power and hydrogen production, and chemical-looping combustion.

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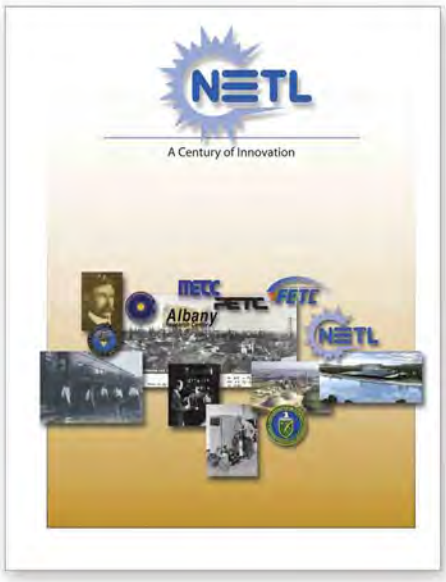
Noteworthy Publications



NETL's history book,
A Century of Innovation.

NETL Recounts History, Details 100 Years of Innovation

May 16, 2010, marked NETL's centennial. To commemorate our organization's many successes along its 100-year journey, NETL published its history, *A Century of Innovation*. The book chronicles NETL's rich past, the evolution of our programs to meet the nation's ever-changing energy needs, and the dedication of the NETL community to solving new energy challenges.

A Century of Innovation places NETL and its predecessor organizations in the context of the energy issues that have shaped today's technology landscape. From mine safety and air quality issues prevalent at the beginning of the 20th century, through World War II's energy demands and the nation's postwar shift from coal to petroleum, to the energy shortages in the 1970s, *A Century of Innovation* presents a comprehensive discussion of how NETL has responded to each new energy hurdle the nation has faced and how those solutions have impacted America's energy frontiers and prosperity.

Limited print copies are available for libraries, and the PDF version may be accessed at NETL's 100-year anniversary website www.netl.doe.gov/newsroom/100yr.

NETL Paper on New Photocatalyst for CO_2 Reuse Among Most Read—In the American Chemical Society publication, *Journal of Physical Chemistry Letters* (Vol. 1, 2010), a paper authored by NETL scientists Congjun Wang, Robert L. Thompson, John Baltrus, and Christopher Matranga was recognized as one of the top 10 most accessed journal articles in 2010. The paper discusses CO_2 management technologies and describes the synthesis and characterization of a new photocatalyst and its ability to convert CO_2 into value-added fuels and chemicals. The new photocatalyst is activated by visible light—comprising the majority of sunlight available at the earth's surface—while previous photocatalysts for this application were activated by ultraviolet light that makes up only 1–5 percent of light reaching the Earth's surface. The use of visible light activation will increase the efficiency of the catalytic process, which is a significant advancement for CO_2 reuse applications.

NETL Research Paper Included Among Top 20—NETL scientist Dr. Charles Taylor co-authored a paper with researchers from Lawrence Berkeley National Laboratory that was among the "top 20 most cited articles" published in a special Elsevier issue in *The Journal of Petroleum Science and Engineering* (Vol. 56. Nos.1–3) for the years 2007–2010. The paper discusses the groundbreaking use of computerized tomography to monitor the formation and dissociation of methane hydrates in sediment. The research provides extensive pressure, temperature, and density data obtained with the use of a large x-ray transparent pressure vessel, and shows significant water migration and possible shifting of mineral grains in response to hydrate formation and dissociation.

NETL Scientists Author Chapter for Encyclopedia of Energy—John Wiley & Sons invited NETL researchers to provide a chapter for the coal section in the *Wiley Encyclopedia of Energy Science, Technology, and Applications*. The researchers discussed an innovative technique called the "pressure transient method," refined by NETL, for making relatively rapid and reliable permeability measurements of coal samples with very low permeability. The method prevents errors that can arise when changes in permeability occur at approximately the same rate as conventional measuring procedures. Upon its 2011 release, the five-volume encyclopedia will become the largest and most comprehensive assortment of information on energy ever published.

NETL Researchers Contribute to New Book on Synthesis Gas Combustion—In response to increased interest in the use of coal- and bio-derived syngas (synthesis gas) in future power generation, CRC Press-Taylor & Francis has released a new title, *Synthesis Gas Combustion: Fundamentals and Applications*. The volume contains chapters authored by NETL's George Richards, Kent Casleton, and Nate Weiland and covers such topics as the background and history of gasification processes, implications of the different gasification technologies, and the tradeoffs and research and development issues associated with using syngas in different application areas, such as fuels, chemicals, electrical production, and CO_2 removal and management. The NETL chapters titled "Gasification Technology to Produce Synthesis Gas" and "Syngas Utilization" have already been cited in several technical publications.

NETL Researchers Profiled in *Innovation* Magazine—A special April/May issue of *Innovation* magazine featuring "Innovators in the Federal Laboratories" details the work of NETL researchers Henry Pennline and Evan Granite in detecting, measuring, and removing mercury from coal-derived flue gas in power plants. Developed over the years with other colleagues, their methods include the Thief Process, which removes partially activated carbon from an operating coal furnace for injection in downstream ductwork; a palladium sorbent that also removes trace pollutants; and ultraviolet radiation that requires no sorbent material at all. The researchers received R&D 100 Awards for the palladium sorbent in 2008 and for the Thief Process in 2009.

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R&D 100 Awards

These yearly awards, the "Oscars of Innovation," identify and celebrate the top 100 technology advancements entering the market place each year from industry, academia, and government-sponsored research.

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International Cooperation

NETL is fully engaged in the worldwide effort to expand paths to clean, affordable energy. We collaborate with global energy partners in joint research, conducting workshops, publishing studies, and exchanging information to advance clean energy sources and reduce the global carbon footprint. By applying our best practices at a global scale, we can prevent risks in technology development, help our partners advance their capabilities in clean coal and carbon storage, and lessen the environmental impact of all energy sources. NETL's commitment to global cooperation is furthering international progress of energy technologies and positively impacting global climate challenges and emerging economies.

NTPC's coal-based Korba power plant, located in Chhattisgarh, India.

Image courtesy of Pankaj Bhartiya, National Thermal Power Corporation

NETL-USAID/India Projects Carry Technology, Best Practices to India

A collaboration between NETL and U.S. manufacturer Paragon Airheater Technologies is expected to improve efficiency in NTPC (National Thermal Power Corporation), Ltd.'s, 200-megawatt Korba, India power plant. NTPC installed Paragon seals, new deflector plates, and other hardware in two air preheaters—rotary devices used in plants to recover the heat in the flue gas exiting a coal-fired boiler. The Paragon seals are expected to last longer than the seals they replaced and reduce air leakage of 15–18 percent to single digits. The project was funded by the U.S. Department of State and NTPC as part of the Greenhouse Gas Pollution Prevention project under the USAID's (U.S. Agency for International Development's) India mission.

NTPC also worked with NETL, AEP (American Electric Power), and Allegheny Energy to organize workshops on U.S. best practices that would improve the knowledge of plant engineers, maximize power generation, and decrease harmful emissions into the environment. AEP and Allegheny Energy executives hosted a four-member NTPC delegation at three U.S. power plants, and two utility experts from AEP and Allegheny Energy paid reciprocal visits to an NTPC power plant to observe practices and exchange information with senior engineers and managers.

It is estimated that the widespread use of advanced technologies and best practices from U.S. utilities by Indian plants will avoid millions of tons of CO_2 emissions in the future, while improving plant reliability and reducing operating costs.

NETL and Polish Institute Researchers Investigate Chemical-Looping Combustion of Synthesis Gas—Thermogravimetric analysis data from chemical-looping combustion experiments conducted with simulated coal-derived syngas (synthesis gas) in the presence of sulfur show that nickel-oxide oxygen carriers performed best when supported on sepiolite (magnesium silicate) compared to the other support materials tested. Sulfur, in the form of hydrogen sulfide, greatly affected the reaction profile by decreasing reduction reaction rates significantly, but the sulfur also increased oxidation rates of reduced samples without affecting capacity. Details of the collaborative study conducted by NETL and the Institute for Chemical Processing of Coal at Zabrze, Poland, appear in *Energy & Fuels* (Vol. 24, No. 8, 2010) published by the American Chemical Society. Using oxygen from metal oxide instead of air to combust fuels has the significant advantage of exhausting concentrated CO_2 without requiring energy for separation or purification.

NETL Collaboration Helps Polish Institute Secure Research Grant—During a recent visit to the Institute for Chemical Processing of Coal at Zabrze, Poland, NETL scientist Dr. Ranjani Siriwardane completed a joint research

paper with Dr. Ewelina Ksepko on aspects of chemical-looping combustion of coal-derived syngas. The paper was based on data obtained during an earlier exchange visit at NETL with samples brought from Poland. The joint research was instrumental in obtaining the substantial sum of 1.5 million Polish zloty (approximately $500,000 USD) over 3 years from a Polish funding agency to develop the Institute's laboratory facilities and continue the collaborative work.

NETL Provides Assistance to Engineers Without Borders—NETL engineer Isaac K. Gamwo participated in a review panel organized by the American Institute of Chemical Engineers to evaluate selected proposals submitted to Engineers Without Borders U.S.A. The nonprofit organization receives hundreds of proposals from developing countries annually asking for assistance in meeting basic human needs, such as clean water, sanitation, and energy. From among five proposals demonstrating the application of chemical engineering principles to humanitarian and sustainable development, the panel unanimously chose a project submitted by Kenya for a 2010 grant award to be conducted in collaboration with Montana State University.

United States–India Utility Executive Exchange Program Successfully Concluded—An institutional development program implemented by NETL as part of a Participating Agency Service Agreement with the India Mission of the USAID/India (U.S. Agency for International Development) completed executive exchanges aimed at creating within India's largest electric generating utility, NTPC (National Thermal Power Corporation) Ltd. , a broader, deeper understanding of U.S. best practices and technologies for coal-fired power plant operations. American Electric Power and Allegheny Energy executives hosted a four-member delegation from NTPC at three U.S. power plants, and two utility experts from Amercian Electric Power and Allegheny Energy paid a reciprocal visit to observe practices at an NTPC power plant and to participate in an information exchange with senior engineers and managers. Widespread use of U.S. utility best practices for plant operations and maintenance at NTPC and other Indian utilities will avoid millions of tons of CO_2 emissions over the long term through greater plant efficiency, while also improving plant reliability and reducing plant operating costs.

New Cooperation Agreements Signed with China—NETL signed two new agreements with leading research and development organizations in China for cooperation on advanced clean coal technologies, including carbon capture and storage. The first agreement was with ENN Group Co., Ltd., as a project under Annex IV: Energy & Environmental Control Technologies of the Fossil Energy Protocol between the Office of Fossil Energy and China's Ministry of Science and Technology. This cooperation focuses on CCUS (carbon capture, utilization, and storage), including using algae to capture CO_2 from flue gases, catalytic gasification, and hybrid power systems that combine fossil and renewable energy sources such as fuel-flexible gasification. The other agreement was the new Annex VI: Advanced Coal-Based Energy Systems Research, Development, and Simulation between NETL, the Pacific Northwest National Laboratory, and the Chinese Academy of Sciences. This agreement focuses on high-volume CO_2 CCUS; advanced gasification and gas turbines; advanced syngas conversion technologies; and multiphase and multi-scale modeling of advanced coal conversion technologies and CCUS. Joint research has been initiated under both agreements with cooperation under the latter agreement already leading to a joint publication, "Computational Science: Enabling Technology Development" (*Chemical Engineering Progress*, January 2011), on how computational science will play a key role in accelerating technology development and in the realization of virtual process engineering of advanced energy systems.

3rd U.S.–China CO_2 Symposium Convened—Following the success of the 2nd Symposium held in 2008 under Annex IV: Energy & Environmental Control Technologies of the Fossil Energy Protocol between the Office of Fossil Energy and China's Ministry of Science and Technology, the 3rd U.S.–China CO_2 Emissions Control Science & Technology Symposium was organized by NETL, Columbia University, Zhejiang University, and China University of Petroleum in Hangzhou, China, on December 10–12, 2010. The event drew over 130 participants from the two countries, including representatives of 16 leading U.S. companies and organizations. The Symposium highlighted China's growing interest in considering CCUS as a CO_2 mitigation option for their rapidly growing power sector, which is about 80 percent coal-based. The presentations represented a cross-section of the state-of-the-art research and development underway in both countries. A 4th Symposium will be organized in late 2011 or 2012.

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Educational Outreach

The stewardship of a clean energy future is in the hands of next-generation researchers and scientists. NETL is encouraging the next wave of science scholars through outreach efforts like DOE's National Science Bowl and NETL's interactive Energy Challenge exhibit, while National Lab Day activities and research experience through programs, such as the Oak Ridge Institute for Science and Education, deepen our educational impact with students. With outreach efforts such as these, our experienced researchers inspire not only student achievement today, but also the energy researchers of tomorrow.

NETL's Energy Challenge kiosk.

NETL's Energy Challenge Fosters the Next Generation of Energy Scientists and Engineers

In 2010, NETL unveiled its innovative educational outreach exhibit at the Carnegie Science Center in Pittsburgh, PA. Dubbed the Energy Challenge, the exhibit is the newest addition to NETL's ongoing education and outreach program to help provide students at all levels a fundamental understanding of energy science and technology.

Designed to teach children and young adults about the science of energy and the importance of energy in our daily lives, the interactive exhibit uses a game-show style presentation and animated videos. The interactive kiosk quizzes contestants on all things energy, from sources of energy, to the science behind energy, to environmental issues and conservation. The game matches players against one another to answer multiple-choice questions. Points are earned by the player that responds with the correct answer first. Questions are grouped by education level and fall into three categories: kindergarten through fourth grade, fifth through eighth grade, and high school. The exhibit also features informative facts about types of energy, how energy is produced and used, and energy efficiency, conservation, and safety. While geared for students, the questions and other content are engaging and challenging for adults, as well.

The Energy Challenge was unveiled during the NETL-sponsored *A Century of Science* celebration held on the occasion of NETL's 100-year anniversary. The event was hosted by the Carnegie Science Center and featured regional DOE Science Bowl champions from Marshall Middle School (Wexford, PA), who helped dedicate the exhibit and served as the Energy Challenge's first contestants.

NETL's Energy Challenge is the first such exhibit to be developed by a national laboratory, and it is increasing public awareness, particularly with young people, about the role that science and technology play in responsible environmental stewardship. The exhibit is a permanent display at the Carnegie Science Center and will continue to be maintained and developed by NETL.

The JASON Project

SEA RESEARCH FOUNDATION NATIONAL GEOGRAPHIC

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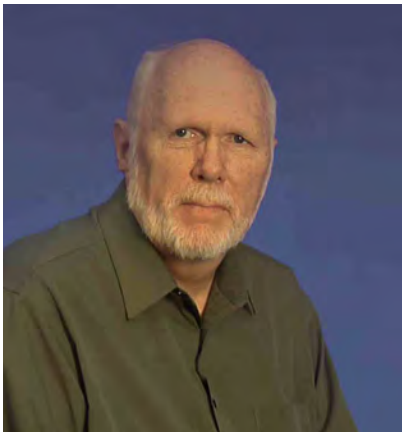
The JASON Project is an interactive software program that connects students with scientists and researchers from NETL, NASA, NOAA, and JASON's parent company, the National Geographic Society. Via video, interactive games, print, and HTML, the students engage in real-time "missions" designed around standard classroom learning objectives.

NETL Collaboration on JASON Project Yields Three CODiE Awards—The JASON Project's multimedia energy curriculum unit "Operation: Infinite Potential," developed in part with NETL assistance, won three coveted CODiE Awards from the SIIA (Software & Information Industry Association). Representing the industry's sole peer-recognition awards program, CODiE Awards celebrate excellence and vision in educational technology, digital content, and software. The SIIA pool of educators and technology experts recognized "Operation: Infinite Potential" as the nation's Best K–12 Instructional Solution, Best Online Instructional Solution, and Best Education Game or Simulation for 2010. Founded by the National Geographic Society, the JASON Project puts student "Argonauts" in contact with practicing explorers and researchers to excite them about learning science. Resulting curricula become available through print, video, games, and free online resources to tens of thousands of teachers and millions of students in the United States and worldwide. "Operation: Infinite Potential" empowers students to work alongside leading scientists to explore past, current, and future challenges in energy generation, storage, and consumption.

NETL Celebrates National Lab Day—On May 6, 2010, scientists and engineers from NETL led 20 fifth-grade students at South Park Middle School, PA, in a series of hands-on science experiments designed to excite the students about science and inspire interest in future careers in science, technology, engineering, and math. The students explored topics such as polymerization, crystallization, and acid-base chemistry in an environment that engaged both hand and mind. The event was part of a nationwide celebration of National Lab Day, a DOE-supported education initiative inviting scientists, engineers, and other technology professionals into classrooms across the country to support the President's stated goals of moving American students to the top of the pack in science and math while expanding science, technology, engineering, and math education and career opportunities for underrepresented groups. The NETL demonstration was webcast live to Memorial Middle School in Albany, OR, West Fairmont Middle School in Fairmont, WV, and Brentwood Middle School in Pittsburgh, PA. To reach additional students and teachers, a video of the demonstration was also posted at the NETL website following the event.



"It's always fun to get in the lab, to put together a new experiment, to work with students on a variety of problems. That's really a highlight to the work, too, when you can take what you do and get excited about it, and work on getting young people to be just as excited about it as you are."

Steve Woodruff
NETL researcher

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Awards and Recognition

The innovative technology and research contributions made by NETL researchers continue to earn our lab recognition. In 2010, the diligence of our scientists and engineers resulted in technology developments that garnered two prestigious R&D 100 Awards, several technology transfer awards, and recognition for leadership in energy research. These awards reflect NETL's experience in resolving energy and environmental challenges and leading innovation. Building on our history of success and accomplishment, NETL continues to help structure America's sustainable energy future with novel innovations and superior research.

NETL Garners FLC Awards and Recognition

The FLC (Federal Laboratory Consortium) each year recognizes both regional and national achievements by federal laboratories in transferring their technologies to the marketplace. The FLC is an organization of federal laboratories, centers, and agencies created to promote technology transfer nationwide. In 2010, the FLC honored several NETL accomplishments.

National Technology Transfer Award—The FLC awarded a 2010 Excellence in Technology Transfer Award to NETL for successfully developing the innovative software, VE-PSI (Virtual Engineering-Process Simulator Interface). VE-PSI facilitates the collaborative design of next-generation energy plants with an interactive 3-D tour of current power plant systems. The capability enables the cost- and time-efficient creation of virtual prototypes for new plant designs, which reduces risks in development on actual pilot- and demonstration-scale plants. The open-source software was a result of collaborative efforts between NETL, Ames National Laboratory, and Reaction Engineering International and is now available to the private sector and other government laboratories.

Technology Transfer Achievement Recognized—The FLC presented a 2010 Excellence in Technology Transfer Award to NETL for successfully developing and commercializing a significant dry sorbent CO_2-capture technology. The sorbent has a high selectivity and capacity for CO_2 capture and low projected heat requirements. Once its capacity is reached, the sorbent can be recycled and used to capture more CO_2, which will increase the overall efficiency in plants. NETL collaborated with ADA-Environmental Solutions to optimize the patented amine sorbent technology for potential use in conventional coal-fired power plants.

NETL Researchers Receive Regional Awards—The outstanding work of two NETL research groups was recognized at the 2010 FLC Regional Awards for establishing innovative approaches to sustainability in materials under high mechanical stresses. Paul Jablonski and David Alman received an Outstanding Technology Development Award for creating a coating material that can extend the lifetime of metal components used in high-efficiency energy production. James Bennett and colleagues received the Outstanding Commercialization Success Award recognizing their development of a high-wear refractory material for use in industrial gasification units.

Partnership Achievement Recognized—The FLC has recognized the developments of DOE and DOD (Department of Defense) national laboratories for the 2010 FLC Interagency Partnership Award. DOE's NETL and DOD's Air Force Research Laboratory have collaborated in support of the Superconductivity Program to develop breakthrough technology for producing large quantities of high-quality superconducting wire. Superconducting wire will increase power transfer while decreasing losses and emissions associated with current wire conductors. The collaboration was conducted through the High-Temperature Superconducting Research and Development agreement managed by both laboratories.

Image courtesy of NASA

The Deepwater Horizon oil spill as captured by NASA's Terra satellite on May 24, 2010.

NETL Researchers Recognized for Exemplary Service to the Nation

NETL researchers George Guthrie, Grant Bromhal, and Franklin Shaffer earned the U.S. Geological Survey Director's Award for Exemplary Service to the Nation. They were recognized for applying advanced techniques under extreme time constraints to estimate leakage rates following the drilling rig explosion at the Macondo oil well in the Gulf of Mexico in April 2010.

The Deepwater Horizon National Incident Command asked the researchers to serve on the Flow Rate Technical Group, which gave scientific estimates of oil flow during the spill. They served with two of four divisions—Plume Analysis and Nodal Analysis—with personnel from other DOE national laboratories, academia, and industry. NETL researchers who also dedicated their expertise to the teams included Bryan Morreale, David Huckaby, George Richards, Madhava Syamlal, Mehrdad Shahnam, Roy Long, and Sofiane Benyahia.

The Plume Analysis Team evaluated oil leak jets 5,000 feet below the sea surface using particle image velocimetry and computational fluid dynamics simulations. In June, NETL researchers from the Plume Team estimated a flow rate of 60,000 bpd (barrels per day), which was proximate to measurements of 55,000 bpd taken in early August after the well was capped. The Nodal Analysis Team simulated flow restrictions in the oil reservoir and wellbore systems to evaluate uncertainties associated with the oil spill well, wellbore system, and fluids and how those uncertainties affected flow rate estimates.

Ultimately, the Unified Command used the Flow Rate Technical Group's estimate of the oil leak rate to set the level of response—such as number of ships and personnel—in the Gulf of Mexico.

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Awards and Recognition

NETL Wins Two R&D 100 Awards in 2010—Selected by an independent panel of judges and the editors of *R&D Magazine*, the R&D 100 Awards are presented to the 100 most technologically significant products to enter the marketplace in the past year. NETL technologies garnered two of these prestigious awards in 2010: Cerium Oxide Coatings for Oxidation Rate Reduction in Stainless Steels and Nickel Superalloys, and osgBullet.

Cerium Oxide Coating for Oxidation Rate Reduction in Stainless Steels and Nickel Superalloys—This surface treatment extends the lifetime of metal components exposed to oxidizing environments. Higher efficiency in energy production can save resources, such as coal and petroleum, while protecting our environment. However, higher efficiency also generally means more severe operating conditions. To avoid the premature failure of components associated with such extreme conditions, NETL researchers developed a cerium oxide–based coating that can be applied as a slurry to a metal part by brushing, spraying, or dipping. Because these methods of application are simpler and less costly than alternative approaches, the novel surface treatment could help extend our natural resources at a substantial savings.

osgBullet—This set of computational modeling tools provides an integration interface that links two object visualization tools, OpenSceneGraph and Bullet, and significantly enhances engineering design and simulation. With osgBullet, researchers can investigate multiple alternatives and explore the "what if" questions that can lead to breakthroughs in design. Users can create and modify design scenarios collaboratively in real time, experimenting with numerous design changes on the fly and instantly visualizing the impact of those changes on the overall system. This capability provides engineers, designers, managers, and their customers with a dynamic decision-making environment for immediate product assessment and development. The osgBullet was developed jointly by NETL, Ames Laboratory, Idaho National Laboratory, Skew Matrix Software, and the U.S. Army.

NETL Wins 2010 Communications Award—NETL captured an Award of Excellence for the publication of its *2008 Accomplishments Report* in the Technical/Statistical Report category. The award was presented at the Blue Pencil/Gold Screen annual competition conducted by the NAGC (National Association of Government Communicators). The award honors excellence in publications, media relations, photography, video, multimedia, and other visual communications. NAGC recognizes writers, editors, graphic artists, and others who work in communications for federal, state, and local governments.

NETL's Expertise Requested in Development of Standard Test—The American Society for Testing and Materials consulted NETL in developing a standard test for evaluating the performance of carbon used for mercury capture from coal-derived flue and fuel gases. The request was made based on NETL research that shows that a simple packed-bed reactor treating simulated gas mixes can qualitatively predict the performance of sorbents in actual flue or fuel gas even though contact time and gas composition may differ significantly from the full-scale application.

U.S. Environmental Protection Agency Selects NETL Model for National Standard—The EPA (Environmental Protection Agency) is referencing NETL's life cycle analysis of petroleum-based transportation fuels to determine the level of reduction in greenhouse gases that can be expected from compliance with the EPA's Renewable Fuel Standards. Selected for its accuracy and transparency, the NETL study provides a comprehensive baseline of greenhouse gas emissions generated over the life cycle of conventional transportation fuels—gasoline, diesel fuel, and kerosene-based jet fuel—in the United States. The study also identifies greenhouse gas reduction opportunities in each life cycle stage of the conventional fuels. According to the EPA's Renewable Fuel Standards program, the volume of renewable fuels that refiners and importers are required to phase into their products will now be based on greenhouse gas reduction goals measured from NETL's 2005 life cycle baseline.

NETL's Decision Tool Selected for National Science Foundation Project—NETL collaborated with researchers at the University of Alaska Fairbanks to develop an ice-road planning model. The model was selected by the NSF (National Science Foundation) Data Conservancy Team at Johns Hopkins University as an exemplar case of how to create cyber infrastructure and methodologies for preserving and presenting scientific data. By incorporating spatial databases, mathematical optimization, and user-defined values, the model determines multiple route options and associated tradeoffs relative to objectives such as risk, cost, and construction time. The model is part of the North Slope Decision Support System being developed for water resources planning and management related to oil and gas development on the Alaskan North Slope.

Our Vision for the Future

NETL-Regional University Alliance

NETL-RUA
Regional University Alliance

NETL officials and representatives from the five universities that form the NETL-Regional University Alliance executive committee.

NETL-RUA: Innovation for the Future

Today's energy challenges require timely solutions to ensure that our nation realizes a clean energy future. The 2010 launch of the NETL-RUA (National Energy Technology Laboratory-Regional University Alliance) offers solutions. By engaging faculty and students from five regional universities—Carnegie Mellon University, Penn State, the University of Pittsburgh, Virginia Tech, and West Virginia University—in conducting research alongside scientists and engineers at NETL and the Alliance's industry partner, URS Corporation. These established research institutions are combining their expertise and resources, including analytical, computational, and experimental facilities, to achieve a common set of research, education, and economic objectives.

NETL-RUA was formally launched October 13, 2010, during a celebration at the Carnegie Science Center in Pittsburgh, PA. As a growing force for economic advancement and a fusion of intellectual property and resources, the Alliance is a platform for developing clean, affordable, abundant energy. NETL-RUA is conducting basic and applied energy research, educating emerging scientists and engineers, and fostering energy innovation and accelerating its deployment—efforts that will not only advance energy solutions but will also spur business development and create jobs.

Developed collaboratively by its member organizations, NETL-RUA's fully integrated research program allows researchers from across the Alliance to work side by side; share facilities, data, and ideas; and jointly identify technology solutions to such challenges as carbon management and transitioning to sustainable energy systems for the future. The complementary strengths of the Alliance combine to broaden each institution's research capacity, allowing NETL-RUA to explore multiple paths to multiple solutions in shorter periods of time. With projects ranging from bench-scale demonstrations and computational modeling to field experiments to commercialized innovations, this collaboration is ready to make its mark on the energy industry.

The Alliance is working to find energy solutions through its research and technology developments, but it's NETL-RUA's investment

in education that will allow it to stay a step ahead of future challenges. NETL-RUA is connecting current accomplishment and future potential by transferring knowledge to the next generation of researchers. Students are stepping out of the classroom and into the lab, working with premier scientists and faculty to conduct research in response to real energy concerns. Through its educational programs, the Alliance develops students' laboratory skills and instills in them an entrepreneurial mindset, which they need to both succeed in the fields of science and engineering and produce meaningful benefits to our society.

Once a technology demonstrates commercial potential, it must make the leap from laboratory to marketplace to affect positive change. Located in a region that is a hub of the energy industry—rich in raw materials, power-production facilities, high-tech energy businesses, and research organizations—NETL-RUA is well positioned to accelerate commercial technology deployment. The Alliance can draw on the engineering, design, and construction expertise of URS to help commercialize NETL-RUA innovations, spur new businesses, and promote job growth. This will build the bridge between research and commercialization and help the region continue to provide maximum returns on research investment to the nation.

From inception to marketplace, NETL-RUA is poised to play a pivotal role in expanding the frontiers of energy technology. As this powerful collaboration builds momentum, its combined efforts will provide a greater impact than would the seven institutions working alone. A multifaceted organization with common research pursuits, the Alliance will focus on its long-term goals of mapping its expertise and capabilities against our nation's most pressing energy challenges. NETL-RUA's ability to provide the framework, commitment, and integration of regional capabilities will address these challenges with energy solutions.

"NETL-RUA has already tackled a large feat—identifying the right problems to address, the right research to answer these problems, and bringing together the right people to carry out those tasks."

Cindy Powell,
Director, NETL Office of Research and Development

NETL-RUA Mission

NETL-RUA draws upon our collective intellectual, research, and commercialization infrastructure to develop the advanced energy technologies required to solve domestic and global energy and environmental issues, train future generations of energy researchers, and promote regional economic development.

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