NETL Accomplishments in Brief

2011

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

Mission

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

Cover image: NETL researcher Corinne Disenhof examines a basalt thin section under a Geoscience Laboratory petrographic microscope. NETL is investigating the effects of microbes on basalt during carbon sequestration, and petrography is one of several analysis methods being used. Others include scanning electron microscopy and x-ray diffraction .

2011

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Letter from the Director

Without question, the first quarter of the 21st century is an exciting time in the world of energy. The nation's push to develop sound energy policy is strong. The need to curb CO_2 emissions is urgent. The call for clean, affordable power is clear.

This is also an exciting time for energy researchers. The challenges we strive to overcome require far-reaching solutions: designing and building next-generation, near-zero-emission power plants; capturing, utilizing, and storing manmade carbon emissions; maximizing efficiencies; and getting the most from our energy resources with the least impact on our air, land, and waterways.

At the National Energy Technology Laboratory (NETL), we are confident in our ability to help America meet 21st-century challenges linked to fossil fuel recovery and use. After all, we have been meeting such challenges for generations. From mine safety to synthetic fuels, acid rain to mercury control, enhanced oil production to unconventional natural gas recovery, the legacy of public benefits realized by our programs stands as a testimony to the importance of our research and the careful means by which we steward federal investment in those programs.

Today, we continue to address complex energy issues—reducing the environmental impacts of shale gas recovery, mitigating carbon emissions,

utilizing CO_2 to enhance our nation's oil and natural gas resources, and more. Our research is making a fundamental difference to the welfare of our nation. It also gives NETL and our stakeholders an opportunity to enhance our citizens' quality of life for generations to come.

In 2011, NETL realized a host of technical accomplishments and received recognition for our contributions to the energy arena. A full review of those achievements will be available this spring in the *2011 NETL Accomplishments*. Until then, get an early glimpse of our diverse contributions in the *2011 NETL Accomplishments in Brief*. It contains selected highlights of our current research and a review of the realized and estimated benefits provided by the programs implemented by our lab through the Office of Fossil Energy (FE).

Thank you for taking time to browse our successes. I am proud of NETL's achievements and of the researchers and professional staff that make them possible.

Anthony V. Cugini, Director
National Energy Technology Laboratory

The NETL Hanford site team with Energy Secretary Stephen Chu.

NETL Teams Earn High Awards from Secretary of Energy

—Secretary Steven Chu presented 2011 Secretary of Energy Achievement Awards to NETL and partner agencies for significant contributions made to two critical national efforts in 2010. Secretary Chu honored NETL for the Lab's part in our nation's response to the Deepwater Horizon oil spill in the Gulf of Mexico and teh Department of Energy's (DOE) remediation activities at the Hanford nuclear materials production site in Washington State.

In both efforts, researchers dedicated their time, effort, and expertise to solving critical problems facing the United States. NETL federal and contractor staff members that responded to Deepwater Horizon were George Guthrie and Grant Bromhal—both team leads—and Brian Anderson, Bob Enick, Roy Long, Shahab Mohaghegh, Bryan Morreale, Neal Sams, and Doug Wyatt. The Hanford Site team was co-led by John VanOsdol and Tom O'Brien and staffed by Sofiane Benyahia, Syam Syamlal, Tingwen Li, and Mehrdad Shahnam.

In congratulating all of the 2011 Honor Award winners, Secretary Chu stated, "The employees recognized today have gone above and beyond the call of duty, demonstrating an exceptional commitment to public service. Their dedication, knowledge, and skills have served to strengthen our nation's economic and energy security and the work of the Energy Department."

For more information, visit
www.netl.doe.gov/teams.html

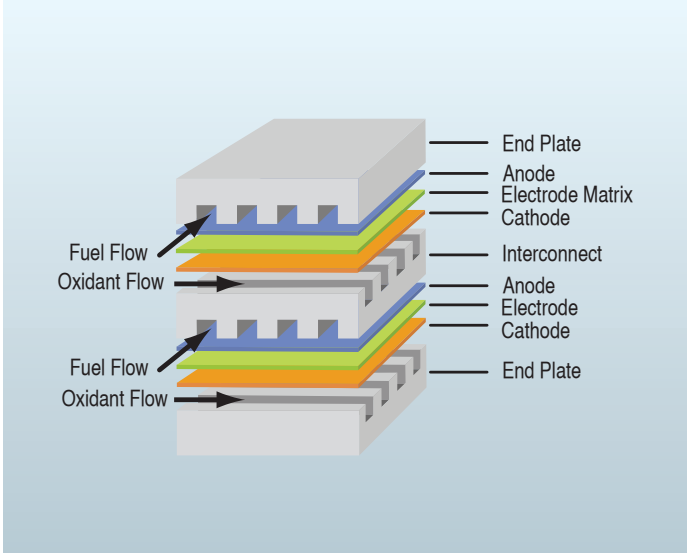
Using APECS v.2.0, design engineers can integrate, solve, and analyze co-simulations, such as for an integrated gasification combined cycle (IGCC) power plant.

Innovating Faster with APECS v.2.0

—NETL developed the Advanced Process Engineering Co-Simulator (APECS) v.2.0 with ANSYS® DesignXplorer™ and ROM Builder in response to demand by the process and energy industries for sophisticated, computer-aided process design, simulation, and optimization tools to provide solutions to energy and environmental challenges.

APECS v.2.0, which won an R&D 100 award in 2011, can design and optimize existing and next-generation plants for aggressive performance that meets strict economic and environmental objectives. Version 2.0, created in collaboration with ANSYS, Inc., reduces the time and cost needed to foster plant innovations by combining process simulation with fast reduced-order models based on high-fidelity equipment-scale models.

APECS v.2.0 continues APECS's R&D 100 Award-winning tradition. The first version, APECS v.1.0 with ANSYS Engineering Knowledge Manager™, won an award in 2008. Version 2.0 improves on the previous version by offering many new features that make it easier, faster, and cheaper for engineers to optimize existing and future designs. The Energy Department's multi-laboratory Carbon Capture Simulation Initiative uses APECS v.2.0 to accelerate the development of carbon capture technologies from initial design to deployment in hundreds of power plants.



This schematic of stacked SOFCs indicates fuel flow, oxidizer, interconnect, and electrolyte.

The AltelaRain® 600 turns flowback water resulting from shale gas production into rain-water quality

Fuel Cells Live Longer with NETL Coating

—NETL's manganese-cobalt (Mn-Co) coating for solid oxide fuel cell (SOFC) interconnects, which garnered a 2011 R&D 100 Award, prevents the evaporation of chromium from the interconnects in an SOFC stack, thereby extending the stack's ability to conduct electricity.

Individual SOFC cells generate a relatively small amount of power on their own. However, when cells are joined together—or stacked—they generate enough power to meet residential, commercial, and even industrial demand. The cells are joined by "interconnects" to link the individual SOFCs electrically while keeping air and fuel properly separated. Preventing chromium from evaporating out of these interconnects increases the SOFC stack's lifetime, ultimately making the power generated less expensive for the consumer.

Through an extended research effort, NETL and West Virginia University collaborators determined that a $(Mn,Co)_3O_4$ spinel makes the best interconnect coating, and it can be applied using their low-cost plating process. The Mn-Co coating method offers significant advantages in cost, ease of coating large samples, capability of scaling up for mass production, and environmental friendliness.

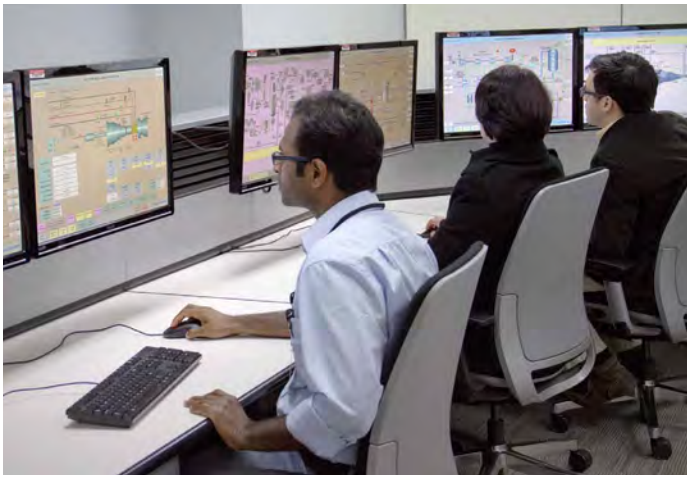
Let It Rain: Treating Marcellus Shale Waters

—Altela, Inc.'s AltelaRain® 600 water desalination system is successfully turning flowback water from shale gas development in Pennsylvania into clean water, ready for reuse by the gas industry or even for discharge into waterways.

In an NETL demonstration project, AltelaRain effectively treated flowback water at BLX, Inc.'s Sleppy well site in Indiana County, PA, during nine months of operation. The system processed 77 percent of onsite water to rainwater quality, cut disposal costs, and reduced the need to truck wastewater to an offsite facility. Altela is now offering its desalination system commercially, with modules sold and installed in Williamsport, PA, and a second installation underway in McKean County, PA.

In two other NETL projects, researchers at West Virginia University (WVU), FilterSure, Inc., and ABSMaterials have tested other flowback and produced water treatment technologies. WVU and FilterSure used their Mobile Treatment Unit to process more than 500,000 gallons of flowback water for reuse at a Chesapeake Energy shale gas production site. ABSMaterials successfully tested its Osorb® material, which removes hydrocarbons from the flowback and produced water from oil and natural gas production.

For more information, visit
www.netl.doe.gov/rain.html and
www.netl.doe.gov/shale.html



The AVESTAR Center is focused on developing a workforce well prepared to effectively operate, control, and manage the next-generation of high-efficiency IGCC power plants. Operators can interact with the system in real time, simulating real-world power plant conditions.

The AVESTAR™ Center: Simulating the Next Generation of Clean Coal Technologies

—A world-class training and research center focused on the safe, reliable, and efficient operation of clean energy plants is now up and running at NETL. Known as Advanced Virtual Energy Simulation Training and Research, or AVESTAR™, the Center was established as part of DOE's initiative to advance new clean coal technology for power generation.

AVESTAR features a state-of-the-art, highly realistic, dynamic simulator and operator training system for integrated gasification combined cycle (ICGG) power plants with carbon dioxide (CO_2) capture. The IGCC simulator is unique among power plant simulators in that it merges, for the first time, a "gasification with CO_2 capture" process simulator with a "combined-cycle" power simulator. The simulator trains operators, engineers, and researchers on normal and faulted IGCC plant operations, as well as plant start-up, shutdown, and power demand load changes. The simulator also allows users to test different types of fuel sources, such as petcoke and biomass, as well as cofiring fuel mixtures.

NETL plans to continue building the AVESTAR portfolio of dynamic simulators, immersive training systems, and advanced research capabilities to satisfy industry's growing need for training in the operation and control of high-efficiency, near-zero emission energy plants.

For more information, visit
www.netl.doe.gov/avestar.html

In this pilot solvent test unit at the PC4, NCCC tests new solvents against a baseline reference.

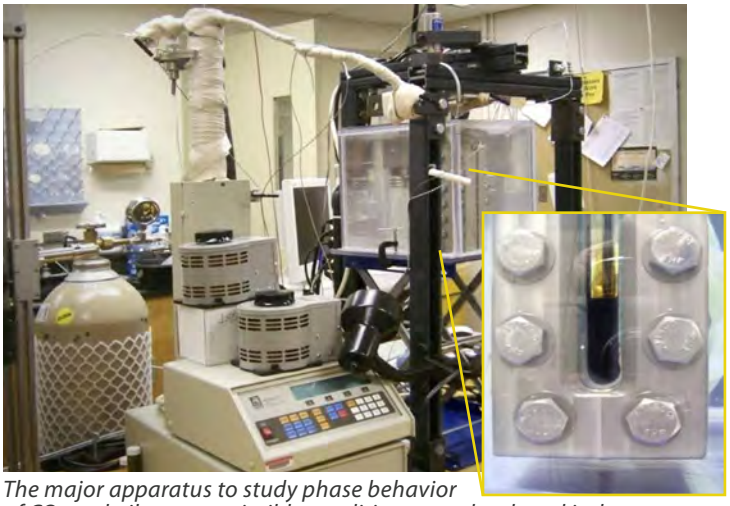
Testing Post-combustion Carbon Capture at PC4

—In another step forward in the research that will speed deployment of innovative CO_2 capture techniques for coal-based power plants, NETL and Southern Company Services have commissioned the new Post-Combustion Carbon Capture Center, or PC4, at the National Carbon Capture Center (NCCC) in Alabama.

At PC4, technology developers worldwide are testing and evaluating post-combustion carbon capture technologies under power plant conditions, with the purpose of developing a wide variety of CO_2 capture technologies. Activities are ongoing at several scales and include the testing of new CO_2-capturing solvents and gas-liquid contacting systems, the regeneration of solvents at high pressures, the evaluation of novel technologies like sorbents and membranes, and the reduction of capital and operational costs associated with adding CO_2 capture to existing plants.

The NCCC was established in 2009 by NETL, Southern Company, and other partners. Current participants include American Electric Power, Arch Coal, the Electric Power Research Institute, Luminant, NRG Energy, Peabody Energy, and RioTinto.

For more information, visit
www.netl.doe.gov/innovating.html



The major apparatus to study phase behavior of CO_2 and oil at near miscible conditions was developed in-house at the University of Kansas. This is a close up of a vapor liquid equilibrium view cell, which is used to measure the swelling and extraction of oil samples as a result of interaction with CO_2.

Storing CO_2 and Boosting U.S. Oil Recovery: A Win-Win for Everyone—

One way of reducing the amount of CO_2 being released into our atmosphere is to capture and store it safely underground. But why only store a potentially useful product?

For instance, NETL has been on the forefront of using injected CO_2 for enhanced oil recovery (EOR) for decades. Especially useful for mature oilfields, EOR prevents them from being abandoned prematurely. Typically, as much as two thirds of the oil remains stranded in a reservoir after primary and secondary recovery processes.

A study of oilfields in Kansas, funded by DOE through NETL and administered through the Research Partnership to Secure Energy for America, demonstrates the possibility of recovering between 250 million and 500 million barrels of oil using near-miscible CO_2 flooding for extending the life of mature oilfields. Because 90 percent of the Kansas wells are operated by more than 100 small producers and pump less than 5 barrels per day, enhancement of yield with CO_2 would be a great boon—and the CO_2 can be permanently stored underground via the wells when oil production is truly exhausted.

NETL is also exploring CO_2 as a component in plastic production, chemicals production, and a mineralization process for building projects.

For more information, visit
www.netl.doe.gov/recovery.html

Developing smartphone software programs is one approach being taken by the Stripper Well Consortium to help in the recovery of oil and natural gas by small operators.

Enhancing Environmental Protection, Increasing Domestic Production—

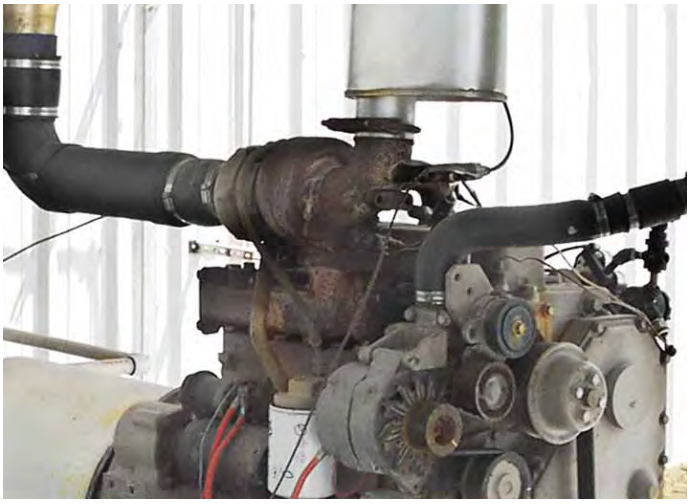
"Stripper" wells are oil and natural gas wells that are nearly depleted but can still produce up to 10 barrels of oil or 60,000 standard cubic feet of natural gas per day. They provide about 20 percent of current U.S. oil and gas production.

The Stripper Well Consortium, partially funded by NETL, has supported nearly 100 technology-driven projects since 2000. Reservoir remediation, wellbore clean-up, and surface system optimization projects have helped maximize resource recovery in stripper wells while minimizing environmental impacts and, ultimately, strengthening our nation's energy security.

Some of the technologies developed through these projects include—

- A gas-operated automatic plunger lift tool to remove fluids from stripper wells.
- A second tool for removing liquids from gas wells and gathering lines.
- A highly efficient submersible electric pump that reduces electricity costs.
- A smaller, lighter variable-capacity compressor and pump.
- A low-cost, real-time, wireless gauge for permanent or service applications.
- Pumper-well tender PDA and Smartphone software programs.
- An economical chemical delivery system that reduces corrosion and maintenance costs.
- A low-cost control box that optimizes production.
- A low-cost soil amendment technology for remediation and re-vegetation of brine-contaminated soils.

For more information, visit
www.netl.doe.gov/production.html



Test engine at Kansas State University's National Gas Machinery Laboratory has been used to evaluate new retrofit technologies for emissions control. Image courtesy of Kansas State University.

Retrofit Technology: Improves Performance, Reduces Emissions—

In the natural gas industry, thousands of reciprocating engines are used to produce electricity, compress and re-inject natural gas to increase oil production, or compress natural gas to feed it into gas transmission pipelines. These engines are aging, and new federal Environmental Protection Agency (EPA) emissions regulations may mean cost-prohibitive replacements are needed.

However, with funding from NETL, researchers at Kansas State University (KSU) and partners are designing and testing retrofit emissions control and monitoring technologies for these engines that will efficiently upgrade them while mitigating greenhouse gases—at a fraction of the cost of new engine replacements.

KSU researchers have developed a four-stroke cycle engine model and exhaust gas oxygen sensor model that will predict emissions from small engines better than current emission compliance measures, which are based on plume models for larger emission sources. The updated KSU models take into account small-engine characteristics and preferred catalytic conditions. Once validated, the models can be used in field engine control boards that can help meet new EPA emission standards by replacing outdated air fuel controllers.

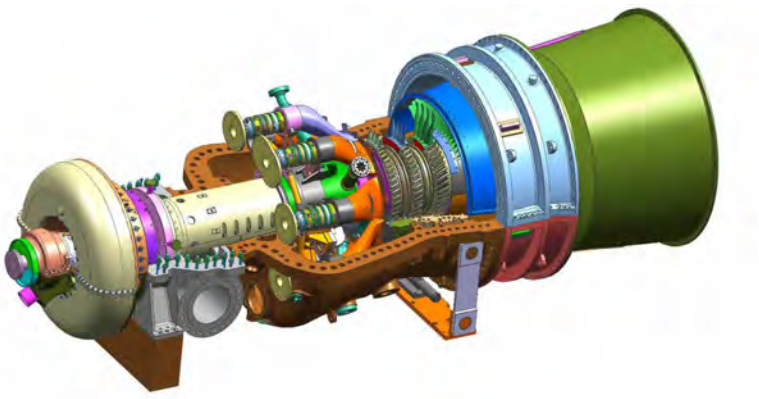
Construction of the LG Chem 850,000-square-foot lithium-ion polymer battery cell and battery manufacturing facility is taking place in Holland, Michigan. LG Chem is a key supplier of batteries to General Motors for the Volt Program.

Building a New Domestic Industry—

The Electric Drive Vehicle Battery & Component Manufacturing Initiative, funded by DOE through the American Recovery and Reinvestment Act (ARRA), supports a portfolio of 30 projects for the construction of a domestic battery and electric drive component industry.

The projects will create a complete U.S. battery and electric-drive vehicle manufacturing industry to meet the President's goal of having 1,000,000 plug-in hybrid electric vehicles (PHEV) on the road by 2015. The projects already have a manufacturing capacity of 113,800 vehicle-equivalent batteries, and construction is being completed for 7 new facilities. These projects have inserted over $1 billion into the economy already and should create nearly 7,000 long-term domestic jobs.

This industry is still in its infancy and is expected to grow dramatically as the electric vehicle market grows due to the paradigm shift from petroleum use to battery technologies. The result will be a new era of highly skilled jobs in the United States. The DOE National Energy Technology Laboratory's Power & Vehicles Technology Division manages these projects in support of the Energy Efficiency and Renewable Energy (EERE) Vehicle Technologies Program, with a $2 billion DOE investment matched dollar-for-dollar by industry.

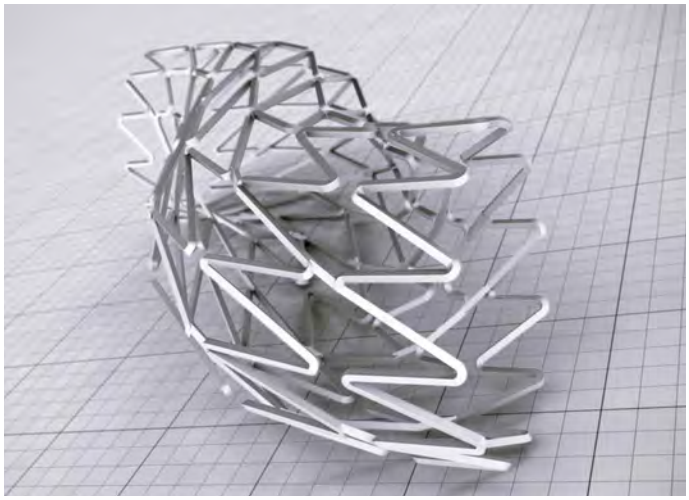


CES's oxy-fuel gas turbine, the OFT-900 is a key component of CES's oxy-fuel power generation system, which is capable of capturing greater than 99 percent of CO_2 produced in the combustion of a variety of fuels, including coal syngas and natural gas. Image courtesy of Florida Turbine Technologies, Inc. and Clean Energy Systems, Inc.

Recovery Act Projects Reach High—

New jobs created, old jobs sustained, and the environment protected in diverse ways: the American Recovery and Reinvestment Act (ARRA) provides funds through the DOE Office of Fossil Energy's National Energy Technology Laboratory for many projects that benefit our nation. Here are three of the many ways NETL is investing ARRA funding:

- NETL, Archer Daniels Midland, and others are constructing an Illinois ethanol plant that will demonstrate carbon capture and storage and move the technology closer to commercial deployment. It includes construction of a National Sequestration Education Center to be located at Richland Community College. Approximately 260 new jobs will be created by this project.
- Mikro Systems, Inc., managed by NETL with ARRA funding, is developing their proprietary technology for the fabrication of next-generation gas turbine blades that will shorten development time and improve performance. This Small Business Innovation Research Phase III Xlerator project will result in cleaner, more reliable, and more affordable energy.
- Clean Energy Systems, Inc., (CES) and partners are developing ARRA-supported oxy-fuel power systems that are capable of capturing over 99 percent of CO_2 emissions from power generation using coal syngas and other fossil fuels. This advanced turbo-machinery project is part of the Industrial Carbon Capture and Sequestration portfolio.



Coronary stents made from a novel platinum-chromium alloy are more flexible and conformable than traditional stainless steel stents. The novel alloy was developed by scientists at NETL and BSC. Image courtesy of BSC.

State-of-the-Art Stent Sales Top $1 Billion—

The use of coronary stents saves thousands of lives each year by reopening blocked or restricted arteries, allowing blood to flow freely again to cardiac tissue. A new coronary stent, which incorporates an innovative metal alloy developed by scientists at NETL and Boston Scientific Corporation (BSC) has achieved more than $1 billion in sales and captured a 45 percent share of the coronary stent market. The platinum-chromium alloy is the first stainless steel formulation with a significant concentration of a highly radiopaque element, platinum, which makes it visible on x-ray and easier for coronary specialists to see during placement.

Utilizing the improved alloy, BSC developed new coronary stents with superior properties compared to existing stainless steel stents. After a lengthy series of clinical trials, BSC received foreign regulatory market approval in November 2009, and in early 2011 approval was received from U.S. and Canadian regulatory agencies, followed by approval from India. Recently, BSC announced that they have received regulatory approval in China, the world's largest stent market. BSC has announced that all future stents will use this innovative alloy in their manufacture.

For more information, visit **www.netl.doe.gov/stents.html**

Auxiliary power units can help truckers meet anti-idling regulations. However, the weight, expense, and noise associated with conventional small internal combustion engines make it hard for industry to adopt them. Fuel cells could be the answer.

Pyrochlore Catalyst: Taking Fuel Cells to Market

—Fuel cells produce electricity using half the fuel of conventional internal combustion systems and release fewer emissions, but they have not realized their potential for everyday energy applications. If we could easily transform a readily available fuel—like diesel—into syngas to power fuel cells, however, they could begin to supply us with day-to-day energy.

NETL's pyrochlore catalyst, developed in partnership with URS Corporation and Louisiana State University, is the first catalyst shown to be highly effective in transforming diesel and other heavy-carbon fuels into syngas. NETL has licensed the catalyst to Pyrochem Catalyst Company, a start-up company founded to develop market-ready reforming technologies based on the pyrochlore catalysts, which earned NETL a 2011 Federal Laboratory Consortium award for excellence in technology transfer.

If the pyrocholore catalyst technologies prove successful, fuel cells could quickly make their way into the trucking industry to supply auxiliary power for HVAC, lighting, and other necessities, helping the industry meet anti-idling regulations. They could also be used in military operations, in recreational vehicles, and for primary and emergency power in homes and businesses.

For more information, visit **www.netl.doe.gov/catalyst.html**

NETL won an FLC award for its technology transfer efforts related to the CO_2-capturing BIAS process. This image shows one of several sorbents that are used during the process.

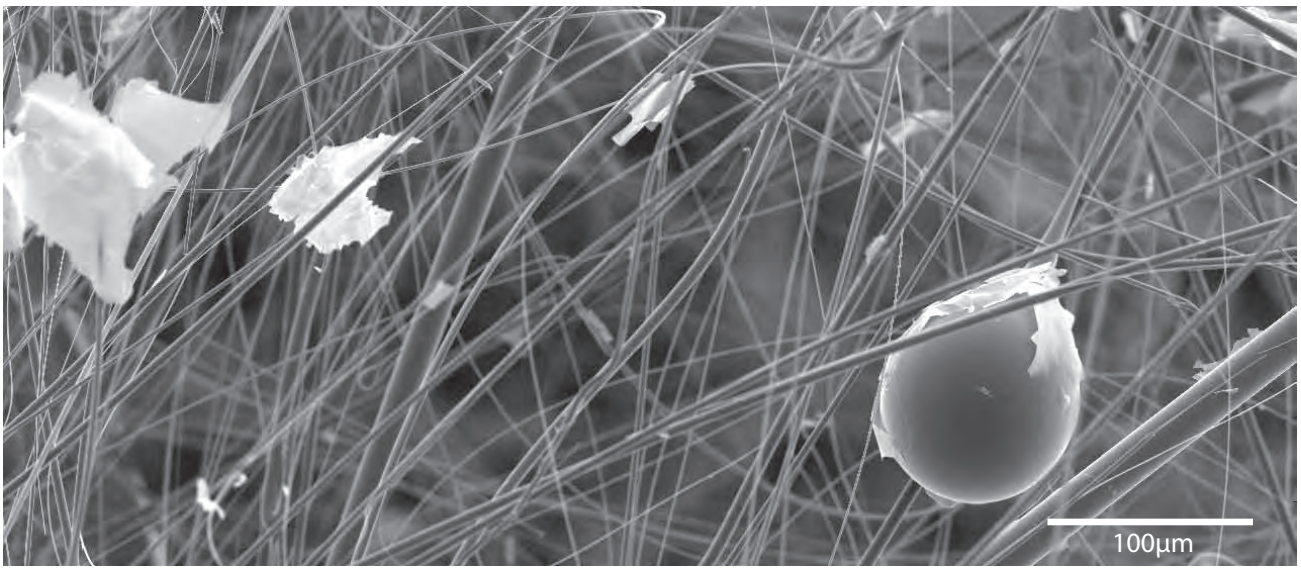
CO_2 Capture Process Wins National Award for Technology Transfer Excellence

—The NETL-developed Basic Immobilized Amine Sorbent (BIAS) process, which prevents the release of CO_2 into the air from the flue or stack gas of power plants, received a 2011 Award for Excellence in Technology Transfer from the Federal Laboratory Consortium for Technology Transfer (FLC). Application of the technology reduces the costs and energy penalty associated with more conventional scrubbing processes to capture CO_2.

The BIAS process uses a regenerable, solid, amine-based sorbent to capture CO_2 from the flue gas. Once the CO_2 is captured, the sorbent is heated to release the greenhouse gas for either storage or utilization in other products, thereby refreshing the sorbent for reuse.

Because of NETL's technology transfer efforts, one company is beginning to develop commercial applications based on the BIAS process and several other organizations are investigating the potential for using it outside the power industry. Transfer of BIAS from the laboratory to the marketplace is another important step in NETL's effort to deploy innovations that will decrease man-made emissions of greenhouse gases.

For more information, visit **www.netl.doe.gov/award.html**



These mineral wool fibers, as seen by a scanning electron microscope secondary electron image, range from 2–12 microns in diameter. The spherical particle with fiber "tail" is indicative of the formation process and is formed by elongation of droplets of the molten (liquid) slag. Image courtesy of Florida Turbine Technologies, Inc., and Clean Energy Systems, Inc.

NETL Garners Six U.S. Patents—Researchers at NETL received six patents in 2011 for inventions in energy-related technology, including the following:

- An integrated process for removing multiple pollutants from fossil fuel combustion systems.
- Mercury detection within, and removal from, coal-derived flue and fuel gases.
- A process for neutralization of toxic bauxite residues resulting from aluminum extraction via flue gas and brine.
- A method for production of mineral wool for use in insulation materials, with co-production of iron (see image).
- A microchannel reactor technology that allows for higher conversion efficiency in chemical synthesis.
- Biomass and syngas processing.

NETL pursues patent protection for novel technologies as a means to protect taxpayer's investment in energy-related research. NETL's Technology Transfer office manages the process, identifying those technologies having greatest commercial potential. Deployment of these technologies will lead to enhanced energy efficiencies and better pollution monitoring and control.

A Legacy of Benefit

The Return on Federal Research at NETL

In the world of technology innovation, both the private and public sectors play critical roles in bringing scientific and engineering solutions to American markets.

Breakthroughs that have revolutionized the energy industry have often been made possible by our collective investment in the ideas of the researchers who are tackling problems presented by the production and use of fossil fuels, the generation of nuclear power, the promise of renewable energy, and our need to continuously improve energy efficiencies. Federal research often pursues high-risk technologies that have the potential for great public benefit and require long-term investments the private sector can find difficult to make. It also helps industry bring novel innovations to commercial readiness by sharing in demonstration-scale research.

In 2011, the Office of Fossil Energy took a look at the many public benefits that have been realized by technologies and processes developed and supported by its office and NETL.

Did you know the United States has reduced its NO_x emissions 88 percent and SO_2 emissions 82 percent since 1970, essentially eliminating acid rain?

Major contributors to these reductions have been the scrubbers, low-NO_x burners, and selective catalytic reduction systems demonstrated through the clean coal programs managed by NETL. Continued research is expected to directly realize another 37 million ton reduction in SO_2 emissions and 16 million ton reduction in NO_x emissions between 2000 and 2020, while also reducing other pollutants.

Did you know that low-cost mercury controls developed at NETL are being deployed on U.S. coal-fired power plants?

NETL's Mercury Control program research reduced the cost of controlling the mercury emitted by coal power systems by 50–70 percent. As of 2010, vendors have sold nearly 150 full-scale activated carbon injection (ACI) systems, a signature technology of the program, to U.S. coal-fired power generators. This represents more than 56 gigawatts of our coal-fired electric generating capacity. The U.S. Environmental Protection Agency projects that 60 percent of our coal capacity (146 gigawatts) will use ACI by 2015.

Did you know that NETL has been a pioneer in enhanced oil recovery for nearly a century?

Since the 1920s, NETL and its predecessors have pioneered enhanced oil recovery (EOR) techniques like water flooding, chemical applications, and CO_2 injection. Coaxing hard-to-recover oil out of the ground adds to our domestic petroleum resources—today enhanced recovery amounts to nearly 13 percent of total U.S. oil production. CO_2-EOR, especially if next-generation technologies are developed and deployed, promises a profitable avenue for sequestering manmade CO_2 emissions deep underground.

Did you know that U.S. shale gas production has increased 12-fold over the last decade?

Advanced technologies have helped increase oil and natural gas production from abundant shale resources. NETL helped

lead the characterization of shale plays and development of such techniques as horizontal drilling, microseismic monitoring, and hydraulic fracturing, making it possible for us to tap widely present shale layers and release the natural gas trapped inside. With these technologies comes the potential for the United States to move closer to energy independence and even export natural gas.

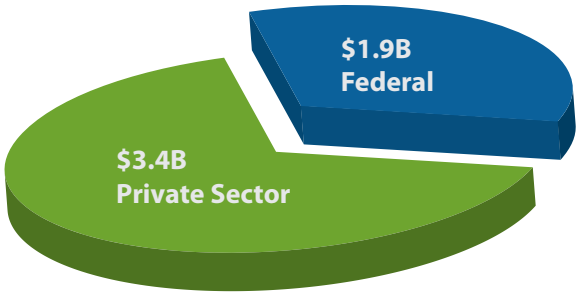
Did you know the Clean Coal Technology program, implemented by NETL, is expected to realize a $13 benefit for every taxpayer dollar invested?

In fact, between 2000 and 2020, the clean coal program is expected to realize $111 billion in total monetary benefits. Our air will be cleaner, we'll see further reductions in pollution, energy efficiencies and U.S. exports will increase, and national security will be enhanced. The program is also expected to generate 1.2 million jobs, predominantly well-paid manufacturing-related employment.

Like our nation's domestic energy supplies, American taxpayer dollars are a precious resource. They must be carefully managed and they must yield real benefits. From sustainable coal technologies to unconventional petroleum recovery and beyond, the extraordinary economic returns FE and NETL have realized on the investments made through our organizations is a testament to the productivity of our research.

The risks are sometimes high, but so is the return. Our researchers and our partners will continue to work ahead of the curve, and we will continue to achieve the technological breakthroughs needed to keep our nation's energy industry on the cutting edge.

To see FE's complete Legacy of Benefits series, visit them on the Web at **www.fossil.energy.gov**



Total cost of the original Clean Coal Technology Demonstration program was $5.3 billion. The cost-share requirement was a 50/50 split, but private sector confidence in the program was high enough to spur a 2/3 investment.

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