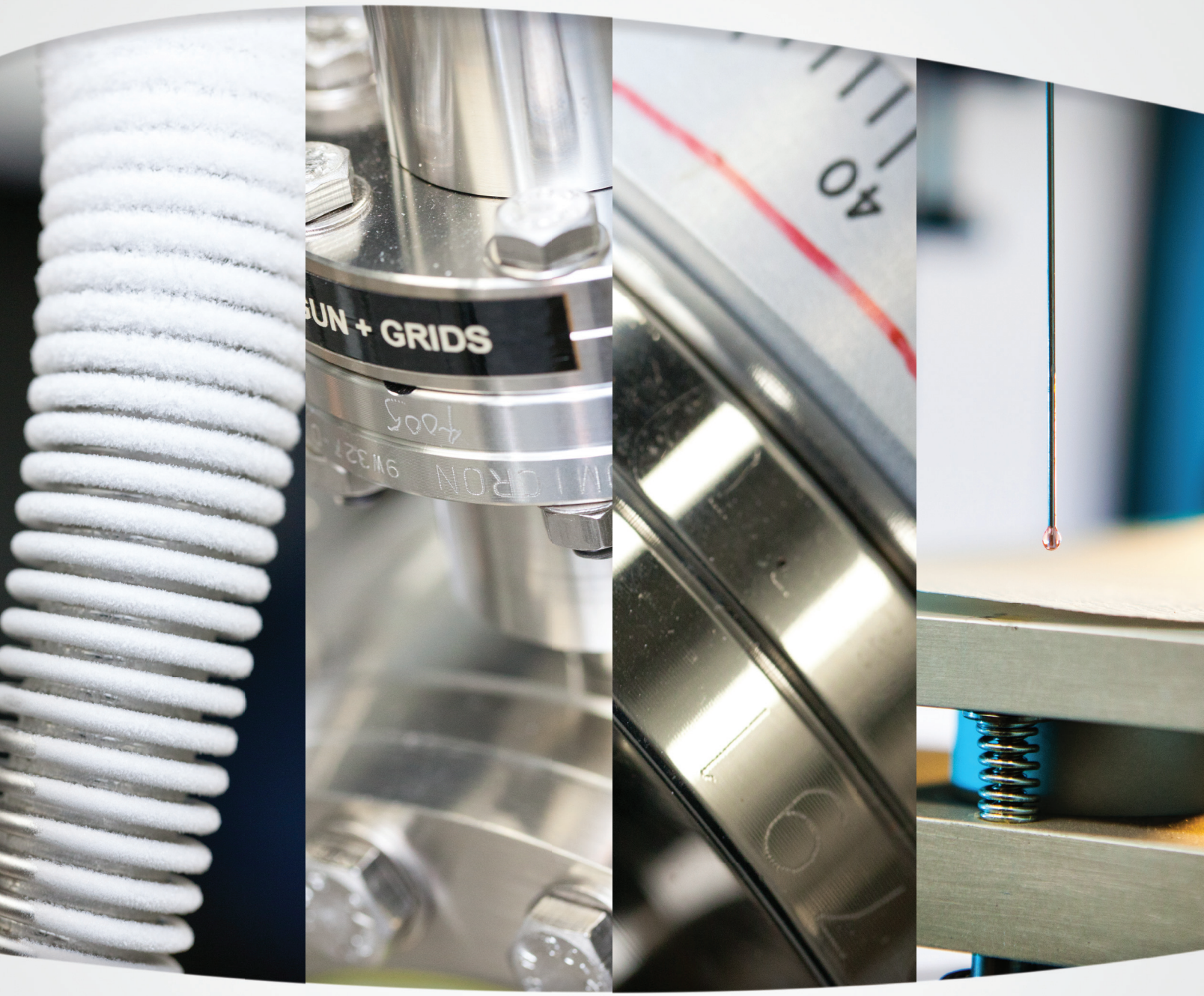
NATIONAL ENERGY TECHNOLOGY LABORATORY

NETL ANNUAL REPORT 2015



U.S. DEPARTMENT OF ENERGY | National Energy Technology Laboratory

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Director's Overview

Human nature often causes us to take conveniences for granted. We flip a switch to illuminate a darkened room, microwave a bowl of popcorn, drive to the grocery store, or tackle hundreds of other machine-assisted chores without a second thought about all that must occur to make it possible. Most often, energy from fossil fuels makes those actions happen, and it will remain that way for quite some time. In fact, fossil fuels will be meeting more than 80 percent of national and global energy demands well into 2040.

At the National Energy Technology Laboratory (NETL), the only laboratory in the U.S. Department of Energy's (DOE) national laboratory system focused on fossil fuels, we have a responsibility to discover, integrate, and mature new technologies and approaches into our nation's energy bloodstream to keep us strong, secure, and to protect the environment while we continue to use fossil energy. This is a mission our researchers have pursued aggressively under a variety of names and federal agencies for more than 100 years with major success. The work that our people performed in fiscal year 2015 (FY15) was particularly fruitful.

In addition to conducting cutting-edge fossil energy research, NETL manages a wide-ranging portfolio of strategic research projects for DOE's Office of Electricity Delivery and Energy Reliability and the Office of Energy Efficiency and Renewable Energy. And, we conduct a variety of energy analysis studies to identify promising research and development opportunities to advance NETL's mission. We do all of that work and more in world-class research facilities in Pittsburgh, PA; Morgantown, WV; and Albany, OR, and in offices in Sugarland, TX, and Anchorage, AK. These locations give us a presence in regions critical to our national energy security, rich in coal, oil, and natural gas.

NETL conducts much of its important work through partnerships and cooperative research and development agreements with universities and the private sector. Our expertise has allowed us to become a leading voice on research devoted to safe and efficient recovery of natural gas and oil resources, advanced energy systems, carbon dioxide (CO_2) capture and storage, crosscutting research to meet the needs of future near-zero emission power systems, and major demonstrations of commercial-scale clean coal technology demonstration projects.

In the coming year, we will be implementing a new organizational structure that will enhance integration within the Lab and facilitate collaboration with our research partners. This new structure represents a fundamental shift for NETL and charts a path forward to drive innovation and promote better science.

As Director, I am extremely proud of the breakthroughs and contributions we achieved in FY15 and I am particularly excited about our plans to build upon those accomplishments. Please review the following pages to learn more about how NETL made a difference in FY15.

Dr. Grace Bochenek
Director, NETL

NETL Mission

NETL’s mission is to discover, integrate, and mature technology solutions that protect the environment and enhance the nation’s energy foundation for future generations.

NETL Vision

Be the nation’s renowned fossil-energy science and engineering resource, delivering world-class technology solutions today and tomorrow.

Core Competencies

NETL's core competencies help the Laboratory's researchers address national energy challenges such as carbon capture and storage; advanced coal processing; enhanced natural gas exploration and production; next-generation emissions controls; production of materials for extreme environments; and advanced, clean, high-efficiency gasification and combustion-based energy conversion systems. Our core competencies are:

Computational Sciences & Engineering

Materials Engineering & Manufacturing

Geological & Environmental Systems

Energy Conversion Engineering

Systems Engineering & Analysis

Program Execution & Integration

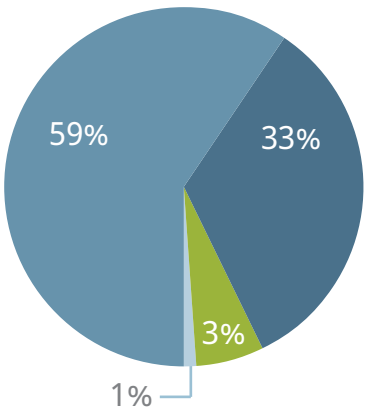
We apply our expertise in these enduring core competencies to address technical thrusts in coal and oil & gas.

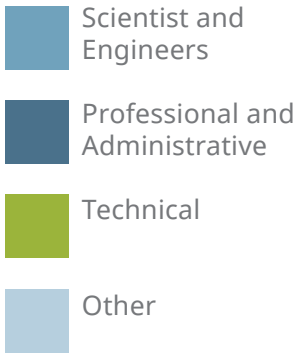
Budget

NETL's FY15 federal budget funding was $717 million.

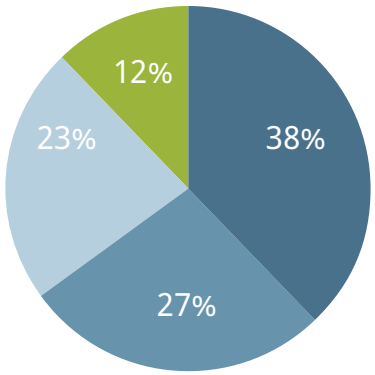
Nearly 1,400 employees work at NETL's five sites, a workforce of highly skilled federal and contract staff. Each year, NETL contributes nearly $200 million to the economies of the regions where it has locations. Through multi-year R&D agreements and contracts, NETL and its research partners inject another $1.1 billion, which includes private-sector cost share, into these regional economies. The Laboratory's three research sites provide further economic benefits by drawing a total of more than 2,500 visitors per year.

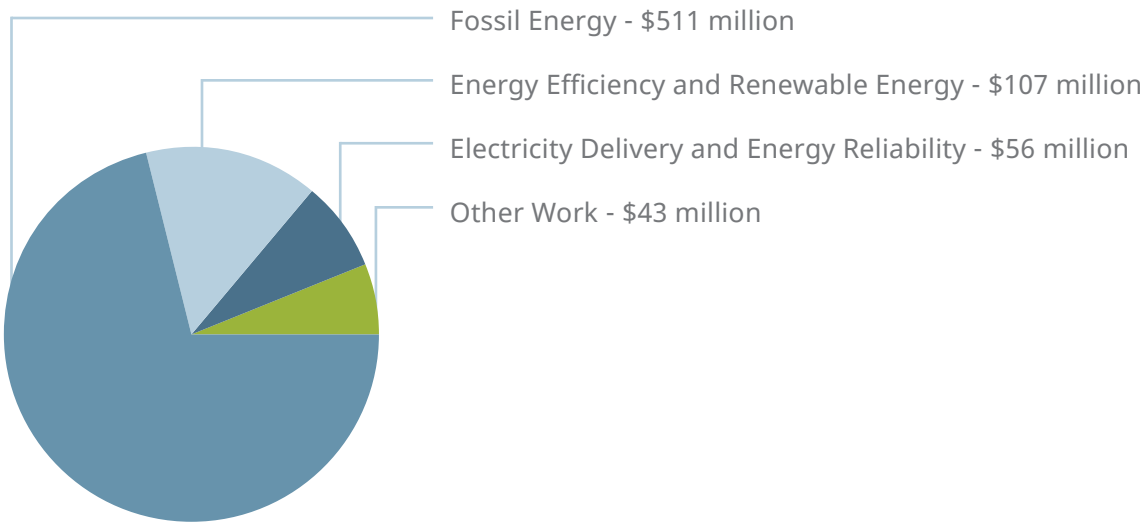
Federal Employees





Site-Support Contractors

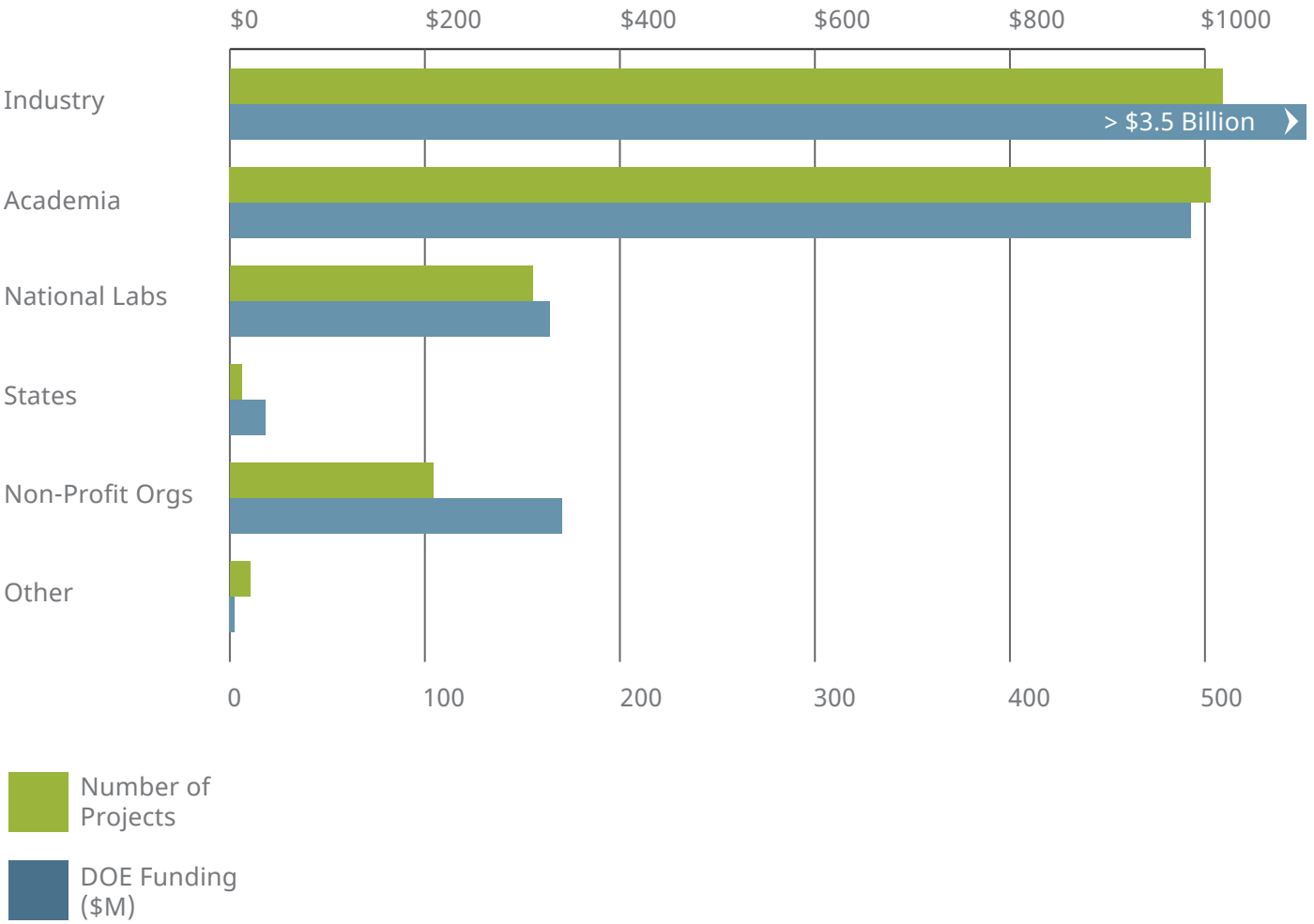




Many Partners, One Mission

NETL engages many partners at other federal agencies and laboratories, the private sector, and some of the nation's most prestigious research universities in pursuit of its energy mission. By leveraging resources and blending skills and knowledge, we are able to efficiently and affordably create and deploy technologies to enhance the nation's energy foundation and protect the environment for future generations.

NETL's ongoing portfolio of responsibility features nearly 1,400 nationwide energy research activities that engage experts and facilities in the private sector, academia, and government with a total award value of more than $15 billion and a nearly $10 billion performer cost-share.



Proven Expertise

For more than 100 years, NETL has led the way in energy innovation and research. NETL continues to discover and adapt new technologies and innovations that maintain the nation's energy independence with safe, clean, and reliable sources of power. Each year, researchers push the boundaries of scientific advancement, and FY15 signaled another productive year of achievement across a wide range of energy technologies.

The stories on the following pages are examples of NETL's work and how the Laboratory continues to support DOE's mission to promote the energy security of the United States. These accomplishment descriptions summarize projects and technologies that showcase the far-reaching capabilities demonstrated in NETL's world-class facilities. NETL continues to lead the world in energy innovation and environmental stewardship.

Preparing Workforce for Energy Sector Jobs

The RAND Corporation released two energy-sector workforce development studies conducted on behalf of NETL. The two studies, one targeting the state of West Virginia and one the southwestern Pennsylvania (SWPA) region, provided recommendations that support DOE's strategic objective to increase energy productivity and ensure safe and responsible development of domestic energy resources.

The West Virginia study evaluated how the state's high schools and the West Virginia Community and Technical College System are preparing workers for the shale gas industry. The second study focused on the 32 contiguous counties in Pennsylvania, Maryland, West Virginia, and Ohio that take part in the Power of 32 regional visioning project and collaborative initiative. The SWPA study focused on ways to recognize the direction of technological innovations and then align energy-sector workforce training to match the trends.

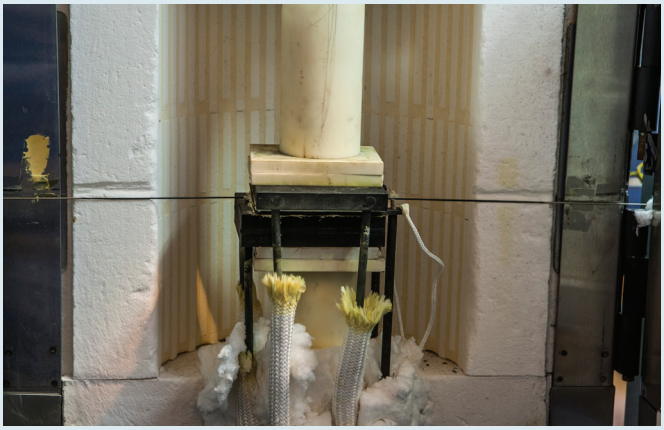
The results of the new studies, along with other programs currently underway by NETL, continue to build a solid foundation for creating an educated workforce that will be prepared for the challenges and novel technologies of tomorrow's energy industry.

Demonstrating CO_2 Capture and Conversion in Texas

DOE and Skyonic Corporation marked the opening of a major project demonstration for converting CO_2 into commercial products. The technology builds upon several years of modeling, testing, and analysis performed by Skyonic and supported by the Energy Department through NETL management. The new Skymine® plant is using a first-of-its-kind process to capture 75,000 tons of CO_2 from a San Antonio, TX, cement plant and converting the greenhouse gas into other products, including sodium carbonate and sodium bicarbonate, hydrochloric acid, and bleach. The process will also remove most of the sulfur oxides, nitric oxides, mercury, and other heavy metals from the flue gas.

The SkyMine technology was designed to retrofit existing coal-burning facilities but also holds potential for heavy-industry applications, including cement, glass, steel, and natural gas power. The byproducts produced through this process will offset other products with higher carbon footprints, and they can be safely stored indefinitely.

The SkyMine project has already had a substantial impact on the local economy, creating more than 250 jobs during construction, and will provide more than 40 new permanent full-time jobs.



Testing Optical Sensors for Improved Energy Efficiency

NETL, in collaboration with the University of Pittsburgh, successfully tested an optical-based sensor that analyzed chemical composition, process temperature, and other conditions within the harsh environments of chemical reactors, solid oxide fuel cells (SOFC), and other advanced energy-related processes. The utility of the new sensing device was demonstrated in a SOFC capable of operating at 1500 °F and will assist operators in controlling the energy processes.

The ability to remotely monitor parameters inside the harsh environments found in energy production systems will provide insights that could lead researchers to optimize the internal reactions or reaction gradients and improve efficiencies. Data from the sensor can also be used to predict long-term performance and monitor operational changes in SOFCs with higher precision than presently available.

An international patent application entitled “System and Method for Monitoring a Reactor System Using Optical Fiber Based Sensors” was filed jointly with the University of Pittsburgh.

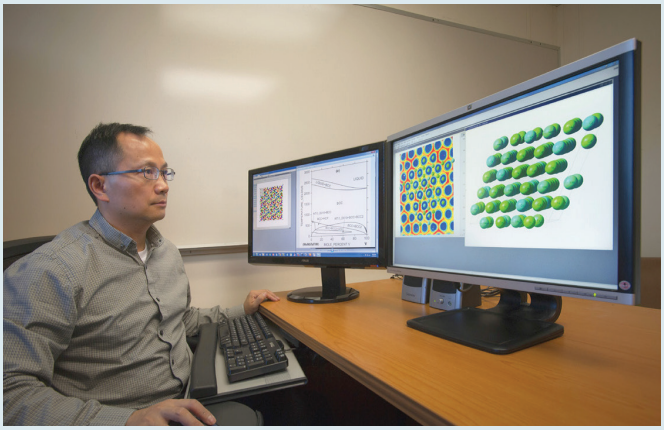
Photo courtesy of the National Alternative Fuels Training Consortium

Advancing EV and Smart Grid Projects

Four infrastructure improvement projects, managed by NETL as part of the DOE Office of Electricity Delivery and Energy Reliability’s Smart Grid Research and Development Program, have successfully reduced the cost of electric vehicle (EV) charging equipment by 45–55 percent of the current price point.

Two of the projects were aimed at improving EV charging at residential locations (Siemens and Delta) and two targeted commercial sites (GE Global Research and Eaton Corp.). The projects were required to deliver innovations for infrastructure improvements that were independently tested before moving into a demonstration phase. Successful cost reductions were achieved by consolidating circuitry, improving manufacturing methods, and incorporating modular designs.

EVs have become increasingly popular on America’s highways, as evidenced by an anticipated 60 new commercial models on the market horizon. With this growing popularity, providing a reliable way of charging all of these new EVs has become an important issue. The Energy Department strives to increase the availability of reduced-cost EV supply equipment—the equipment that provides electricity for charging EVs—because increasing the availability of charging infrastructure across the country will increase the attractiveness of EV ownership.



Aiding Advanced Alloy Development with New Database

Recognizing a need for more complete input data for alloy design, NETL researchers collaborated with their partners at Pennsylvania State University to develop new databases that incorporate specific design parameters to better predict how environmental factors will affect alloy performance.

Computational models capable of predicting how alloys will perform in complex environments are important tools for successfully developing new alloys. However, predictive models and simulations for designing complex alloys are often limited by the availability and integrity of the data from which they are constructed.

The research team developed a unique set of thermodynamic and kinetic databases for an alloy system consisting of five components: nickel, iron, aluminum, oxygen, and hydrogen. The databases help predict important parameters of the elements in the alloy. These parameters are key inputs for simulations aimed at determining environmental effects on a material's performance.

Alloy-based materials that are both cost effective and able to withstand severe environments are required for advanced energy systems, which will operate at higher temperatures, pressures, and under potentially harsher and more corrosive conditions compared to traditional power plants.

Reducing Peak Power Loads at the Nation's Largest Jail

A California jail, the fifth largest in the nation, hosted a demonstration project managed by NETL that showed how a microgrid can reduce energy consumption and shave thousands of dollars off an annual electricity bill.

A microgrid is a small-scale power grid that can operate independently of or in conjunction with an area's main electrical grid. In the NETL-managed project, Chevron Energy Solutions installed a microgrid at the Santa Rita Jail in Dublin, CA, as part of the DOE Office of Electricity Delivery and Energy Reliability's Renewable and Distributed Systems Integration Program.

Several factors are involved in a productive microgrid: dedicated power-generation sources, customer loads, a defined electrical boundary, and a switchable connection to the main power system. The microgrid at the Santa Rita Jail includes a fuel cell capable of producing heat and power, a solar photovoltaic system, wind turbine generators, battery energy storage, backup diesel generators, and smart grid control features.

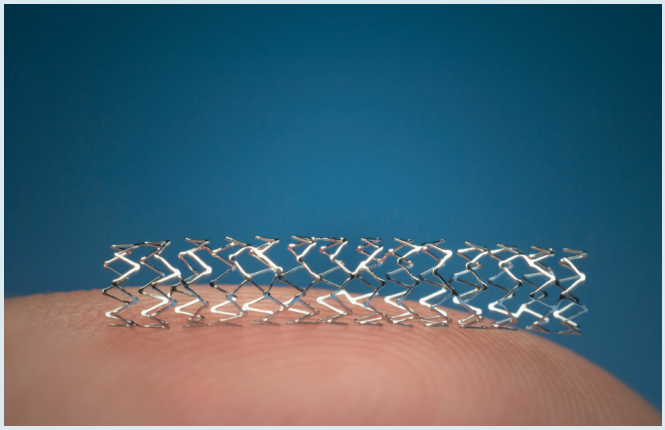
During the demonstration, the microgrid reduced the jail's peak power load by 95 percent and reduced energy consumption during peak hours by 98 percent while achieving an annual savings of $110,000 on electricity bills. Operation of the microgrid also reduced the load on the local distribution feeder serving the jail by about 15 percent, reducing wear-and-tear on substation equipment.

Encouraging Students to Pursue Energy Careers

NETL's Pittsburgh site hosted a "My Brother's Keeper Day at the Lab" in July. The Laboratory was one of four in the country selected to host the event as part of President Obama's My Brother's Keeper initiative, which challenges cities to focus on programming for at-risk youth.

My Brother's Keeper is a nonprofit organization that helps students overcome barriers to success. The organization focuses on six milestones: getting a healthy start and entering school ready to learn; reading at grade level by third grade; graduating from high school ready for college and career; completing postsecondary education or training; successfully entering the workforce; and keeping kids on track and offering second chances.

More than 100 middle and high school students attended the event, participating in hands-on, age-appropriate experiments designed around science, technology, engineering, and math. Students also toured the research facility, with site tours highlighting the process of extracting natural gas from the Marcellus Shale. Students also learned how drones discover sites for well pads, how drillers find shale deep underground, and how to clean up an oil spill. The Pittsburgh CARES Mentoring Movement and the Urban League of Greater Pittsburgh, a nonprofit that provides educational programs for under-served minority students, also sponsored the event.



Receiving Honors for NETL Alloy Innovation

For their work on the development, transfer, and successful commercialization of a novel platinum-chromium alloy used in next-generation coronary stents, scientists at NETL and their colleagues received the 2015 ASM Engineering Materials Achievement Award from the materials science and engineering society ASM International.

NETL developed the alloy in collaboration with researchers at Boston Scientific Corporation. It is the first stainless steel formulation for stents with a significant concentration of platinum, making it easier for coronary specialists to see the stent on x-ray during placement and expansion. The alloy also increases the stent's corrosive resistance, strength, and flexibility.

Stents made from the alloy benefit patients by shortening recovery time and avoiding follow-on procedures and more invasive surgery, which reduces healthcare costs. Since their commercial introduction in 2010, the stents have generated more than $6 billion in sales and captured a 33 percent U.S. share and a 25 percent global share of the coronary stent market using the platinum-chromium alloy.

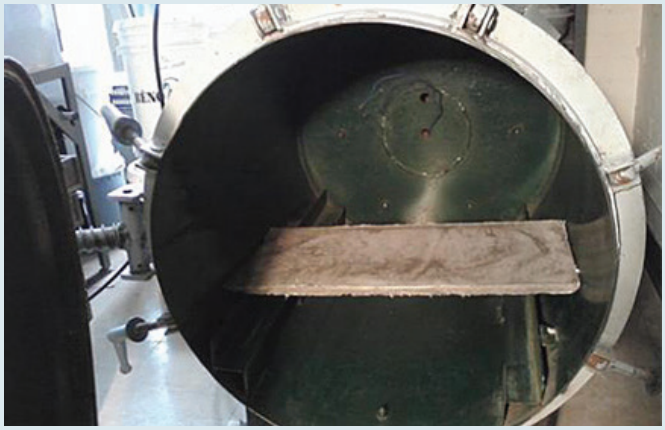
Engineered and manufactured in the United States, the stent series has created 450 sustainable domestic jobs. Carpenter Specialty Alloys, Accellent, and Minitubes Corporation also played a role in the progression from laboratory to market that made the alloy and subsequent stents a success.

Converting CO_2 with Renewable Energy

A new process conceived and developed by NETL researchers can efficiently convert CO_2 into usable chemicals and fuels—a breakthrough that could lead to an effective industrial-scale way to reduce CO_2 emissions for a positive impact on the environment.

An effective CO_2 conversion process must change CO_2 from a waste product into a useful feedstock in an environmentally sustainable way, allowing the manufacture of renewable fuels and chemicals at costs comparable to more traditional processes. The problem is that most fossil-fuel-powered CO_2 conversion processes are currently "carbon positive" and do not help mitigate CO_2 emissions. NETL's new process incorporates a special form of gold nanoparticle to convert CO_2 and uses renewable energy sources to recycle waste CO_2 into chemicals and fuels without generating new CO_2 emissions. The result is a "carbon neutral" energy cycle. The process will help slow global climate change by limiting CO_2 emitted to the atmosphere, offer an environmentally friendly supplement to traditional energy sources, and enable sustainable use of our current fossil fuel resources.

Data obtained from the study also informs critical performance estimates needed to move the carbon-neutral energy cycle out of the lab and into industrially relevant applications. Based on their results, the research team estimates that state-of-the-art renewable energy sources like solar cells and wind turbines are sufficient to convert metric tonnes of CO_2 per day.



Developing Concrete CO_2 Curing Technology

Highly specialized new equipment designed to increase the efficiency of a novel concrete CO_2 curing process, which not only reduces greenhouse gas emissions but also significantly reduces the amount of water needed in the curing process, has resulted from a productive new partnership of companies that received key NETL support.

Solidia Technologies developed the curing process with NETL funding. The new partnership involving Solidia and CDS Group, the world's largest company specializing in curing and drying concrete.

The new innovations include technological upgrades for existing curing chambers and the design and manufacture of new curing chambers.

According to current analysis by Solidia, the manufacture and curing of cement using the new approach reduces the carbon footprint by about 60 percent. In addition, the process uses 90 percent less water compared to traditional preformed products.

Solidia reports that the technology offers manufacturers significant cost savings compared to water-based curing of conventional cement as a result of faster curing times, lower energy and raw material consumption, reduced waste generation and reduced labor requirements, while improving the performance of building materials using existing equipment, materials, and formulas.

Advancing Solid-State Lighting Technologies

By 2030, solid-state lighting (SSL), such as light-emitting diodes (LED), could potentially reduce national lighting electricity use by nearly one-half, which is the annual equivalent of saving $30 billion (in today's dollars), or the output of 50 1,000-megawatt power plants. NETL manages SSL projects as part of DOE's Energy Efficiency and Renewable Energy Buildings Program aimed at facilitating the advancement of LED technologies, including partnerships with Research Triangle Institute (RTI) to better predict LED lighting product reliability and with Philips Lumileds to achieve significant performance gains.

The RTI project resulted in the development of a reliability prediction tool that uses software to model complex failure mechanisms. The tool considers a wide-range of reliability factors, including the interactions between hardware components, decrease in light output, and color shift over time.

The SSL manufacturing, research, and development project with Philips Lumileds achieved significant performance gains using a low-cost and efficient LED fabrication process. Rapid progress was made in the second-generation technology, which was incorporated into a commercialized product with a 12 percent increase in the perceived brightness of the light.

Completing 15 Years of Stripper Well Tech Transfer

The NETL-led Stripper Well Consortium (SWC), formed in 2000 to assist the nation's stripper well companies, successfully concluded 15 years of technology transfer in 2015. Stripper wells produce natural gas or oil at very low rates (less than 10 barrels of oil per day or less than 60 thousand cubic feet of gas per day). Despite their small output, stripper oil and gas wells contribute significantly to the nation's energy supply and are the lifeblood of thousands of small, independent oil and gas operating companies.

Since its inception, SWC funded nearly 100 projects, resulting in 53 patents. Each proposal was required to provide a minimum of 30 percent cost-share, which project participants provided. Many of the technologies developed through SWC have proved valuable for stripper wells, as well as for unconventional oil and gas resources such as enhanced oil recovery and coalbed methane extraction.

SWC is an industry-driven association of natural gas and petroleum producers, service companies, industry consultants, universities, technology developers, and industrial trade organizations that focuses on the development, demonstration, and deployment of new technologies needed to improve the production performance of natural gas and petroleum stripper wells. For the last 15 years, NETL has helped reduce U.S. dependence on foreign oil by facilitating domestic oil and gas production through funding of the SWC.

Providing Enhanced Oil Recovery Software

New software developed by NITEC LLC (Denver, CO) under a cooperative agreement with NETL enables quicker, more affordable technical studies of CO_2 enhanced oil recovery (CO_2-EOR) for small- to mid-sized U.S. oilfield operators.

The software, called COZView/COZSim, addresses the physical and phase behavior factors that impact the flow and recovery of reservoir fluids, such as solubility of CO_2 in water and oil or swelling of oil in the presence of CO_2, and yet it makes the simulation and evaluation process fast enough that an integrated feasibility study can be completed in a relatively short time period. A CO_2-EOR study on candidate oil-bearing reservoirs using COZView/COZSim can be completed within 1 month, compared to the 6 or more months required for other approaches.

EOR allows oilfields that are nearing the end of prime oil production to continue contributing to the U.S. energy portfolio. By injecting CO_2 into these oilfields, operators can mobilize a portion of the remaining oil, which would otherwise be difficult to extract, thus extending the reservoir's productive life.

Developing Measurement Tools for Underwater Oil Blowouts

NETL teamed with the U.S. Department of Interior's Federal Bureau of Safety and Environmental Enforcement (BSEE) to create the largest subsurface oil leak ever produced in a controlled experiment. It was designed to help researchers from NETL and University of California Berkeley develop a technique to use video from remotely operated vehicles to measure deep sea oil leak rates.

The experiment took place at Ohmsett, BSEE's National Oil Spill Response Research and Renewable Energy Test Facility in Leonardo, NJ, where a subsurface flow of up to 30,000 barrels a day was produced for the study. Ohmsett is the largest outdoor saltwater wave/tow tank facility in North America and is the only facility where full-scale oil spill response equipment testing, research, and training can be conducted in a marine environment with oil under controlled environmental conditions.

NETL's involvement in the project grew out of its work on high-speed imaging of multiphase flows—mixtures of gas, liquids, and particles that are common in advanced fossil fuel systems. NETL experts in multiphase flow issues were invited to be part of the National Incident Command's Flow Rate Technical Group, Plume Team to quickly generate official government estimates of the oil leak rate from the Deepwater Horizon incident. The National Incident Command used the leak-rate estimates to plan a correct level of response.

Testing CO_2 Capture Solvents

Pilot-scale testing of an advanced technology for economically capturing CO_2 from flue gas began in January 2015 at the National Carbon Capture Center in Wilsonville, AL. Under a cooperative agreement with NETL, Linde LLC is operating a nominal 1-megawatt-electric (MWe) pilot plant expected to capture 30 tons of CO_2 per day. Cost-effective carbon capture and storage from fossil-based power generation is a critical component of national efforts to mitigate climate change.

Testing at the pilot plant is validating performance of the Linde-BASF CO_2-capture technology on actual coal-derived flue gas. The technology integrates BASF's advanced aqueous amine-based solvent (OASE® blue) and process technology with novel CO_2 capture process and engineering innovations being developed by Linde.

OASE blue chemically absorbs CO_2 from the flue gas at a relatively low temperature in the absorption column. The CO_2-rich solvent is then transferred to a stripping column where steam is added to heat the solvent, reversing the chemical reaction and releasing high-purity CO_2 for compression and pipeline transport.

Stable pilot plant operations were achieved within 1 week and the pilot plant has operated reliably for approximately 2,000 hours while demonstrating greater than 90 percent capture of a high-purity CO_2 product at elevated pressure.

Inventing Improved Oxygen Carriers

NETL researchers invented promising new oxygen carriers that could play a key role in advancing a cost-saving CO_2-reducing energy generation system known as chemical looping combustion (CLC)—a process that combusts fossil fuels in nearly pure oxygen rather than air.

In CLC systems, oxygen is introduced via oxygen carriers. Successful deployment of chemical looping technologies requires development of affordable, high-performance oxygen carriers. NETL researchers worked to enhance the performance of hematite-based oxygen carriers so they can release oxygen rapidly and stand up to high reactor temperatures typical in chemical looping systems. Researchers also pilot tested a promising mixed metal oxide oxygen carrier that features copper-based oxygen carriers mixed with iron oxide.

Copper-based oxygen carriers have had limited success because of issues at high temperatures. However, NETL experts designed a new oxygen carrier with high copper concentration that allowed it to withstand high temperatures with excellent results during a pilot-scale test that was run in NETL's chemical looping circulating fluidized bed combustor unit.

These new oxygen carriers could have applications beyond electricity generation. CLC is also useful in industrial steam production and can also be used to produce hydrogen or synthesis gas from methane.

Testing Membranes for Post-Combustion CO_2 Capture

A promising new technology sponsored by DOE for economically capturing 90 percent of CO_2 emitted from a coal-burning power plant exceeded expectations during pilot-scale testing in June 2015, with consistent performance of all components on coal-fired flue gas. The testing, which was performed with commercial-grade membrane modules, also successfully proved first-of-a-kind components and advanced commercial manufacturing techniques.

The technology is the Polaris™ membrane system, developed by Membrane Technology and Research Inc. The system uses a specially designed CO_2-selective membrane—a micro-porous film that acts as a semi-permeable barrier—to separate CO_2 from other gases, such as nitrogen, in a coal-burning plant's flue gas. The Polaris system was tested for 1,500 hours at 1 megawatt-electric pilot scale, with over 10,000 hours of the membrane process. The project, managed by NETL, is the largest-scale CO_2 membrane technology in DOE's research portfolio and has the potential to support the reduction of greenhouse gas emissions from coal-fired power plants while minimizing the increase in electricity price.

The Polaris system is 10 times more permeable to CO_2 than conventional gas-separation membranes. That means the membrane area can be reduced, cutting down the cost and size of the system. In addition, the membrane system does not use hazardous chemicals, has no moving parts, and uses less water than other capture technologies.

Creating Fiber-Optic-Based Hydrogen Sensors

NETL researchers developed and tested new high-temperature resistant fiber-optic-based sensors for use in hydrogen sensing applications.

Advanced gas sensors capable of operating under elevated temperatures and harsh environments are required for next-generation fossil fuel power generation and to enhance existing power systems. Innovative optical fiber-based sensing materials capable of functioning in extreme environments will play a key role in improving efficiency while providing global environmental benefits through reduced greenhouse gas emissions.

NETL's new hydrogen sensors showed rapid, reproducible sensing response to hydrogen fuel gas streams at elevated temperatures. The new sensing material has the potential to improve process monitoring and control of solid oxide fuel cells resulting in improved operating efficiency, long-term durability, and functionality through improved embedded hydrogen sensing. Optical fiber-based hydrogen sensors can be applied to additional energy systems including gas turbines, boilers, and oxy-fuel combustion.

Optical-based sensors offer distinct advantages including broadband wavelength and compatibility, resistance to electromagnetic interference, and the elimination of electrical wires and contacts, which are commonly associated with sensor failure.

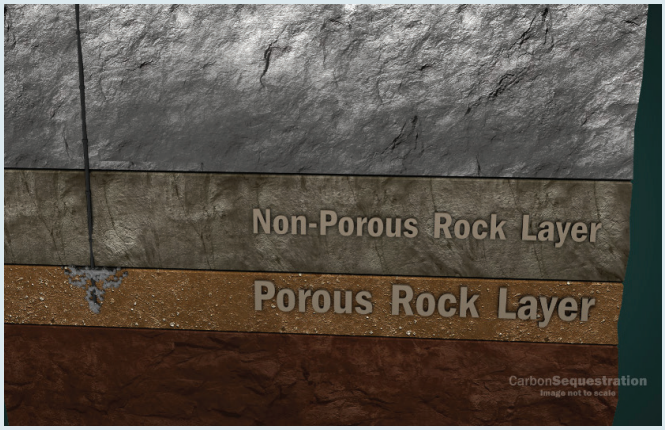
Testing Novel Method to Increase Oil Recovery

Successful laboratory tests by NETL verified that the use of a brine-soluble ionic surfactant could improve the efficiency of CO_2 enhanced oil recovery (CO_2-EOR).

Surfactants stabilize the formation of foams composed of high-pressure CO_2 bubbles separated by thin films of surfactant-stabilized brine. The tiny foam bubbles allow the CO_2 to function as an extremely thick fluid that an operator can use to effectively clog high-permeability, oil-depleted "thief" zones, in which fluids could be lost. CO_2 injected after a foam is established will tend to flow into the oil-rich low-permeability layers, thereby increasing incremental oil production, decreasing CO_2 used, and reducing associated recycling and re-compression costs.

The testing paves the way for the first field test in which a surfactant will be dissolved in both the brine and CO_2 phase of a new EOR effort. This new process supports technologies being developed by the Office of Fossil Energy's Natural Gas and Oil Program to increase oil recovery beyond current state-of-the-art techniques.

CO_2-EOR facilitates the extraction of oil from reserves that would otherwise be too difficult or costly to retrieve. NETL's research focuses on a process in which a commercial surfactant is dissolved in high-salinity brine. Researchers are also focusing on a novel process in which a surfactant is dissolved in the brine and a different surfactant is dissolved in the CO_2.



Collaborating to Advance CO_2 Storage

DOE and Shell Canada announced in February 2015 that they will collaborate in field tests to validate advanced monitoring, verification, and accounting (MVA) technologies for underground storage of CO_2.

The tests will take place at Shell's Quest Carbon Capture and Storage (CCS) project in Alberta, Canada. The Shell Quest team and technology developers funded by DOE and managed by NETL, have discussed opportunities to field test and validate advanced MVA technologies at the Quest CO_2 underground storage site.

The Quest project is primarily funded by the Government of Canada and the Canadian Province of Alberta. DOE is leveraging a federal investment of approximately $3 million in existing and ongoing projects in its research and development program by proposing roughly $500,000 for the collaborative effort to field test advanced MVA technologies that have the potential to provide highly reliable, robust, and lower-cost monitoring technologies to CCS projects in the United States and throughout the world.

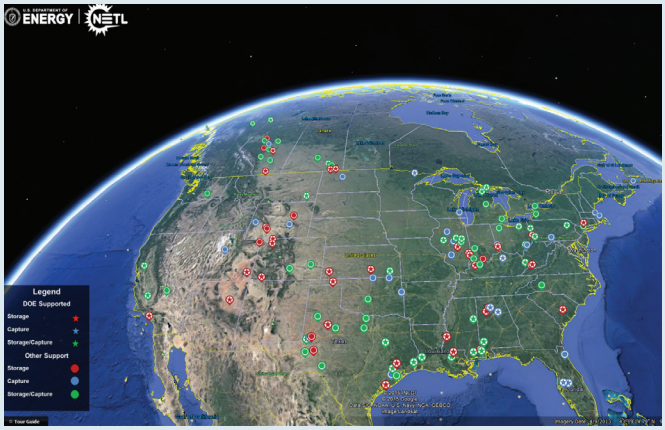
Demonstrating Syngas Cleanup Technology

In a project sponsored by DOE and managed by NETL, a commercially relevant scale-up of RTI International's warm synthesis gas (syngas) cleanup process technology achieved a key operational milestone by accumulating 1,000 hours of operation at Tampa Electric Company's coal gasification plant in Polk County, FL.

By the end of the project in September 2015, the 50 megawatt equivalent (MWe) warm desulfurization process unit accumulated 1,465 hours of operation on a coal- and petroleum-coke-based syngas feed and achieved 99.9 percent sulfur removal at temperatures as high as 600 degrees Celsius.

The project integrated its warm desulfurization process with a downstream carbon capture system that also polished residual sulfur from syngas. The integrated warm syngas desulfurization and carbon capture processes achieved a total sulfur concentration at less than 1 part per million, resulting in more than 99.99 percent total sulfur removal. The new, lower-cost process cleans the syngas to levels below U.S. Environmental Protection Agency requirements and enables the syngas to be used cost-effectively in the production of chemicals and fuels.

RTI's syngas cleanup technology removes contaminants at warm process temperatures, reducing or eliminating the need for syngas cooling and heat-recovery systems, increases thermal efficiency and reduces the capital and operating costs of new gasification-based systems.



Showing Where CO_2 Is Captured and Stored

Capturing carbon emissions and storing them safely and permanently so they don't reach the atmosphere is a key technology in mitigating climate change. The technology, called carbon capture and storage (CCS), allows a wide range of fuels to be used to generate power while still protecting the environment.

NETL released an updated version of a database that identifies 274 proposed, active, or completed CCS projects worldwide—a significant increase from the initial 192 projects identified in 2009. The projects are found in more than 30 countries across 6 continents.

Information from the database is loaded into a layer on Google Earth™ to provide the location of each project, where available. Clicking on a project location opens a new window containing a summary of the project—information such as estimated costs, start and completion dates, method of capture or source of CO_2, and status and amount of CO_2 captured and stored. If a user would like even more detail, external links are provided.

The database is also available for download in a Microsoft® Excel® file. All of the projects are updated yearly, or as new information becomes available.

Confirming Resources in Residual Oil Zones

A geologic core extracted from a West Texas well during a CO_2 flood and analyzed by NETL-sponsored researchers has confirmed that CO_2 enhanced oil recovery (CO_2-EOR) can "push out" oil from largely untapped areas called residual oil zones (ROZs). This finding further demonstrates that these zones hold the potential to harvest billions of barrels of additional oil that could increase domestic supply, reduce imports, and increase U.S. energy security.

ROZs are areas of immobile oil between or beneath oil-bearing reservoirs that are found below the oil-water contact (the first observance of water). In these zones, natural water flooding has swept away much of the original oil, leaving the residual oil behind. Since water has already swept the mobile oil, recovery of the oil in these zones is not feasible using primary or secondary oil recovery. Enhanced oil recovery techniques, such as CO_2-EOR, are needed to successfully produce it and can offer tremendous CO_2 storage capacity during the process.

In the NETL project, a research team led by the University of Texas-Permian Basin analyzed a geologic core taken during a pilot test from a well at the Goldsmith-Landreth San Andres Unit in the Permian Basin, Ector County, TX. The results provide unique insights into the residual oil saturation and potential oil displacement efficiency of the CO_2-EOR process.

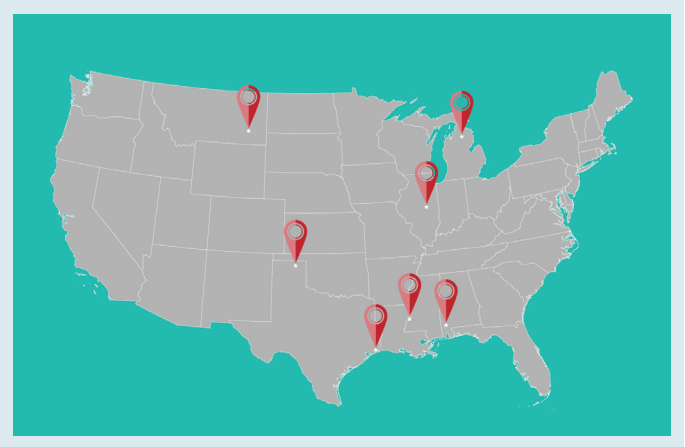
Producing Global Outlook on Natural Gas Hydrates

Researchers at NETL were part of an international team, including the United Nations Environmental Programme that contributed to a newly released report explaining the prospect of gas hydrates as a potential worldwide energy source that can contribute in the transition to the low-carbon energy systems of the future.

Frozen Heat: A Global Outlook on Methane Hydrates details the science and history of gas hydrates, evaluates the current state of gas hydrate research, and explores the potential impacts of gas hydrates on the future global energy mix. Gas hydrates contain an immense quantity of methane gas—a fossil fuel that, when combusted, emits up to 40 percent less CO_2 than coal and 20 percent less than oil. According to the report, there may be regions in the world realizing meaningful production of natural gas from gas hydrates in the next 10 to 20 years.

NETL has been investigating this resource and the environmental implications of gas hydrates as part of DOE's all-of-the-above energy strategy and to improve our understanding of ongoing climate change.

In the United States, gas hydrates are confirmed to exist in great quantities onshore on Alaska's North Slope and underneath the seabed throughout the Outer Continental Shelf where water depth exceeds 500 meters. In the Gulf of Mexico alone, more than 6,000 trillion cubic feet of gas is estimated to exist within the most promising gas hydrate accumulations.



Marking 10 Millionth Metric Ton of CO_2 Captured

In a landmark accomplishment, DOE announced in April 2015 that a group of carbon capture and storage (CCS) projects supported by the Department safely captured 10 million metric tons of CO_2—the equivalent of a year's worth of emissions from 2 million passenger vehicles. CCS is the separation and capture of CO_2 from power plant and industrial emissions. The captured CO_2 is then injected and stored in deep underground geologic formations. In a number of CCS projects, the CO_2 is utilized to enhance oil recovery from mature wells.

This milestone builds on the Obama Administration's goals of providing clean energy, supporting American jobs, and reducing emissions of carbon pollution. Rapid commercial development and deployment of clean coal technologies, particularly CCS, will help position the United States as a leader in the clean energy race.

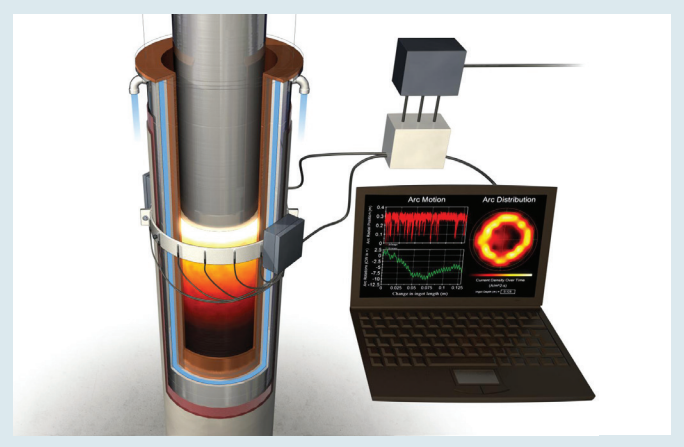
Advancing Exploration of Utica Shale Play

In a 2-year study organized by West Virginia University (WVU), and supported by NETL and 14 industry partners, the Utica Shale Appalachian Basin Exploration Consortium investigated and produced a report entitled, the *Geologic Play Book for Utica Shale Appalachian Basin Exploration*. The pioneering study indicated that that the newly explored Utica Shale, which underlies the better-known Marcellus Shale, could hold far more natural gas and oil than previously estimated.

The 2-year study estimates technically recoverable volumes of 782 trillion cubic feet of natural gas and nearly 2 billion barrels of oil. These results, which build upon and further refine previous estimates, far exceed a 2012 assessment conducted by the U.S. Geological Survey and highlight new potential for the Utica Shale.

Results from the comprehensive study were incorporated into the *Geologic Play Book for Utica Shale Appalachian Basin Exploration* and made publicly available at the Utica Shale Play Book Study Workshop, which was hosted by WVU and sponsored by the Petroleum Technology Transfer Council and the Environmentally Friendly Drilling Systems program. The results are also available in a searchable and interactive database.

In addition to NETL, financial sponsors of the study included Anadarko, Chevron, CNX, ConocoPhillips, Devon, EnerVest, EOG Resources, EQT, Hess, Range Resources, Seneca Resources, Shell, Southwestern Energy, and Tracker Resources.



Licensing Arc Position Sensing Technology

NETL issued two licenses involving its arc position sensing technology to KW Associates LLC, an Oregon-based company founded by the technology's inventors. Arc position sensing technology is a patented, award-winning measurement technology developed for the specialty metals industry to identify arc distribution conditions during arc melting. The unique technology allows operators to optimize the processing to improve material yield, decrease energy use, and improve safety systems.

Specialty metals, such as titanium or zirconium, that are used in aerospace, airline, and other advanced applications often undergo a metallurgical casting process called vacuum arc remelting to refine an alloy's chemical and physical homogeneity. During the process, electrical power heats a consumable electrode by means of an electric arc—a luminous electrical discharge like a lightning strike—and the melting material drops into a water-cooled copper crucible. Poor processing can lead to defects in the resulting ingot; the defects, in turn, can cause failure in engineering applications, so manufacturers must perform extensive testing on all ingots.

NETL's arc position sensing technology digitally monitors arc locations during vacuum arc remelting. Knowing where the arcs are helps the engineer control them and the melting process to produce consistently defect-free materials. Ultimately, the technology is expected to increase a manufacturer's yield and decrease the energy required to manufacture high-quality alloys.

Studying Shale Gas Production

NETL partnered with West Virginia University, Northeast Natural Energy, and The Ohio State University on a project to monitor the process and progress of unconventional gas production at a Marcellus Shale well near Morgantown, WV.

The Marcellus Shale Energy and Environmental Laboratory (MSEEL) project—the first of its kind—will enable continuous monitoring of produced water and air quality. The project also gives researchers access to a dedicated science well for subsurface geophysical observation while Northeast Natural Energy deploys a range of next-generation well-completion technologies designed to increase operational efficiency and reduce environmental impact. MSEEL will also provide a venue to train and educate next-generation scientists and engineers.

Northeast Natural Energy began drilling two production wells in the Morgantown Industrial Park in June 2015. A third well, the dedicated vertical science well, is situated between the two horizontal production wells, will be used to gather valuable information that will assist with optimizing lateral well placement and hydraulic fracture design during well stimulation in the Marcellus Shale.

Conducting First Shear Fracture Visualization Test

For the first time, researchers at NETL have developed a way to observe shear fractures—which could impact CO_2 storage—in rock cores at the elevated pressures that would occur underground. Using a specially designed holder in NETL's CT Imaging Facility, computed tomography (CT) scans of the core during shearing showed how changes in a rock's fracture geometry lead to changes in its permeability. Changes in rock permeability can change how CO_2 moves once injected in geologic formations and may determine how much CO_2 can be stored in a given reservoir.

Shearing occurs when one layer of rock "slips" over another. Existing fractures can shear when local pressures change in a reservoir, such as during the injection of CO_2. Shearing events are important to study because little is known about how slippage influences rock characteristics like permeability.

Researchers created fractures in the lab by manually breaking rock cores. Then two metal prongs were attached to the ends of the core and pushed toward each other, creating the shearing force on the fracture. During the shearing event, fluid is injected through the core sample and CT scans are made over time. The resulting scans show how the fracture changes as the shearing force alters its geometry.

Improving Power Plant Sensor Network Design

Researchers at NETL and West Virginia University (WVU) developed a powerful optimization-based algorithm for large-scale power plant applications that help engineers design better plant-wide sensor networks.

Modern power generation systems—like integrated gasification combined cycles (IGCC) with carbon capture—rely heavily on sensor networks to provide feedback for use in plant operation, control, and monitoring. Sensors are physical devices that measure process variables like temperature, flow rate, pressure, and chemical composition.

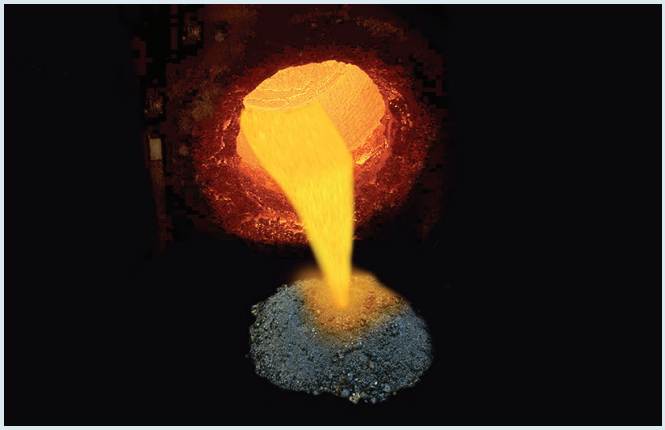
Until now, a myriad of possible configurations made it nearly impossible to manually design an optimal plant-wide sensor network. Powerful computational tools are required for systematically determining where best to locate sensors. Sensor network design (SND) involves multiple complex objectives including maximizing the accuracy of process measurements, minimizing the sensor network cost, and improving process monitoring and fault diagnosis capabilities.

NETL and WVU researchers have applied a new SND algorithm to the CO_2 capture process for an IGCC power plant. Results show that an optimal sensor network design can lead to a reduction in CO_2 emissions of more than 12,500 tons per year for a 735 megawatt IGCC power plant with 90 percent CO_2 capture—that's the equivalent of removing the yearly emissions from 2,600 cars.

Improving U.S./U.K. Power Generation

DOE, through NETL, and the U.K. Department of Energy and Climate Change supported a memorandum of understanding to share and develop knowledge and expertise in the key area of high-temperature materials for advanced fossil energy power plant applications. The Advanced Materials Collaboration has yielded key results on steam oxidation, boiler corrosion, gas turbines fired on syngas and other fuel gases, and oxide dispersion strengthened alloys.

U.S. and U.K. researchers worked together to generate more than one million hours of new steam oxidation data for 30 alloys; created two new high-pressure steam test facilities; improved service life prediction methodologies for future power plant designs; examined and measured the effects of novel technologies on boiler corrosion problems; tested and ranked a range of alloys and coating systems for gas turbines fired on syngas; successfully demonstrated the strength of new alloys for allowing power plants to operate at maximum operating stress; and made many more technology improvements.



Making Energy from Waste

Slag—waste from power plants and steel factories—was once thought worthy of little more than dumping in landfills worldwide. Now, as a result of technology developed by two NETL researchers, it can be used as a new source of energy and help reduce CO_2 emissions.

Different types of slags are produced as byproducts from different industrial processes. For example, one type of slag waste that is produced in steel processing is high in calcium oxide from mineral impurities and fluxing agents. Meanwhile, gasification that uses petcoke carbon feedstock results in slag that contains high levels of vanadium oxide.

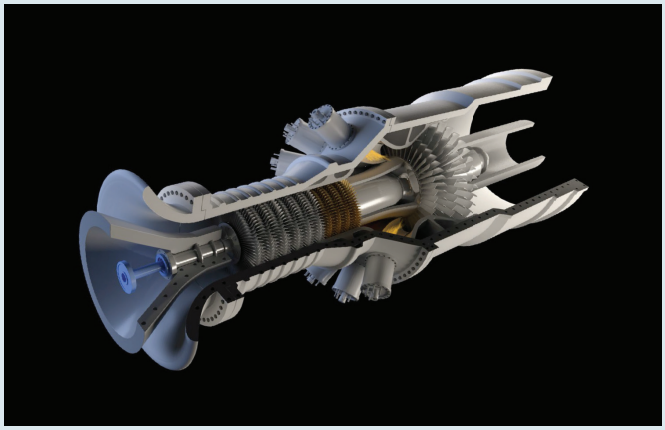
NETL researchers determined that if those two types of slag are mixed together in specific proportions upon discharge at molten temperatures in an atmosphere of CO_2 and/or H_2O, specific chemical reactions occur with positive implications for generating a syngas fuel (CO and/or H_2) for gas turbine or chemical production and producing exothermic heat for a steam turbine, which ultimately reduces CO_2 emissions.

The work was published in the *International Journal of Hydrogen Energy*, and it ranked among Elsevier's most downloaded articles of the journal. A provisional patent for the technology was filed that addresses the broad industrial applications for the approach.

Developing Ways to Measure CO_2 in Groundwater

NETL successfully tested two methods for detecting CO_2 at thermal springs and coal mine drainage sites. The work is important because if CO_2 were to leak from a geological storage site, it could migrate into overlying groundwater aquifers, some of which supply drinking water.

To spot leaks early and protect the water supply, sensitive and accurate methods are needed to measure CO_2 concentrations in the field. One method tested by NETL employs a carbonation meter to expand a sealed volume of water, via a process called "multiple volumetric expansion." The technique releases gases from solution in a controlled manner based on their relative ability to be dissolved. The resulting changes in temperature and pressure allow the CO_2 concentration to be accurately determined. A second method uses a non-dispersive infrared detector to identify CO_2 that escapes from the water and through a waterproof but gas-permeable membrane.



Raising the Bar for Alloy Performance

NETL materials scientists have developed a new alloy that displays superior performance under high-temperature conditions. This patent-pending alloy, called CPJ-7, could find applications in advanced boilers and turbines, which would require materials with superior high-temperature creep strength (the ability to resist deformation over long times due to applied stress), oxidation and hot corrosion resistance, and thermal fatigue resistance.

The operating efficiency of coal-fired power plants is directly related to combustion system temperature and pressure. Incorporating new heat resistant alloys into existing ultrasupercritical (USC) and new generation advanced ultrasupercritical (AUSC) steam conditions into new or existing power plants can increase efficiency, thereby reducing coal use and CO_2 emissions. Under both USC and AUSC conditions, system components in boilers and turbines are exposed to extremely high temperatures and pressures. These conditions contribute to already aggressive oxidizing environments that either shorten component functional life or require the use of thicker components or more costly alloys, resulting in increased power plant production and maintenance costs. Conventional materials do not possess optimal heat resistant characteristics for most efficient operation under USC and AUSC conditions.

Netting Award for CO_2 Capture Technology

NETL researchers have created a breakthrough technology that economically and efficiently absorbs CO_2 from fossil-fuel-burning power plant stack emissions—work that has attracted national innovation awards, as well as the attention of commercialization-minded private companies and a federal agency with plans to adapt it for space travel.

The basic immobilized amine sorbent (BIAS) technology is considered a breakthrough for two key reasons. First, it uses new high-capacity amine-based solid sorbents that maximize CO_2 removal. Second, these new sorbents can be regenerated for reuse in a novel process that reduces energy loss and minimizes moisture in the overall sorbent process, resulting in lower energy and water usage than today's wet scrubbing technology. BIAS can significantly reduce the cost penalty associated with carbon capture processes resulting in a more affordable means of generating cleaner energy from fossil fuels. Once captured, the CO_2 can be sequestered underground, or used in processes such as enhanced oil recovery.

Using Laser Technology for CO_2 Storage

NETL is attracting private industry attention and winning innovation awards for harnessing the power of lasers to monitor the safe and permanent underground storage of CO_2 resulting from fossil fuel combustion in power plants.

CO_2 is a greenhouse gas and byproduct of burning coal, oil, and natural gas. There are increasing calls to isolate CO_2 from the atmosphere to reduce its impact on global climate change. Once captured from a power plant, the CO_2 can be piped into underground geologic formations for permanent storage. NETL experts developed a technique, laser induced breakdown spectroscopy (LIBS), that can be used to validate that a storage site is not emitting CO_2, or provide early detection of leaks if they do occur.

Early leak detection will enable site operators to implement a faster mitigation response to stop the leak. This innovative laser technology is ideal for this application because it can analyze solids, liquids, and gases quickly from a distance at little expense.

Developing Harsh Environment Optical-Based Sensors

A new series of sensing materials developed and demonstrated by NETL researchers provides unprecedented real-time sensing capabilities. The materials are able to withstand the harsh environments associated with subsurface applications such as CO_2 storage and oil and gas drilling.

The novel materials are integrated with optical fiber-based sensors that respond to changes in pH. Levels of pH determine a range of geochemical reactions in subsurface environments and can indicate wellbore chemistry conditions that could lead to corrosion or other issues. The sensors are more compatible with high-temperature and high-pressure operation than traditional organic indicator dye-based pH sensors.

Innovative sensors can provide real-time information about temperature, pressure, flow, and chemistry, which are important parameters for monitoring CO_2 migration in geological formations and in drilling and hydraulic fracturing processes. Such sensors also hold potential for monitoring underground sources of drinking water to ensure that groundwater is not impacted by subsurface activities such as geological storage of CO_2.

Releasing New Carbon Storage Atlas

NETL released the fifth edition of the *Carbon Storage Atlas* (*Atlas V*) in September 2015, which shows prospective CO_2 storage resources of at least 2,600 billion metric tons—an increase over the findings of the 2012 Atlas. The increase is a result of improved accuracy and precision in storage resource calculations, additional information from formation studies, and refinement of storage efficiency.

Atlas V is a coordinated update of carbon storage resources, activities, and large-scale field projects in the United States. It showcases the progress that NETL scientists and engineers have made with their partners toward wide-scale deployment of carbon storage technologies. It also underscores the importance of the research partnerships and projects that are increasing our understanding of safe, permanent geologic storage of CO_2.

Deep geologic formations have the potential to store hundreds of years' worth of industrial greenhouse gas emissions, permanently preventing their release into the atmosphere. Of particular importance for U.S. energy security is the finding in *Atlas V* that approximately 230 billion metric tons of CO_2 could be stored in depleted oil and natural gas fields. This storage estimate equates to several decades' worth of emissions from stationary sources with the added benefit of enhancing oil and gas recovery.

Atlas V includes input from the more than 400 organizations in 43 states and four Canadian provinces that make up DOE's 7 Regional Carbon Sequestration Partnerships.

Delivering the CCSI 4th Generation Toolset

A team of researchers from the NETL-led Carbon Capture Simulation Initiative (CCSI) completed development of a new generation of the CCSI Toolset. The 4th Generation CCSI Toolset builds on the success of previous generations, which have provided industry with a higher level of confidence in the projected performance of carbon-capturing solvent systems on fossil fuel burning plants. The more confidence industry has in the safety, economy, and efficiency of new carbon capture technologies, the more likely those innovations can be deployed to remove greenhouse gases from emissions.

The capabilities of the tools in the 4th Generation CCSI Toolset were demonstrated via a number of case studies and were presented at several national and international conferences. Eleven companies have licensed the suite of computational tools and models, including GE, B&W, Alstom Power, Chevron, Phillips 66, EPRI, ESI, WS Corporation, Clean Energy Systems, SRI and GSE Systems. These companies are actively using the CCSI Toolset under a test and evaluation license.

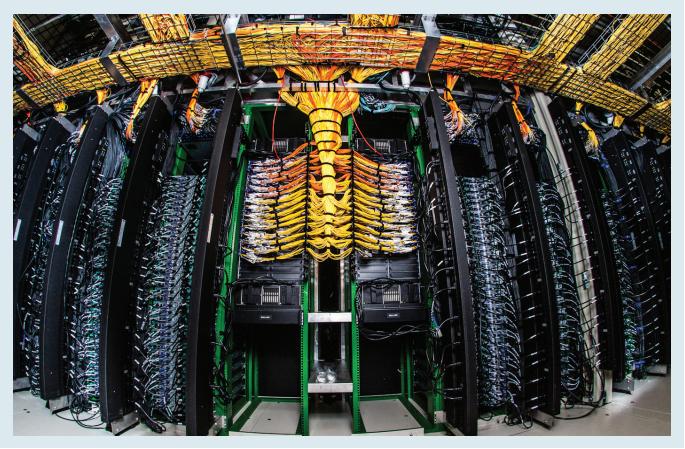
CCSI is a partnership of national laboratories, industry, and academic institutions that facilitates the development of computational modeling and simulation tools to accelerate the commercialization of carbon capture technologies.

Predicting and Preventing Underwater Oil Spills

A new modeling tool created by NETL scientists is helping to prevent future hydrocarbon leaks and providing a greater understanding of how hydrocarbon leaks from all sources are transported throughout offshore systems.

The Blowout and Spill Occurrence Model, or BLOSOM, can rapidly simulate offshore spills and leaks in hypothetical, “what if” scenarios. The resulting data, combined with other tools in DOE’s offshore hydrocarbon risk-assessment toolkit, can help prevent future incidents by identifying spatial trends and pinpointing knowledge and technology gaps that contribute to a higher risk of spills. BLOSOM comprises a suite of modeling components that can be run individually, to assess specific portions of a three-dimensional spill system (seafloor plume, intra-water column, and sea surface), or run together, to simulate an entire system’s behavior.

The new tool is part of DOE’s integrated risk-assessment modeling effort of offshore hydrocarbon systems, which aims to reduce uncertainty and improve science-based decision-making for stakeholders involved in supplying safe and reliable domestic energy. NETL developed BLOSOM using lessons learned from the Laboratory’s response to hurricanes Katrina and Rita in the Gulf of Mexico and the 2010 Deepwater Horizon oil spill.



Releasing Modeling Breakthroughs

NETL develops and supports innovative computational fluid dynamics models for evaluating multiphase flow in energy systems. The NETL-developed MFIX code, along with the supporting software package C3M, serves as a valuable tool to help industrial designers and operators improve process efficiency and reduce risks in design and operation. In FY15, NETL released two major updates to MFIX users, allowing faster and more efficient processing of data.

Gasifier performance over a range of operating conditions was modeled to verify the model's ability to predict specific behavior. Researchers observed excellent agreement between model predictions and experimental measurements over a broad range of operating conditions.

MFIX (Multiphase Flow with Interphase Exchanges) is a suite of multiphase flow computer code for describing the hydrodynamics, heat transfer, and chemical reactions in fluid-solid systems. C3M (Carbonaceous Chemistry for Computational Modeling) is a coal chemistry tool that works with MFIX to analyze the complex chemical kinetic reactions associated with coal gasification.

Discovering Technologies for Fuel Cell Improvement

Solid oxide fuel cell (SOFC) performance can be improved through cathode infiltration—the process of depositing a special coating on fuel cells to facilitate chemical reactions. NETL researchers have discovered three significant advancements for cathode infiltration of SOFCs that could lead to improved durability and performance as well as lower costs for electricity production, and ultimately commercialization.

The first technique involves using the NETL one-step nano-engineering electrocatalyst (NONA-lyst) process to infiltrate more than 40 full-scale commercial SOFCs, which were then evaluated by industry partners. The NONA-lyst process is commercially scalable and improves SOFC power density and durability, accelerating the infiltrated cell production by more than 5 times.

A second technique for cathode infiltration uses atomic layer deposition (ALD) to apply electrocatalyst onto the nanostructure of SOFC cathode surfaces. The highly precise ALD infiltration technology is commercially scalable and was proven to enhance total fuel cell peak performance by more than 60 percent in laboratory tests.

The third technique is a way to tailor SOFC cathodes and optimally distribute the electrocatalyst through functional grading. This technique enables the electrochemical activity within SOFC electrodes to be controlled locally, rather than across the entire electrode, for optimized SOFC performance.

Solving Big City Energy Challenges in Pittsburgh

The City of Pittsburgh and NETL signed a memorandum of understanding (MOU) in July to jointly design a 21st Century Energy Infrastructure that would showcase Pittsburgh as a "City of the Future" focusing on environmental, economic, and job-creation benefits. Work conducted under this MOU will position Pittsburgh as a national and global leader in the application of strategic energy models to solve the city's energy challenges.

The scope of the activities under this MOU will support Pittsburgh's efforts to modernize its energy grid, particularly involving combined heat and power systems. Other district-scale energy approaches will be undertaken, such as microgrids and expanding clean, renewable energy development. The MOU will serve as a model of cooperation between government, academia, and industry for other communities seeking to update aging infrastructure and legacy systems.

Aiding Schools with STEM Outreach Opportunities

Early engagement with science sparks the fire of curiosity and propels students into careers in science, technology, engineering, and math (STEM). STEM education increases scientific literacy, creates critical thinkers, and provides the tools for the next generation of innovators to take their place in the world.

During the 2014–2015 school year, NETL assisted with 12 Science Lab Days at regional elementary and middle schools. NETL also assisted with a Girls of STEM Day at Point Park University in Pittsburgh, PA, designed to inspire middle school and high school female minority students to pursue careers in STEM.

Science Lab Days are an important facet of NETL's educational outreach efforts. Staffed by NETL volunteers and held at regional schools, Science Lab Days deliver hands-on science to students between kindergarten and 8th grade. With simple experiments that teach complex concepts—from the power of ultraviolet light to understanding diffusion through scent—Science Lab Days make science accessible and augment classroom curriculums. Every activity NETL offers is designed to meet the National Research Council's National Science Education Standards.

Awards

The Society of Petroleum Engineers Reservoir Description and Dynamics Award for Eastern North America

The Reservoir Description and Dynamics Award for Eastern North America recognizes members who have contributed exceptional service and leadership to the society, as well as those who have made major professional contributions to their technical disciplines at the regional level.

Sinisha Jikich

The Council for Chemical Research Rising Star Poster Competition

The Rising Star Poster Competition highlights research from up-and-coming researchers whose work is seen as impactful on the chemical research community.

Jordan Musser for outstanding development efforts to enhance the code capabilities of Multiphase Flow with Interface eXchange (MFIX)

Pittsburgh Business Times Energy Leadership Award

The Pittsburgh Business Times Energy Leadership Awards honor individuals and organizations for their efforts in advancing energy business interests in western Pennsylvania.

Barbara Kutchko for her work in ensuring that oil and natural gas resources in volatile environments will be produced sustainably with minimal environmental impact

Shiwoo Lee for his one-step cathode infiltration technique

Society of Petroleum Engineers Star Fellowship

The Star scholarships and fellowships support those pursuing degrees related to the oil and gas industry. Recipients are awarded a single payment of USD 2,500.

Debb Glosser

Elsevier Highly Cited Review Paper 2012–2013

This recognition for publications appearing in Elsevier's *Applied Energy* journal was awarded to the 30 most highly cited papers in 2012–2013. The selected papers represent 1.75 percent of all papers published in *Applied Energy* during this time period.

Yuhua Duan, Bryan Morreale for *Advances in CO_2 Capture Technology: A Patent Review*

DOE Secretarial Small Business Award Program's Federal Small Business Program Manager of the Year Award

This award recognizes the efforts and commitment of DOE's small business advocates who take every opportunity to utilize small business concerns to meet its requirements. Small businesses are essential in stimulating the economy and DOE endeavors to be a leader in providing contract and subcontract opportunities to small businesses.

Larry Sullivan

American Institute of Chemical Engineers Special Fellow (Highest Grade of Membership)

Steve Zitney

The George Washington University Arthur S. Flemming Award

Established in 1948, the Flemming Awards honor outstanding federal employees. Recognized by the president of the United States, agency heads, and the private sector, the winners are selected from all areas of the federal service. The awards were established in honor of Arthur Flemming's commitment to public service throughout his distinguished career.

David Miller for his vision and leadership of the Carbon Capture Simulation Initiative (CCSI)

Pittsburgh Federal Executive Board Prestigious Woman Award

Mary Sullivan for outstanding project management, engineering, communication skills, effective teamwork and leadership, and community service

Pittsburgh Federal Executive Board Awards

William Aljoe (Outstanding Professional Employee, Gold)
Jamie Brown (Outstanding Supervisor, Silver)
Sydni Credle (Rookie of the Year, Bronze)
Doug Kauffman (Rookie of the Year, Gold)
Kate Nielsen (Outstanding Professional Employee, Bronze)
Petra Nova Project Team (Outstanding Team, Bronze)
Heather Quedenfeld (Outstanding Supervisor, Bronze)
Kelly Rose (Outstanding Professional Employee, Silver)
Timothy Skone (Outstanding Professional Employee, Bronze)
Solid Oxide Fuel Cell Team (Outstanding Team, Bronze)

15th SIAM Conference on Mathematics and Computational Issues in Geosciences Early Career Poster Winner

SIAM conferences focus on timely topics in applied and computational mathematics and applications and provide a place for members to exchange ideas and to expand their network of colleagues in both academia and industry.

Rodrigo Duran

2015 Joint Conference on Process Systems Engineering (PSE) and Computer Aided Process Engineering (CAPE) Best Poster

Tom Adams, Farida Nor Harun, David Tucker for "Dynamic Response of Fuel Cell Gas Turbine Hybrid to Fuel Composition Changes Using Hardware-based Simulations"

The Metals, Minerals, and Materials Society 3rd World Conference on Integrated Computation Materials Engineer 1st Prize for Poster Presentation

Jeffrey Hawk, Paul Jablonski, Joseph Licavoli, John Sears for "High Entropy Nickel Superalloys Designed via the CALPHAD Method"

Patents Awarded

Poly(Hydroxyl Urethane) Compositions and Methods of Making and Using the Same, **David Luebke** (DOE/NETL); **Hunaid Nulwala, Chau Tang** (ORISE); 8,912,303, issued December 16, 2014.

Production of Methane-Rich Syngas from Hydrocarbon Fuels Using Multifunctional Catalyst/Capture Agent, **David A. Berry, Dushyant Shekhawat, Wayne Surdoval, Nicholas Siefert** (DOE/NETL); 8,920,526, issued December 30, 2014.

Method of CO_2 Removal from a Gaseous Stream at Reduced Temperature, **Ranjani V. Siriwardane** (DOE/NETL); **George A. Richards, David A. Berry, James C. Fisher, II** (URS); 8,888,895, issued November, 18, 2014.

Method of Purifying a Gas Stream Using 1,2,3-Triazolium Ionic Liquids, **Chau Tang, Hunaid Nulwala** (ORISE); **David Luebke** (DOE/NETL); 8,906,135, issued December 9, 2014.

1,2,3-Triazolium Ionic Liquids, **David Luebke** (DOE/NETL); **Hunaid Nulwala, Chau Tang** (ORISE); 8,907,105, issued December 9, 2014.

Layered Solid Sorbents for Carbon Dioxide Capture, **Bingbing Jiang, Bingyun Li** (West Virginia University); **Daniel J. Fauth, George A. Richards, Henry W. Pennline, McMahan L. Gray** (NETL); 8,889,589, issued November 18, 2014.

Visible Light Photoreduction of CO_2 Using Heterostructured Catalysts, **Robert L. Thompson, Congjun Wang** (Parsons); **Christopher Matranga** (DOE/NETL); 8,986,511, issued March 24, 2015.

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Methods for the Production of Fabricated Hollow Microspheroids, **David Luebke** (DOE/NETL); **Shan Wickramanayake** (URS); 9,050,579, issued June 9, 2015.

Apparatus and Method for Solid Fuel Chemical Looping Combustion, **Ranjani V. Siriwardane, Justin M. Weber** (DOE/NETL); 9,004,911, issued April 14, 2015.

Electronically Conductive Perovskite-Based Oxide Nanoparticles and Films for Optical Gas Sensing Applications, **Paul Ohodnicki, Jr.** (DOE/NETL); **Andrew M Schultz** (ORISE); 9,019,502, issued April 28, 2015.

MCrAlY Bond Coat with Enhanced Yttrium, **Paul D. Jablonski, Jeffrey Hawk** (DOE/NETL); 9,012,032, issued April 21, 2015.

Efficient Electrocatalytic Conversion of CO_2 to CO Using Ligand-Protected Au25 Clusters, **Christopher Matranga, Dominic Alfonso** (DOE/NETL); **Rongchao Jin, Huifeng Qian** (Carnegie Mellon); **Douglas Kauffman** (Global Energy Services, DOE/NETL); 9,139,920, issued September 22, 2015.

Method of Preparation of a CO_2 Removal Sorbent with High Chemical Stability during Multiple Cycles, **Ranjani V. Siriwardane** (DOE/NETL); **Shira Rosencwaig** (EnVerid Systems, Inc.); 9,079,160, issued July 14, 2015.

Method for Continuous Synthesis of Pyrochlore Catalyst Powders, **David A. Berry, Dushyant Shekhawat, Daniel J. Haynes** (DOE/NETL); **Mark Smith** (URS); 9,126,833, issued September 8, 2015.

FY15 Licenses

Pyrochem Catalyst Company (Jeffersontown, KY), exclusive license for *Method for Continuous Synthesis of Metal Oxide Powders*, issued March 25, 2015.

KW Associates LLC (Albany, OR), exclusive license for *Arc Position Sensor* (also known as Electric Current Locator), issued March 3, 2015.

LumiShield Technologies Inc. (Pittsburgh, PA), exclusive license for *Ionic Solvent for the Aluminum Electroplating Process*, issued June 12, 2015.

CogniTek (Northbrook, IL), exclusive license for *Process for CO_2 Capture Using a Regenerable Magnesium Hydroxide Sorbent and Minimization of Steam Requirements for Enhancement of Water-Gas Shift Reaction with Warm Gas Temperature CO_2 Removal*, issued August 10, 2015.

Developing Future Innovators through University Collaborations, Mentorship, and STEM Outreach

The knowledge uncovered through NETL research provides a foundation that the next generation of innovators will build upon to create exciting new energy technologies, leading to new products, new industries, and new jobs that fulfill the nation's ever-demanding energy needs and keeps its economy strong and its people secure. To encourage that evolutionary process, the Laboratory aggressively pursues research collaborations with university partners, hosts mentorship programs, and leads educational outreach activities that stoke the fires of imagination in inquisitive young minds and encourages creativity and discovery in future energy innovators.

Molding Future Scientists and Engineers through Mentorship

NETL recognizes the benefits of mentorship and actively promotes energy research opportunities through programs like the Oak Ridge Institute for Science and Education (ORISE) internships and the Mickey Leland Energy Fellowship (MLEF). NETL's ORISE program is administered by Oak Ridge Associated Universities and provides opportunities for undergraduate students, recent graduates, graduate students, postdoctoral researchers, and faculty researchers to perform energy-related research at NETL. The ORISE program helps to ensure that NETL has a robust supply of scientists and engineers to meet future science and technology needs.

For 20 years, the MLEF program has provided students, especially women and minorities, with opportunities to gain hands-on research experience with fossil energy. NETL has hosted fellows since the program's inception, helping train students—many from traditionally underrepresented groups—for careers in science, engineering, technology, and math. In the process, mentors also educate them on how NETL is working to address the energy challenges of the future. Today's energy researchers hope that some of the students will become part of NETL's scientific and technical workforce.

In 2015, NETL hosted 34 MLEF interns between June and August and was the largest recipient of MLEF fellows across DOE. This diverse group of interns was presented with solid challenges and given a firm foundation for future success. Among many activities: they investigated advanced combustion technologies like chemical looping, which will enable cleaner use of America's abundant coal resources; they worked in NETL's world-class Hyper facility, running simulations on ultra-efficient hybrid systems that pair fuel cells with gas turbines; and they explored the stability and properties of foamed cement to help make offshore oil and gas drilling safer for the environment.

NETL also offers fellowships with The National Research Council and participates in the DOE Office of Science Computational Science Graduate Fellowship (CSGF) as well as the DOE Office of Science Graduate Student Research (SCGSR) program.

Engaging Youth through STEM Outreach and Partnerships

NETL sponsors STEM-related outreach activities for K–12 students including educational partnerships, regional Science Bowls, and Earth Day activities that encourage students to pursue the science, technology, engineering, and math disciplines that are so critical for America's future.

Among its educational partnerships, NETL works with the Spectroscopy Society of Pittsburgh to host two programs, the Triple E and the Light, Color, and Spectroscopy workshops, which provide valuable information and supplies that teachers take back to bolster interest and learning in their classrooms. Additionally, NETL works with the Society for Analytical Chemists of Pittsburgh to host a computer workshop that allows educators to improve their knowledge of data manipulation software, physics laboratory simulation software, and simulation and classroom programs.

While these partnerships culminate in annual workshops, NETL also participates in a year-round partnership with the Carnegie Science Center to provide the Center's Energy Challenge exhibit. Since its installation in 2010, NETL's Energy Challenge has been one of the most popular stops at the Carnegie Science Center. Players of all ages enjoy the energy quiz game designed to educate visitors about the importance of energy in our daily lives, how energy works, and how we can conserve and reduce our energy use.

NETL annually hosts the Southwestern Pennsylvania Regional Science Bowl and cohosts the West Virginia Regional Science Bowl with West Virginia University. The tournaments bring together the best and brightest youths from area middle and high schools to compete as teams in a fast-paced quiz bowl format to answer questions on science, math, and engineering. For younger students, NETL raises awareness of energy and environment by hosting an annual Earth Day poster contest that challenges students in kindergarten through fifth grade to design a poster about their favorite way to keep the Earth beautiful.

From elementary school through graduate school and beyond, NETL's mentorship enriches young people, guiding them on their journey toward rewarding careers in STEM and future technology breakthroughs.

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