2009 NETL Accomplishments

09

NATIONAL ENERGY TECHNOLOGY LABORATORY — the ENERGY lab

U.S. DEPARTMENT OF ENERGY | NETL

Mission

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

Contents

Cover page—*Dr. William J. Kroll experiments with an early zirconium reactor at the Albany Research Center circa 1948. In 2009, Albany's Marisa Arnold conducts materials research using a scanning electron microscope.*

Our History Powers America's Future

It is my pleasure to present the National Energy Technology Laboratory's (NETL's) 2009 accomplishments report. The report describes the results of our work during the calendar year and showcases the triumphs we have achieved during our 100-year history of innovative energy research.

Each accomplishment demonstrates NETL's commitment to uphold America's trust through wise investment of U.S. taxpayer dollars. Our funding is provided through the U.S. Department of Energy's Office of Fossil Energy, as well as other Department offices and federal agencies. Our achievements fulfill our long-standing promise to the American people to perform cutting-edge research and support the development of advanced technologies, which contribute to the clean production and use of our nation's domestic energy resources.

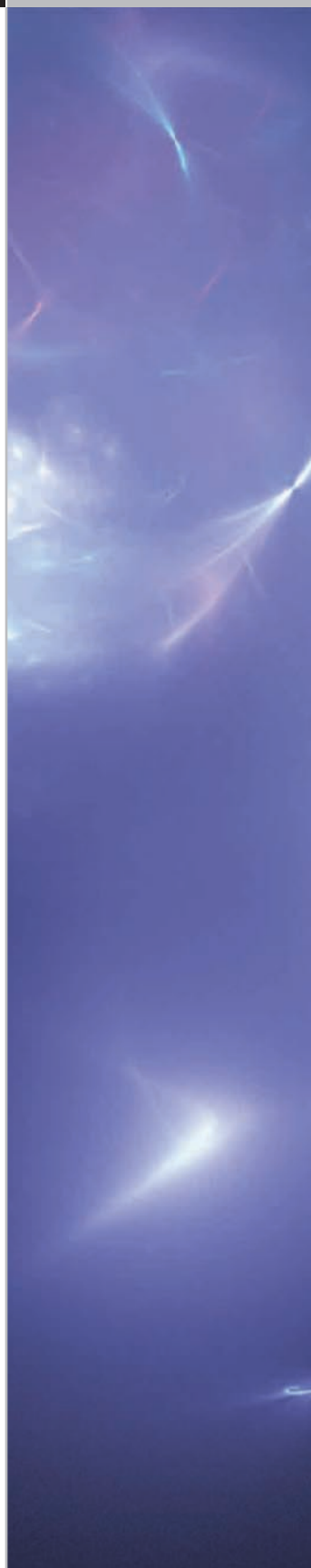
NETL's reputation as an innovator reaches back to the 1910 creation of the Pittsburgh Experiment Station. Since that time, our methods, technologies, and processes have answered each decade's pressing energy issues. Our evolution has paralleled the transformation of the U.S. energy infrastructure from a system run almost entirely on fossil fuels to an expanding energy portfolio that includes new and sustainable energy resources.

NETL's major focus continues to be the development of clean fossil-based systems integrated with carbon capture and storage. Our scientists, engineers, and analysts are also working to develop new and exciting domestic resources, such as methane hydrates, and enhancing the efficiency, reliability, and economics of renewable wind-, solar-, and biomass-based systems.

The successes NETL achieved in 2009 are the result of extensive onsite and contracted research, as well as collaboration with our fellow national laboratories, other government agencies, industry, academia, and international research organizations. As NETL supports the Department of Energy in its mission to advance the national, economic, and energy security of the United States, it has implemented a broad spectrum of complementary energy and environmental research and development programs to satisfy the energy needs of today and those of generations to come.

I invite you to read through these pages and see NETL's diverse contributions to our energy past, present, and future. We believe NETL can help make our nation's next 100 years our finest.

Anthony V. Cugini, Director
National Energy Technology Laboratory



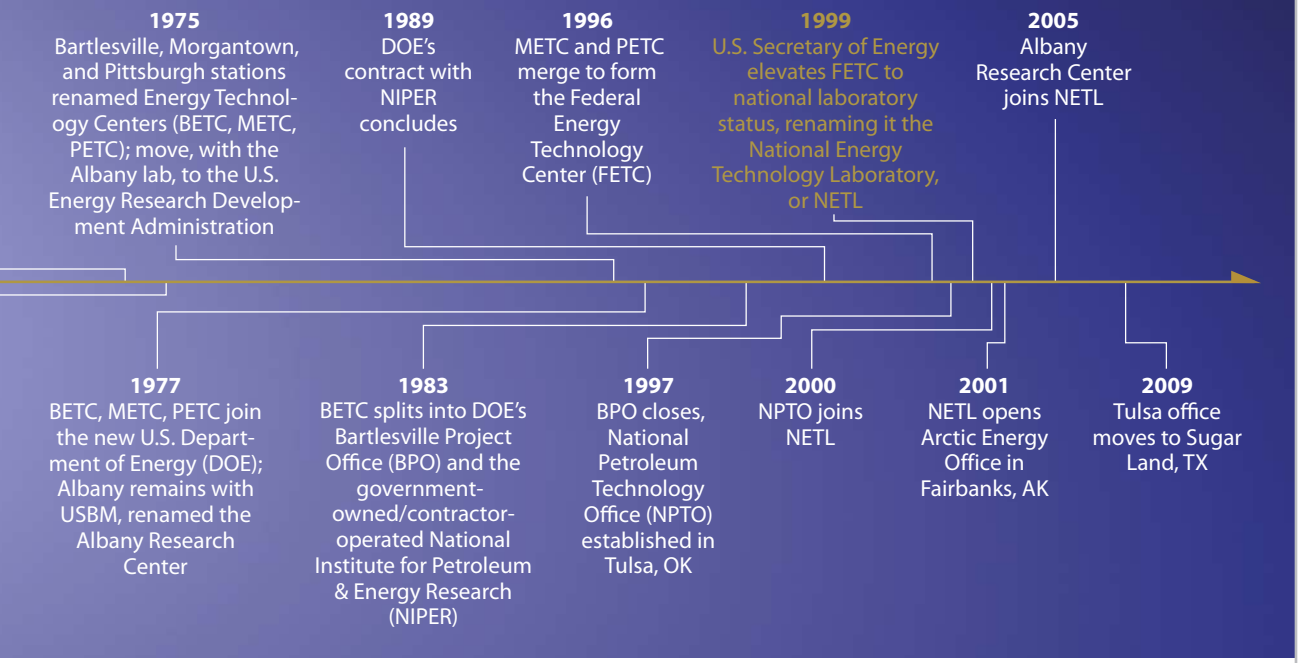
NETL: The First 100 Years

For 100 years, innovation, dedication, and collaboration have enabled NETL to address the monumental energy challenges that face our nation. Though we have worn many hats during the last century, our main mission remains unchanged: to provide safe, reliable, and affordable energy to the American people.

At NETL, science inspires us to embrace new perspectives and consider the impossible as we seek unique solutions for specific problems. Our organization has evolved to meet national energy needs—from energy conservation efforts in the Great Depression, through urgent World War II research into aviation fuels and nuclear materials, to today's discovery of next-generation technologies that capture and store carbon emissions.

NETL's historic accomplishments began in the early 20th century, after a series of catastrophic explosions in 1907 spotlighted dangerous and wasteful mining practices. On May 16, 1910, the U.S. Bureau of Mines (USBM) was created in the Department of the Interior to focus on safety issues within the coal industry. The new organization established its main field office and first laboratory in Pittsburgh, PA, the heart of the rich Central Appalachian coal region.

The Bureau's first director, Joseph Austin Holmes, and his staff propelled disaster prevention through the development of coal dust controls, cooler-burning explosives, and equipment that minimized sparks and flame. Their efforts saved thousands of lives and made the Pittsburgh station a center of expertise on coal, toxic gases, and the phenomena of ignition, explosion, and combustion.



In the decades following, USBM expanded its research inquiries, creating a nationwide network of regionally focused laboratories to investigate petroleum and natural gas production, the mining and refining of rare metals, and the conversion of coal into gas and liquid fuels. The Bartlesville, OK, station pioneered enhanced oil recovery efforts by developing water-flooding techniques and chemical solutions that freed oil trapped within rocks underground. In Albany, OR, researchers developed advanced materials that could withstand a range of harsh environments. And in Morgantown, WV, engineers improved efficiencies, removed impurities, and reduced the cost of operating coal-based power systems.

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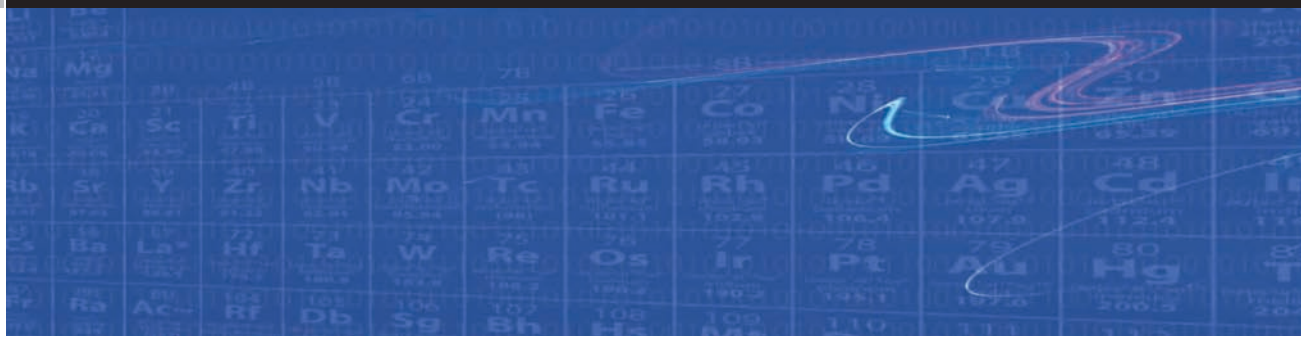
YEARS OF INNOVATION

Joseph Austin Holmes became the first director of the U.S. Bureau of Mines when it was founded by Congress on May 16, 1910. Its mandate: develop technologies and processes to protect coal mine workers. Holmes enthusiastically led Bureau efforts by proving the explosive nature of coal dust and driving the discovery of other practices to make coal mining safer.

NETL: The First 100 Years



The multiple threads of these programs came together between 1996 and 2005. In 1996, the Pittsburgh and Morgantown centers merged to form the Federal Energy Technology Center. Three years later, this organization was elevated to national laboratory status within the Department of Energy (DOE) and given its current designation, NETL. The National Petroleum Technology Office, successor to the Bartlesville, OK, station was incorporated into NETL in 2000, and in 2001, our Arctic Energy Office was established in Fairbanks, Alaska. Finally, the Albany Research Center—which had remained with USBM until the agency closed in 1996—rejoined its former partners at NETL in 2005, making our Laboratory complete.

Our past successes include producing the zirconium that powered the first nuclear submarine, clarifying the composition and cause of smog, and being one of a select group to study lunar rock samples brought back from Apollo missions to the moon. NETL's leading role in coalbed methane and gas shale research in the 1970s and 80s has fulfilled its promise, as coalbed methane now makes up almost 10 percent of our nation's natural gas, and gas shale is an emerging resource.

Today's accomplishments are equally significant, as we transfer our technologies from bench-scale investigation to commercial demonstration. NETL is making strides in carbon management by developing the infrastructure needed to capture and permanently store carbon

dioxide (CO_2) emissions. Our groundbreaking work in the computational sciences enables us to conduct research in simulated environments so we can realize tangible results at reduced cost and risk. We are maximizing our nation's natural gas resources through cutting-edge drilling techniques. We are also enhancing our nation's energy delivery system through projects that pursue "smart" power grid technologies and next-generation lighting that burns brighter and longer with less power consumption.

For 100 years, NETL and its predecessor organizations have helped our nation navigate the diverse challenges associated with energy production and use. Our accomplishments demonstrate real and measurable progress toward national energy security, a cleaner environment, and a robust American economy. NETL will continue to explore the energy frontier and develop exciting technologies that ensure a sustainable and promising energy future for the United States and the world.

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YEARS OF INNOVATION

A planned coal-mine explosion at the Bureau of Mine's first research site in Pittsburgh, PA, proved beyond doubt the highly explosive nature of coal dust, which had been widely considered inert and harmless. The Bureau's efforts to improve coal mine safety saved countless lives, as researchers went on to develop coal-dust controls, cooler-burning explosives, and techniques for minimizing spark and flame.

Advanced Power Systems

Low-Impact, Cost-Effective Energy

NETL's advanced power systems innovations are securing environmentally sound, affordable energy for the 21st century. Our researchers are developing fossil-fuel systems with greater efficiencies and advancing next-generation technologies, such as hydrogen-based energy, coal gasification with CO_2 capture, and fuel cells that run on coal-derived synthesis gas. The research effort NETL is making today will help our nation realize advanced energy systems for tomorrow.

Facing page—Under DOE's Clean Coal Technology Demonstration Program, the Morgantown and Pittsburgh Energy Technology Centers promoted integrated gasification combined cycle—or IGCC—power plants, which combined three of the technology centers' research specialties: coal gasification, gas purification, and advanced turbine engines. Under this program, the Wabash River Power Station in Indiana and Tampa Electric Company's Polk Power Station in Florida, pictured here, came online. Today, they are still two of the world's cleanest coal-fired power plants.

Advanced Power Systems

Low-Impact, Cost-Effective Energy

Gasification

The USBM gasification research program, begun at the Bureau's Morgantown Experiment Station in 1946, was the first of its kind in the United States. Its mission: improve synthesis gas production. The station's earliest specialties became coal gasification and the removal of harmful impurities from manufactured gas. In the new millennium, NETL's Advanced Power Program is developing gasification technologies and turbines that produce clean electrical energy while yielding an easily captured CO_2 stream. Computational fluid dynamics models aid researchers in developing gasification technologies that will operate at lower cost and higher thermal efficiency, making them reliable and able to operate economically on coal and petroleum coke.

NETL Researchers Identify Possible Cause of Low Gasifier Availability—Deposits of minerals in downstream coolers, known as fouling, can adversely affect the reliability and availability of commercial coal gasifiers. NETL researchers have found that during gasification a small amount of large, pyrite-containing coal particles may convert into iron in the presence of partially gasified coal. The iron does not dissolve in slag, but rather pools on the surface of the slag and becomes a potential fouling agent if reintroduced into the gas stream. The findings will aid gasifier efficiency by helping operators to optimize the performance of mineral preparation processes—such as coal grinding and slurry processes—and decrease fouling agents.

NETL Assesses Current and Future Power Plant Technologies with Carbon Capture—A new NETL report analyzes a variety of process configurations for producing electric power from bituminous coal. Representing the second of a two-volume study, the report considers pre-combustion carbon capture scenarios whereas the first volume focused on non-capture scenarios. Each volume adds a series of process modifications representing advanced technologies within DOE's research and development portfolio. Assessing the impacts that each technology can make on the cost and performance of future power systems allows its contribution to DOE programmatic goals to be measured and prioritized. With successful commercialization of the technologies, the study estimates that a 7–8 percentage-point efficiency improvement over conventional gasification technology is possible. With fuel cell technology, even greater process efficiency improvements (24 percentage points) are potentially achievable. Moreover, successful deployment of the advanced technologies evaluated would result in capital costs and cost of electricity more than 30 percent below that of conventional integrated gasification combined cycle (IGCC) technology with carbon capture and storage.

NETL Model Selected for Designing High-Temperature Desulfurization Process Plant—Results produced by a computational fluid dynamic (CFD) model developed by NETL agreed favorably with actual data obtained from a high-temperature desulfurization process (HTDP) pilot plant at the Eastman Chemical Company facility in Kingsport, TN, and developed and constructed by Research Triangle Institute (RTI). The NETL model determined the absorption and regeneration of a porous zinc-based sorbent for various operating conditions. The model, which could also be applied to any sorbent-based CO_2 capture process, accounts for mass transfer resistance through the product layer and inside the porous pellet. Validated against lab-scale NETL experiments, literature data, and pilot plant data, the NETL desulfurization model will be utilized to design and optimize RTI's 50 megawatt HTDP demonstration unit to be slipstream-tested at the Tampa Electric Company's Polk Power Station.

Integrated Gasification Fuel Cell Performance and Cost Assessment—As part of an overall effort to compare the economics of fuel cell-based systems in central station and distributed generation applications, an NETL team analyzed the projected cost of electricity produced by two integrated coal gasification-fuel cell (IGFC) power plants that use planar solid oxide fuel cell (SOFC) technology to convert synthesis gas (syngas) to electricity. Results show that while the fuel cell system is more expensive than a conventional combustion turbine, that expense is counterbalanced by the decrease in the unit cost of upstream equipment due to the higher IGFC system efficiency. Moreover, as a natural part of operation, the fuel cell platform offers the opportunity for nearly 100 percent CO_2 capture.

New Advanced Process Engineering Co-simulator Released—Version 2.0 of NETL's R&D 100 Award-winning Advanced Process Co-Simulator (APECS) is now available. APECS version 2.0 provides solutions on both ends of the performance spectrum, including parallel execution of multiple computational fluid dynamics (CFD) models on high-performance computers and the use of fast reduced-order models based on CFD results. The new version reduces the computational time required for equipment simulations based on high-fidelity CFD models (versus simplified engineering models), especially for cases in which one or more CFD models are embedded in large-scale energy system co-simulations.

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YEARS OF INNOVATION

Image courtesy of National Archives & Records Administration

In the early 1930s, Bureau of Mines researchers mastered the basic technique of deriving synthetic crude oil from coals. Crude oil from Pittsburgh's pilot plant yielded gasoline that fueled the station's motor pool, including this truck photographed in 1941. Pittsburgh's early work on synthetic fuels determined that carbon-rich coals, though harder to work with, tended to be the best oil sources. These results indicated that most of the country's vast coal reserves qualified as usable raw material for synthetic liquid fuel production.

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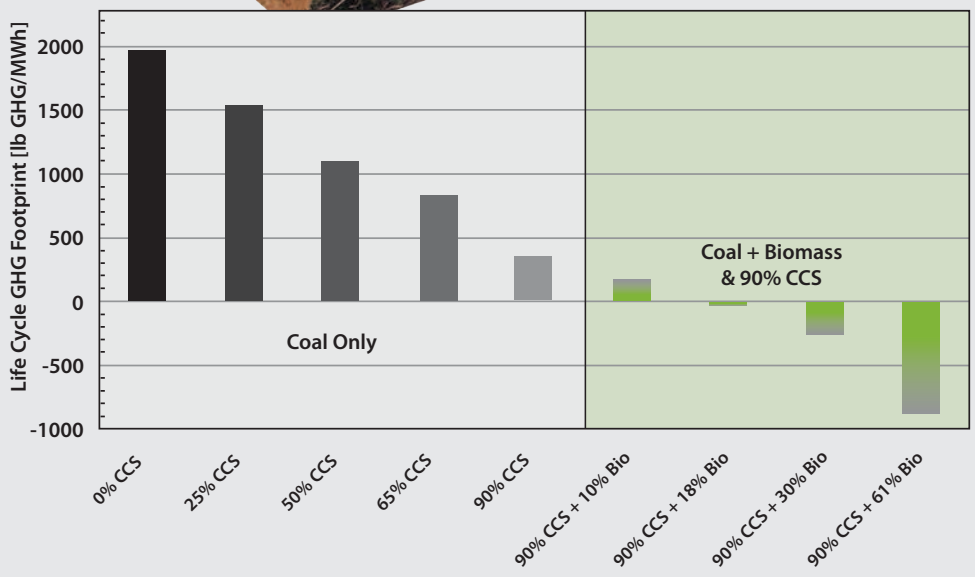
Switching to Switchgrass: Using Biomass To Reduce Greenhouse Gas Emissions

Reducing GHG Footprint with Carbon Capture and Biomass



NETL's Office of Systems, Analyses, and Planning (OSAP) has a mission: guide research and development toward balanced energy solutions in areas such as economic sustainability, supply security, and mitigation of global climate change. With this in mind, OSAP took a careful look at firing biomass along with coal (called co-firing) in integrated gasification combined cycle (IGCC) power plants to see how this approach could play a part in low-carbon power generation.

Coal-fired power plants account for approximately 50 percent of U.S. electric power generation and approximately 80 percent of greenhouse gas (GHG) emissions from power generation. With continuing concerns about climate change, it is critical for us to find ways to reduce these emissions while continuing to generate secure and sustainable electric power. Lowering GHG emissions from power generation becomes even more important when we consider reducing transportation-related emissions via plug-in hybrid vehicles. Although plug-in hybrids individually produce less GHG emissions than standard vehicles, their widespread use will increase our nation's overall need for electric power.

Biomass is a nearly carbon-neutral fuel, meaning that during growth, the plants remove carbon from the air through photosynthesis and release it again during combustion. However, with the addition of carbon capture and storage (CCS), biomass combustion becomes carbon negative—actually removing CO_2 from the atmosphere. Carbon is pulled from the air during photosynthesis, released during combustion, and then captured and permanently stored underground.

So far, commercial tests at Tampa Electric's Polk Power Station in Florida and NUON Power's Buggenum Plant in the Netherlands have demonstrated that up to 30 percent biomass by weight can be co-fired with coal. The chief constraint has been delivering an adequate supply of biomass to the power plant. The OSAP study chose switchgrass for the biomass because it is not a food crop, it is robust and fast growing, and it does not compete for agricultural land.

OSAP analyzed the performance of the coal-biomass combination in terms of energy efficiency, CO_2 capture, and cost. Additionally, they looked at the impacts that regulated pricing could have on GHG emissions. The study considered two scenarios: one at sea level using Illinois #6 bituminous coal, and the second at 3,400 feet elevation with Powder River Basin subbituminous coal to better understand the effects that higher elevations might have.

OSAP's findings show that adding biomass generally decreases plant efficiency because it is a lower-quality fuel than coal. However, when used as a GHG mitigation strategy, biomass reduces the need to use conventional CO_2 capture and compression, both of which require substantial auxiliary loads. As a result, when targeting a certain GHG emission level, plant efficiency actually increases as the proportion of biomass increases. These efficiency trends are similar for both coal types and elevations examined in this study. Furthermore, in terms of GHG emissions, adding biomass to coal along with CCS can achieve net-zero life-cycle emissions because CO_2 released from the switchgrass is captured and stored permanently away from the atmosphere.

One drawback the study revealed is that despite the higher efficiencies in CCS systems achieved with biomass, producing biomass is more expensive than producing coal, so using it as a fuel raises the cost of electricity. However, because of OSAP's study we know that with a regulated price on GHG emissions, the coal-biomass combination for IGCC power plants may become economically as well as environmentally desirable in the future.

Through complex analytical studies like this, OSAP helps NETL, DOE, and the United Sates make informed, thoughtful, objective decisions about new ideas and methods for producing and consuming energy. OSAP's goal in these studies is to help researchers identify and develop technologies that make the most sense in terms of the environment, economics, and the availability of different fuels to meet our energy needs—now and in the future.

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Tracer Technique Evaluates Mixing Process—The gasification effectiveness of a transport reactor depends on its ability to mix adequately the incoming flows of reactants: fuel, sorbent, and air. These reactants must be dispersed across the reactor's cross-sectional area by the different mixing mechanisms. A gas tracer method applied by NETL scientists has led to a better understanding of gas and solids mixing behavior in the dense region of a transport reactor, where a significant portion of the reaction takes place. Gas tracers injected in the midst of the circulating solids showed that both gas velocity and solids circulation rate were instrumental in achieving good radial distribution in this region. A good description of the flow behavior is essential to develop and validate predictable reactor models and to develop crucial gas and solids mixing relationships that can be incorporated and validated for CFD codes, such as Multiphase Flow with Interphase eXchanges (MFIX).

Integrated Gasification Fuel Cell Combined Cycle (IGFC) System Assessed—Using today's state-of-the-art fuel cell design, NETL analysts determined a fuel cell-based power plant has the potential to capture greater than 90 percent of CO_2 emissions and still be more efficient than a conventional IGCC plant without carbon capture. The plant uses coal gasification to produce syngas, which serves as the feedstock for a planar SOFC with separate anode and cathode outlet streams. This unique feature results in an effluent rich in fuel-cell reaction products that does not suffer from dilution by nitrogen present in air. Cooling the effluent to condense water produces near-pipeline-purity CO_2. A stack gas undiluted by nitrogen represents an advantage over pulverized coal or IGCC plants. Continued research and development could improve system efficiency to approximately 56 percent, including carbon capture and sequestration.

Plant-Wide Dynamic Simulation Studies Advanced Power Plants—Researchers with the NETL Institute for Advanced Energy Solutions have developed a simulation to study the operability and control of coal-fired IGCC power plants with CO_2 capture. The 640 megawatt-electric IGCC reference plant features an entrained down-flow gasifier with radiant syngas cooler, a two-stage water-gas-shift conversion process with interstage cooling, a dual-stage Selexol process for acid-gas removal and CO_2 separation, two advanced "F" class combustion turbines partially integrated with an elevated-pressure air separation unit, and a subcritical steam cycle for heat recovery steam generation. Developed using commercial Aspen Plus Dynamics® software, the dynamic simulation has been used to evaluate transient performance of the IGCC system under various control scenarios involving fluctuations in coal feed.

Simulation Technology Optimizes Pressure Swing Adsorption Systems for Pre- and Postcombustion CO_2 Capture—Developed under an NETL Institute for Advanced Energy Solutions project, this new simulation technology yields maximum hydrogen recovery when applied to a two-bed four-step pressure swing adsorption process for separating hydrogen from methane. Described in the March 14, 2009, issue of the American Chemical Society journal, *Industry & Engineering Chemistry Research*, the technique is particularly useful for evaluating the suitability of different adsorbents, feedstocks, and operating strategies for pressure swing adsorption used in pre- and postcombustion CO_2 capture.

NETL Computational Fluid Dynamics Code Simulates Polydisperse Systems—Aided by NETL optical imaging technology, collaborators at Colorado University, Iowa State University, Princeton University, and Particle Science Research Institute have formulated a new polydispersity equation set to add to the NETL MFIX code. When applied to the flow of fluids through transparent, artificial media, NETL's optical imaging technology provides data to validate and verify multiphase flow codes that describe particle-scale phenomena. The new capability will allow the team to model the flow of polydisperse systems, such as powders consisting of grains with different size, density, or chemical composition, that are found in coal combustion or gasification. Additionally, by enhancing the MFIX code to handle a distribution of particle sizes rather than a single particle size, researchers have improved the accuracy of model predictions.

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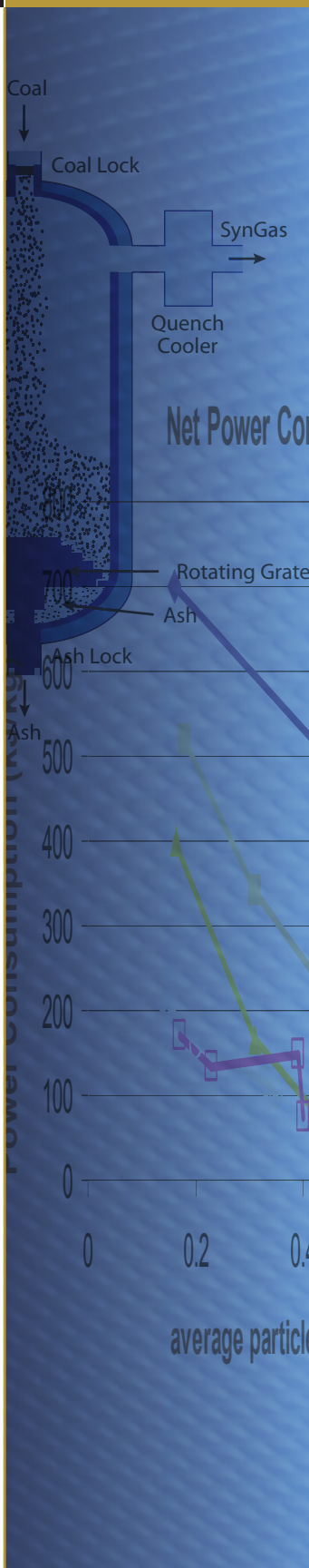
YEARS OF INNOVATION

Image courtesy of Bureau of Mines publication

In the 1940s, the Bureau of Mines determined that lignite coal had value for manufacturing industrial organic chemicals, including synthesis gas, also called water gas. Using its Reyerson-Gernes generator, the Grand Forks plant turned 381 tons of lignite into 16 million cubic feet of water gas in one year's time and demonstrated the feasibility of gasifying lignite on a commercial scale. Here, an interior view of the retort building at the Grand Forks gasification plant shows the hopper and charging valves that fed lignite into the top of the Reyerson-Gernes water-gas generator.



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Hydrogen

With water as its only by-product, hydrogen is the ultimate in clean energy. Its value as a fuel has long been recognized, but economically producing hydrogen remains a challenge. NETL's history of fuels separation—from coal hydrogenation studies beginning in the 1920s to the more recent successes with sulfur oxide (SO_x)- and mercury-removal technologies—is informing the research pathway toward cost-effective production of pure hydrogen from coal-derived gases. Since 2003, NETL's hydrogen research has focused on pioneering efforts to develop hydrogen gas–separation membranes. Our research is exploring ways to centrally produce great volumes of ultra-pure hydrogen, which would ultimately enable a hydrogen-energy economy based on abundant domestic coal.

NETL Study Reveals Atomic Structure of Fischer-Tropsch Catalysts—Using advanced surface analysis techniques, NETL scientists have obtained detailed images of the atomic structure of iron oxide catalysts similar to those used for converting gasified coal into liquids that can be used as hydrogen carriers or fuels. The study investigated the production of model iron and iron oxide catalyst particles on an inert gold growth substrate, reproducing the size, shape, defects, and other important structural features of real-world iron-based catalysts used for the Fischer-Tropsch process. The findings are important for understanding the reactivity of Fischer-Tropsch catalysts and the mechanisms involved in activating the iron-oxides into iron-carbide phases. The work is described in the June 2009 issue of the peer-reviewed publication, *Journal of Physical Chemistry C*.

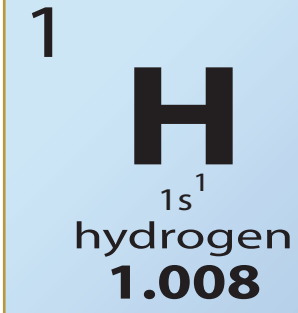
Image courtesy of Arno A. Evers

NETL Helps Establish First Hydrogen Fueling Station

Acting through the West Virginia Hydrogen Working Group, NETL funded and coordinated the construction of West Virginia's first hydrogen fueling station as part of a planned "hydrogen corridor" that will eventually refuel hydrogen-powered vehicles from Charleston, WV, to Morgantown, WV.

The new facility is designed to fuel vehicles and other equipment while serving as a place for hydrogen research, development, and evaluation. It was dedicated at a ribbon-cutting ceremony on August 17, 2009, as part of the 5th Annual Hydrogen Implementation Conference organized by the Mountain States Hydrogen Business Council.

Located at Charleston's Yeager Airport, the fueling station produces hydrogen by electrolysis from water supplied by Yeager. It is operated by its primary user, Yeager Airport, where it currently fuels the airport's hydrogen-powered pickup truck, a standard heavy-duty 2004 model refitted to run on hydrogen. Hydrogen also powers an Air National Guard fork lift at the Guard unit stationed at Yeager.



Unique Catalyst Designed To Improve Methane Reforming—Working in cooperation with NETL, researchers at Iowa State University developed and patented a new material that catalyzes the reactions of steam with methane or carbon monoxide to produce hydrogen while simultaneously separating the CO_2 by-product. The core-in-shell pellet material is prepared in the laboratory and consists of calcium oxide cores surrounded by alumina-based shells that support a nickel catalyst. The core absorbs CO_2 as it is produced, thereby eliminating that gas's reaction-inhibiting effects and simultaneously providing a means for its recovery in useful form. The innovative approach would vastly simplify the current industrial practice for steam reforming methane and allow the product of a coal gasifier to be converted into nearly pure hydrogen in a single step. This project was conducted under the Office of Fossil Energy's University Coal Research Program.

Prototype Membrane Reactor Exceeds Hydrogen Production Expectation—Working in cooperation with NETL, researchers at Western Research Institute successfully completed the 100-hour testing of an integrated device that removes hydrogen concurrently with the conversion of synthesis gas through the water-gas-shift reaction. Fabricated by hydrogen equipment manufacturer REB Research & Consulting, Oak Park, MI, the device operated in a coal-derived syngas environment that contained significant amounts of carbon monoxide (20 percent) and hydrogen sulfide (125 parts per million), and it exceeded the project's hydrogen production goal of 10,000 liters per day.

Advanced Power Systems

Low-Impact, Cost-Effective Energy

Fuel Cells

NETL's fuel cell research focuses on technologies suitable for coal-fueled central generation. In the 1980s, the Morgantown Energy Technology Center initiated fuel cell investigations to develop power systems that avoided burning coal directly. In 2000, the Solid State Energy Conversion Alliance (SECA) was formed. SECA, an NETL-managed collaboration of industry, university, and national laboratory research facilities, develops low-cost, efficient, and clean solid oxide fuel cell (SOFC) technology that will enable the use of the nation's coal resources in an environmentally benign manner. SOFCs are modular and fuel-flexible, and SOFC-based integrated gasification fuel cell systems are capable of 60 percent efficiency and 99 percent CO_2 capture.

Liquid Tin Anode-Solid Oxide Fuel Cell Voltage Reaches Theoretical Limit—A new liquid tin anode SOFC test cell designed by NETL produced open circuit voltages equivalent to theoretical values of 1.1 volts at 900 ˚C under hydrogen. The new cell design features a closed-end, tubular electrolyte onto which a cathode is painted, with extra sensors for more precise and reproducible measurement of the movement of oxygen into, through, and out of the liquid tin layer. Ongoing research is directed at identifying the reactions causing the greatest losses in anode performance, thus guiding the development of an ideal anode composition and support structure for optimal cell performance. Molten metal anodes are of interest because of their ability to produce electricity directly from solid fuel sources, such as biomass and coal dust, without the need for gasification. Such direct consumption of coal would greatly increase system efficiency and reduce total system cost. Liquid tin anodes are also more resistant to coal contaminants that poison conventional nickel-based anodes.

NETL Creates Multi-cell Array To Test Fuel Cells Operating on Coal Synthesis Gas

A skid-mounted array of 12 SOFCs completed continuous testing during gasifier operation at DOE's National Carbon Capture Center in Wilsonville, AL. The results will be used to design a cleanup system for SOFCs operating on coal-derived synthesis gas (syngas).

Using syngas for powering fuel cells can help secure our energy independence by extending the useful lifetime of our most abundant energy resource, coal. Since SOFCs operate very efficiently, they can produce more energy from coal than can coal-fired power plants.

NETL researchers designed the array to obtain data on the effects of trace syngas materials on SOFC performance over a range of electric load conditions and for extended periods of operation. Contaminants such as arsenic, phosphorous, selenium, and mercury can foul SOFCs and limit their performance. By understanding what happens—and how—researchers can devise ways to overcome these limitations.

Approximately 4,500 cell-hours of test data, together with post-operational microscopy, are providing insight on degradation mechanisms, including unwanted deposition of trace material.

The mobile fuel cell test platform is also available to support SOFC performance testing at other coal gasification sites.

SECA Core Technology Program Overcomes Technical Challenges—Fuel cell scale-up is part of the SECA manufacturing strategy for achieving the lowest possible SOFC system cost. Higher-power density and a larger active area combine to reduce the number of cells, cell interfaces, and raw materials required for a system of given power output. SECA aims to develop large fuel cell power blocks (greater than 100 megawatts) that will produce power with greater than 50 percent overall efficiency for $700 per kilowatt of electricity or less. 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. The core teams realized the following accomplishments in 2009:

- In collaboration with Carnegie Mellon University, researchers working at Argonne National Laboratory's Advanced Photon Source have used synchrotron x-rays to examine the atomic and chemical structure of model SOFC cathodes over a range of conditions. Studies have shown the surface chemistry and structure of strontium-containing cathodes to be the same under room-temperature laboratory conditions as under the high temperatures typical of SOFCs. The unexpected finding suggests that SOFC cathode materials may be studied using analytical techniques under room-temperature, ultrahigh vacuum conditions, enabling a detailed description of their electronic structures. The data will be collected and subsequently interpreted to guide SOFC developers toward cathode architectures with improved stability and activity.

- Researchers at Lawrence Berkeley National Laboratory have developed a low-cost technique for applying a continuous coating of nanocatalyst into porous SOFC electrodes. With this technique, catalyst application occurs after high-temperature SOFC treatments, allowing for expanded design flexibility and increased nanocatalyst diversity. Development of alternative nanocatalyst formulations afforded by this technique can yield increased SOFC performance, which will contribute to lower cell and stack costs.

Advanced Power Systems

Low-Impact, Cost-Effective Energy

SECA Industry Teams Reach Milestone for Central Plant Fuel Cell—Two industry teams participating in SECA have completed initial testing of SOFC stacks designed as building blocks for modules that can produce up to 1 megawatt of electricity of power. The test stacks were each produced with commercial manufacturing processes that result in high-volume stack costs under $290. Test results in both cases were consistent with those obtained at smaller scale.

- Versa Power Systems, Inc., Littleton, CO, (first-tier subcontractor for the team led by FuelCell Energy, Inc., of Danbury, CT) has provided SOFC stacks that are 50 percent larger than the previous design and which produced approximately 20 kilowatts of electricity for more than 5,000 continuous hours of operation at an average temperature of 705 °C and 61.5 percent fuel use with simulated coal syngas.

- Delphi Automotive LLP, Troy, MI, (first-tier subcontractor for the team led by UTC Power Corporation, South Windsor, CT) has developed a new "Gen4" cell that represents an increase in active area by a factor of four over that of the previous design.

100 YEARS OF INNOVATION

Image courtesy of Phipps Conservatory & Botanical Gardens

In 2007, Phipps Conservatory and Botanical Gardens in Pittsburgh, PA, became the first conservatory in the world to take advantage of fuel cell technology. Under an NETL building efficiency project, a 5-kilowatt solid oxide fuel cell system powered the 12,000-square-foot, 60-foot-tall Tropical Forest exhibit and provided energy for heating water. The primary by-products of the fuel cell were heat, water, and CO_2, which were used in adjacent production greenhouses. The project added modern "green" efficiency to the Victorian glasshouse originally built in 1893.

Initiated in the fall of 1999, the Solid State Energy Conversion Alliance (SECA) unites government, industry, and the scientific community in the common mission of advancing solid oxide fuel cell technology. NETL independently tests and verifies the concepts and products the SECA teams devise and renews funding to projects only as long as they continue to best stringent technical performance expectations. In 2007, the Office of Management and Budget lauded SECA's approach: "This novel incentive structure has generated a high level of competition between the teams and an impressive array of technical approaches."

Advanced Power Systems

Low-Impact, Cost-Effective Energy

Turbines

NETL's turbine research began in the early 1960s, when Morgantown researchers converted a railroad turbine engine to a coal-based turbine energy system capable of powering a stationary plant. Today, NETL researchers and our partners continue to advance the science and technology behind turbines, which are the heart of nearly all the world's electric generating systems. NETL manages a research, development, and demonstration project portfolio designed to develop high-performance, low-emission gas turbine technologies. With the use of unique laboratory facilities and equipment, NETL is evaluating new concepts in combustion, turbine materials, aerodynamics, and heat transfer designs.

Diluting with Nitrogen Reduces Nitrous Oxides (NO_x) Emissions—NETL scientists demonstrated reduced NO_x emissions from a high-hydrogen diffusion flame gas turbine combustor by diluting the fuel stream with nitrogen rather than air, as currently practiced industrially. Results obtained in NETL's Fundamental Combustion Laboratory show that for all lean-diffusion-flame combustor types, including swirl-stabilized combustors, flame temperatures are always minimized by diluting the fuel stream, leading to lower NO_x emissions. For non-swirl combustor types, such as lean direct injection combustors, fuel-side dilution (versus airside dilution) reduces NO_x formation times, which also has important implications for the design of high-hydrogen combustors.

IGCC Catalyst Scalable for Commercial Applicaton—Commercial-sized catalyst samples for the novel selective catalytic reduction process developed at Siemens Energy, Inc., NY, have undergone performance verification within a simulated integrated gasification combined cycle (IGCC) gas turbine exhaust using third-party test results. This accomplishment demonstrates that the Siemens novel selective catalytic reduction process can lower NO_x emissions from the high-temperature gas turbine in an IGCC application to a level that meets program goals while high-firing temperatures and exhaust temperatures are maintained, both of which contribute significantly to the efficiency of the IGCC power block. The milestone verified the performance of the novel selective catalytic reduction catalyst for simulated IGCC gas turbine exhaust, and the commercial size of the sample demonstrated that the technology can be readily scaled to full-sized application. This project is funded by the Advanced Turbine Program and managed by NETL's Power Systems Division.

Holes in Theory Hold Up to Demonstration—In collaboration with NETL, researchers at Virginia Polytechnic Institute and State University investigating synthesis gas-ash deposition dynamics demonstrated that a three-row scheme of cooling holes located in the leading edge of a turbine blade provided effective protection to the blade surface by blowing away ash particles and cooling the ash below its deposition temperature. The study also showed that because low melting-point polyvinyl chloride and Teflon® particles at low temperature mimic the behavior of ash particles at high temperature, deposition at engine conditions could be studied through low-temperature experimentation.

Hole Geometry Cools Film, Protects Turbines—In cooperation with NETL, engineers at the GE Energy, Inc., Steam Turbine Technology Laboratory in Schenectady, NY, completed final performance validation of an improved film-cooling hole geometry. Film cooling extends the service lifetime of turbines operating in high-temperature environments, and film-cooling geometry determines the effectiveness of the film cooling. With high-speed test data, researchers quantitatively measured improvements in the film-cooling effectiveness of components that use novel cooling hole concepts developed under the Office of Fossil Energy's Advanced IGCC/Hydrogen Turbine Development Program. The improved design will contribute to increased turbine plant efficiency. As part of the same project, researchers also obtained information on mechanical response for the initial design concept of the largest bucket blade to be used in the last-stage expansion annulus of an advanced hydrogen gas turbine, which meets DOE turbine performance goals for IGCC- and FutureGen-type applications. Larger-than-usual buckets are required to meet desired power and performance levels because low-Btu fuel and diluents are expected in those applications.

Angle Makes a Difference in Blade Life—University of Pittsburgh investigators participating in the NETL-supported University Turbine System Research Program compared three surface features for thermal barrier coatings that would improve the distribution and effectiveness of films of cooling air, which pass over a turbine blade and protect it from thermal degradation. Results obtained from both experimental measurement and computational fluid dynamics simulation suggest that downstream performance may be improved by ramps with an inclined angle of 20–25 degrees located upstream of the film holes through which air emerges from the blade.

100 YEARS OF INNOVATION

Image courtesy of National Archives & Records Administration

Essential to the U.S. Government's wartime preparation was ensuring America's energy security. Boilers were a key component in this strategy, because boiler outages could snarl critical industries and hinder military operations. To deal with the problem of embrittlement, in which waterborne caustic minerals trigger cracks in steel boiler components, engineers at the Pittsburgh and College Park experiment stations developed an embrittlement detector that gave advance warning of hazardous mineral concentrations. In 1943, the Bureau of Mines received a patent for this device, displayed here by project lead Wilburn C. Schroeder.

In 1959, a gas turbine designed for locomotives was installed at the Morgantown Experiment Station for study. Engineers transformed the coal-based railroad engine into a stationary power plant for generating electricity; they developed new, longer-lasting blades and revamped the combustor to run on synthesis gas—a solution to the problem of coal dust and ash. In 1967, a new gasifier came online at Morgantown that could turn low-rank coal into synthesis gas, offering an excellent, inexpensive fuel source. By 1970, the Morgantown Station was en route to integrating its coal gasification, dust removal, and turbine technologies.

Advanced Power Systems

Low-Impact, Cost-Effective Energy

Advanced Combustion

Among NETL's major historic accomplishments is the development of groundbreaking environmental solutions for combustion technologies. During the 1980s and 1990s, PETC and METC partnered with the coal and electric-utility industries to showcase creative engineering solutions for mitigating acid rain. One solution: replace conventional burners with fluidized-bed burners. The development of advanced combustion technologies for fossil-fuel power plants is still paramount for producing power with negligible environmental impact. NETL's advanced combustion research now focuses on technologies such as chemical looping and oxy-fuel combustion, reducing NO_x emissions, and improving the efficiency of the combustion process while producing a sequestration-ready CO_2 stream.

NETL Scientists Determine Drag Coefficient for Range of Powders at Key Transport Velocities—The single most significant parameter defining the fluid dynamic behavior of particles in a gas flow stream is the drag that gas exerts on the particle. Current methods to establish a baseline for the drag of a specific granular material use the drag at extreme conditions for single particles and dense fluidization—conditions unrepresentative of the particle-dominated transport flow behavior found in circulating and transport fluidized beds. NETL scientists have now developed a transient method to define flow regime transitions. Researchers have applied the method to various granular materials over a variety of transport flow regimes and found that the resulting drag coefficient was constant for all granular materials examined near the regime transitions. This finding will allow CFD modelers to develop a better baseline for the drag law as applied to particular powders at well-defined conditions nearer to those for circulating fluidized beds.

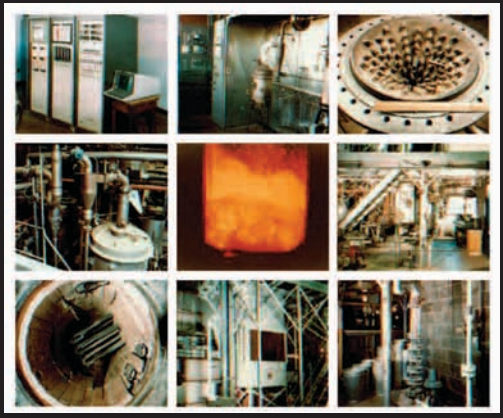
NETL Research Shows Feasibility of Direct Coal Chemical-Looping Combustion—Results of thermogravimetric analysis and bench-scale fixed-bed flow reactor studies by NETL indicate it is feasible to develop chemical-looping combustion directly with coal using metal oxides as oxygen carriers. Among various metal oxides evaluated by NETL, copper oxide performed the best. Chemical-looping combustion is a novel, flameless combustion technology that employs a reusable metal oxide as an oxygen carrier to deliver oxygen from the air to the fuel. By carrying oxygen from combustion air to the fuel without involving other air constituents, chemical-looping combustion produces sequestration-ready CO_2 streams, while avoiding a significant energy penalty. The combustion products formed during the chemical-looping combustion reaction of the coal-metal oxide mixture were CO_2 and water with no carbon monoxide observed. Results of the study appear in the July 8, 2009, issue of the American Chemical Society journal, *Energy & Fuels*.

Innovative Technique Dramatically Reduces Computational Time in Multiphase Flow Three-Dimensional Simulation—Working in cooperation with NETL, researchers at Princeton University have discovered a method to relate corresponding computational fluid dynamics parameters (e.g., drag coefficient) in fine-grid and coarse-grid simulations. The accurate simulation of fine-grid phenomena with a coarse-grid model can reduce the model size by more than 1,000 times, thereby reducing the time required to obtain a solution. When fully implemented, the technique will facilitate in little more than 2 hours the solution to a problem that now takes 3 months to solve. Faster computation times will allow numerous real system configurations to be analyzed for the best alternative.

Novel Moving-Bed Heat Exchanger Operational in Field Test—As part of an extended-duration field test, a novel heat exchanger designed to cool the solids stream of a circulating moving-bed combustion system while heating a working fluid, such as steam or compressed air, has achieved target flow rates. Researchers tested the moving-bed heat exchanger unit at the American Bituminous Power Partners facility in Grant Town, WV, where the unit recovered heat from recycled fly ash from the boiler. In cooperation with NETL, major energy equipment supplier ALSTOM Power is testing the moving-bed heat exchanger to support development of other technologies, including an oxygen-fired circulating fluid bed, chemical looping, and an ultra-supercritical circulating moving bed.

Test Evaluates Oxy-combustion Retrofit Technology for Tangentially Fired Coal Boilers—In cooperation with NETL, engineers at ALSTOM Power completed the first in a series of test campaigns designed to evaluate oxy-combustion in tangentially fired boilers. Testing took place in a 15-megawatt thermal tangentially fired boiler simulation facility and a 15-megawatt thermal industrial-scale burner facility located in Windsor, CT, using Powder River Basin coal from the Black Thunder mine. Test results confirmed predictions that Powder River Basin coal is highly reactive under both air and oxy-combustion conditions, producing low concentrations of carbon monoxide and little unburned carbon in the ash. By controlling the amount and location of oxygen added, operators were able to achieve similar heat transfer rates for both air and oxy-fired operations. The results indicate that the oxy-combustion mode of operation may produce equivalent power with smaller boiler designs. Tangentially fired boilers represent 41 percent of the U.S. installed base and 44 percent worldwide. The research is providing key data for commercialization of oxy-combustion processes, which could prevent emissions of criteria pollutants while providing a highly concentrated stream of CO_2 for sequestration or enhanced oil recovery without costly gas separation.

100 YEARS OF INNOVATION



The Clean Air Act of 1970 put strict air-pollution regulations into effect. In response, Morgantown researchers built and operated the first U.S. industrial-size fluidized-bed boiler at Monongahela Power Company's Rivesville, WV, power plant. Fluidized-bed combustion proved to be a lower-cost, higher-efficiency, and cleaner way to burn coal. In the early 1990s, *POWER Magazine* called the development of fluidized bed coal combustors "the commercial success story of the last decade in the power generation business." Today, fluidized bed boilers are generating electricity throughout the world.

Advanced Power Systems

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Oxygen Transport Membrane Technology Reaches Fuel Utilization Target—As part of a cooperative agreement with NETL, process developers at Praxair, Inc., Tonawanda, NY, have successfully tested an oxygen transport membrane that separates oxygen from air at a rate sufficient to achieve fuel utilization greater than 90 percent. This highly efficient rate of fuel use indicates a better performing membrane and a more cost-effective commercial-scale end product. More efficient use of fuel requires less membrane (fewer materials) and less expense. Oxygen transport membranes can separate oxygen from air less expensively than conventional cryogenics, while reducing the parasitic power consumption typically associated with cryogenic separation technologies. The partial pressure of oxygen, which is negligible at the activation surface where oxygen reacts with natural or coal-derived gases, drives the oxygen across the membrane. Using oxygen instead of air in fossil fuel combustion more cost-effectively produces CO_2 that is concentrated and easily captured.

Significant Milestones Reached Toward Commercialization of Ion-Transport Membrane Oxygen Technology—Ion-transport oxygen-production technology is a cutting-edge approach to producing low-cost, high-quality oxygen to enhance the performance of integrated gasification combined cycles (IGCCs) that produce coal-derived synthesis gas, which is used to generate electricity and can be used as a feedstock to produce hydrogen, chemicals, and liquid fuels. In cooperation with its research partners, NETL is leading the way to developing the ion-transport membrane oxygen process that will produce oxygen at a cost and energy requirement approximately one-third lower than conventional cryogenic processes. The process could also have lower demand for cooling water and space requirements than other oxygen separation approaches. IGCC and other advanced power-generation systems, as well as other oxygen-intensive plants, stand to benefit from the technology. In 2009, researchers accomplished the following achievements:

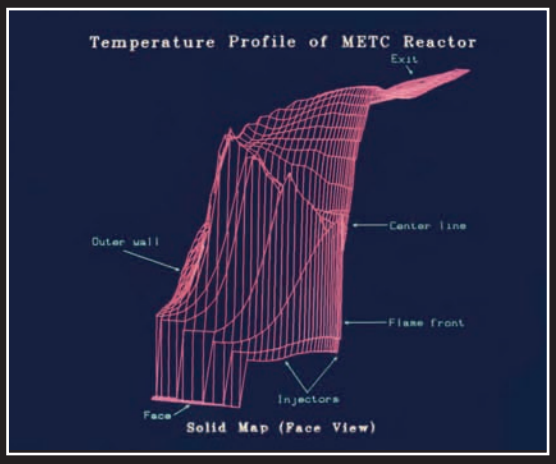
- As part of a team led by Air Products and Chemicals, Inc., (Allentown, PA) and working in cooperation with NETL, engineers at Ceramatec, Inc., a small business in Salt Lake City, UT, have cast nearly 2 miles of thin, ion-transport membrane precursor material. This ion-transport membrane precursor tape can be shaped and layered to make commercial-size membrane wafers for tonnage-scale oxygen production modules. The collaboration between Electric Power Research Institute and Air Products and Chemicals, Inc., will examine process and equipment scale-up, and integration of ion-transport membrane technology with IGCC and other advanced coal power systems.

- A 5 ton-per-day ion-transport membrane oxygen prototype facility has operated more than 14,600 hours and confirmed technical performance expectations that forecast lower capital costs and better efficiency for IGCC power plants. The facility's 0.5 ton-per-day modules met or surpassed commercial targets for oxygen production rate and purity. Operating campaigns are ongoing to test proprietary process-control techniques, assess the robustness of ceramic membranes to significantly improve module reliability, and meet other technology challenges for potential pre-commercial readiness by 2014.

- To aid commercialization efforts, Electric Power Research Institute has organized a collaboration of several utility companies to help ion-transport membrane oxygen technology developers focus on features and designs relevant to the power industry as well as specific studies aimed at rapid technology commercialization. The collaboration will examine scale-up issues and integration of ion-transport membrane technology with other advanced coal power operations, and participants will gain a first-hand understanding of the advantages of ion-transport membrane technology over conventional oxygen supply systems.

100 YEARS OF INNOVATION

J. W. Ambrose, who headed the Bureau of Mines from 1920 to 1921, began the strategy of modeling so that oil field operators could "see" the lay of the land before drilling. These three-dimensional (3-D) peg models represented ground contours and underground geologic structures with cross-sectional layers—such as the sand layer known to contain oil—helping speculators determine drilling and shot depths.



Computer modeling shows temperature variations inside a coal combustor. Engineers in Morgantown, WV, adapted the ASPEN modeling system developed at the Massachusetts Institute of Technology for use in fossil-fuel research during the early 1980s. Today, NETL's award-winning Computational Sciences Division creates computer models of everything from individual technologies to power plants to geologic formations for carbon storage.

Advanced Power Systems

Low-Impact, Cost-Effective Energy

Materials

NETL's world-class materials research dates back to the establishment of the Northwest Electrodevelopment Station in 1944 in Albany, OR. Albany researchers actualized technologies for coal and minerals use, piloted catalyst systems for synthetic fuels, launched the first production of ductile zirconium, and helmed the successful processing of titanium and its alloys. Today, NETL scientists and engineers are using advanced experiential and computational approaches to develop materials that will perform effectively in harsh environments and enable systems to operate at extreme temperatures and pressures—advances that will increase efficiencies and reduce the environmental impact of producing power with fossil fuels.

Ceramic Materials Help Preserve Oxidation Resistance of Ultra-supercritical Boiler Materials—Tests conducted by the Electric Power Research Institute, Palo Alto, CA, in cooperation with NETL, determined that nitrides of titanium and aluminum applied between a steel substrate and nanostructured oxidation-resistant top coatings form effective barriers to aluminum diffusion. Corrosion may cause unscheduled outages in conventional coal-fired plants and is anticipated to be even more severe for advanced boilers operating at ultra-supercritical steam conditions, as well as for oxy-fuel combustion systems. Nanostructured coatings may provide excellent corrosion resistance for the high-temperature materials required in advanced coal-fired plants, but the loss of aluminum through diffusion limits the lifetime of these coatings. Using titanium and aluminum nitrides to prevent aluminum diffusion may help ensure the reliability and availability of ultra-supercritical fossil-fuel boilers and advanced combustion systems.

Electroplated Interconnects Improve Solid Oxide Fuel Cell Performance

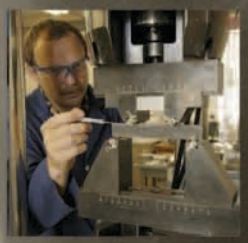
An electroplating technique developed by NETL researchers in collaboration with West Virginia University holds great promise for improving solid oxide fuel cell performance. Testing by NETL showed that inexpensive ferritic stainless steel interconnects coated with manganese cobalt oxide degraded by less than 1.5 percent after 600 hours, whereas cell performance with uncoated interconnects degraded approximately 20 percent during the same test period. Longer-term testing at Pacific Northwest National Laboratory with similar material achieved excellent performance and stability in terms of both oxidation resistance and electrical conductivity. The NETL interconnects were coated using an environmentally friendly process based on electroplating, which is cheaper and easier to employ than other coating methods.

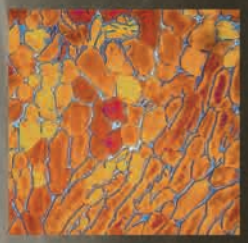
"Cold Spray" Oxidation-Resistant Coating Strongly Adheres to Metal Substrates—As part of an NETL-administered Phase I Small Business Innovation Research project, researchers have successfully applied a cold-spray oxidation-resistant coating on iron alloys using a low-temperature process called Kinetic Metallization developed by Inovati, Santa Barbara, CA. Because Kinetic Metallization is performed at temperatures significantly below the melting point of the substrate materials, the coating can be applied without compromising the mechanical strength of the base material. Kinetic Metallization produces adhesion strengths comparable to those of thermal spray coatings, and oxidation testing demonstrated stable oxidation performance of the coated materials. These results confirm the potential of the environmentally innocuous Kinetic Metallization method to provide superior oxidation and hot corrosion protection for ultra-supercritical boiler structures at a cost lower than that of competing processes.

New Thermal Barrier Coating Improves Turbine Efficiency—An advanced thermal barrier coating developed by Solar Turbines, Inc., San Diego, CA, in cooperation with NETL, is now a standard material for use in all advanced, backside-cooled combustor liners manufactured by Solar Turbines. A fully integrated Mercury 50 combustion system, modified with the advanced materials technology, operated successfully for 4,000 hours at a host site. Combustors outfitted with the new thermal barrier coating will operate more efficiently between regular overhauls. NETL managed the project for the Office of Electricity Delivery and Energy Reliability.

Ceramic Matrix Composite Combustor Demonstrated—As part of an interagency agreement between DOE and the Office of Naval Research, United Technologies Corporation (Hartford, CT) successfully demonstrated a ceramic matrix composite combustor. Ceramic matrix composites are favorable for their high-temperature stability and high-corrosion-resistance properties. The combustor demonstrated a 40–50 percent reduction in temperature distribution and a 30 percent reduction in NO_x levels at maximum power conditions. Results were determined by fabricating ceramic matrix composites into complex shapes, applying environmental barrier coatings to engine hardware, testing a ceramic matrix composite-combustor in a Pratt and Whitney Aircraft engine test rig, and validating performance benefits against a metal baseline. NETL managed this project in support of DOE's Office of Electricity Delivery and Energy Reliability.

Novel Brazing Process Could Seal Ceramic Membranes to High-Temperature Metals—Working in cooperation with NETL, product developers at Aegis Technology, Inc., Santa Ana, CA, have successfully joined various ceramic membrane materials and stainless steels with filler material that exhibited high bending strength at both room and elevated temperatures. Researchers used a novel, cost-effective method called reactive air brazing, which provides stronger, more reliable joints than conventional approaches. This technical achievement is a significant milestone in the development of a method for hermetically joining ceramic membranes to underlying metallic support structures in high-temperature gas separation devices—an enabling technology essential for high-efficiency, low-emission fossil energy systems.





Advanced Power Systems

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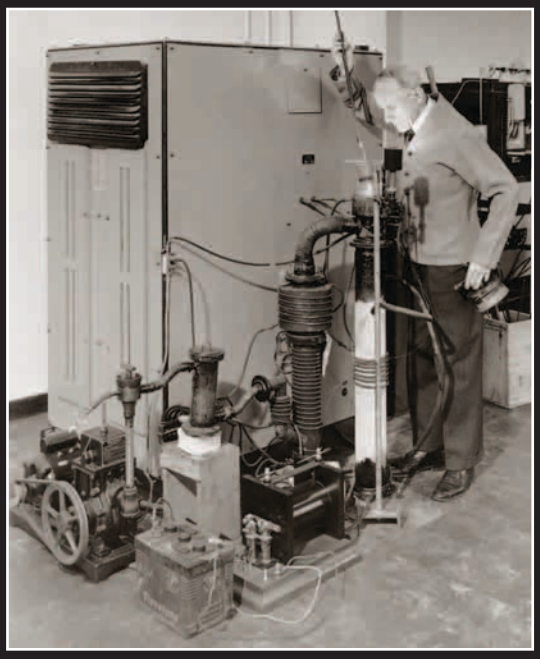
100
YEARS OF INNOVATION



Famed metallurgist Dr. William Kroll spearheaded the development of zirconium casting in the 1940s at the Northwest Electrodevelopment Laboratory in Albany, OR. Later, in 1959, the Lab's successful casting of molybdenum caused stocks in light metals to rise sharply. Zirconium proved to be the key for powering nuclear applications, while molybdenum's stability at high temperatures made it an ideal candidate for critical assemblies in extreme environments, such as the exhaust pipe of a rocket or missile.

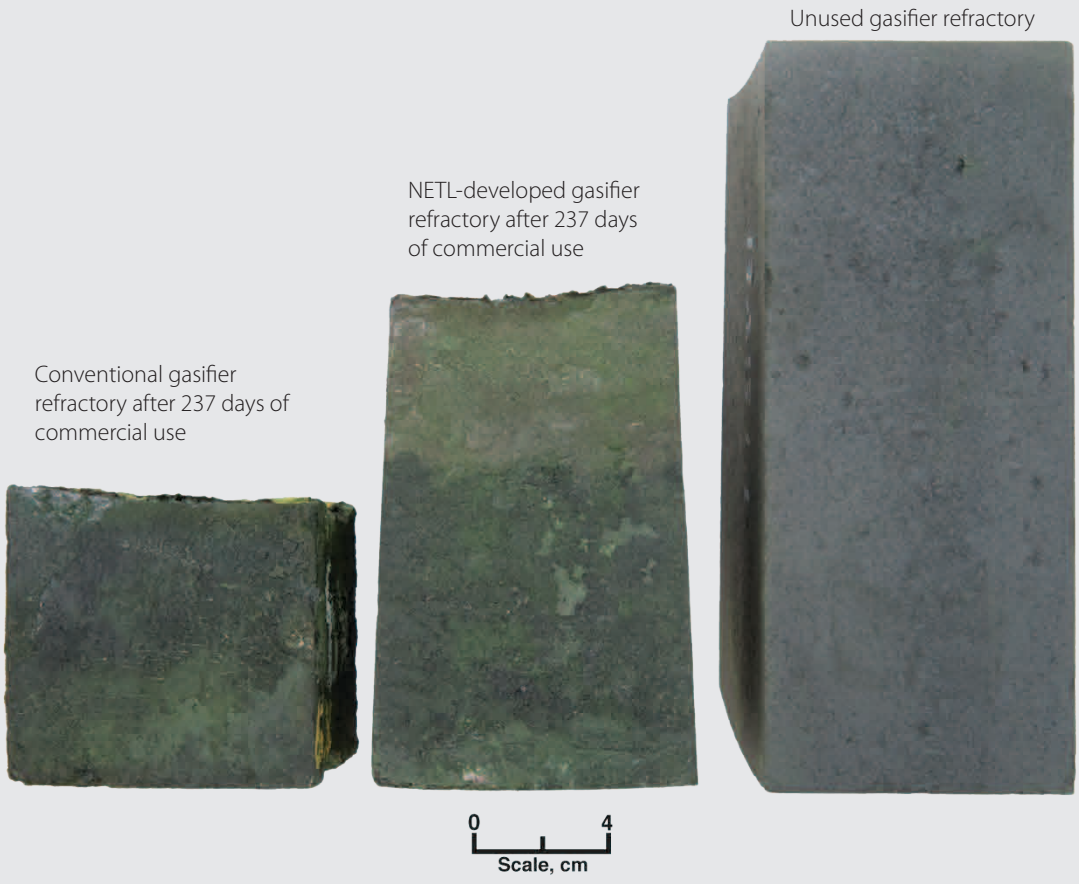
Using the zirconium casting process developed by William Kroll, Albany supplied 85 percent of the zirconium raw material for the first nuclear submarine USS Nautilus. As zirconium production was in progress, Admiral Hyman Rickover made several hurried trips to Albany to inspect the equipment and discuss the results. On January 17, 1955, the Nautilus was launched, marking the beginning of the era of naval nuclear propulsion.

In 1953, scientists at Bartlesville, OK, and the University of Lund, Sweden, invented the world's first rotating bomb calorimeter to obtain precise measurements of thermodynamic properties. Applied to crude petroleum, such knowledge optimized the refining process and allowed chemists to make reliable predictions about the properties of other compounds. A bomb calorimeter comprises two containers—an outer container filled with water and an inner container that houses chemical reactions. The thermodynamic heat of these reactions is determined from the temperature increase of the surrounding water. Chemical reactions within the calorimeter's inner container are nearly explosive, hence the name "bomb."

Advanced Power Systems

Low-Impact, Cost-Effective Energy

Meeting the Challenge: NETL's Materials Capabilities



NETL's accomplished materials research groups tackle the toughest of challenges daily as they investigate the theoretical and fundamental makeup of fossil energy and renewable energy systems. Addressing fundamental mechanisms and processes, the materials labs are capable of melting, casting, and fabricating up to one ton of materials; completely characterizing the physical properties of materials; and addressing the waste and by-product issues of materials processes.

NETL scientists and engineers also work closely with industrial partners to identify material issues such as the required performance characteristics for specific applications. They then engineer improved materials, develop methods to produce those materials at an affordable cost, and evaluate material performance, both in the laboratory and in the field. For more than half a century, the NETL materials labs have been recognized for expertise and capabilities in wear and corrosion, melting and casting, and in materials development.

As an example, NETL recently developed an advanced refractory brick to be used in the severe service environment of gasification.

Gasification is a clean and efficient way to produce energy using available carbon sources such as coal, petcoke, or biomass. Gasification also has enormous potential for aiding capture and storage of the greenhouse gas CO_2, which makes gasification one of the most promising technologies for energy plants of the future. Coal gasification is an advantageous way to use our most abundant energy resource, coal, in an environmentally responsible manner.

One drawback of gasification, however, is that it operates at such a high temperature and under such harsh internal conditions that the refractory brick protecting the reaction chamber where gasification occurs can fail in as little as 3 months, at which time the whole system must be shut down while the expensive refractory is replaced. The lack of reliable and long-lasting refractory linings has caused limitations to a widespread acceptance and use of this otherwise very desirable technology. It is for this reason that gasifier users have identified improved refractory as one of the top research needs for gasifiers.

To meet these challenges, scientists at NETL developed an improved refractory material, worked with industry to commercially produce the material and evaluate its performance in industrial gasifiers, and then licensed the technology to the private sector. This NETL-developed refractory is now commercially available to the gasifier industry as AUREX™ 95P, and it is becoming the refractory of choice for advanced, high-temperature plants.

The success of AUREX 95P represents the most significant improvement in gasifier refractories in over 25 years. It reduces or eliminates the structural spalling that has been one of the major wear problems in existing refractory material. The new refractory lasts over 50 percent longer, and its commercial availability paves the way for an increase in the use of gasification as a clean and efficient means of producing electrical power and other products.

In addition, the new refractory helps DOE meet several of its goals for its gasification technology research and development, including—

- To achieve between 45 and 50 percent electrical efficiency at a capital cost of $1,600 per kilowatt (in constant 2007 dollars) or less for a coal-based plant.

- To be able to sequester 90 percent of the CO_2 from coal with minimal impact to the cost of electricity.

In other areas, the materials research groups at NETL are also addressing the challenges associated with minimizing the carbon footprint of fossil fuel use. This includes developing materials for CO_2 capture and sequestration, improving the performance of solid oxide fuel cell systems, and designing the materials that will enable the development and construction of next-generation gas turbines associated with coal-gasification systems producing synthetic gas.

Other recent contributions by NETL include new protection strategies for the nation's bridges (infrastructure); new protection strategies for thermocouples used in gasifiers; CO_2 sequestration by mineral carbonation; micro-reactors for reforming and continuous reforming and separation of hydrogen for fuel cells; and alloys for fuel cells, gasifiers, and supercritical and ultra-supercritical power plants.

From the atomic-level design of new materials to the development of pilot-scale processes, NETL's materials scientists and engineers provide answers as they engage in basic research and partner with industry, academia, and other government agencies to research and resolve vital materials issues.

Clean Energy

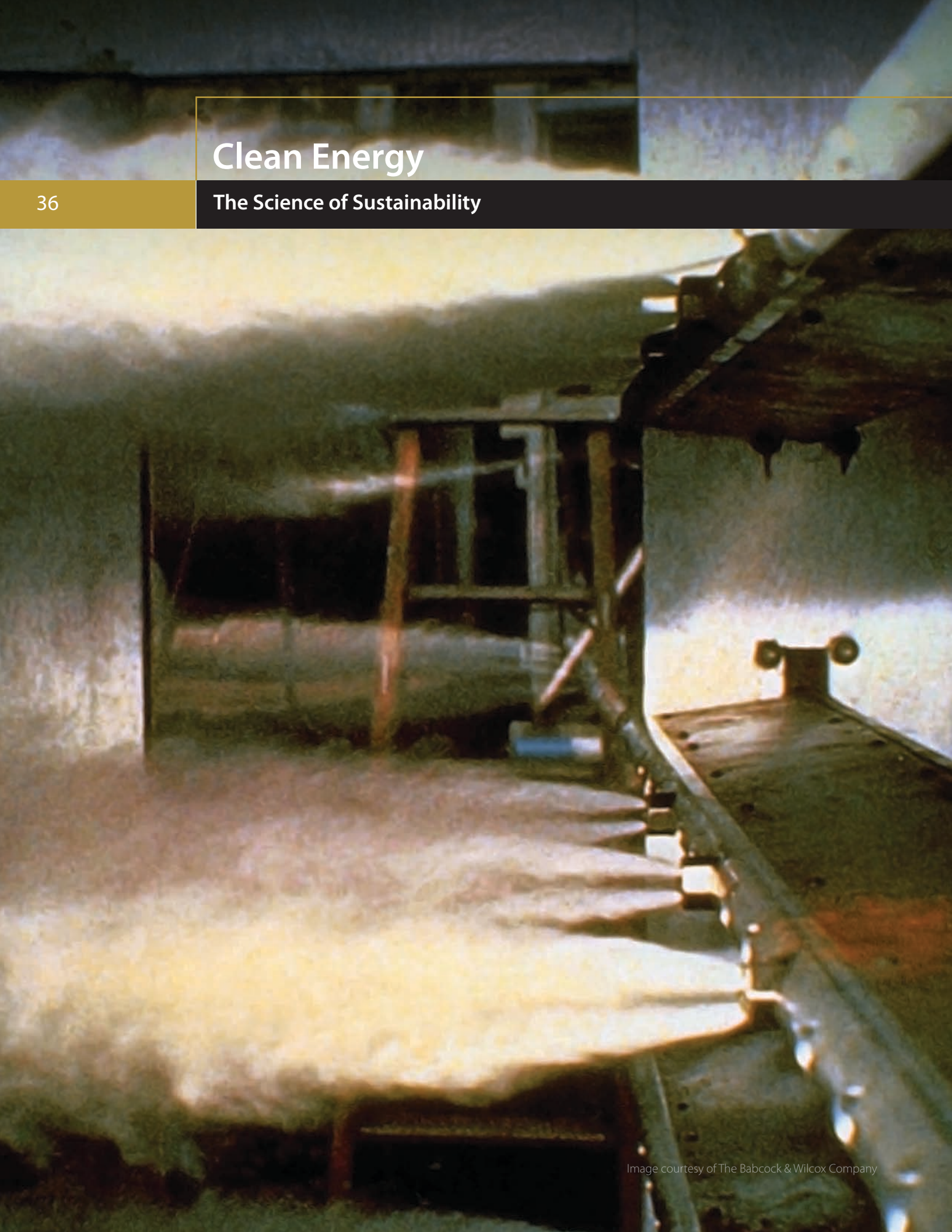


Image courtesy of The Babcock & Wilcox Company

Environmentally safe energy production became an important focus for NETL in 1926 when automobile exhaust in heavy traffic areas was a noted atmospheric pollutant. The Pittsburgh Experiment Station sampled the air in downtown Pittsburgh and discovered that excessive exposure to pollutants and smog could harm humans. In 2010, we are creating cleaner fuels and enabling more efficient production and use by reducing emissions and reusing waste products. Abundant, affordable fossil fuels will remain a key part of our nation's energy economy, and NETL has set the stage for their continued use through groundbreaking research on capture of greenhouse gases, lighting and vehicle technologies, and carbon storage.

Facing page—In the 1980s, acid rain was identified as causing damage to forests, aquatic life, and historic buildings. By the early 1990s, new technologies were being developed to remove SO_x and NO_x emissions from coal-fueled power plants, helping eliminate this threat. Sorbents injected into the gas stream at these power plants were one of the earliest NETL successes in reducing pollutants released without decreasing electricity production or increasing cost to consumers.

Clean Energy

The Science of Sustainability

Carbon Capture

NETL's gas separation research began with SO_x capture in the 1960s, expanding to include NO_x and mercury capture in the 1980s and early 1990s. CO_2 capture was added to the NETL research portfolio in the late 90s. Managing CO_2 at its source using solvents, sorbents, membranes, and other technologies will help prevent atmospheric CO_2 accumulation, which contributes to global climate change. NETL works toward cost reduction, improved capture technology efficiency, and more effective methods to prepare CO_2 for storage or conversion for other uses. Promoting the development of cost-effective CO_2 reduction technologies underpins NETL's efforts to achieve 90-percent carbon capture systems ready for commercial deployment beginning in 2020.

NETL Develops Regenerable Sorbent Suitable for Coal Gasification Applications—NETL scientists developed and patented a warm-gas-temperature sorbent for CO_2 capture at temperatures of 200–315 °C, often encountered in coal gasification. This unique magnesium hydroxide sorbent exhibits a high CO_2 capture capacity, is unaffected by steam, and can be regenerated at 375 °C and high pressure. High-pressure regeneration incurs lower compression costs when preparing captured CO_2 for geologic sequestration. A multi-cycle test conducted in a high-pressure, fixed-bed flow reactor at 200 °C with 28 percent CO_2 showed stable reactivity and increasing capture capacity with increasing pressure. The study is described in the American Chemical Society publication *Industrial & Engineering Chemistry Research*.

NETL Creates National Carbon Capture Center

In May 2009, the first National Carbon Capture Center (NCCC) opened its doors. NETL, along with Southern Company Service, Inc., and other industrial participants have established the NCCC to further national efforts in reducing greenhouse gas emissions, such as CO_2, that are thought to contribute to global climate change.

Test equipment for precombustion CO_2 capture includes an existing transport reactor, a hot-gas filter using candle-type filter elements, syngas cooling, and high-pressure solids-handling systems. Multiple slipstreams containing CO_2 are available for testing capture technologies on coal-derived synthesis gas (syngas) in an industrial setting. Further, a flexible post combustion test facility is being built close by. The post combustion facility is designed to support multiple, parallel test bays to investigate candidate processes at scale.

For projects that have been successfully tested at bench scale, the NCCC will provide a 1,000 pounds-per-hour flue gas slipstream for screening tests. And for technologies that have been successfully tested at screening scale, the NCCC will provide a flue gas stream for pilot-scale testing. Construction has already begun on the pilot-scale unit, planned as a versatile pilot solvent test unit and designed for a 5,000 pound-per-hour flue gas slipstream for testing advanced solvents. The pilot-scale unit will be equivalent to a 0.5-megawatt power plant.

NETL Completes Costs Analysis of Retrofitting U.S. Coal-Fired Power Plants with CO_2 Capture—An NETL analysis shows that approximately 142 gigawatts of pulverized-coal power plant capacity could be retrofitted with carbon capture technology for $61 or less per metric ton of CO_2. The candidate power plants had a combined unit generation capacity greater than 100 megawatts, an average heat rate below 12,500 Btu per kilowatt hour, and were located within 25 miles of a potential carbon sequestration site. Analysts completed the study using the Carbon Capture Model, which comprises programmatically linked databases, report spreadsheets, and geographic information system map documents. The model considers space constraints in calculating capital expense, operating expense, and parasitic load associated with retrofitted carbon capture technology.

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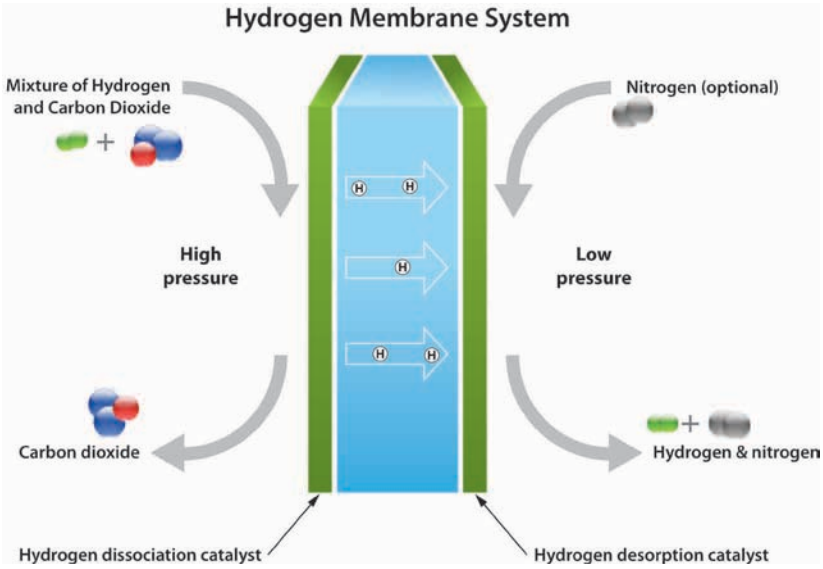
YEARS OF INNOVATION

Image courtesy of National Archives & Records Administration

"Clean coal" research began in the 1950s, with researchers removing sulfur-containing pyrite from coal, as shown here, to prevent the sulfur from causing extensive equipment damage and interfering with chemical reactions during power production. In the 1980s and 90s, investigators turned their attention to separating SO_x, NO_x, mercury, ash, water, and particulate matter from the power production waste stream. This work has positioned NETL to develop the technologies needed to separate and capture CO_2 emissions from power plants and other industrial facilities.



"Thick" Hydrogen Separation Membrane Exceeds Performance Target

NETL and Eltron Research & Development, Inc., of Boulder, CO, have developed a freestanding hydrogen transport membrane (HTM) that has exceeded the DOE hydrogen flux target for 2010. The new HTM, which is 131 microns thick, operated more than 300 hours without failure or loss of performance.

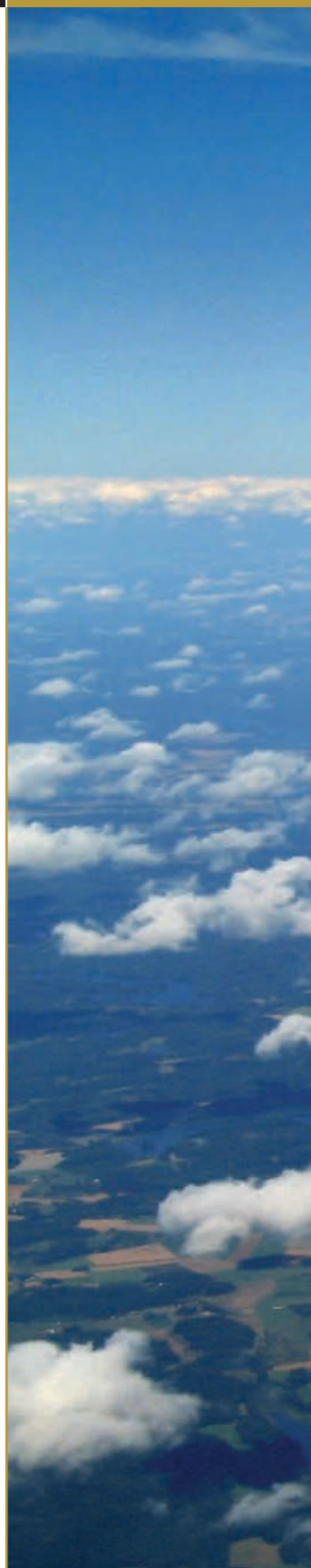
System studies show that the new HTM, integrated with warm gas cleaning at an integrated gasification combined cycle (IGCC) plant, improves efficiency by 6.2 percent compared to a two-stage gas cleanup process with CO_2 capture using conventional solvents. It achieves 99 percent CO_2 capture and reduces the cost of electricity by 9.5 percent.

Thick hydrogen transport membranes have the advantages of being robust, easily shaped with conventional techniques, and resistant to failure during thermal and pressure cycling. Further, they are less complex than substrate-supported thin membranes. HTMs are important because they make a high degree of CO_2 capture possible, thus minimizing CO_2 emissions into the atmosphere.

Novel Solvent Improves Precombustion CO_2 Capture—NETL collaborators at the University of Pittsburgh have demonstrated a new class of solvents particularly suited to capturing CO_2 produced in IGCCs. The materials, which are solid under normal conditions, melt under the high pressures encountered in synthesis gas production, forming a liquid phase containing as much as 50 weight percent of CO_2 captured from the syngas. The liquid may then be decanted and the solid recovered by a slight reduction in pressure, releasing purified CO_2 at a pressure higher than conventional approaches. Production at higher pressure reduces the penalty associated with compressing the CO_2 for purposes such as geologic sequestration.

Second-Generation Ionic Liquids Synthesized for CO_2 Capture—In NETL-sponsored testing, University of Notre Dame researchers synthesized amine-functionalized ionic liquids that have potentially higher CO_2-carrying capacities than conventional amine-based solvents. Synthesis efforts were based on molecular modeling studies, which revealed that the strategic attachment of the amine group to the ionic liquid can lead to an increased CO_2 capacity. This increase in capacity is an important step in the development of a novel solvent aimed at enabling more cost-effective post combustion CO_2 capture from power plant emissions.

NETL Sorbents Exhibit Exceptional Performance for CO_2 Capture—In cooperation with NETL, investigators at ADA-ES, Inc., of Littleton, CO, evaluated the laboratory-scale CO_2 capture performance of solid sorbents in a temperature-swing adsorption process. These were collected from over 15 developers in 7 different countries. Using simulated and actual flue gas, more than 100 sorbents were tested in a fixed-bed system through multiple adsorption and regeneration cycles for comparison to the benchmark aqueous monoethanolamine solvent. The superior performance of NETL-patented sorbents during the evaluation has made them leading candidates for use in solid sorbent-based CO_2 capture technology development.



Clean Energy

The Science of Sustainability

Carbon Storage

Because CO_2 is closely linked to global climate change, methods must be found to stabilize atmospheric levels of this greenhouse gas. Since 1997, NETL's Sequestration Program has explored many facets of carbon sequestration, including direct and indirect storage options and monitoring storage sites. We lead the nation's innovation of technologies for permanently sequestering CO_2 in deep underground geologic formations and terrestrial sinks. We also pursue coupling CO_2 storage with enhanced oil recovery. Numerous successes over the years have paved the way for extending the life of depleted oil fields while developing productive ways to sequester CO_2.

NETL Report Estimates CO_2 Storage Potential Beneath Federal Land—A newly completed NETL report estimates potential storage for 126–375 billion metric tons of CO_2 lies beneath 400 million acres of leasable federal lands. Of that estimate, 68 percent can be found in Montana, Wyoming, North Dakota, and South Dakota. The report also summarizes relevant laws, regulations, and federal and state legislation, and locates wells on and near federal land, pipeline rights-of-way, and point sources that might utilize federal lands for CO_2 storage. Complementing DOE's *Carbon Sequestration Atlas of the United States and Canada,* the report "Storage of Captured Carbon Dioxide Beneath Federal Lands" is based on information obtained from the National Carbon Sequestration Database and Geographic Information System and can be accessed at http://www.netl.doe.gov/energy-analyses/pubs/Fed%20Land_403.01.02_050809.pdf

Image courtesy of Apogee Scientific

Balloons, Bees, and Pollen Make a Novel Approach to CO_2 Monitoring

NETL researchers field-tested the use of balloons, bees, and pollen to verify that CO_2 is permanently stored in sequestration sites.

At the Center for Zero Emissions Research and Technology, researchers and bee experts from Montana State University placed hives around a known CO_2 source marked with perfluorocarbon tracers to determine if the bees or the pollen they collected would carry measurable quantities of tracer. In parallel, Apogee Scientific used balloons to test for atmospheric variations in tracer content. Apogee elevated carousels containing sealed sorbent tubes above the field using platforms tethered to large helium-filled balloons.

NETL will continue to pursue tracer research using balloons, towers, and groundwater chemistry.

Field Data Validate NETL Simulations of CO_2 Sequestration Field Project—An advanced model developed by NETL to account for coal shrinkage and swelling effects encountered when coalbed methane production is enhanced by CO_2 injection has been validated with field data from the Allison Field in northern New Mexico—site of the first commercial enhanced coalbed-methane production project. Simulation results agreed with the field data, yielding values for several geophysical and geochemical parameters. A paper describing the coal shrinkage and swelling model and the interpretation of the Allison Field data appears in the Elsevier publication, *International Journal of Coal Geology* (2009).

NETL Assists in Reducing the Carbon Footprint of Iron Production—NETL's unique capabilities in ore processing are helping to reduce the amount of CO_2 produced during iron smelting by the Cardero Iron Ore Company, Ltd., a subsidiary of the Cardero Resources Corporation. Natural processes of erosion and deposition have created a deposit of finely divided particles that do not require grinding before further processing, avoiding the energy cost of size reduction—up to about 30 kilowatt hours per ton of ore. In initial series tests, NETL researchers briquetted 500 pounds of a magnetic concentrate provided by Cardero Iron, and then performed direct smelting tests on the unsintered briquettes in an electric arc furnace. Eliminating sintering, which oxidizes the magnetite to hematite, reduces the production of CO_2 during the smelting operation by approximately 11 percent.

Long-Term Test Successful for Large-Scale Biofixation of CO_2—A successful 32-day period of continuous, automated operation demonstrated that a scalable prototype algae cultivator could grow nannochloropsis—a green algae—during the winter months in Phoenix, AZ, by providing aggressive mixing and efficient CO_2 distribution throughout the unit's growth area. In cooperation with NETL, Arizona Public Service (APS) is evaluating the techno-economic feasibility of capturing and beneficially using CO_2 from the power plant to cultivate algal biomass as a component of hydro-gasification fuel for the coproduction of substitute natural gas and electric power from western coals. APS will eventually supply a slipstream of flue gas to a cluster of eight prototype 6-meter radius bioreactors at the Red Hawk power plant near Phoenix.

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YEARS OF INNOVATION

Developed by NETL and its partners in 2007, SEQURE™ technology uses magnetic and methane sensors to quickly locate abandoned and leaking wells. This R&D 100 Award-winning technology can be attached to helicopters to cover large areas to determine if possible sequestration sites will retain injected CO_2.

Clean Energy

Carbon Sequestration Partnerships

The NETL-managed Regional Carbon Sequestration Partnership (RCSP) Program was launched in 2003 as the centerpiece of national efforts to commercialize carbon capture and storage technologies. Representing more than 400 state agencies, universities, and private companies in 43 states and 4 Canadian provinces, the RCSPs are working toward the capture and storage of CO_2 according to the differing needs and resources of seven North American regions. In Phase I of the program, the Partnerships identified CO_2 stationary sources and estimated the CO_2 storage resources available in geologic formations within each RCSP region. In Phases II and III, now underway, they are performing small- and large-scale injection testing. RCSP information on identified CO_2 sources and storage is available through the Carbon Sequestration Atlas of the United States and Canada.

Partnerships Team with NETL for Best Practices Manuals—Collaboration between the RCSPs and NETL has resulted in two best practices manuals based on lessons learned during the first 6 years of the partnerships program. *Best Practices Manual: Monitoring, Verification, and Accounting of CO_2 Stored in Deep Geologic Formations*—available to regulatory organizations, project developers, national and state policymakers, and interested public—provides a comprehensive overview of monitoring, verification, and accounting (MVA) techniques for improving the accuracy of greenhouse gas inventory estimates and ensuring the safety and efficacy of carbon storage projects. Available technologies can already verify 95 percent retention of sequestered CO_2, and a suite of technologies ensuring 99 percent retention is expected from the Office of Fossil Energy research and development program by 2012. *Best Practices Manual: Public Outreach and Education for Carbon Storage Projects* provides project developers with guidance on designing and applying best outreach practices for siting and operating CO_2 storage projects. These manuals can be downloaded from the NETL website at www.netl.doe.gov/technologies/carbon_seq/refshelf/refshelf.html.

Completed Injection Uses Methane Recovery Offset Costs—Approximately 1,000 tons of CO_2 have been injected into unmineable coal seams in Russell County, VA, under SECARB leadership. The project site represents an area that could store 1.3 billion tons of CO_2 while producing up to 2.5 trillion cubic feet of natural gas. Prior to the injection, the seams were fractured hydraulically to increase the number and size of CO_2 pathways into the coal, doubling the initial estimated injection rate to 40 tons of CO_2 per day. Underlying saline formations could store additional CO_2 when the storage capacity of the coal seams is reached. The project is designed to demonstrate the cost-effectiveness of utilizing the immediate commercial benefits of methane recovery to offset infrastructure development costs for the safe and permanent storage of larger volumes of CO_2.

Sequestration Project Shows Promise for Maintaining Injected CO_2—MRCSP partners have successfully injected 1,000 metric tons of CO_2 into the Mount Simon Sandstone, a deep saline formation widespread across much of the Midwest. Preliminary results indicate the formation has good potential for serving as a repository for CO_2 emissions captured from stationary sources in the region. Liquefied CO_2 was injected at Duke Energy's East Bend Generating Station located along the Ohio River near the town of Rabbit Hash, KY. Formation properties in this area, such as depth, thickness, porosity, and permeability, are considered conducive to CO_2 storage. Overlain by layers of low-permeability rock, the formation is expected to keep the CO_2 safely and permanently confined.

Additional Injection of CO_2 Completed in Michigan Basin—Building on an initial injection of 10,000 metric tons of CO_2, MRCSP partners injected an additional 50,000 metric tons into the deep saline Silurian-age Bass Island dolomite formation in the Michigan Basin near Gaylord, MI. This formation may be capable of storing hundreds of years' worth of CO_2. MRCSP injected the CO_2 in the summer of 2009.

First Injection of CO_2 into Lignite Coals Initiated—The Plains CO_2 Partnership (PCOR) member organizations have begun injecting CO_2 into a deep lignite coal seam in Burke County, ND, to demonstrate the economic and environmental viability of geologic

CO_2 storage in the U.S. Great Plains region. Previous characterization activities suggest the region's low-rank coal seams could store up to 8 billion tons of CO_2 while releasing more than 17 trillion cubic feet of methane. The first to focus on lignite coals, the demonstration will provide insight broadly applicable throughout western North America.

Injection Project Set To Assess Enhanced Oil Recovery Potential—MGSC partners have begun injecting 8,000 tons of CO_2 to evaluate the carbon storage strategies and potential of the Mississippian-aged Clore Formation in Posey County, IN. The injection will also help assess the potential for enhanced oil recovery (EOR) from abandoned wells. DOE researchers believe EOR programs can dramatically improve the efficiency and economics of using the technology in a wider variety of geologic applications.

Equipment Installed To Track Post-Injection CO_2 Movement—SECARB has installed scientific instrumentation 2 miles beneath the surface to track movement of 1 million metric tons of CO_2 from injections by Texas-based Denbury Resources, Inc., near Natchez, MS. Use of in-zone and above-zone pressure-response monitoring techniques has proven a cost-effective strategy for MVA that can be widely deployed in CO_2 storage projects. The project is designed to demonstrate that 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-bearing formations.

Preliminary Activities Completed in Anticipation of CO_2 Injection—Drilling operations organized by MGSC were completed upon reaching the Precambrian-granite basement rock underlying the Mount Simon sandstone formation near Decatur, IL. More than 1 million tons of CO_2 from a nearby Archer Daniels Midland ethanol facility will be injected into the formation over a 3-year period. A core sample of the overlying Eau Claire shale formation was recovered to evaluate the sealing properties of the 500-foot-thick cap rock.

Core Samples Collected in Preparation for Major Sequestration Activity—To assess the viability of carbon storage in brine-saturated formations, PCOR collected core samples from a new characterization well near the Spectra Energy Fort Nelson natural gas processing plant in British Columbia, Canada. The samples are being analyzed in conjunction with a sophisticated well logging program. With plans to inject more than 2 million tons of CO_2 per year, the international project will be one of the largest carbon sequestration projects in the world and among the first commercial-scale carbon capture and storage projects at a North American saline formation.

SECARB
Southeast Regional Carbon Sequestration Partnership

The Plains CO_2 Reduction Partnership PCOR

MRCSP
MIDWEST REGIONAL CARBON SEQUESTRATION PARTNERSHIP

BIG SKY CARBON SEQUESTRATION PARTNERSHIP

WEST COAST REGIONAL CARBON SEQUESTRATION PARTNERSHIP
westcarb.org

MGSC
Midwest Geological Sequestration Consortium

SWP
SOUTHWEST PARTNERSHIP CO_2 SEQUESTRATION

Clean Energy

The Science of Sustainability

Demand-Side Efficiency

After World War II, USBM began conducting research on a new gasifier design, which allowed researchers to examine variables affecting efficiency and costs, such as temperature, pressure, and type of coal. The final design brought NETL into a new era of technology, as the Laboratory collaborated with boiler manufacturer Babcock & Wilcox to establish a second-generation pilot plant. Today, NETL projects continue to address efficency issues in both power plants and consumer products. Reducing power consumed by lighting, making transportation more efficient, and decreasing home energy use are all important to maximize our energy supplies. Creating more efficient and cost-effective means of fuel use preserves our resources, reduces our dependence on foreign oil, and lessens our environmental impact.

NETL Commissions Appliance Technology Evaluation Center—NETL has commissioned an Appliance Technology Evaluation Center (ATEC) that will support the Appliances and Commercial Equipment Standards Program at the DOE Office of Energy Efficiency and Renewable Energy (EERE). ATEC will establish minimum efficiency standards for residential appliances and commercial equipment and develop procedures for testing these products. ATEC is located in a 1,600-square-foot facility specially designed for engineers to improve test methodologies for measuring the energy efficiencies of modern appliances. Appliance testing performed at ATEC guides energy rulemaking teams in determining possible upgrades in energy efficiency that can be applied to new models of these appliances. In 2009, ATEC staff completed standby power testing for residential clothes washers, dehumidifiers, dishwashers, stoves, ovens, cook tops, battery chargers, and external power supplies.

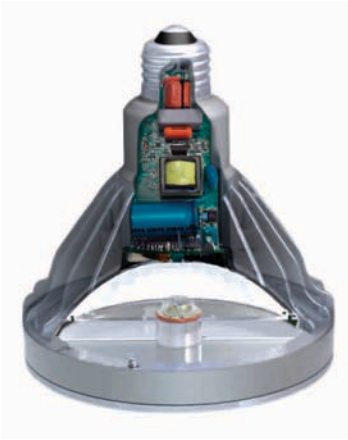


Image courtesy of Cree, Inc.

NETL and Cree, Inc., Help Shed New Light on Walmart Goods

Cree, Inc., is installing its LRP-38 LED lights in 650 Walmart stores across America. Cree designed a key element of this lamp, the prototype multi-chip component for the PAR38 envelope, in partnership with NETL, before completing development and taking the lamp to market. Cree LEDs will replace existing lights in produce and electronics departments in both new and remodeled buildings. The lamp was selected for its energy efficiency, long life, and high color rendition. The tightly focused beam of the LRP-38 also reduces glare for customers.

LED lights are gaining popularity as an environmentally friendly alternative to other common light bulbs. Incandescent and fluorescent bulbs provide adequate light for daily life but are vastly inefficient. Cree's mercury-free LED lamps use 82 percent less energy and deliver no produce-degrading UV or infrared energy. In addition, the lamp has an operating life of 50,000 hours—lasting roughly 5 years before replacement and reducing the number of bulbs that find their way into municipal landfills.

Weatherization Assistance Program Awards Federal Grants—Low-income families spend an average of 10 percent of their income on energy, compared to a 3.3 percent average nationwide. Through DOE's Weatherization Assistance Program, NETL and EERE's Golden Field Office collaborate with state and local agencies to help these families make their homes more energy efficient, reducing home energy bills by an average of 24 percent or $437 per year. In 2009, Weatherization Assistance Program funding helped weatherize 95,000 homes, and additional funds were allocated to weatherize 600,000 homes over 3 years under the American Recovery and Reinvestment Act of 2009. The Weatherization Assistance Program decreases overall U.S. energy use by the equivalent of 24.1 million barrels of oil annually and generates thousands of direct jobs and even more through indirect employment. Each dollar invested in the program returns $2.50 in benefits.

NETL-Managed Projects Make Lighting Systems Brighter, Warmer, and More Efficient—DOE's demand-side efficiency goals include cost-effective, market-ready lighting systems that by 2025 will produce 160 lumens per watt, compared to the 15 lumens per watt obtained today from a standard 60-watt incandescent lamp. The research conducted in cooperation with NETL by industrial partners produced several accomplishments in the quest to reduce power consumed for lighting purposes—

- A product development team at Universal Display Corporation is working with Armstrong World Industries to incorporate a white organic light emitting diode (OLED) lighting panel into a commercial TechZone™ Ceiling System. The OLED achieves 68 lumens per watt, correlated color temperature (CCT) of 3420 K, and color rendering index (CRI) of 80.

- Add-Vision's high-quality, flexible, cool-white OLED device features small cross sections that allow it to be easily integrated into a variety of lighting products designed to use significantly less energy. The OLED acheives a CRI of 70 and a CCT of 5000 K, a significant step in developing an efficient, long-lived, low-cost OLED.

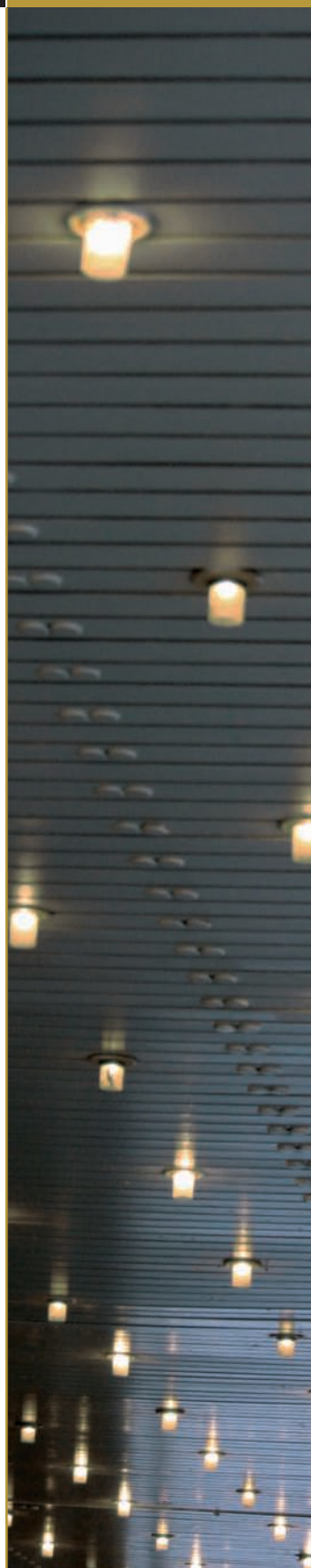
- Whereas typical phosphors used in solid-state lighting only emit at one color with efficiencies that drop rapidly as temperature increases, proprietary new phosphors developed at PhosphorTech are efficient, can emit at a range of colors, and become more efficient at higher temperatures. The phosphors can be blended to achieve good quality color that remains stable at typical operating temperatures.

- A power supply developed by Osram Sylvania (Danvers, MA) has been demonstrated to be 90 percent efficient with a power factor greater than 99 percent and a total harmonic distortion of less than 5 percent. Unlike constant voltage sources used in most power supplies for electronics, the constant current sources needed for solid-state lighting are especially challenged by size restrictions, thermal environments, and cost constraints.

- Osram Sylvania has also demonstrated a light engine consisting of an array of blue LEDs on a circuit board covered by a glass disk coated with new red phosphor that converts blue light into a warm white light, achieving greater efficiency, CCT of 3500 K, and CRI of 80. Thermal simulations show that a luminaire designed with these components would have a peak circuit-board temperature only 4 °C above the surrounding heat sink, and the center LED in the array would be only 1 °C hotter than those on the edge.

- Philips Lumileds Lighting Company has demonstrated a warm white 2x2 mm2 LED with 573 lumens light output and CCT of 2650 K. Small, efficient, and high-output light sources would give luminaire manufacturers more flexibility when designing lighting products.

- Rensselaer Polytechnic Institute has demonstrated a wavelength-stable green LED grown on a non-polar plane of a gallium nitride crystal. Growing LEDs on non-polar surfaces eliminates polarization effects that reduce efficiency. Efficient green LEDs are also important when using the color-mixing approach to produce white light.



Clean Energy

The Science of Sustainability

Air, Water, Land

Realizing economical, secure, abundant fuel supplies must balance with protecting our air, water, and land. NETL's pursuit of environmental technologies dates back to 1919, when USBM mine safety experts helped design the Holland Tunnel's ventilation system to control carbon monoxide levels. Today, NETL seeks to protect the environment on a global scale, including development of the latest water conservation and treatment methods, soil remediation approaches, and air-pollutant removal technologies.

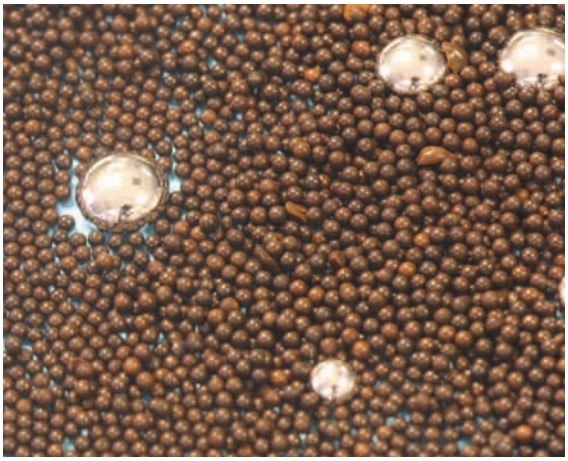


Image courtesy of Johnson Matthey

Sorbents Successful in Sweet and Sour Syngas

Palladium sorbents, previously found successful in removing mercury from sweet synthesis gas (syngas), have also seen success in removing mercury, arsenic, and selenium from sour syngas. Using technology developed by NETL and Johnson Matthey, Southern Company tested the palladium sorbent, shown here with drops of mercury, in sour syngas at a higher flow-rate than used in experiments with sweet syngas. The palladium sorbent removed over 98 percent of the mercury, over 99 percent of the arsenic, and over 99 percent of the selenium during extended exposures to real syngas at 550 °F—an outstanding outcome.

Syngas, the end product of gasification, is either "sweet" or "sour" depending on the amount of sulfur present, with sour syngas containing more. Higher levels of sulfur make removal of trace elements more difficult. Once trace elements are removed, syngas can be used in fuel production.

With a national mercury-control regulation expected by November 2011, low-cost mercury-removal techniques must be developed for integrated gasification combined cycle (IGCC) plants. By removing these trace elements at high temperatures with palladium sorbents, an IGCC plant can maintain better efficiency—leading to lower operating costs—than by using low-temperature capture by activated carbons. Because so few sorbents have been shown to remove mercury from high temperature syngas, this is a major success.

NETL and Industry Experts Look To Reduce Carbon Emissions by Improving Power Plant Efficiency—An industry workshop hosted by NETL in Chicago, IL, July 2009, explored opportunities for improving the thermal efficiency of existing and future coal-fired power plants, which is one of the most promising, low-cost options for reducing near-term carbon emissions. Participants included utility owners and operators, equipment vendors, energy consultants, and power industry associations. Workshop proceedings established the following objectives: to refine cost-savings estimates of efficiency improvement and related carbon savings; build a public-private partnership to leverage the available resources of industry and federal and state governments; and educate key audiences about opportunities to reduce greenhouse gas emissions by developing public outreach and stakeholder engagement. A workshop report is available from the Energy Analysis Reference Shelf at the NETL website.

Multi-pollutant Clean Coal Power Initiative Demonstration Meets All Goals—In partnership with NETL, We Energies, a subsidiary of Wisconsin Energy Corporation, successfully demonstrated TOXECON™ Mercury and Multi-Pollutant Control Technology at the Presque Isle Power Plant, in Marquette, MI. By injecting sorbents such as powdered activated carbon downstream of existing particulate-control devices but upstream of a pulsed-jet baghouse, the process captures mercury while retaining the sales value of fly ash as a cement additive. The technology consistently

removed more than 90 percent of the mercury contained in the flue gas combined from three units (270 megawatts total) firing Powder River Basin coal, which contains a high percentage of difficult-to-remove elemental mercury. TOXECON is expected to remove 97 pounds of mercury and 32 tons of fine particulate matter annually at the plant, and represents a low-cost retrofit option for an estimated 167 gigawatts of existing coal-fired capacity.

Final Technical Report Completes Series for Power Plant Improvement Initiative—The Greenidge Multi-Pollutant Control Project final report has been approved and posted on the Clean Coal Technology Compendium page of the NETL website. This last of five Power Plant Improvement Initiative (PPII) projects successfully demonstrated the commercial readiness of an emissions-control system that—due to low capital and maintenance costs and small space demands—is particularly suited to existing small- to medium-size electricity generating facilities. Completed by CONSOL Energy, Inc., AES Greenidge, and other industrial partners working in cooperation with NETL, the project met all goals for the removal of NO_x, sulfur dioxide, sulfur trioxide, hydrochloric acid, hydrofluoric acid, and mercury, demonstrating that multiple pollutants can be controlled collectively for less money than it would cost to control them separately. The PPII was launched in October 2000 to further demonstrate the commercial-scale, clean coal technologies at existing and new electric generating facilities.

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YEARS OF INNOVATION

Image courtesy of National Archives & Records Administration

In 1921, the Pittsburgh Experiment Station, having worked on mine safety through ventilation of dangerous gases, helped develop a safe ventilation system for New York's new Holland Tunnel. Testing was done at the Bruceton site's Experimental Mine, shown here. Researchers built life-size tunnel models and monitored volunteers breathing the air near running vehicles to determine the effects of concentrated exhaust fumes. The resulting ventilation system kept carbon monoxide levels far below the safety threshold.

Clean Energy

The Science of Sustainability

Mercury-Removal Goal Met in Long-Term Field Test—In cooperation with NETL, investigators from ADA-ES, Inc. (Littleton, CO) effectively and economically achieved 90-percent mercury removal using sorbent injection technology at the Rocky Mountain Power station located in Hardin, MT. The 121-megawatt Hardin Station fires Powder River Basin coal and is equipped with a selective catalytic reduction unit for NO_x control, a spray dryer absorber for SO_2 control, and a fabric filter for particulate control—an appealing configuration for new plants. Integrating the commercial-grade activated-carbon injection system with new-generation continuous emissions monitors allows sorbent injection to be regulated based on actual mercury levels. Activated carbon consumption then automatically decreases at low load as mercury capture at Hardin increases from less than 20 percent to about 50 percent. Project results will help develop technology options for the current fleet of coal-fired power plants to comply cost-effectively with any future mercury regulations

Commercial Deployment of NO_x-Control Technology Expands—Novel NO_x-control technology developed at Reaction Engineering International (REI) of Salt Lake City, UT, and field-tested in cooperation with NETL, has been installed on eight cyclone power boilers, totaling 1,460 megawatts in generating capacity. By employing reagent injection and over-fire air hardware similar to systems commercially available for cyclone boilers, REI's Advanced Layered Technology Approach (ALTA) for NO_x control appeals to utility personnel seeking to attain compliance, particularly with smaller, older facilities where economic considerations and space constraints make selective catalytic reduction installation difficult. ALTA technology was field-tested at AmerenUE's Sioux Unit 1 Station near St. Louis, MO. At the Kansas City Power & Light Sibley Plant, two ALTA-equipped 50-megawatt cyclone boilers demonstrated NO_x-removal efficiencies up to 70 percent at a capital cost of $32.5 per kilowatt—85 percent lower than an installed selective catalytic reduction unit.

Adverse Impact Reduction Handbook Released—An NETL-initiated study has resulted in a new publication on technologies and practices that help minimize the potential of environmental impact attendant to oil and gas development. Based on input from stakeholders, including non-governmental organizations, local governmental bodies, industry, state and federal agencies, and individual landowners, the handbook outlines key practices for onshore exploration and production that avoid, minimize, and mitigate environmental impacts. Recommended solutions apply to rural and urban areas nationally. Prepared by the Interstate Oil and Gas Compact Commission (IOGCC) with ALL Consulting, the handbook can be downloaded from the NETL website, which links to the IOGCC website for ordering hard copies.

Primer on Shale Gas Development Now Available—The Ground Water Protection Council (GWPC), a national association of state ground water and underground injection agencies that promotes the protection and conservation of ground water for all beneficial uses, has released *Modern Shale Gas Development in the United States: A Primer* in cooperation with NETL. Natural gas production from hydrocarbon rich shale formations, known as "shale gas," is one of the most rapidly expanding trends in onshore domestic oil and gas exploration and production today. Key to the emergence of shale gas production has been the refinement of horizontal drilling and hydraulic fracturing technologies, which enable industry to produce more natural gas from the shale formations economically and with fewer disturbances to surface environments. Available at the GWPC website, the primer is an objective source of fact-based technical information for public education and informed regulatory and policy decisions regarding environmentally responsible development of the nation's shale gas resources.

Online Tool Helps Operators Prepare Drilling Plans in Environmentally Sensitive Areas—The University of Arkansas partnered with Argonne National Laboratory and NETL to develop a Web-based decision-support tool to help minimize adverse ecosystem impacts associated with oil and gas recovery in sensitive areas in central Arkansas's Fayetteville Shale Play. With more than 2 million acres currently under lease, the 50-mile wide Fayetteville Shale is becoming one of the most active shale plays in the United States. By mapping the intersection of proposed features with sensitive water locations, existing transmission lines, soil data, etc., the Infrastructure Placement Analysis System can help small- and mid-sized oil and gas exploration and production companies plan more effectively, streamlining the process for well-placement permitting and infrastructure development.

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YEARS OF INNOVATION

Over a 15-year period, NETL's mercury program—the world's premiere mercury research and development initiative for coal-fired power plants—brought a suite of low-cost capture technologies to the marketplace. From 2006 to 2009, the We Energies Presque Isle Power Plant in Marquette, MI, shown here, demonstrated the TOXECON™ mercury and multi-pollutant control system as part of NETL's Clean Coal Power Initiative. The artificial-intelligence system updates older power plants to deal with modern environmental concerns by monitoring performance and making adjustments for optimized pollution control.

Clean Energy

The Science of Sustainability

Ice Road Planning Model Developed—Researchers at the University of Alaska Fairbanks, working in cooperation with NETL, have developed a novel planning model that could reduce costs and improve environmental compliance when constructing ice roads. Incorporating spatial databases, mathematical optimization, and user-defined values, the model determines multiple route options and associated tradeoffs relative to various planning objectives such as risk, cost, and construction time. The Water Resources Section of the Alaska Department of Natural Resources has shown particular interest in the tool, noting its timely development in view of recent increases in the number of operators new to the North Slope.

Project Restores Capacity of Water Supply to North Dakota Municipality—As part of a joint venture between NETL and the University of North Dakota Energy & Environmental Research Center (EERC), contaminant levels in soils and groundwater menacing a municipal well near the Vining Oil Co. (Carrington, ND) have been reduced below regulatory limits. The equivalent of 2,022 gallons of gasoline was removed from within the capture zone of the municipal well using multiphase extraction and soil-vapor-extraction techniques integrated with air-oxidant sparging.

Reports Assess Impact of Drought on Power Plant Operations—Argonne National Laboratory researchers working with NETL produced two reports on the impact of drought on power-plant cooling-water intake. Based on data obtained for 423 power plants in 44 states, one report concludes that high precursory water-supply temperature or shallow intake depth could cause some power plants to curtail or shut down operations during moderate or severe drought. Priority systems governing water use during droughts to enable preferred uses, such as continued power plant operations, may reduce the risk of losing power capacity. A second report modeled the effect of drought on western power production and identified five plants in four states that could face curtailed operations or be shut down. The study also found that hydroelectric generation could drop by almost 30 percent in a severe drought, but natural gas plants would replace virtually all lost generation. Increases in competing water demands and warmer or more variable climatic conditions in coming years could exacerbate future droughts. Drought-related power losses that prevent running air conditioners and fans during hot weather can have devastating effects on populations.

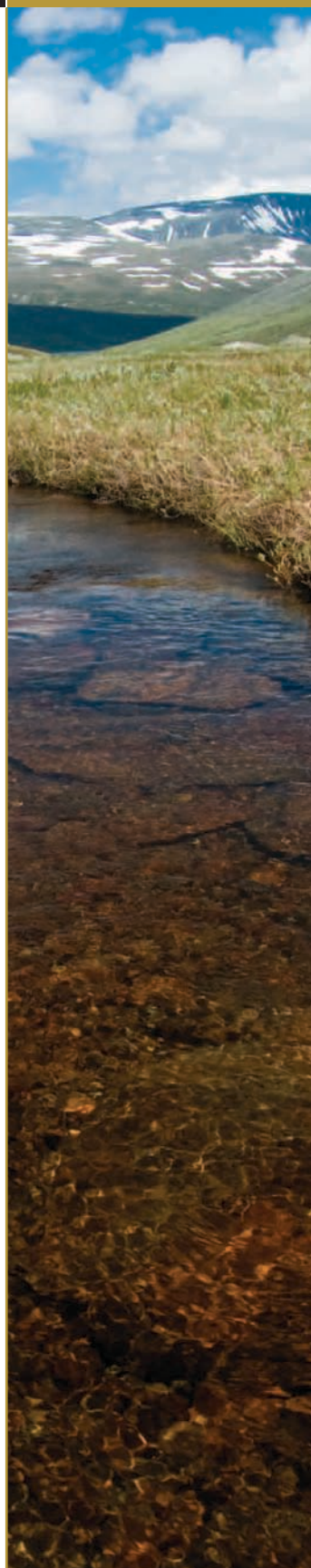
New Contaminant Prediction Method Can Reduce Soil Remediation Costs—Used to determine polycyclic aromatic hydrocarbon levels in soils, the solid-phase micro-extraction (SPME) method promises to reduce the quantity of soil or sediment contaminated by coal tar, pitch, and a variety of industrial waste products that requires massive remediation. This new approach will help to protect endemic species from contaminants and reduce costs of remediation. Developed by RETEC and the EERC at the University of North Dakota in cooperation with NETL, the approach has been accepted both by ASTM International and the U.S. Environmental Protection Agency (EPA) and welcomed by many public and private organizations. The SPME method is valued for its speed and accuracy of assessment compared to other regulatory models on the market and is now being applied at industrial, EPA Superfund, and U.S. Department of Defense sites.

Water-Saving Technology Successful in Power-Plant Field Test—An Air2Air™ Water Conservation Cooling Tower installed at the San Juan Generating Station near Farmington, NM, extracted heat contained in hot saturated air from evaporative cooling, and returned high-purity condensate to the plant for boiler makeup or other purposes. The field test was conducted by SPX Cooling Technologies as part of an NETL-managed project under the Office of Fossil Energy's Innovations for Existing Plants program. Nationally, power-plant cooling towers evaporate 3 billion gallons of water each day. Recovering a portion of that amount at the 18.5 percent condensation rate demonstrated during the field test would provide relief from drought conditions or allow growth in many water-starved areas of the country.

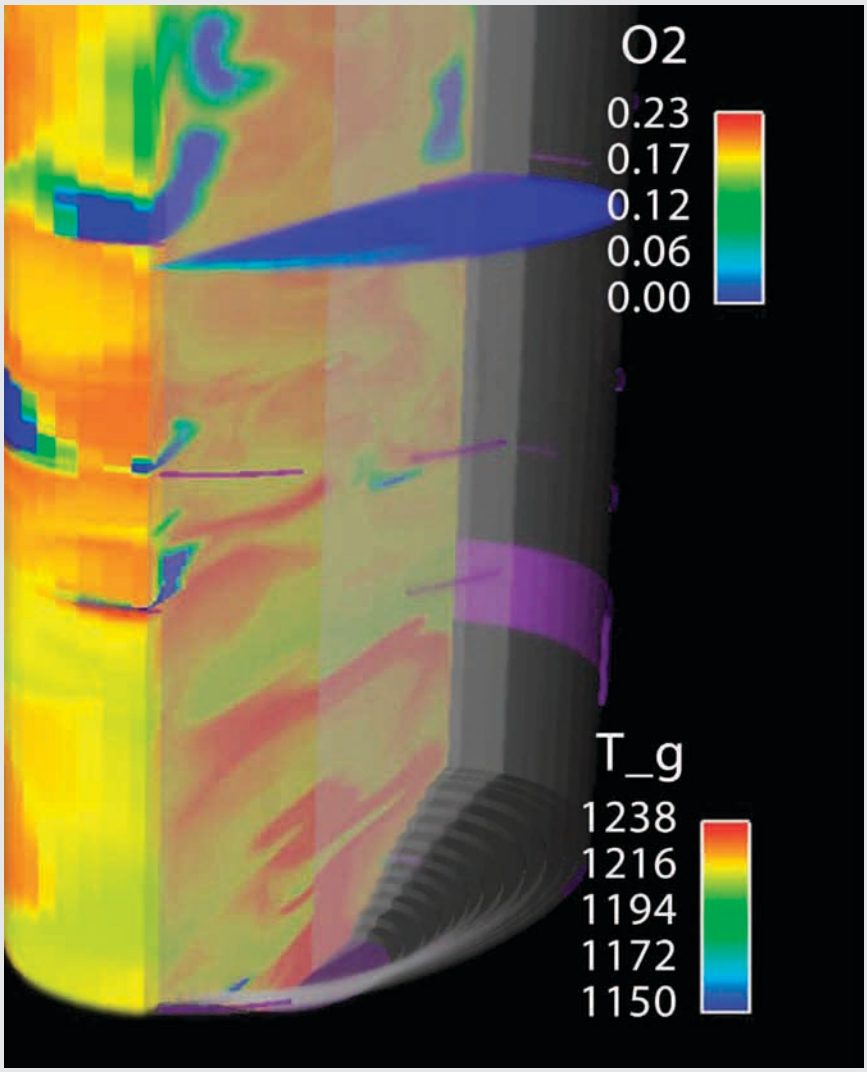
Water Recovery Technique Field-Tested at Georgia Power Plant—Slip-stream testing of acid and water recovery from flue gas was completed at Southern Company's Plant Yates near Newnan, GA, using a series of four condensing heat exchangers installed downstream of the wet flue gas desulfurization unit. Organized by Lehigh University researchers in cooperation with NETL, testing was conducted over a range of flue gas and cooling water flow rates to simulate the effects of changes in unit load. Preliminary results suggest that acid traps located before and after the first heat exchanger were successful in collecting a small amount of concentrated acid. The heat rate and emissions co-benefits of the technology could be significant by recovering sensible and latent heat, removing some mercury constituents, and condensing sulfuric, hydrochloric, and nitric acid vapors from the flue gas. Based on U.S. annual averages, the amount of cooling tower makeup water that could be provided by condensing heat exchangers is estimated at approximately 6–8 percent for units firing low-moisture bituminous coals (e.g., Plant Yates), 14–16 percent for units firing Powder River Basin coals, and 22–25 percent for units firing high-moisture U.S. lignite coals.

Constructed Wetlands Could Make Non-Traditional Sources of Water Suitable for Power Plant Use—Clemson University researchers working in cooperation with NETL have successfully tested the application of constructed wetlands for treating non-traditional water sources that could serve in power plants. Four non-traditional waters—ash basin water, cooling water, flue gas desulfurization water, and produced water—were treated using the approach and tested against EPA water quality criteria, USDA irrigation standards, and power plant reuse standards. The pilot-scale test results show that while limited to chloride concentrations of less than 4,000 milligrams per liter, constructed wetland treatment systems can remediate the water sources tested for reuse or discharge, offering an economical alternative to conventional approaches that are comparatively costly and often unable to achieve new, rigorous water-quality standards.

Laboratory Tests Validate Novel Water-Saving Filtration Method—Drexel University researchers working in cooperation with NETL have confirmed that pulsed electric fields can prevent fouling in filters used to limit solids content in power plant cooling-water circuits. The researchers showed that the pressure drop across a filter in an experimental circulating water loop equipped with a pulsed power system could be maintained almost indefinitely at a value corresponding to that of the initial clean state. Self-cleaning filters could curtail wasteful water blow-downs, which account for approximately 30 percent of cooling tower water loss, reducing the impact of power plant cooling on freshwater supplies by nearly 4 million gallons per day for a 1,000-megawatt fossil fuel power plant. Results of the study are discussed in the *International Journal of Heat and Mass Transfer* (2009).



Computational Sciences: It's a Virtual World



This image shows a detailed look into a gasifier simulated by NETL's in-house model, MFIX. Design engineers use information from this simulation to evaluate mixing in the gasifier and determine which areas of the gasifier are operating in a combustion mode versus a gasification mode. Conducted in 2009, this simulation used more than 10 million computational cells and was run using more than 4,000 central processing units.

Imagine designing and operating highly efficient and environmentally friendly power plants without sufficient insight, understanding, and analysis of the underlying physical and chemical processes. NETL's Computational Science (CS) division combines physical and chemical research with computational sciences to provide tools for designers to understand, develop, and optimize technologies for advanced fossil fuel utilization, including carbon management.

The computational models, methods, and tools developed and used by NETL enable virtual energy and environmental research, from small-scale scenarios through virtual plant simulations, reducing the time and research dollars needed to achieve ultimate success. Technologies developed by CS are enhanced in each subject area and then passed to the next. This builds on prior research, culminating in multiple levels of investigation and capabilities.

The Multiphase Flow Research Group within CS accelerates the development of simulation capability and promotes its use in the design, operation, and troubleshooting of multiphase flow devices in fossil fuel power plants. One tool developed by NETL is Multiphase Flow with Interphase eXchanges (MFIX): a computer code that provides data on pressure, velocity, gas-solid species mass fractions, and temperature in gas-solids systems. MFIX is applied in areas where gases and solids come into contact, such as integrated gasification combined cycle (IGCC) power generation. It has also met with significant success in researching subbituminous, bituminous, and lignite fuels. MFIX is open-source software, and over 1,600 users from national and international laboratories, universities, and industry are contributing to the software's ongoing development.

CS's Device-Scale Modeling Research Group develops computational fluid dynamic (CFD) models for carbon capture, carbon management, and gas cleanup systems for use by NETL and industrial organizations. One example is a CFD model for postcombustion CO_2 capture using MFIX. This reactor design has been used for NETL's studies of a CO_2 capture system in which inert solids are injected into the reactor with the sorbent. Researchers are also working on CFD models for chemical looping and pulverized-coal oxyfuel combustion—two other CO_2 capture technologies—and are using a recently developed transport desulfurizer model to aid industry in the commercialization of this gas clean-up technology. During 2009, chemical looping CFD models were developed and simulations performed of several gas- and coal-based experiments.

The Model Validation Research Group generates experimental data used to validate computational models and identify ways to improve and update the models for a more accurate representation of phenomena of interest to industry. Recently, NETL and Particulate Solids Research, Inc., evaluated variation in time and space in the gas-solids mixing for different granular materials over a range of flow conditions. This data set resulted in a challenge problem for modelers worldwide to evaluate their computational models against this data. The problem is available on the MFIX website along with historical fluidization data and results. As another project, a facility to test sorbent-based CO_2 capture is being built that will validate computer models and assess the economic viability of commercial concepts being proposed to remove this greenhouse gas.

NETL's final CS area, Process and Dynamic Systems Modeling Research Group, accelerates research, development, and application of advanced simulation and optimization solutions for process systems engineering challenges arising across the energy plant life cycle. One software tool, NETL's Advanced Process Engineering Co-Simulator (APECS), was upgraded in 2009, offering important enhancements for large-scale energy applications, such as IGCC and chemical looping systems. The availability of APECS helps industry design next-generation energy plants that operate efficiently at low cost and with near-zero emissions. In collaboration with Ames National Laboratory and Reaction Engineering International, NETL has also developed the Virtual Engineering-Process Simulator Interface (VE-PSI). Used with APECS, the VE-PSI software enables engineers to improve existing designs and create virtual prototypes of new energy plant designs more quickly, efficiently, and cost-effectively than ever before.

The collaboration of these four groups of NETL's CS division results in computational tools that simulate and facilitate the development of clean, highly efficient energy systems for the future. By working in a computational environment, researchers can accelerate technology development and deployment, as well as troubleshoot problems in existing systems, all while minimizing environmental impacts and reducing cost. Creating a computational model allows engineers—both at NETL and elsewhere—to view systems in a virtual world.

Reliable Supply

Abundant, Secure, Affordable

When the petroleum embargo in the early 1970s resulted in gas shortages, soaring fuel prices, and an economic slump, our nation urgently needed to discover ways and means to increase our energy security and independence. This 20th century crisis illustrates America's continuing concern for abundant, accessible, and affordable energy supplies. Over the last century, NETL and its predecessors have addressed this concern through a diverse research agenda. We have advanced technologies for the efficient and environmentally safe production of domestic energy resources, modernized U.S. energy transmission and distribution systems, and investigated novel techniques to produce and recover conventional and unconventional energy resources.

Reliable Supply

Abundant, Secure, Affordable

Energy Infrastructure

America's energy challenges are demanding, requiring our undivided attention to every phase of the energy cycle. It is not enough to produce and generate reliable energy; we must also transmit and distribute it safely to the consumer. USBM was established in 1910 to address safety in our nation's coal mines. In the late 1920s, research began at the Bartlesville Petroleum Experiment Station in Oklahoma that included the detection and prevention of leaks in natural gas pipelines and evaporation of stored petroleum and gasoline. Today, our efforts have expanded to include support for development of sustainable communities, implementation of a modernized electricity grid, research into unconventional fuel resources, and improved federal response to national emergencies. NETL lends its century of expertise to confront these infrastructure challenges economically and with minimal environmental impact.

NETL Produces First Statewide Smart Grid Implementation Plan—NETL analysts have identified technological approaches that could close the gap between today's electricity grid conditions in West Virginia—a state with grid reliability well below the national average—and those likely to be required for a 21st-century economy. If implemented in a coordinated effort rather than independently, the 20-year cost (less than $10 billion) of the recommended solutions would provide more than $12 billion in benefits to consumers, utilities, and society. The solutions include a distribution management system, distributed energy resources, demand response tools, an advanced meter infrastructure, and an upgraded customer information system to accommodate advanced meter infrastructure and demand response functionality and outage management. Details of the plan can be accessed from the Energy Analysis Reference Shelf at the NETL website.

DOE Office Releases First-of-a-Kind Analysis of Hurricane Impacts on U.S. Energy Sector—The Infrastructure Security and Energy Restoration Division of the DOE Office of Electricity Delivery and Energy Reliability (OE) released a report analyzing hurricane impacts on our national energy infrastructure during the 2005 and 2008 storm seasons. The report compares the magnitude and duration of hurricane-induced production and supply disruptions, as well as the extent of damage to the energy sector (e.g., electricity, natural gas, petroleum, energy prices, and supply). Whereas previous studies measured the effect on a single energy sector during a single season, the NETL-supported study examines the impacts on all U.S. energy sectors during two hurricane seasons (Hurricanes Katrina, Rita, Wilma, Gustav, and Ike). The study finds that experience gained from the 2005 season better prepared the energy industry to mount extensive restoration efforts in 2008, and describes actions taken by DOE and other federal agencies to assist in these efforts. The report title *Comparing the Impacts of the 2005 and 2008 Hurricanes on U.S. Energy Infrastructure*, is publicly available at www.oe.netl.doe.gov/outreach.aspx.

Sustainable Communities Proven To Be Feasible—The Energy-Efficient Community Development: Chula Vista Research project has proven that developing sustainable communities through energy-reduction strategies in large-scale commercial, residential, and mixed-use developments is feasible. Completed in cooperation with NETL for DOE's OE, the study involved 188 commercial and 863 residential structures in Chula Vista, CA, and suggests energy requirements could be reduced from 31 to 36 percent, while community peak electricity demand could be reduced from 16 to 29 percent. Developers estimate investment payback periods of 5–15 years and realization of market interest in energy and environmental benefits. Corresponding reduction in CO_2 emissions from the community would be 31 to 35 percent. A related "Green Analysis" completed by Consolidated Edison of New York with support from Verizon, Innoventive Power, Infotility, and Enernex found that simply using a fuel cell in a Verizon network of 30 telecom facilities can annually avoid nearly 1,500 tons of CO_2 emissions for each megawatt of installed capacity. In addition to the environmental benefits, installation costs are estimated at about $4 million per megawatt and annual revenues (net costs) are estimated at about $1 million per megawatt.

Image courtesy of Marek Czachorski, Gas Technology Institute

Brooklyn ShopRite Saves More than Pennies with Energy Innovation

Most supermarket shoppers focus on prices and produce and take for granted the technologies and expense required to maintain fresh fruits and frozen foods. But energy is vital to supermarket operations. Refrigeration units place a high demand for electricity and can reduce a supermarket's profit by half. NETL research partners have discovered a way to restock the energy shelves with waste heat from a supermarket's power-generating equipment.

ShopRite Supermarket in Brooklyn, NY, was the feature location for an NETL-managed project funded by the Office of Energy Efficiency and Renewable Energy and carried out by the Gas Technology Institute (GTI). GTI product developers designed and installed a combined heat-and-power system that uses waste heat from a natural gas combustion engine/electric generator to provide cooling and increase the efficiency of ShopRite's refrigeration system. Based on a conventional generator, the integrated system provides base electric load power for the supermarket. Recovered heat is used to indirectly fire a 20-ton absorption chiller, which in turn provides cooling for the store's refrigeration system. The configuration maximizes generator output and assures maximum recovery of waste thermal energy while reducing demand for grid-supplied power and providing cost-effective outage protection.

Reliable Supply

Abundant, Secure, Affordable

Latest Second-Generation High-Temperature Superconducting Wire Goes to Greater Lengths—NETL and industry partners have achieved the domestic capacity to produce high-volume, high-quality second-generation high-temperature superconducting (HTS) wire as part of an interagency agreement between DOE and the Air Force Research Laboratory in Dayton, OH. As a result of the partnership formed under Title III of the Defense Production Act, two domestic suppliers (SuperPower and American Superconductor) of HTS wire can now offer an affordable enabling technology with benefits for military and commercial applications. One example of this technology was the successful production of wire for the world's first HTS transmission cable in a commercial power grid. Prior to the Title III work, both supply companies were achieving nominal conductor lengths of 10- to 20-meter production runs capable of carrying less than 50 amps per centimeter of conductor width. At the conclusion of the Title III work, production capability for wires made from yttrium barium copper oxide—an HTS material—is over 1,500 meters per run with a current-carrying capacity of greater than 280 amps per centimeter of conductor width.

World's Largest Commercial Order Placed for Second Generation , High-Temperature Superconductor Wire—Under a current NETL-managed award, the American Superconductor Corporation (AMSC) refines second generation (2G) HTS wire, develops optimum manufacturing methodologies, and demonstrates the ability to manufacture large quantities of superconductor wire. On an unprecedented scale, Korean company LS Cable, Ltd., has ordered approximately 50 miles of 2G HTS wire proprietary to AMSC. Known as "344 superconductors," the wire will become part of a 22.9-kilovolt cable system to be installed and energized in the Korea Electric Power Corporation commercial power delivery network by the end of 2010. The cable system will be nearly a half-mile in length, making it the world's longest distribution-voltage superconductor cable system. The proposed cable installation near Seoul follows similar recent superconductor cable deployments in U.S. power grids partially funded by DOE's OE. Among them is the world's first transmission-voltage cable system, which was energized on the Long Island Power Authority's 138-kilovolt system in April 2008.

New Compact Design for Superconducting Fault Current Limiter Tests Successfully at High Voltage—As part of an NETL-managed project to develop a 138-kilovolt Superconducting Fault Current Limiter (SFCL), engineers at Zenergy Power, Inc. successfully completed high-voltage fault testing of a three-phase prototype compact SFCL design. The test was conducted at the world-class facilities of Powertech Laboratories in British Columbia. In the compact design, the direct current is generated by high-temperature superconducting coils, called "magnets," directly on the iron holding the coil in which the current is to be limited. Successful testing of this critical component is an important milestone in developing a method of limiting ever-increasing fault currents in today's transmission systems.

New Cyber Security Tool Protects Electric Power Systems—Product developers at Schweitzer Engineering Laboratories, Inc., (SEL), a world leader in protecting electric power systems, have designed, built, and successfully tested a prototype cryptographic daughter card (CDC). The hardware plug-in card secures serial communications using the Secure Supervisory Control and Data Acquisition (SCADA) communications protocol developed at Pacific Northwest National Laboratories (PNNL). SCADA systems serve as the link between the Internet and critical infrastructure systems, such as power networks, making them a key vulnerability in the infrastructure cyber security loop. The new SEL product will improve energy infrastructure security uniformly and independently of protocols or configurations by ensuring the authenticity and integrity of communications and engineering access to new and existing control systems. Managed by NETL on behalf of DOE's OE, the CDC was developed as part of the "Hallmark project," an alliance among SEL, PNNL, and Houston-based CenterPoint Energy.

Alpha Version of Cyber Security Tool for Utilities Released—Working under a DOE-OE contract managed by NETL, Digital Bond, Inc., released the first Portaledge© files as part of a cyber security audit and attack detection toolkit. Designed to work with OSIsoft's plant information server, which is widely implemented in the energy sector, Portaledge collects security events from a variety of data sources on the control system network, and then correlates the events to identify cyber attacks. The initial set of Portaledge files will detect and analyze events relating to degradation in plant performance or in the availability of computer systems, networks, or network and field devices. Available to owners and operators from Digital Bond through a subscription service, the Portaledge tool will detect intrusions and identify potential attack modes and vulnerabilities without requiring purchase or deployment of additional systems.

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YEARS OF INNOVATION

Before and during World War II, the Bartlesville Petroleum Experiment Station conducted a national survey of crude petroleum samples to identify which domestic supplies could be converted into high-quality, high-octane fuels for fighter planes. Here, a Bartlesville worker checks a shipment on its way to the lab for chemical and physical testing. Results helped guide the production of aviation fuel, asphalt, and lubricants.

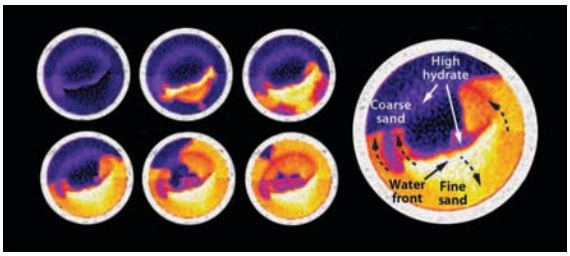
Reliable Supply

Abundant, Secure, Affordable

Methane Hydrates

As traditional fuel resources have become scarcer and increasingly difficult to retrieve, NETL has continuously looked ahead to using non-traditional fuel sources, such as coalbed methane, and processes, such as enhanced oil recovery, to help meet our national energy demand. In 1983, the Morgantown Energy Technology Center began studying a new source of natural gas: methane hydrates. Known as "fire in the ice," and found within deepwater sediments and in association with Arctic permafrost, methane hydrates are crystal structures of water-ice containing trapped molecules of methane gas. Through the DOE-led National Methane Hydrates Research and Development Program, NETL has focused its research on establishing a basic understanding of hydrate resources and developing technologies to enable hydrate exploration in both marine and Arctic environments. A team of NETL researchers is currently working with a wide range of domestic and international partners to assess methane hydrate's energy resource potential and to understand its role in the global environment.

NETL Simulations Provide Insight on Hydrate Dissociation Mechanisms—Using molecular-level simulations, collaborators at NETL and the University of Pittsburgh have gained a better understanding of how methane hydrates decompose under conditions anticipated for methane production. Researchers observed transitory, partial hydrate structures at the point of decomposition—a key finding since these structures, in the presence of methane molecules and at appropriate conditions, could serve as potential sites for bulk hydrate reformation. Reservoir-scale simulations have shown that such formation causes lower gas production. Improved understanding of this phenomenon could lead to better predictive reservoir-scale models. The study appears in the January 7, 2009, issue of *The Journal of Physical Chemistry A* of the American Chemical Society.



CT Images Capture Methane Hydrates Formation

NETL scientists have successfully captured the first real-time x-ray-computed tomography (CT) images of methane hydrates being formed in a sandy porous media. The technique allows the hydrate to be viewed without destroying its structure, a major milestone.

The experiment was designed to study how hydrates are formed and how water migrates through hydrate-bearing sediments. Depending on hydrate saturation, water can migrate into the hydrate region or go around the region, first filling areas with less hydrate. Using the CT images, researchers have created 3-D maps showing the distribution of solid hydrate and any liquids and gases present. They have also conducted simulation studies to predict water flow through hydrate-bearing sediments. Results will aid researchers in designing production techniques, understanding mechanisms responsible for gas leaks in hydrate-rich areas, and characterizing samples for use in methane production tests.

Beaufort Sea Expedition Explores Role of Methane in Global Climate Cycle—An international, multidisciplinary science team, including an NETL geologist serving as co-chief and senior scientist for the project, completed a 12-day research expedition into the Beaufort Sea aboard the U.S. Coast Guard icebreaker Polar Sea. Completed in fall 2009, the Beaufort Sea expedition, which was the first dedicated to a comprehensive study of marine methane hydrates systems off Alaska's North Slope, included research partners from the U.S. Naval Research Laboratory and Royal Netherlands Institute for Sea Research. The science team collected geophysical surveys, subsurface sediment cores, and water column samples for analyses

aimed at characterizing the fate of methane from the sub-seafloor sediment through the water column above and into the atmosphere. Understanding these systems provides key insights into hydrate's role in global climate change and its potential as an energy resource.

Methane Seepage from Arctic Lake Could Reveal Impacts of Global Climate Change—A team of scientists from the University of Alaska Fairbanks (UAF) collected sediment cores and samples of gas and water from Lake Qalluuraq. Like other lakes in the North Slope region, Lake Qalluuraq has shown methane actively bubbling up from the bottom for several years. Scientists from NETL, the UAF, the University of California at Santa Barbara, and the U.S. Geological Survey are investigating these thermokarst lakes—formed by meltwater from permafrost—to study their role in global climate change. The current analysis will determine the spatial and temporal distribution of the methane seeps, the amount and rate of methane being released to the atmosphere, and the linkages, if any, between ongoing methane out-gassing and permafrost-associated gas hydrates. The 8-day field sampling excursion southwest of Barrow, AK, produced 15 sediment cores and water samples from more than 20 locations, far exceeding planned sampling expectations. Upcoming analyses will focus on determining the exact methane source and the correlation of past climate-warming events to increased methane flux from these arctic lakes.

Novel Technique Estimates Hydrate Concentration from Advanced Geophysical Data—Working in cooperation with NETL, researchers with the Bureau of Economic Geology at the University of Texas at Austin have demonstrated the value of combining ocean-bottom cable, chirp-sonar, and new rock physics models to estimate the concentration of hydrate in near-seafloor sediments. The innovative technique advances industry's ability to obtain valuable detail about the stratigraphic architecture and sedimentary properties of deep-water gas hydrate systems and to assess them as a future energy resource. Geomechanical studies that provide a more comprehensive understanding of the relationship between seafloor stability and the transition of gas captured during marine hydrate formation were conducted at two project sites in the Green Canyon area of the Gulf of Mexico.

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YEARS OF INNOVATION

A Bartlesville Petroleum Experiment Station engineer shows a display of the "five square" water flooding technique for secondary recovery of oil in May 1948. Water flooding was a technology developed in the 1910s to release petroleum that remained behind in a well after the "easy oil" was extracted. Bartlesville perfected the flooding technique depicted here, in which operators drilled four wells in a square pattern and pumped water into all four. Secondary oil was forced out through the fifth well in the middle of the square.

Reliable Supply

Abundant, Secure, Affordable

Natural Gas and Oil Production

U.S. natural gas and oil resources are tremendous energy assets to our nation, providing more than 60 percent of the total energy used by commercial and residential consumers. However, more than two-thirds of all the oil discovered in America to date remains in the ground, in geologically and operationally complex settings that are often economically unrecoverable with current technology. In 1913, Joseph Austin Holmes, first director of USBM, urged the conservation of natural resources and claimed that one of the most urgent areas of reform was the unnecessary waste of oil and natural gas. Following this mindset, NETL explores ways to retrieve our nation's vital petroleum resources responsibly. Our progressive research in gas shales, "tight gas," enhanced oil recovery, and ultradeep drilling gives 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 protecting our environment.

Innovative Device Increases Marginal Oil Well Production—An easy-to-use control box for reciprocating oil pumps increased production 25–50 percent for several marginal wells in a demonstration funded through the Stripper Well Consortium (SWC). Unlike conventional controllers, the Oil Well Sentry prevented the pumps from operating when intake fluids slowed or stopped, eliminating excessive wear and tear on the pumps while reducing energy consumption up to 30 percent. Moreover, the device can pay for itself in less than 1 month by optimizing several operating conditions and parameters. Marginal wells account for 9 percent of total natural gas and 18 percent of domestic onshore oil production, and the SWC offers small, independent operators the opportunity to work together with technology developers and researchers from across the country to solve production problems. Managed by The Pennsylvania State University, the consortium has more than 75 members and receives funding from NETL and the New York State Energy Research and Development Authority.

Image courtesy of Impact Technologies

Advanced Mud Handling System Drills Microholes in a FLASH

In cooperation with NETL, product developers at Impact Technologies, LLC, of Tulsa, OK, have designed and assembled an advanced cutting technique and mud-handling and processing system for microhole drilling. Impact's FLASH abrasive slurry jetting system quickly bores through nearly any material encountered in oil and gas wells, including steel, cement, and rock. The pump directs mud slurry at the rock, carving a hole while removing debris as the slurry is deflected back out of the hole. Cuttings and abrasives are captured at the surface and can be recycled into the system for deeper boring. As pictured here, water was used during testing.

Microhole drilling—less than a 4-inch diameter drill hole—allows for quicker oil and gas exploration and production. It also minimizes costs and environmental impacts by using less fluid and energy and creating less debris for disposal. Impact's compact, portable FLASH system requires much less space than a standard drilling rig, permitting drilling in tight, previously inaccessible spaces and the possibility of transportation via helicopter. Further, its small footprint makes environmentally responsible drilling possible in sensitive areas.

Innovative Technology Finds More Oil in Kansas and Colorado—A project team led by the University of Kansas Center for Research and funded by NETL has successfully applied a new visualization technology in two Midwest oil fields. The technology can identify sizeable undrained compartments in new and mature fields, particularly karst-modified carbonate reservoirs, in which water erodes carbonate rock and increases subterranean drainage and rock porosity. Such reservoirs account for 30–50 percent of the hydrocarbon production in the U.S. Midcontinent. Using the technology, Mull Drilling Company completed an oil well in Gove County, KS, that produced approximately 850 barrels of water-free oil. The company also completed a well in Cheyenne County, CO, where 10 feet of oil-rich reservoir rock in the productive zone has remained unaffected by drainage from nearby productive wells. Karst-modified reservoirs are often characterized by low matrix permeability, fluid-control problems, and low hydrocarbon recoveries. The new technology is able to image karst sinkholes, field-scale fracture systems, and other usually elusive sub-seismic features in relatively low-cost, conventionally acquired 3-D seismic surveys.

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YEARS OF INNOVATION

In this picture from 1947, a worker mixes drilling mud. Investigation into "mud" for drilling—a fluid needed to flush drilled-out material to the surface when boring for gas or oil—began as early as 1915 by the Petroleum Division of USBM. The mud is forced into the borehole, thereby clearing it, cooling the drill bit, and protecting the drill hole from fluids in the surrounding area. Today, specialized mud may be a water-based, oil-based, or a gaseous fluid, depending on the kind of drilling to be done.

Reliable Supply

Abundant, Secure, Affordable

Project Develops High-Temperature, Downhole Data Acquisition Processor—Product developers at Honeywell International, Inc., working in cooperation with NETL, have demonstrated the functionality of a compact cofired ceramic package that uses multiple high-temperature (225 °C) electronic components for acquiring data in oil- and gas-field operations. The multichip module is a rugged, reconfigurable processor capable of providing a wide range of digital functionality for deep downhole oil and gas well logging, measurement-while-drilling, and permanent installation applications.

Seismic-While-Drilling System Attracts Industry Interest—A new technology that will enable operators to steer a drill bit toward desired targets and away from hazards, such as pockets of high-pressure gas and undrillable tars, was successfully demonstrated at the Rocky Mountain Oilfield Testing Center. The advanced seismic-while-drilling (SWD) system features a novel acoustic source that can produce low frequencies at depths of 15,000 feet or more. Powered by a drill-string turbine generator and control subsystem located directly above the drill bit, the source is designed to generate seismic information from subsurface to surface, creating real-time images of geologic conditions (e.g., rock properties, pore pressure) approximately 1,000 feet ahead. Developed in cooperation with NETL by a team led by Technology International, Inc. (Kingwood, TX), the technology will significantly improve well safety and economics. The success of the SWD demonstration has prompted licensing discussions with petroleum service companies and trade press coverage at PennWell and Hart Energy Publishing Companies.

New Databases Help "Tight Gas" Resource Development—Independent operators now provide data online to help expand natural gas recovery in the San Juan Basin of New Mexico and the central Appalachian Basin of West Virginia and Pennsylvania. Developed in cooperation with NETL, the geospatial databases are Web-accessible from the New Mexico Institute of Mining and Technology and the West Virginia Geological and Economic Survey sites. The digitized databases contain well logs, core analysis data, natural gas production results, and other information useful to researchers and operators for identifying natural gas targets and selecting new drilling prospects. As production from conventional natural gas resources declines, "tight gas" or natural gas from low permeability sandstone formations is expected to contribute a growing percentage to the nation's energy supply. Improved data availability, analysis, and synthesis for these tight sandstone reservoirs will enable operators to expand natural gas recovery through more cost-effective exploration strategies and more efficient infill drilling and recompletion programs.

100 YEARS OF INNOVATION

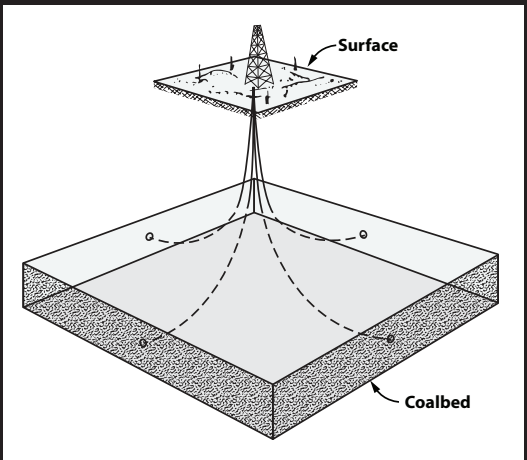

Image courtesy of Bureau of Mines publication

Leading the way to increased production of oil wells, Pittsburgh and Bartlesville researchers developed directional drilling, which can substantially increase production of domestic oil and gas reserves while minimizing damage to the environment. Directional drilling reaches laterally under the surface to follow oil and gas reserves for miles from the drilling site. In 1976, the U.S. Patent office awarded a patent to our staff for work in adapting directional drilling to coalbed methane recovery.

Rocking at the Extreme Drilling Laboratory

In January 2009, researchers at NETL's Extreme Drilling Laboratory (XDL) celebrated the much-anticipated arrival of the lab's prototype Ultradeep Drilling Simulator (UDS). The XDL's new "rock star" achieves operating pressure and temperature ranges three times greater than similar drilling rigs, enabling researchers to conduct drilling research in an aboveground setting at conditions found in ultradeep wells with total vertical depths approaching 30,000 feet.

A significant decline in domestic annual oil and natural gas production rates, as well as more accessible foreign resources, has required U.S. energy stakeholders to tap resources in increasingly challenging geologic environments. Only 30 years ago, deepwater drilling referred to offshore wells drilled hundreds of feet underwater. Today, ultra-deepwater drilling can occur in water depths greater than 10,000 feet, with the majority of deep wells expected to be drilled in water depths greater than 5,000 feet.

This substantial increase in depth is matched by significant increases in well pressures and temperatures, which hinder the drilling rate of penetration. In addition, costs for unconventional production methods such as deep-well drilling can be staggering, since deeper wells command higher investments. Through its high-tech equipment and advanced research, the XDL is hoping to optimize drilling methods and technologies that reduce risks and cost of drilling deep.

Much of the work done in the UDS will literally be cutting-edge research. By studying the physical phenomenon present at the cutter-to-rock interface, researchers can explore and develop the technology required to drill rock efficiently.

The UDS was designed and constructed with the unique capability of replicating well pressures up to 30,000 pounds per square inch and temperatures up to 250 °C through a computer control system. This world-class prototype simulator consists of a pressure vessel, load frame, and ancillary equipment, such as high-pressure pumps and hydraulics. The rock test specimen is mounted in the bottom of the pressure vessel to the bottom plug, which has been designed and fitted with a hydraulic motor and actuator. The rock is then rotated and forced against a stationary cutter assembly, which measures the magnitude of force vectors created during the cutting process.

Two visualization systems will enable researchers to observe events inside the reaction chamber. XDL currently uses a high-speed video imaging system that visually captures the rock-to-cutter interface in slow motion at full-system pressure. In the near future, XDL researchers expect to use x-ray imaging in a novel application to visualize the cutting in the presence of opaque drilling fluids.

Since its arrival last year, the UDS has undergone a multitude of intricate instrumentation and system checks to prepare for initial research operations in the third quarter of 2010.

In addition to the UDS, the XDL features a state-of-the-art Drilling Fluids Lab (Mud Lab), Mineralogy and Materials Lab (Rock Lab), and Modeling Lab, which complement the simulator and enhance the diversity of research conducted.

- In the Mud Lab, XDL researchers mix and measure the properties of various mud compositions to create lubricants optimized for specific rock formations and bit-rock interfaces and to simulate rock and pore pressure interactions.

- The Rock Lab enables preparation of rock samples, detailed analyses of test specimens, and assessment of typical rock properties, such as hardness, porosity, and permeability.

- The Modeling Lab uses computer-based mathematical models to provide modeling and simulation capabilities that advance the science of rock mechanics, cutter design, and drilling fluids technology.

The high-tech drilling facility located in Morgantown, WV, was conceived in cooperation with industry and funded by the federal government under Section 999 of the Energy Policy Act of 2005. Research conducted in the XDL is expected to have a direct impact on increasing our nation's supply of oil and natural gas by developing affordable, efficient, and environmentally safe means to harvest ultradeep oil and natural gas resources.

Science & Technology Leadership

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NETL and its predecessors have long been on the cutting edge of research and development. We impact our country—and the world—in a positive way by sharing our research and development discoveries, expertise, and lessons learned. We do that in several ways: partnering with private industry to put new technologies into the public domain; partnering with colleges and universities in both research initiatives and outreach such as the Science Bowl for students in middle schools and high schools; helping other nations become more energy-efficient and environmentally friendly; and writing and publishing papers, books, and software that are freely available to the public.

Facing page—NETL has long been a leader in improving air quality. When smog became an international concern in the 1950s, staff at Bartlesville created one of the first environmental smog chambers in the world, shown here. The mystery researchers sought to solve—how is smog made? The answer—by a photochemical reaction between sunlight, exhaust fumes, and air. Today, NETL is working to find ways to capture industrially produced CO_2 and store it securely away from the atmosphere.

Science & Technology Leadership

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Technology Transfer

NETL's goal is to discover and develop energy technologies that, when brought to the marketplace, offer improved solutions to today's energy challenges. We partner with commercial, educational, not-for-profit, and government entities to investigate new ways to produce, manage, and streamline advanced innovations that can cut costs, improve efficiency, and preserve our environment—and we shepherd these advances from the laboratory to the marketplace. NETL's technology transfer maximizes returns to the American people and supports international causes such as the curbing of greenhouse gas emissions. Through partnerships, patents, licensing, publications, and policy discussions, NETL ensures our discoveries profit our nation.

Regenerable Sorbents Capture CO_2 from Moderate and High-Temperature Gas Streams—Patent Number 7,314,847 has been awarded to NETL researchers for developing a sorbent that outperforms existing sorbents in capturing CO_2. The new sorbents also reduce the cost of capture. The innovative sorbents remove CO_2 at high temperature before combusting the fuel in applications such as turbine systems. The ability to remove CO_2 at high temperatures avoids the compromise in efficiency caused by other methods of CO_2 removal that require cooling the CO_2-containing fuel gas stream. NETL's novel sorbents are not only inexpensive but also possess higher CO_2-sorption capacities than existing sorbents, and they can be regenerated for reuse in additional cycles. The high-CO_2 sorption-capture capacity of the sorbent will also contribute to size reduction of the equipment required for the CO_2-removal process, contributing to further cost savings.

NETL Patents Mercury-Removal Method—Applying a novel approach that employs sorbent particles embedded in commercial baghouse fabricator material, NETL researchers have received Patent 7,494,632 for a mercury-capture method that demonstrated over 90 percent capture from a flue-gas slipstream from a 500-pound-per-hour pulverized-coal-fired combustion unit. In principle, other sorbent materials also can be incorporated into the fabric, not only for mercury capture but also for mercury oxidation to facilitate capture further downstream when a wet scrubber is available. This new approach avoids cross-contamination of fly ash by activated carbons and mercury, which adversely affect the fly ash's suitability for use as a concrete amendment. This mercury-removal method makes easier the cleanup of aqueous waste streams and synthesis gas (syngas) when sorbent and supporting membrane are compatible with process conditions.

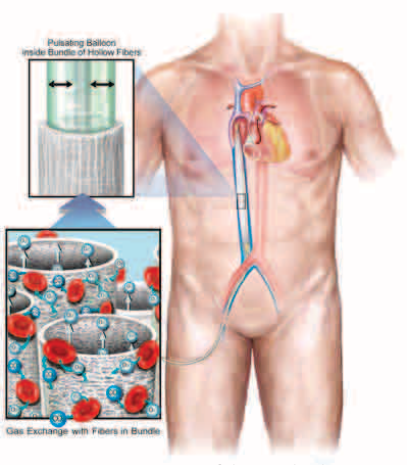

Image courtesy of the Medical Devices Laboratory-McGowan Institute

NETL's High-Speed Particle Imaging System Studies Energy Systems—and Blood Flow

It is nearly impossible to follow a moving particle smaller than a grain of salt. Now imagine following that particle if it is one of millions moving randomly in a high-speed liquid or gas stream. NETL's high-speed particle imaging (HSPI) system can do just that, allowing researchers to observe, measure, and study particle motion via thousands of high-speed video frames. Now, NETL's HSPI system has left the laboratory, finding application in commercial energy research and medical investigations.

Using HSPI, members of Particulate Solid Research, Inc., of Chicago have been the first to observe the important phenomenon of clustering in fluidized bed combustion. Clustering can dramatically affect particle dynamics, the basis for half of all industrial chemical processes. Researchers have also produced new views of particle phenomena in simulated gasifier flow fields.

The human "machine" can be studied under similar terms, because blood is a mixture of fluid and particles—in this case, blood cells. The University of Pittsburgh's McGowan Institute for Regenerative Medicine employed NETL's HSPI system as part of its hemodynamics (blood flow) study in an oxygenation catheter that functions as an artificial lung. The device, named the Percutaneous Respiratory Assist Catheter, is intended to provide partial breathing support independent of the lungs and could be used to treat patients who suffer from short-term reversible lung failure. Data provided by HSPI are being used to validate a computational fluid dynamics model and optimize the design of impellers within the device.

Module-based Oxy-fuel Boiler Is Practically Emissions-Free—U.S. Patent Number 7,516,620 has been assigned to NETL researchers for an invention that applies an oxy-fuel combustion system to a boiler, resulting in reduced environmental pollution and a higher-efficiency operation. The novel system comprises a series of oxy-fuel boilers that work independently of each other, creating a system for producing steam from water. Unlike conventional boilers, which use air to carry in oxygen for the combustion process, the oxy-fuel system uses only oxygen. Accordingly, the volume and flow rate of gas is lower, which affords the opportunity for an overall smaller physical plant and lower capital cost for the system. Because NETL's oxy-fuel boiler system is designed to capture and sequester CO_2, this system results in a near-zero emissions plant.

NETL Patents Ionization-Based Multidirectional Flow Sensor—NETL researchers have received U.S. Patent 7,523,673 for the invention of an ionization-based multidirectional flow sensor for monitoring flow speed and direction in advanced power systems such as hybrid fuel cell-turbine systems. The new sensor technology will provide a fast-response flow measurement to enable the efficient and safe operation of such hybrid systems. The innovation works by measuring ion movement in flames to detect changes in flow and will be especially useful for monitoring airflows at critical locations in systems where flow reversal can be detrimental to performance. The pressure-drop penalty of the sensor is low, which is important to maintaining the improved efficiency expected from hybrid systems. Because fuel cell–turbine hybrid systems are expected to dramatically increase power generation efficiency from fossil fuels while reducing emissions, this new sensor promises to boost efforts toward clean, abundant energy at an affordable cost.

100 YEARS OF INNOVATION

Because of its strong early focus on mining safety, Pittsburgh personnel gained great expertise in the field of explosives while developing safe ways to wrest coal from mines. This experience with explosives placed Pittsburgh in a position to share its know-how by helping solve the mystery of a massive explosion on Wall Street in 1920, which killed 38 people and injured hundreds. Pittsburgh experts determined through tests that a bomb containing about 100 pounds of dynamite had caused the explosion, probably set off by anarchists.

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NETL Patents Method To Reduce Metal Wastage— The U.S. Patent and Trademark Office awarded NETL researchers Patent Number 7,553,517 for "Method of Applying a Cerium Diffusion Coating to a Metallic Alloy." Laboratory tests show that the simple and inexpensive surface treatment of chromia-forming alloys with a rare earth element, such as cerium, can allow them to dramatically improve oxidation resistance at high temperature. Applicable to flat or curved structures, including the interior surfaces of tubes, the method is of particular interest where system performance, reliability, and affordability are significantly affected by the corrosion of structural materials in hostile service environments, such as power generation. By several factors, the process has reduced oxidation for ferritic steels used in solid oxide fuel cells (SOFC), as well as for martensitic, austenitic, and nickel-based alloys for advanced ultra-supercritical boiler and turbine applications.

NETL Patents Real-Time Combustion-Control Monitor—NETL researchers have received U.S. Patent Number 7,559,234 for the invention of a monitor that controls combustion and senses and diagnoses pressure oscillations in gas turbines. Lean premixed gas-turbine combustors operate near the fuel-lean flame extinction limit to achieve very low NO_x emission levels, but operating near the lean limit may result in combustion instabilities that can reduce the life of engine components and significantly increase maintenance costs. This new NETL monitor will help improve cost and efficiency of power generated by fossil fuels by detecting and mitigating potentially detrimental combustion instabilities before they can cause damage to engine components. Using an electrode integrated into the combustor, this monitor measures hydrocarbon ions produced by the combustion process by using a calibrated relationship to determine the amplitudes of the pressure oscillations. The turbine control system then uses these calculations to assess the operating condition of the combustor and adjust the amount of fuel to maintain stable combustion.

NETL Patents Method for Determining Optimum Catalyst Size for Chemical Reactors—U.S. Patent 7,619,011 has been assigned to scientists at NETL for a significantly advanced method of employing multiphase computational fluid dynamics to predict systematically the optimum particle size for hydrocarbon-producing reactors. This advanced method produces results more accurately than models currently used. NETL researchers successfully applied the technique to determine that the optimum catalyst size is 60–70 microns for methanol production from syngas in a slurry bubble-column reactor.

Process for Sequestering CO_2 and SO_2 Mimics Nature—The U.S. Patent Office has awarded Patent Number 7,604,787 for an innovation that mimics the naturally occurring weathering of rocks to provide a route for carbon sequestration. Developed by NETL in conjunction with research partners, the cyclic process employs mineral CO_2 sequestration in which magnesium-rich minerals react with CO_2 to form geologically stable mineral carbonates. The process will provide for the safe and permanent storage of CO_2 in solid form. While mineral CO_2 sequestration occurs very slowly in nature, this invention significantly increases the reaction rates and efficiencies for forming carbonates from the mineral matrix, thereby speeding up the process. This alternative acid-based technology uses exothermic reactions rather than the high-temperatures and pressures of other methods, providing a cost-effective option toward the environmentally safe use of fossil fuels.

Electrochemical Society Publishes NETL Research on Turbine-Fuel Cell Hybrid Systems—An article co-authored by NETL scientists for the Electrochemical Society's Fall 2009 issue of *Interface* describes the unique flexibility of systems tested in the NETL Hybrid Performance (Hyper) project facility. Results show that synergies obtainable from a hybrid configuration that couples a SOFC topping cycle with a gas turbine bottoming cycle could result in the highest electrical conversion efficiency ever realized. The article was one of only four contributions selected for the publication's fall issue that focused on SOFC research. *Interface* reaches more than 10,000 readers worldwide in the fields of electrochemical and solid-state science and technology.

New NETL Model Aids in Examination of Hybrid-System Response to Power-Demand Change—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 to determine the effects of key configuration parameters on system temperature. Temperature control is one of the most critical problems that must be addressed in gas turbine-fuel cell hybrid technology because a hybrid system designed to operate efficiently for a given base load may not easily accommodate peak loads. A discussion of the results of scaling the configuration model over a range of fuel input and power output has been accepted for the February 2010 issue of the *Journal of Fuel Cell Science and Technology*, a quarterly publication of the American Society of Mechanical Engineers.

Scientists Report Unique Reaction in Molecular Chains Self-Assembled on a Metallic Surface—Scientists at NETL and the University of Pittsburgh demonstrated the possibility of inducing a self-perpetuating chain reaction on a metal surface with low-energy electrons injected from the tip of a scanning tunneling microscope. The researchers demonstrated that a single electron caused a self-perpetuating chain reaction that rearranged the bonds in 10 consecutive dimethyldisulfide (CH_3SSCH_3) molecules self-assembled on a gold surface. As the original bond of each molecule was broken by the reaction, the molecule rearranged itself to form a new molecule. The scientists provide theoretical and experimental evidence supporting a mechanism involving electron attachment followed by dissociation of a CH_3SSCH_3 molecule and initiation of a chain reaction by one or both of the resulting methylthio radical (CH_3S) intermediates. The ability to sustain chain reactions on metal surfaces has potential implications in areas such as nanotechnology, photocatalysis, and data storage.

100
YEARS OF INNOVATION

In the 1970s, Albany, Morgantown, and Pittsburgh shared their expertise with the U.S. space program. This cryogenic device at Albany was used to rapidly cool metals to low temperatures to simulate conditions they might encounter in outer space. The Pittsburgh Explosives Research Center conducted research on solid rocket propellants, safety procedures for liquid hydrogen fuel, the behavior of explosives in lunar-like atmospheres, and shielding for space vehicles. In addition, Morgantown researchers analyzed rock samples brought back from the moon.

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Noteworthy Publications

Essential to NETL's mission is transferring to the public domain our lessons learned and project results. To encourage access to this information, NETL publishes its latest ideas, innovations, and discoveries in books, scientific journals, and other media.

Metallographic Masterpiece Showcases NETL Materials Expertise

Since 1961, NETL metallographer Paul Danielson has fused science and art, and since 2001 he has practiced his craft as part of NETL's materials program. International scientific instruments manufacturer Buehler featured one of Danielson's photomicrographic works in its "2009 Materials Masterpieces" calendar. The image, shown here, illustrates the microstructure of zircaloy-4 under polarized light at 400 magnification.

Danielson's craft is an integral part of alloy development and performance assessments by NETL. The art of metallography is to create the most striking contrast of the microstructures with the most pleasing colors while still representing the product. Capturing the perfect image is a blend of technique and technology. Using a fine abrasive and acid, Danielson polished a zircaloy sample to emphasize the various grains. When he applied heat, gases in the atmosphere added a colorized layer to the microstructure, and polarized reflective lighting brought out the contrast among the grains, represented by the different colors. The resulting image details the as-cast microstructure and provides information about localized changes in chemistry and structure during manufacture and service.

When Danielson first entered the field, metallographic images were limited to black and white and contrasting the grays in between. Today's advanced metallography employs digital cameras and software, such as Adobe® PhotoShop®, to enhance the colors. An adroit use of color, Danielson notes, accentuates features that black and white simply cannot capture.

NETL Scientist Co-authors Practical Introduction to Density Functional Theory—John Wiley & Sons, Inc., has published a new title, *Density Functional Theory: A Practical Introduction,* authored by NETL Physical Scientist Janice A. Steckel and Georgia Institute of Technology Professor David S. Sholl. The book provides a readable guide for anyone in math, science, or engineering who wishes to study physical processes such as adsorption or chemical reactions in gas phase, bulk materials, interfaces, or on surfaces. Density Functional Theory (DFT) may be used to give important insight into the structure or reactivity of known materials as well as predictive information regarding possible new materials. Without relying heavily on complicated theoretical derivations, the book covers key concepts and provides examples, exercises, and extensive references for students, theorists, and experimentalists interested in performing DFT calculations.

New Book Captures NETL Research on Laser Spark Plug Development—VDM Verlag, publisher of academic research, has released the title, *Laser Spark Plug Development and Engine Testing: Design of a Diode Side Pumped Solid State Passively Q-Switched Laser for Use as an Ignition Source for a Lean-Burn Stationary Natural Gas Engine*. The book describes the development of a miniaturized laser spark plug designed to enable operation of large-bore natural gas engines at higher efficiencies and leaner conditions than current standard operating conditions. The spark plug can replace traditional electrical spark plugs that quickly wear out at the modified engine conditions needed to achieve higher efficiencies. Conducted by NETL, the research was sponsored under DOE's Advanced Reciprocating Engines Systems Program from 2002 to 2007.

NETL Team Writes Book Chapter on New Sensor Technology—By invitation, collaborators at NETL and the University of Pittsburgh have prepared a chapter for the book, *Trends in Photonics*, edited by University of Sydney Professor John Canning. The chapter, titled "Photonic-Bandgap-Fiber Sensors for Gas Detection," summarizes results of recent NETL work completed under the NETL University Research Initiative on developing fast-response gas sensors for power generation applications. The book was produced by Research Signpost, publisher of more than 2,000 high-quality review books written by eminent scientists at major laboratories around the world.

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YEARS OF INNOVATION

One of NETL's primary objectives has always been education and public service. In this photo of a USBM exhibition booth from the 1930s, two manikins demonstrate the then-new way to resuscitate someone who has stopped breathing. Today, NETL's educational outreach includes the Regional University Alliance, the National Science Bowl for middle school and high school students, and internships through which university students work on real-life challenges in the energy field.

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International Cooperation

As the global marketplace brings the world closer together, NETL is increasingly involved in global technology issues. Today, energy security and the environment are of paramount importance worldwide. Global climate change driven by the rising amounts of CO_2 in our atmosphere is a major research area for today's scientists, engineers, and policy makers. NETL is taking a lead in international efforts to reduce CO_2 emissions from power generation sources through joint research and development initiatives, exchange of researchers, and information exchange at meetings and seminars with developed and developing countries.

NETL Assists India in Cutting CO_2 Emissions

An NETL-led team is helping power plant operators at Indian state utilities upgrade operations using U.S. utility industry best practices and protocols for operations and maintenance. These protocols can improve plant efficiency and reliability, avoid millions of tons of CO_2 emissions, and reduce operating costs.

In 2009, NETL's project team identified improvements at two power plants that could avoid approximately 124,000 metric tons of CO_2 emissions annually per unit tested at each plant. Defficiencies included air leakage into the furnace, inadequate insulation, improper sensor locations, coal leakage from pulverizers, and steam leaks. Storm Technologies, Inc., a U.S. specialist in combustion-performance improvement, and the Centre for Power Efficiency and Environmental Protection of NTPC, Ltd., India's largest power generator, provided technical support.

NETL's efforts are being implemented under the Power Generation and Transmission Task Force of the Asia Pacific Partnership on Clean Development and Climate, as part of their Power Generation Best Practices project. The project traces its roots to similar NETL-supported activities conducted over the past 15 years in India under the U.S. Agency for International Development's Greenhouse Gas Pollution Prevention project. To date, nearly 100 million metric tons of CO_2 emissions from coal activities in the Asia-Pacific region have been avoided through NETL's efforts.

United States and United Kingdom Celebrate Collaboration on Virtual Power Plant Simulation—The U.S. Patent Office has awarded Patent Number 7,604,787 for an innovation that mimics the naturally occurring weathering of rocks to provide a route for carbon sequestration. Developed by NETL in conjunction with research partners, the cyclic process employs mineral CO_2 sequestration in which magnesium-rich minerals react with CO_2 to form geologically stable mineral carbonates. The process will provide for the safe and permanent storage of CO_2 in solid form. While mineral CO_2 sequestration occurs very slowly in nature, this invention significantly increases the reaction rates and efficiencies for forming carbonates from the mineral matrix, thereby speeding up the process. This alternative acid-based technology uses exothermic reactions rather than the high-temperatures and pressures of other methods, providing a cost-effective option toward the environmentally safe use of fossil fuels.

NETL and Chinese Scientists Initiate Technical Exchange—In June 2009, NETL scientists and engineers met with representatives of the Chinese Academy of Sciences and with scientists, engineers, and managers representing the China National Petroleum Corporation —China's largest oil company—for initial technology dialogues under memorandums of understanding (MOUs) signed earlier by the organizations. The MOUs aim to foster U.S.-China collaboration in studies relating

to the efficient use of fossil fuels and the capture and storage of CO_2. Such collaboration by the two largest users of fossil fuels and generators of CO_2 is essential for ensuring energy security and addressing climate change in a synergistic manner.

NETL Contributes to Administration's Efforts for Greater Middle East Stability—In advance of a visit to Turkey by President Obama, the U.S. Trade and Development Agency (USTDA) awarded Turkish Coal Enterprises the funds to use competitively selected U.S. consulting and engineering firms to study the commercial feasibility of a lignite gasification plant in that country. NETL staff developed the underlying general statement of work and cost estimates for the award after participating with other U.S. energy experts on a USTDA-funded assessment mission to Turkey in January 2009. Estimates made during the mission indicated that a single large coal gasification facility, similar in capacity to the Great Plains Gasification Plant in Beulah, ND, could displace approximately 10 percent of the annual growth projected for Turkey's natural gas imports. Diversifying Turkey's energy sources is an element of the Administration's strategy for improving economic and political stability in the region.

NETL Researchers Participate in International Gas Hydrates Science Advisory Committees—By invitation, NETL geoscientists completed trips to Daejeon, South Korea, and Delhi, India, to assist national gas hydrate programs for those countries in selecting potential drill sites for major marine drilling and coring expeditions planned for the summer of 2010. Officials for the national programs expressed interest in pursuing a targeted search for gas hydrate within sand reservoirs suitable for future production testing, and they were eager to implement the integrated geologic and geophysical approach that guided the highly successful drilling expedition recently completed in the Gulf of Mexico by participants in the DOE-Chevron Joint Industry project. In support of individual MOUs signed with Korea and India in 2008, NETL participated in the International Gas Hydrates Science Advisory Committees to offer recommendations regarding site evaluations, operational planning, and drilling-and-coring locations that would ensure the success of these expeditions.

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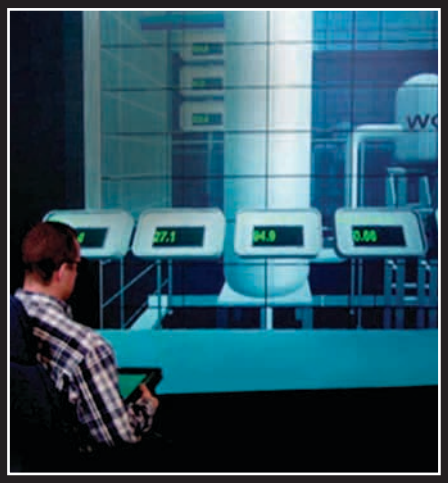
YEARS OF INNOVATION



During a 3-year collaborative effort, researchers from NETL and the United Kingdom developed compatible software platforms for virtual process and equipment co-simulations of advanced power plants. Using NETL's Advanced Process Engineering Co-Simulator and the U.K. Virtual Plant Demonstration Model, process engineers analyze and optimize plant performance by looking at complex fluid flows, heat and mass transfer, chemical reactions, and other dynamics that impact power plant design and operation. This type of computer-based research speeds up technology development and can help researchers and operators achieve aggressive environmental, performance, and economic goals for advanced fossil-based power generation systems.

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NETL Hosts Delegation from Eurasia—On May 6, 2009, NETL hosted a group of 16 delegates representing government agencies and private-sector organizations in the coal areas of the former Soviet republics of Georgia, Kazakhstan, Kyrgyzstan, Tajikistan, and Ukraine. The U.S. Department of Commerce (DOC) arranged the visit to NETL as part of the Special American Business Internship Training (SABIT) Coal Mining and Clean Coal Program. SABIT provides mid- to senior-level specialists with a comprehensive understanding of the U.S. coal industry as well as opportunities to establish U.S. business contacts. The visitors and DOC considered their visit to NETL a highlight of the program, and commented favorably about the valuable technical interchange that familiarized them with DOE's work in clean coal technologies, mining, and cooperation with the private sector on technology transfer.

Educational Outreach

NETL actively encourages tomorrow's energy problem-solvers to pursue careers in science. Through the Regional University Alliance, NETL partners with university students and faculty to find solutions to energy challenges. We sponsor Science Bowl competitions each year for middle school and high school students, and we welcome undergraduate and graduate students as they intern in the fields of energy sciences and engineering.

NETL Initiates Leadership Program for Young Scientists and Engineers from India—NETL staff met with interested faculty, students, and research fellows at several of India's leading educational institutions and national laboratories to launch a new international post-graduate program consistent with education and outreach objectives of high-level, multinational partnerships, such as the Carbon Sequestration Leadership Forum and the Asia-Pacific Partnership on Clean Development and Climate. Through the Young Scientists and Engineers Leadership Program, NETL aims to attract young researchers interested in specializing in the areas of carbon capture, transport, and storage. Organizations visited included Anna University, the Indian Institutes of Technology in Madras and Delhi, the National Geophysical Research Institute in Hyderabad, and the National Environmental Engineering Research Institute in Nagpur. NETL and its university partners are contacting several prospective candidates who expressed interest in the program.

JASON Project on Geology Curriculum Development

A large contingent of NETL researchers shared their expertise in the study of earth materials with a visiting team of three students, a middle school teacher, and a JASON Project film crew. Founded by the National Geographic Society, the JASON Project puts student "Argonauts" in contact with practicing explorers and researchers to motivate them about learning science. The resulting curriculum in geology will be available through print, video, games, and online resources to tens of thousands of teachers and millions of students in the United States and worldwide.

Awards and Recognition

NETL encourages a culture of excellence and accomplishment. We are proud of the awards and recognition our scientists and engineers achieved in 2009. From such prestigious honors as technology transfer and R&D 100 Awards to recognition given to NETL's partners in various projects, NETL has long been acknowledged and valued for superior contributions in the field of energy research and development.

NETL Technology Transfer Achievements Recognized—The Federal Laboratory Consortium selected two flue gas cleaning processes invented by NETL for 2009 Awards of Excellence in Technology Transfer. The first is the Thief Process for mercury capture. Patented by NETL researchers and licensed to Nalco-Mobotec for commercial development, the Thief Process extracts partially combusted coal from the furnace of a coal-fired power boiler for re-injection downstream into flue gas ductwork. Tests up to and including pilot-scale

have shown that Thief sorbent capacities for mercury are comparable to those of commercially available activated carbons, but, because they are cheaper, the novel sorbents promise to reduce significantly the cost of mercury removal from flue gas. The second award went to a wet scrubbing process that uses an ammonia-based solution to remove SO_2, NO_x, and CO_2 from flue gas. Licensed to Powerspan Corp., the process produces a salable commodity in the form of ammonium sulfate or nitrate fertilizer, and, with respect to capturing the greenhouse gas CO_2, the ammonia solution can be regenerated and recycled to minimize cost.

NETL Technologies Earn Five R&D 100 Awards—Following years of development, five NETL technologies captured *R&D Magazine's* prestigious R&D 100 awards, which represent the top 100 innovations introduced into the marketplace during the previous year:

- Virtual Engineering Process Simulation Interface (VE-PSI)—Developed in collaboration with Ames National Laboratory (ANL) and Reaction Engineering International (Salt Lake City, UT), the VE-PSI software gives engineers the ability to create virtual prototypes of new plant designs and to improve existing designs more quickly, efficiently, and at less cost than ever before.

- Clay-Liquid CO_2-Removal Sorbent—This sorbent, developed in cooperation with Sud-Chemie (Louisville, KY), removes CO_2 and other gases from coal combustion exhausts at temperatures ranging from ambient to 60 °C. The regenerable sorbent's low cost, availability, and simple preparation can significantly reduce total energy costs compared to those of commercially available carbon capture methods.

- Thief Mercury-Removal Process—Licensed to Nalco-Mobotec for commercial development, the Thief Process extracts sorbent in the form of partially combusted coal from the furnace of a coal-fired power boiler for re-injection downstream into flue gas ductwork.

- SEQURE™ Tracer Technology—This innovation uses perfluorocarbon tracers to tag CO_2 stored in geologic formations, differentiating it from natural CO_2 fluxes. The technology has proven successful in detecting tagged CO_2 in field-simulation tests at several pilot-scale sequestration sites.

- Super Hard and Slick (SSC) Material— A super hard and slick coating jointly developed by a team from ANL and Istanbul Technical University as a nanomanufacturing activity under the Industrial Technologies Program of DOE's Office of Energy Efficiency and Renewable Energy (EERE) captured one of *R&D Magazine's* prestigious awards in the Thin Film category. Applied using high-power impulse magnetron sputtering, the computer-designed metallic composition reduced friction in test engines by 80 percent when compared to uncoated steel, and it virtually eliminated wear under severe boundary-lubricated sliding regimes. Friction losses in vehicle engines can waste 10–20 percent of total fuel energy. NETL is managing this and other nanomanufacturing activities for DOE's EERE.

NETL-Patented Refractory Judged Superior—AUREX™ 95P is now specified as the approved product for high-wear areas of any future gasifier built by GE Energy. The NETL-developed refractory has shown "exceptional" or "excellent" performance at four gasifier sites. The high phophate-modified chrome oxide refractory is produced and marketed under license to ANH Refractories Company near Pittsburgh, PA. Refractory brick with greater longevity will help make gasification a more reliable and economic technology for coal-based power and hydrogen production.

Science & Technology Leadership

Communication, Collaboration, Commercialization

Interagency Partnership Honors NETL Technology Development Leader—NETL scientist Mary Anne Alvin received the 2009 Propulsion and Power Systems Alliance (PPSA) Chairman's Award for outstanding contributions to PPSA objectives both individually and as team leader. Alvin was recognized for reinvigorating and expanding the Materials Technology Area Team from three participating agencies to five, all of which share an interest in higher temperature materials to achieve greater turbine system efficiency and power. A collaboration among the National Aeronautics and Space Administration and the U.S. Departments of Defense, Energy, and Transportation, the PPSA is designed to utilize existing program resources more effectively in the areas of power and propulsion.

U.S. Environmental Protection Agency Selects NETL Model for National Standard—To determine the level of reduction in greenhouse gases (GHG) that can be expected from compliance with renewable fuel standards, the Environmental Protection Agency (EPA) is referring to the NETL life-cycle analysis of petroleum-based transportation fuels. Selected for its accuracy and transparency, the NETL study, "Development of Baseline Data and Analysis of Life Cycle Greenhouse Gas Emissions of Petroleum-Based Fuels," provides a comprehensive baseline of GHG emissions generated over the life cycle of conventional petroleum-based transportation fuels in the United States. The study also identifies key contributions to the GHG emissions profile in each life- cycle stage of these conventional fuels. According to the EPA final rule on the recently revised Renewable Fuel Standard Program, the volume of renewable fuels that refiners and importers are required to phase into their products will be based on GHG reduction goals measured from the NETL 2005 life-cycle baseline model utilized by EPA. The NETL petroleum baseline report and underlying Microsoft Excel model are both publicly available on the Energy Analysis Reference Shelf at the NETL website. Collaboration with the EPA Office of Transportation and Air Quality over the past 2 years has established NETL as a leader in the field of life-cycle analysis while strengthening the working relationship between DOE and EPA.

NETL Computational Scientists Present Award-Winning Paper—An NETL computational study addressing turbulence modeling for particle-laden swirling flow was awarded a Certificate of Merit at the 2009 International Conference on Modeling, Simulation, and Control. The conference was part of the annual World Congress on Engineering and Computer Science hosted by the International Association of Engineers (IAENG) in San Francisco on October 20–22, 2009. The award-winning NETL paper will appear in a special issue of *Engineering Letters*, an IAENG quarterly on frontier issues in engineering and computer science.

NETL Partner Receives Major International Award—The Centre for Power Efficiency and Environmental Protection (CenPEEP) and its parent company, NTPC, Ltd.—India's largest electric utility—have received the International Star Award for Quality (ISAQ) in the Gold category. ISAQ is the international analogue of awards made based on Total Quality Management, such as the Deming Award (Japan), the Baldrige Award (United States), and the EFQM Excellence Award (Europe). CenPEEP functions as a resource center for acquisition, demonstration, and dissemination of state-of-the-art technologies and practices that optimize the performance of power stations in India. NETL provides technical assistance to CenPEEP as part of the Greenhouse Gas Pollution Prevention project implemented under the 1994 protocol between India and the United States by the New Delhi Mission of the U.S. Agency for International Development. Joint efforts to date have conserved tens of millions of tons of coal, thereby avoiding the emission of millions of tons of CO_2. CenPEEP previously received a 2003 Climate Protection Award from the EPA and a 2002 Climate Technology Award from the Climate Technology Initiative for significant accomplishment in promoting climate-friendly technologies.

NETL-Supported Carbon Sequestration Documentary Recognized for Excellence—The environmental documentary, *Out of the Air—Into the Soil: Land Practices that Reduce Atmospheric Carbon Levels*, produced for a general audience by Prairie Public Broadcasting (Fargo, ND) in collaboration with the Plains CO_2 Reduction (PCOR) Partnership, won two international awards: a 2009 Communicator Award of Excellence honoring creative distinction and a 2009 Golden Aurora Award recognizing film and video excellence. The 30-minute program, for which NETL provided guidance, technical review, and funding, introduces terrestrial CO_2 sequestration as a way of reducing atmospheric CO_2 by using the natural ability of plants to absorb the gas and store the carbon in roots, stems, trunks, leaves, and soils. Led by the Energy & Environmental Research Center at the University of North Dakota, PCOR is one of seven NETL-managed regional partnerships studying the viability of carbon sequestration as a greenhouse gas mitigation strategy. Other PCOR documentaries, *Nature in the Balance* and *Reducing our Carbon Footprint: The Role of Markets*, were released in 2005 and 2008, respectively. The educational series is part of an extensive PCOR outreach effort to raise awareness of the benefits and opportunities of carbon sequestration, both regionally and globally.

NETL Scientist Elected Fellow of ASM International—The Board of Trustees of ASM International—the preeminent worldwide materials science and engineering technical society—elected David Alman, Director of NETL's Materials Performance Division, as a Fellow of the Society. The honor recognizes Alman for his contributions to the field of materials science and engineering, particularly for the development and design of novel materials and surface structures for power generation and high-temperature applications.

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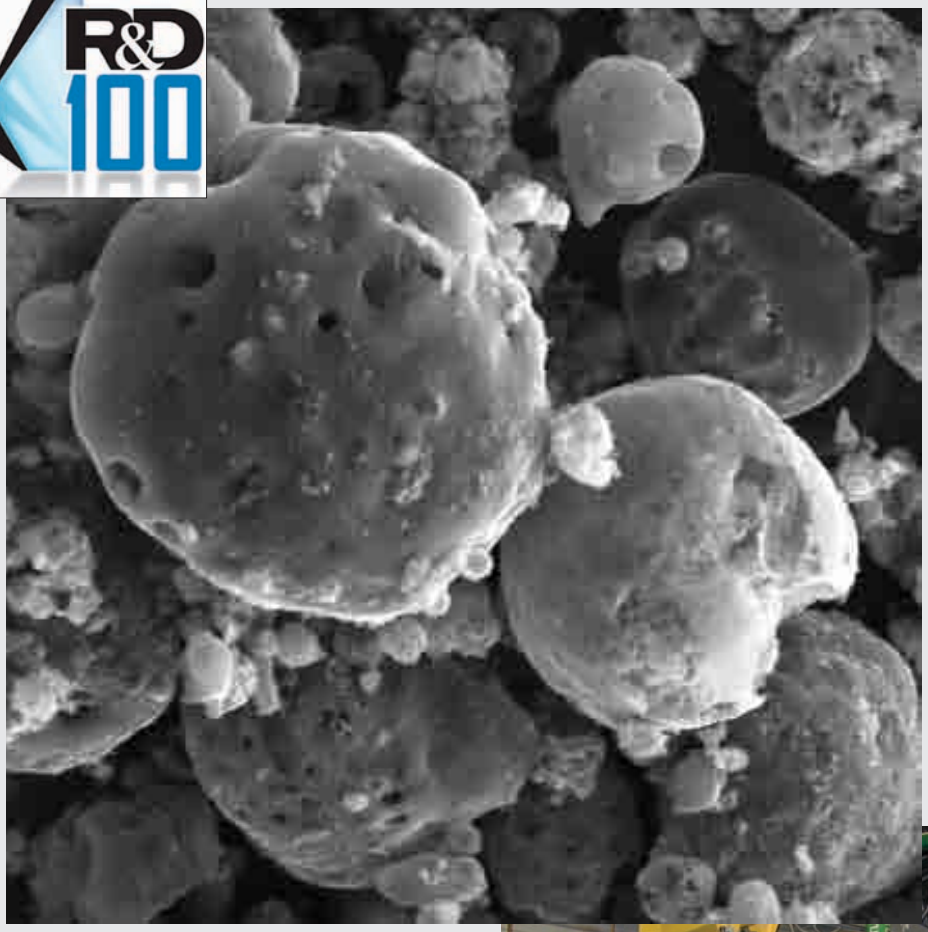
YEARS OF INNOVATION

Image courtesy of National Archives & Records Administration

The Henry H. Storch Award in Fuel Chemistry, sponsored by the Division of Fuel Chemistry of the American Chemical Society and Elsevier, Ltd., was established in 1964 to honor Henry Herman Storch, once director of research and development for the Office of Synthetic Liquid Fuels in Pittsburgh. Storch was a leading figure in American physical chemistry during the mid-twentieth century and a prolific writer. His masterpiece, *The Fischer-Tropsch and Related Syntheses* (1951), is still being cited as valuable source material more than a half century later. Storch awards are given biennially to individuals who make outstanding contributions to research in the field of fuel science.

Science & Technology Leadership

NETL's Thief Process Steals the Show



What if the mercury created by coal burning power plants could simply be plucked from the combustion system? NETL's Thief Process gives operators the means to do just that. Requiring only an innovative lance and an on-hand sorbent, the novel procedure filches unwanted mercury by-products and helps clear the way for environmentally sound fossil energy production.

NETL has a proven record of tackling air quality challenges. Our researchers have realized persistent success in developing technologies that enable the continued use of our most abundant natural resource, coal. In the 1980s, acid rain was found to be a highly detrimental by-product of coal combustion. Power plants emitted SO_x and NO_x into the atmosphere, which then precipitated back into the environment as acid rain. NETL's precursor, the Federal Energy Technology Center, performed and directed advanced research to address these pollutants, equipping new and existing plants with an army of SO_x and NO_x controls. In most of the nation, acid rain was soon put to rest.

In the new millennium, mercury emissions proved to be the next formidable environmental concern related to coal energy. NETL set its goal to achieve greater than 90 percent capture in its mercury-control technologies by 2010. Thanks to the hard work of NETL scientists, that goal was met a full 2 years ahead of schedule—effective, affordable mercury-capture technologies have been on the market since 2008. Today, mercury concerns can be alleviated by cutting-edge innovations like the Thief Process.

In 2009, NETL's Thief Process for the Removal of Mercury from Flue Gas received two prestigious awards. The Federal Laboratory Consortium (FLC) presented its Excellence in Technology Transfer Award to researchers Mark Freeman, Evan Granite, Richard Hargis, William O'Dowd, and Henry Pennline. Additionally, the editors of *R&D Magazine* honored the research team with an R&D 100 Award, which recognizes the 100 most technologically significant products to enter the marketplace each year.

The award-winning Thief Process is NETL's showcase mercury success, providing an economical means to effectively capture more than 90 percent of mercury from coal combustion plants. Patented in 2003, the innovation was licensed to Nalco-Mobotech, Orinda, CA, in May 2005 and made available for sale to coal-burning utilities in December 2008.

The secret to the Thief's success is making use of a ready-made sorbent created during the combustion process. A high-temperature probe (the "thief") snatches partially burned coal from the furnace of a power plant. This coal is then injected into the flue gas downstream where it acts as a sorbent to capture the mercury. Traditionally, coal-burning utilities have relied on activated carbon injection (ACI) to adsorb mercury from flue gas. ACI is a popular method because it is effective, but it is also quite costly. Activated carbons soak up many components of a flue gas stream, so the mercury must compete with other gases for adsorption sites and more carbon must be used. Additionally, activated carbons must be purchased from the manufacturer and delivered to the plant, and this increases costs as well.

The Thief Process avoids both of these drawbacks and enables an overall cost savings over ACI of 82–93 percent. Thief sorbents are also more effective because partially burned coal retains chemicals on its surface that react with mercury and aid in its chemical adsorption, thus increasing the sorbent's capture capability. In short, the Thief process makes mercury clean-up affordable and effective. And, by mitigating the environmental threat posed by mercury associated with coal combustion, the Thief process is helping to ensure safer air, water, and food supplies while protecting both the environment and the economy.

In addition to its 2009 awards, the Thief process has been recognized with a 2008 regional Excellence in Technology Transfer Award for the mid-Atlantic FLC region, as well as articles published in *Fuel*, *Journal of Environmental Management*, and *Fuel Processing Technology*.

The Thief Process adds to a long line of NETL successes in environmental controls. Today, concerns about carbon emissions and global climate change are paramount. While CO_2 emissions remain the next great challenge, NETL's proven track record with acid rain and mercury lays the groundwork for ensuring that carbon-related global climate change will soon be a concern of the past.

Our Vision for the Future

The Next 100 Years

NETL's past successes have contributed to our nation's energy safety and security. We have now entered our next century of innovation and the grand challenge it presents: America's transition to an energy portfolio that is environmentally acceptable, sustainable, and capable of tapping the full potential of our nation's energy resources.

The technical advancements required to meet this challenge are underway at NETL. We are taking the path to achieving scalable renewable energy by looking to coal, natural gas, and oil as transition fuels. This means integrating fossil-energy platforms with renewable energy resources, realizing ever-greater efficiency in our power production and use, and developing an integrated grid structure to transmit electrical power more efficiently and reliably.

NETL's research program is organized around core elements that recognize the systems-design and integration issues posed by a global transition of energy technologies.

- **Carbon capture and storage**—NETL is a leader in technology development aimed at safely, economically, and permanently storing CO_2 from fossil-based energy systems. We target the 2020 timeframe for moving needed technologies to market.

- **Advanced fossil-fuel power systems**—Tomorrow's affordable, ultra-clean, ultra-efficient power systems are under development today. The Office of Fossil Energy's research and development program, implemented by NETL, targets 90 percent carbon capture and storage at electricity costs that approach today's supercritical pulverized coal plant costs without carbon capture.

- **Existing coal plants**—Applying carbon capture to existing coal-fueled power plants through retrofitted technologies imposes an enormous economic penalty. NETL aims to reduce today's incremental capital and operating costs by approximately 50 percent, averaged across the existing fleet, through advanced postcombustion capture and compression.

- **Methane hydrates and gas shale**—These technically and economically challenging resources are under intense investigation at NETL. Our researchers also continue to advance the cost-effective, environmentally sound exploration of domestic oil and natural gas.

- **The Smart Grid**—Through 2009, NETL's Modern Grid Strategy team led development of a national vision to upgrade our electricity distribution system to a 21st-century Smart Grid. NETL is now accelerating America's transition to the grid through implementation-strategy development, key analyses, and technology innovation. NETL also

participates actively in ongoing stakeholder communities consisting of federal government, academic, and industry organizations.

- **Energy efficiency**—Energy efficiency in both supply and demand is critical to America's future. NETL works on both sides of the equation by increasing power-production efficiencies and making strides in demand-side efficiencies. NETL works closely with state energy programs and weatherization projects. Our partners develop, evaluate, and deploy high-efficiency building, vehicle, industrial, and appliance technologies—all of which are key to slashing energy consumption and consumer costs.

NETL also manages $15.5 billion in American Reinvestment and Recovery Act (ARRA) funding for the Office of Fossil Energy, the Office of Energy Reliability and Renewable Energy, and the Office of Electricity Delivery and Energy Reliability. NETL's ARRA activities give independent organizations the opportunity to make significant strides in energy research while they create more than 160,000 job years by the program's 2015 expiration date.

The successes our project partners realize will jump-start new industries for clean transportation, building technologies, industrial efficiencies, and renewable energy. They will translate into achievements for the Regional Carbon Sequestration Partnerships and Smart Grid program, and they will augment intergovernmental programs at the state level.

In addition to conducting sponsored research programs, NETL is committed to acting as a catalyst for regional development. The primary vehicle for this work is our newly formed Regional University Alliance for Energy Technology Innovation, or NETL-RUA. This program combines NETL's fossil energy expertise with the broad capabilities of five regional institutions: Carnegie Mellon University, Pennsylvania State University, the University of Pittsburgh, Virginia Tech, and West Virginia University.

NETL-RUA will help our nation develop a workforce highly skilled in the energy field, providing stimulus for high-tech job creation and economic development. Deployment of new technologies stemming from this Alliance will be aided by key partnerships with the region's commercial energy sector and serve as the basis for regional economic development and nationwide job creation.

Rebuilding our nation's energy infrastructure based on resources with ultralow environmental impact will require decades of technology development and commercialization. NETL is working to help America achieve this complex energy transition. With our scientific, engineering, and administrative talent, we continue to implement the partnerships and manage the programs that can accomplish the mission of providing affordable, reliable, and environmentally safe energy for the 21st century.

100 YEARS OF INNOVATION

Image courtesy of National Archives & Records Administration

We've made a lot of progress in 100 years. In the earliest days of the USBM Experimental Mine in Pittsburgh, mules were used to move coal samples and mining equipment. In contrast, NETL now uses sophisticated methods and instruments to analyze, research, and develop advanced technologies and processes that will enter the public domain. In this way, the Energy Lab is helping our country produce safe, affordable, abundant energy for today—and for the future.

About NETL

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

To accomplish this mission, NETL draws on 1,700 federal and support-contractor employees to implement and manage a broad spectrum of research programs. NETL conducts more than 1,800 research activities in the United States and in more than 40 foreign countries.

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

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