NATIONAL ENERGY TECHNOLOGY LABORATORY

2017 ANNUAL REPORT

U.S. DEPARTMENT OF ENERGY

Contents

Director's Message 3

Core Competencies 5

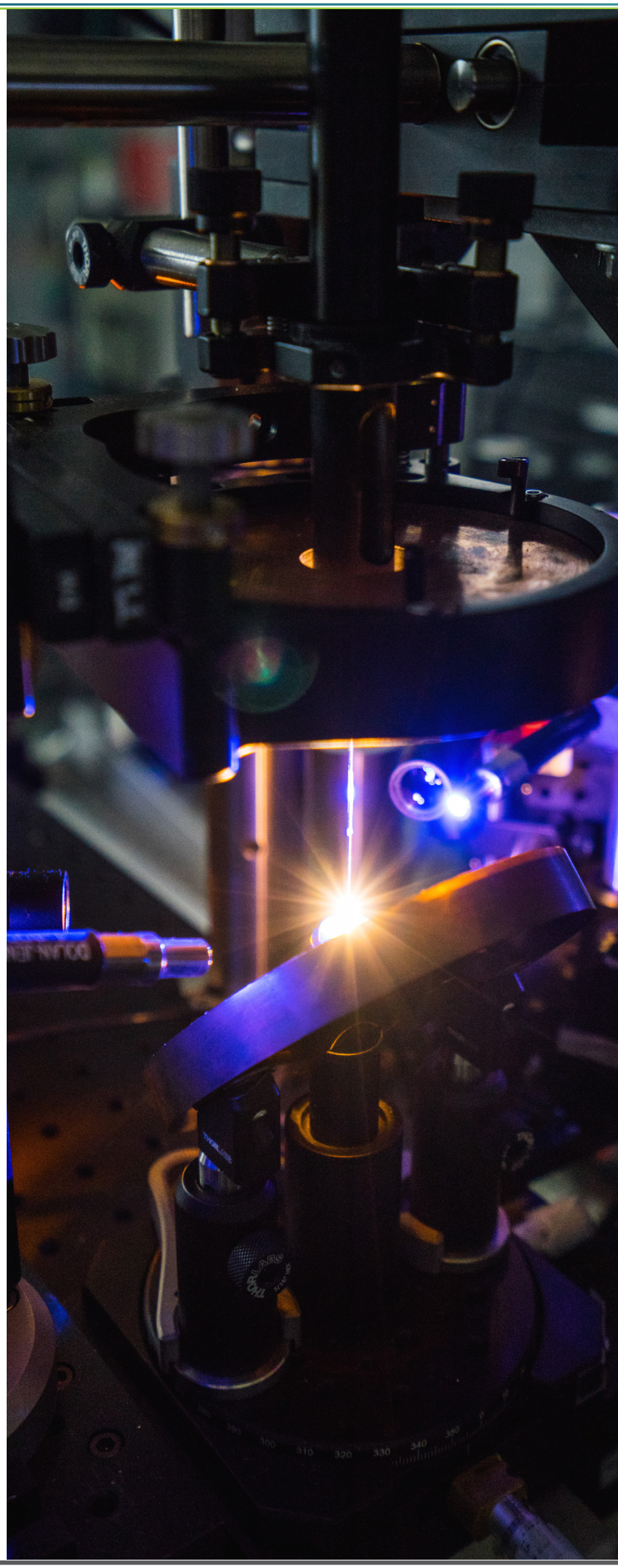
FY17 Budget & Funding 6

Regional Economic Benefits 7

Select Accomplishments 8

Patents & Licenses 21

Awards 22



Director's Message

If yesterday's dreams are today's accomplishments, as one philosopher once suggested, then the U.S. Department of Energy (DOE) National Energy Technology Laboratory (NETL) is a place where that transition occurs on a regular basis. We work to turn ideas into demonstrable technologies that will help the nation realize the full value of its domestic energy resource; attain energy dominance; and reinvigorate jobs, manufacturing and the energy infrastructure for a bright and productive future. The pages of this annual report for fiscal year 2017 offer testimony to the progress made toward those objectives.

At NETL, we have assembled a team of professionals with focused expertise to drive accomplishments and provided them with the right tools and facilities to help them reach their research goals and attain far-ranging benefits to the American public. Our team has the drive and skill to improve the nation's manufacturing competitiveness, inform energy policy makers with unbiased research information, manage public-private research partnerships that enhance our energy infrastructure, expand energy production, and unlock future resources.

NETL's portfolio features nearly 1,400 nationwide energy research activities that engage experts and facilities in the private sector, government, and some of the nation's most prestigious research universities. By leveraging resources and blending skills and knowledge, we are maximizing technology transfer for public benefit, educating future researchers, and, perhaps most importantly, discovering, developing, integrating, and deploying energy technologies that address the nation's energy challenges.

NETL is a valuable resource for the nation, and I am proud to lead our talented and driven group of energy innovators. NETL and its predecessor labs have been at the center of technology development for more than a century, consistently creating safe, affordable technical solutions that satisfy the world's need for energy. We are committed to continuing this important work.

I invite you to read the accomplishment highlights from the past year of NETL's success in the 2017 Annual Report.

Dr. Grace M. Bochenek
Director, NETL

MISSION

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

NETL's enduring mission elements are effective resource development, efficient energy conversion, and environmental sustainability.

VISION

NETL's vision is to be the nation's renowned fossil energy science and engineering resource, delivering world-class technology solutions today and tomorrow.

Core Competencies

1. COMPUTATIONAL SCIENCE & ENGINEERING—advancing modeling and simulation tools that are critical to all NETL research, development, and deployment

2. MATERIALS ENGINEERING & MANUFACTURING—designing materials and manufacturing processes to enable technology solutions

3. GEOLOGICAL & ENVIRONMENTAL SYSTEMS—engineering natural systems toward efficiency and sustainability

4. ENERGY CONVERSION ENGINEERING—engineering energy devices that exhibit transformational increases in conversion efficiencies

5. SYSTEMS ENGINEERING & ANALYSIS—engineering complex multi-scale processes by optimizing process, device, and material

6. PROGRAM EXECUTION & INTEGRATION—defining, soliciting, negotiating, awarding, managing, and delivering federally sponsored research and development benefits to the nation

Oil & Gas Technology Thrusts

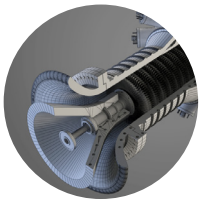
ENHANCED RESOURCE PRODUCTION

ENVIRONMENTALLY PRUDENT DEVELOPMENT

TRANSMISSION & DELIVERY

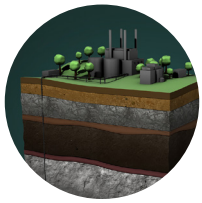
METHANE HYDRATES

Coal Technology Thrusts

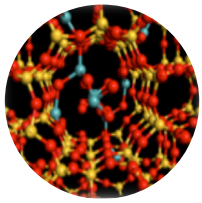


ADVANCED ENERGY SYSTEMS

CARBON CAPTURE



CARBON STORAGE



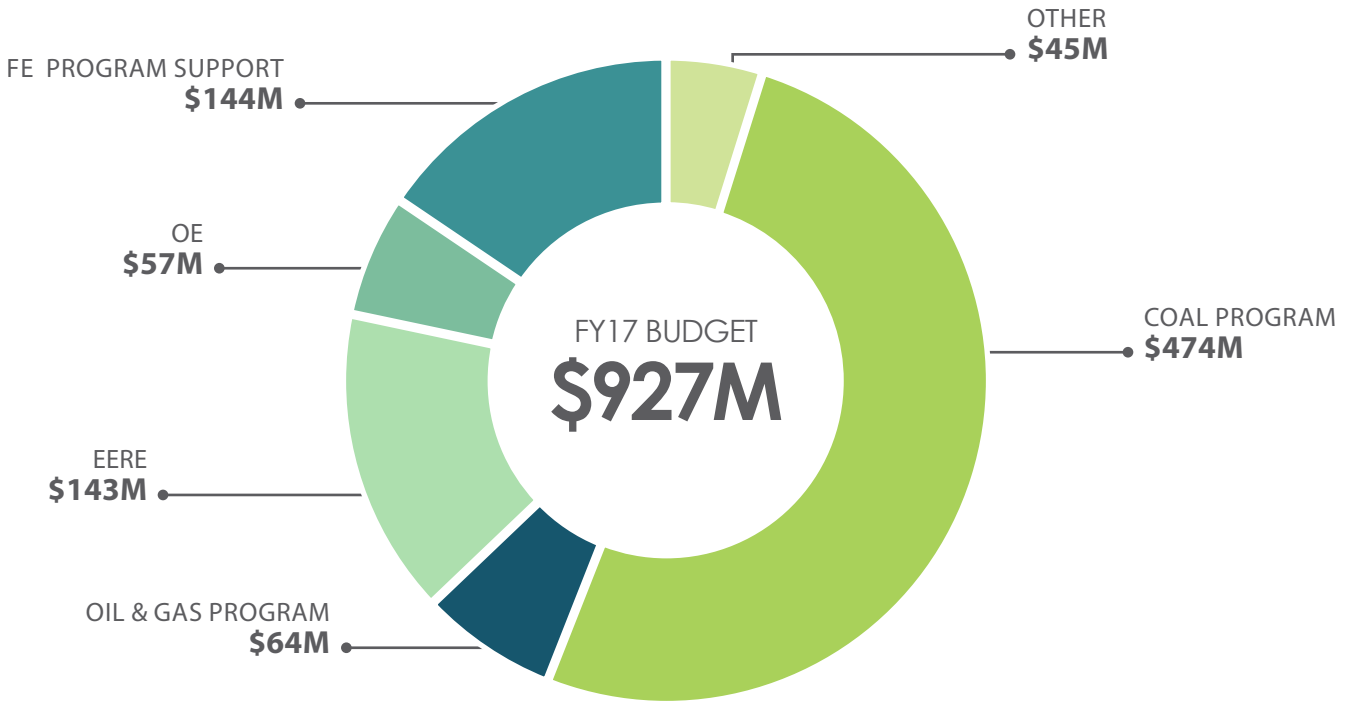
CROSS-CUTTING RESEARCH

RARE EARTH ELEMENTS

FY17 Budget & Funding

NETL's FY17 federal budget funding was $927 million, with a majority of that funding supporting mission work for the Office of Fossil Energy (FE). The Laboratory's research portfolio includes more than 900 projects and activities in all 50 states, with a total value that exceeds $7 billion and private cost-sharing of more than $3.5 billion.

More than 1,200 employees work at NETL—a workforce of 499 highly skilled federal and 732 contract staff.



COAL PROGRAM

- Carbon R&D—**$53M**
- Carbon Capture—**$101M**
- Carbon Storage—**$95M**
- Supercritical Transformational Electric Power (STEP)—**$24M**
- Transformational Coal Technologies—**$50M**
- Advanced Energy Systems—**$105M**
- Crosscutting Research & Analysis—**$46M**

FE PROGRAM SUPPORT

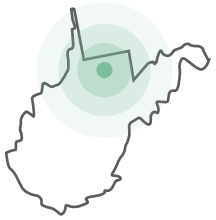
- Program Direction—**$60M**
- Research & Operations—**$43M**
- NETL Infrastructure—**$41M**

OIL & GAS PROGRAM

- Natural Gas Technologies—**$43M**
- Unconventional Fossil Energy Technologies—**$21M**

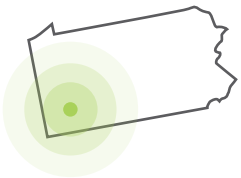
Regional Economic Benefits

An NETL economic analysis revealed that the Laboratory injected a total of $210 million directly into the state economies where the research sites reside—Oregon, Pennsylvania, and West Virginia. These economic impacts include full-time jobs at NETL research sites filled by federal and contractor employees, as well as NETL's spending on grants, research and development awards, cooperative agreements, contracts, and purchase orders within the Laboratory's host states. NETL's impact on the three state economies is greater than the total of the Laboratory's direct spending, because money spent by NETL is spent again by the recipient employees and businesses. NETL had a total estimated impact of $361 million on the three state economies.



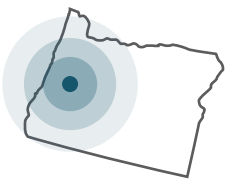
Total Economic Impact of NETL on the **State of West Virginia** [2016]

Jobs (direct, indirect, and induced full-time equivalent jobs)	**930**
Total Economic Impact (direct, indirect, and induced)	**$132M**



Total Economic Impact of NETL on the **State of Pennsylvania** [2016]

Jobs (direct, indirect, and induced full-time equivalent jobs)	**1,219**
Total Economic Impact (direct, indirect, and induced)	**$199M**



Total Economic Impact of NETL on the **State of Oregon** [2016]

Jobs (direct, indirect, and induced full-time equivalent jobs)	**207**
Total Economic Impact (direct, indirect, and induced)	**$30M**

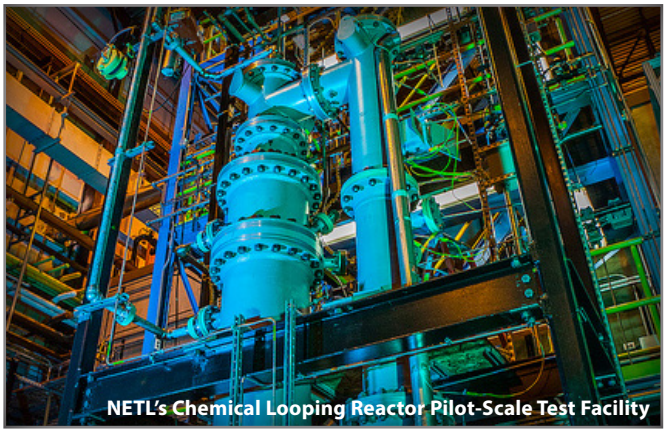
Recovered Pressurized Cores Key to Natural Gas Hydrate Research

An NETL-sponsored team led by the University of Texas at Austin (UT-Austin) recovered the first pressurized cores from a gas hydrate reservoir in the deepwater Gulf of Mexico—a key step in opening the door to a vast untouched natural gas resource.

Gas hydrates are crystal structures that form under specific conditions of low temperature and high pressure, in which frozen water creates a cage that traps methane molecules. Because methane is a clean burning energy source, understanding the potential of this resource is an important goal for NETL.

Retrieving the samples while keeping them pressurized will allow researchers at NETL, UT-Austin, and many other laboratories across the country to make breakthroughs in understanding the nature, occurrence and physio-chemical behavior of gas hydrate systems as well as the Gulf of Mexico hydrate potential.

Capturing and recovering the samples required specialized equipment and techniques. The research team used a revolutionary new coring tool to secure more than 30 meters of pressure core, including samples of some of the highest quality gas hydrate cores ever collected. The project's coordinated effort of collaborative science is helping to advance the study of gas hydrate science and is disseminating critical research results through peer reviewed publications that will enrich the research community and open a potential avenue to a new clean-burning energy resource.


NETL's Chemical Looping Reactor Pilot-Scale Test Facility

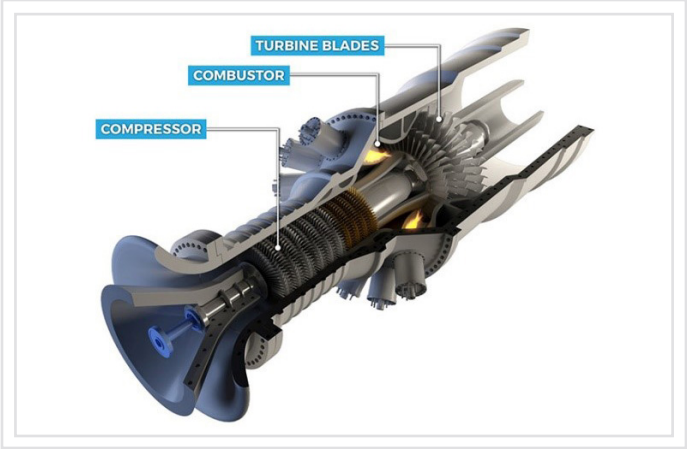
Advanced Copper-Hybrid Oxygen Carrier for Chemical Looping

NETL researchers explored the potential of using copper in a process known as chemical looping to capture CO_2 from coal-fired power plants. Their research bore fruit when the Lab's chemical looping facility operated for more than 40 hours using an advanced copper-hybrid oxygen carrier—a new lab record.

In chemical looping, only oxygen is carried to the combustion process, producing a virtually pure stream of CO_2 that can then be captured and more easily stored or reused. The hurdle has been finding a material that can effectively carry the oxygen to the process.

Copper holds many advantages as an oxygen carrier, including good fuel conversion and heat management. It also generates heat when it reacts with fuel, which makes the operation easy. However, copper melts at temperatures well below those found in power plants. To meet this challenge, NETL researchers designed a mixed-metal oxygen carrier of iron oxide and copper oxide to create an oxygen carrier that could withstand the heat.

NETL researchers have put about 500 pounds of a second-generation particle through stringent testing in the NETL Chemical Looping Reactor Pilot-Scale Test Facility, resulting in the 40-hour chemical looping operation.



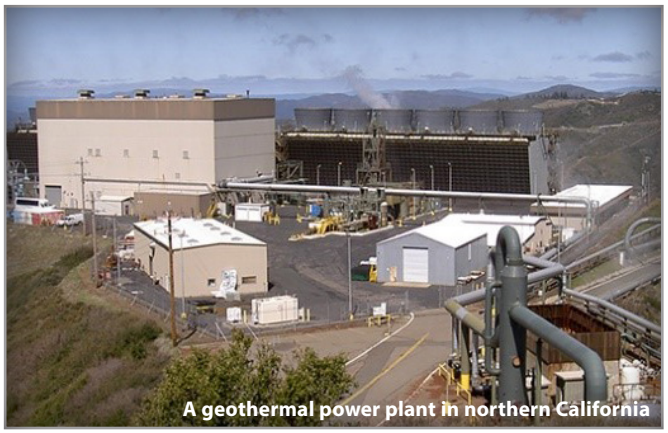
Slashed Emissions from Advanced Turbines with New Combustor Approaches

In a project sponsored NETL, researchers at the Georgia Institute of Technology showed how major reductions of nitrogen oxide (NOx) are possible when new combustor design concepts are applied to advanced gas turbines.

Using a novel computational tool, the research team rapidly screened more than 20,000 design variations, providing insight into optimizing high-temperature combustor performance while generating the lowest possible NOx.

Current combustion technology is unable to meet emissions requirements at very high temperatures without using expensive post-combustion processes that reduce energy efficiency. Georgia Tech's research showed that it may be possible to use the computational tool to design future gas turbines that can operate at turbine inlet temperatures at more than 3,100 degrees Fahrenheit with an unprecedented level of performance while slashing NOx by 80–90 percent compared to conventional designs.

Funded through DOE's University Turbine Systems Research Program, the Georgia Tech project supported the mission to develop and transition advanced turbines and turbine-based systems that will operate efficiently, including fuel-flexible systems. The research team's goal was to enable significant gains in energy efficiency by applying new turbine combustor designs to power plants operating on natural gas, coal-derived syngas, or coal-derived high-hydrogen-content fuels.


A geothermal power plant in northern California

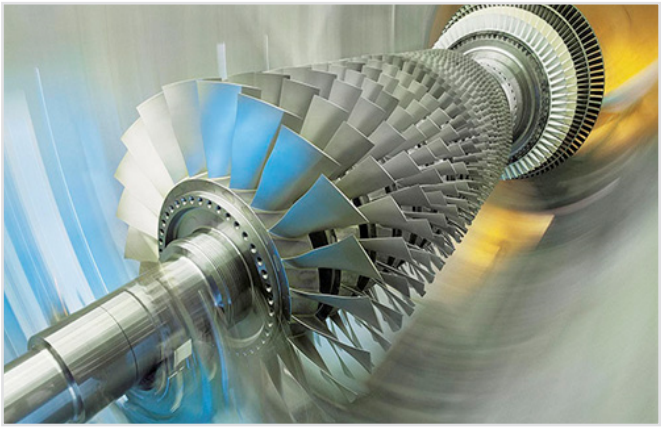
Studied Geothermal Energy Potential in Appalachia

Researchers working with NETL's Synergistic Fossil Integrations with Renewable Energy (SFIRE) initiative are increasing the world's body of knowledge on integrating fossil fuel energy systems with renewable energy technologies—knowledge that could end up powering commercial office complexes and military installations with heat from deep within the Earth.

SFIRE's goal is to find ways to effectively use renewable energy resources—such as biomass feedstock, solid waste gasification, wind, solar, and geothermal—in combination with fossil energy fuels, such as coal and natural gas, and through non-typical cycles, such as solid oxide fuel cells and hybrid cycles.

At the lab level, NETL's SFIRE researchers are helping to determine safe and sustainable ways to expand the direct use of geothermal energy in the context of electricity generation. Beyond the lab, SFIRE researchers are assessing specific fossil and geothermal opportunities in locations near NETL facilities in West Virginia and Pennsylvania to learn how to best use the resources that exist in the eastern United States.

Based on research to date, combining fossil energy with geothermal energy for on-site power generation can offer risk reductions for power generation, as well as a long-term energy resource—good news for the nation's energy security.



Moved Smart Sensing Technology Toward Commercialization

A gas turbine sensing technology, developed as part of a cooperative agreement with NETL, advanced toward commercial use. The technology, called Additive Topology Optimized Manufacturing with embedded Sensing (ATOMeS), seamlessly integrates wireless sensors into aero- and ground-based turbine engine components using additive manufacturing.

Gas turbines are key components of advanced systems designed for new U.S. electric power plants. NETL and its research partners are developing technologies that will enable these turbines to operate efficiently when fueled with coal-derived syngas and hydrogen fuels. These breakthroughs are critical to the creation of power-generation technologies with near-zero emissions.

In a three-year project with NETL, United Technologies Research Center embedded commercial, off-the-shelf sensors into a test structure like a first-stage compressor vane. Using additive techniques and a novel design, a "smart part" was fabricated capable of transmitting its temperature, position, and vibrational data back to a data analyzer outside of the test chamber. This information allows engineers to reduce maintenance costs, save energy, and increase the reliability of gas turbines.

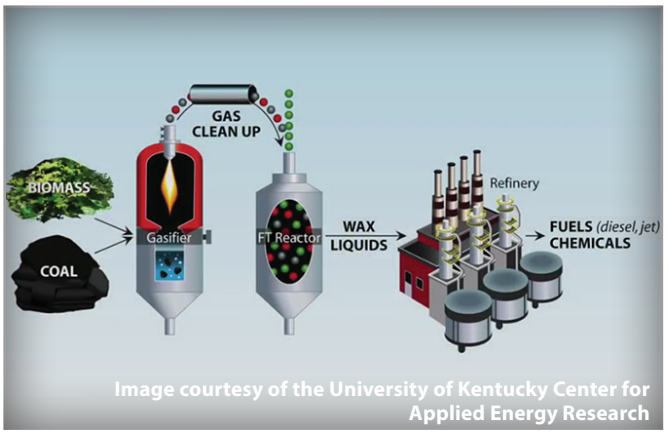
United Technologies business units have begun further developing the technology. ATOMeS is now being supported and assessed for acceptance into product readiness.

Shed Light on Methane Emissions

A two-year study by NETL analysts, in which new methane emission data was synthesized from a series of ground-based field measurements, showed that 1.7 percent of the methane in the U.S. natural gas supply chain is emitted between extraction and delivery. Identifying the magnitude and sources of methane emissions allowed producers to prioritize opportunities to minimize economic losses. Results of the study have been published in the *Journal of Cleaner Production*.

The study identified gathering systems and pneumatic controllers at production sites as top contributors to the emission of methane in the natural gas supply chain. Gathering systems, which play a key role connecting production and processing, represented 22 percent of methane emissions. Production pneumatics, which accounted for 10 percent of methane emissions, intentionally release methane into the atmosphere as part of their function to reduce control line pressure.

Another emission category termed "unassigned emissions" make up 19 percent of methane emissions from multiple sources—production sites with atypically high emission rates, production equipment that requires maintenance, intermittent wellhead maintenance events, or any combination thereof.



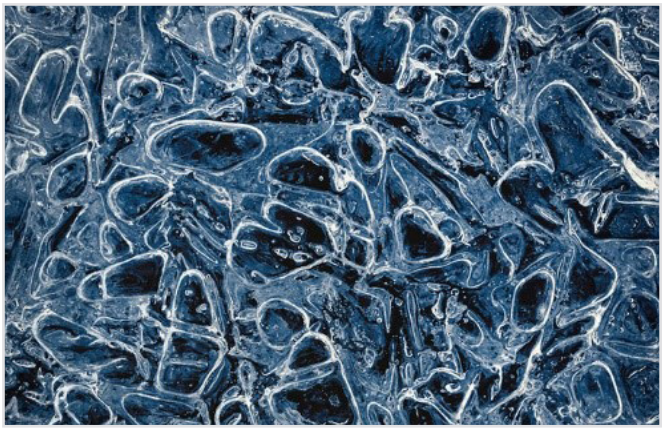
Advanced Better Transportation Fuels

With an eye toward developing coal-derived liquid fuels that can someday power cars, trucks, tanks, and even jets, NETL supported researchers at the University of Kentucky as they close in on an innovation that could someday advance the state of the art for transportation fuels production.

In an ongoing five-year project, the researchers advanced the design, construction, and operation of a small-scale pilot plant that gasifies coal and coal/biomass blends to form syngas (a mixture of carbon monoxide and hydrogen) and then converts it to liquid fuels. The facility, located at the University of Kentucky's Center for Applied Energy Research, has a one barrel per day liquids fuel capacity and is intended to develop meaningful information about the technology; its scalability, cost, and economics; and product characteristics and quality.

Coal-to-liquids fuel products are considered clean burning. Certain constituents, such as sulfur, are removed during the gasification process and oxygen is used instead of air to produce syngas, which allows CO_2 to be more easily stripped away.

In addition to advancing scientific knowledge, the NETL-supported project is identifying efficient ways to handle and process coal/biomass mixtures, ensuring that those mixtures are compatible with delivery systems and amenable to efficient gasifier operations.



Advanced More Efficient Method of Water Desalination

In an NETL-managed project, GE Global Research advanced a method to lower the energy requirement and cut the cost of recovering usable water from high-salinity brines. The new technology offers a way to turn a potential waste product into a usable source of water and minerals.

The lowest energy method of water purification is typically a membrane process, such as reverse osmosis; however, some wastewaters are not good candidates for this because of very high salt concentrations. Reverse osmosis also leaves behind a high-salinity brine requiring proper disposal.

The project aimed to reduce the amount of energy needed to recover water and salt from high-salinity brines. Rather than evaporating and condensing water, which is energy intensive, researchers sprayed brine in a stream of cold refrigerant, freezing the brine droplets. Proper control of the freeze conditions allowed separation of ice crystals from salt crystals.

The process achieved 100 percent water recovery and a 58 percent reduction in the cost of water treatment compared to a thermal crystallizer.

Examples of wastewaters that could be treated with this new freeze process are produced water from oil and gas extraction, brines from deep saline formations that may be used for CO_2 storage, and power plant waste streams that have been reused and concentrated.


SOFC button cells

Explored the Microstructure of Solid Oxide Fuel Cells

NETL searched for new ways to create solid oxide fuel cells (SOFCs) that can effectively operate at lower temperatures with a longer lifespan by taking a deep look on a microstructural level. The process involved an integrated research effort across NETL and its research and industry partners. The work could lead to an effective and economical option for utility-scale power generation.

Changes happening in the microstructure can drastically affect SOFC performance. NETL modeling work is providing a better understanding of how these ultra-efficient devices can be made more durable, economical, and commercially successful.

NETL has created the largest high-resolution electrode reconstructions in the world—some are 100 times larger than any other visualization efforts at the same resolution—to examine SOFC inner workings and quantify changes to their active regions over time. Modeling allows researchers to simulate the SOFC aging process and obtain meaningful results faster and more economically than operating SOFCs for tens of thousands of hours. Coupled with the information gained from 3D microstructure visualization, researchers can determine what operating conditions and microstructures will be most favorable for a given cell, leading to a longer, more productive cell lifespan.

Demonstrated Arctic Oil-Spill Recovery Process

Under a grant awarded to NETL by the U.S. Department of the Interior's Bureau of Safety and Environment Enforcement, NETL researchers demonstrated a new oil spill recovery process under simulated Arctic conditions.

Increasingly, offshore domestic oil and natural gas exploration and production are taking place in more challenging regions, such as the ultra-deepwater in the Gulf of Mexico and the offshore Arctic waters of the United States. Oil spill response is a challenging effort under any conditions, but responding to spills in Arctic waters presents unique challenges. Current mechanical methods are not effective for oil spill recovery in the harsh environment of Arctic regions.

NETL's new process uses a separation unit and an adsorption step to rapidly isolate and capture oil from crushed sea ice and water. The team's results showed high oil recovery rates and a high oil-to-water final product, which significantly reduces wastewater volume.

The NETL system can generate a wastewater stream with residual oil below 5.0 ppm, meeting the U.S. Environmental Protection Agency's requirement of less than 15 ppm of residual oil and allowing direct discharge into the sea. The system also offers easy setup and operation, scalability, and can be transported to remote locations.

Upgraded Learning Environments with Energy Efficient Tunable Lighting

A project managed by NETL in support of the Office of Energy Efficiency and Renewable Energy (EERE) is improving U.S. classrooms by providing a domestically designed and built lighting solution. Under this project, RTI International and Finelite developed and tested an LED-based next-generation integrated classroom lighting system that makes it easy for teachers to control light levels and chromaticity (the color of the light) in three classroom zones. Comprising sensors, a controller, and fixtures, the made-in-USA system is operated from a user interface that is either mounted in the front of a classroom or accessed through a wireless handheld device. The design of the controller's user interface was based on input from more than 80 teachers and school administrators. The lighting system also incorporates daylight harvesting to further reduce energy consumption.

In addition to improving the educational environment for teachers and students, this project illustrated some of the potential benefits of easy-to-control tunable lighting in future classrooms and encourages energy efficient lighting.

Helped Turn Waste into a Resource with Water Management Tool

With project-management support from NETL, the Colorado School of Mines and New Mexico State University completed a project culminating in a new online water-management tool called the Decision Support Tool, which can suggest treatment options for produced water and fracturing flowback.

The tool will help minimize potential impacts of oil and natural gas production on natural water resources, public health, aquatic life, and the environment through informed decision-making.

The Decision Support Tool will enable producers, regulators, consultants, and other users to characterize, treat, beneficially use, and manage produced water and fracturing flowback. It accomplishes this by simulating logical treatment sequences for various types of source water, while considering additional influencing factors such as percent water recovery and temperature.

The unique system allows users to include or exclude treatment technologies and provides an option to the user to generate a single best treatment sequence option or up to three alternative treatment sequence options. The tool can also be used to compare costs of reusing produced waters versus disposing of the produced water, giving operators information needed to determine an economic break-even point for treatment relative to disposal under site-specific conditions.

Highlighted Plug-In Transportation with Electric Vehicle Showcase

An NETL-managed project is transforming the plug-in electrical vehicle (PEV) market in the Pacific Northwest and putting Oregon and Washington on a sustainable path to increase PEV sales more than tenfold, to at least 15 percent of all new cars sold by 2025.

At the heart of the project is the nation's first-ever electric vehicle showcase located in downtown Portland, Oregon. The Go Forth Electric Showcase opened to the public May 2, 2017, at 901 SW 1st Avenue. Developed by Forth Oregon, this educational electric vehicle and charging exhibit location is open six days per week with objective staff and volunteers who are available to assist with short- and long-term test drives and provide information on all queries related to PEV ownership. As of June 30, 2017, more than 500 people visited the showcase, leading to more than 40 test drives completed on site. Additional test drives have been scheduled by consumers.

NETL manages the project with Forth (formerly Drive Oregon) in support of the Office of Energy Efficiency and Renewable Energy (EERE) Vehicles Technologies Office.

Helped Provide More Precise Detection & Understanding of Seismic Activity in Oklahoma

NETL, the University of Oklahoma, and the Oklahoma Geological Survey concluded a highly innovative and integrated study to determine what properties lead to induced seismicity.

The project evaluated the potential for, and increase in, seismic activity in central Oklahoma, including the relationship between oil and gas operations and induced seismicity. Specifically, the study confirmed and more fully investigated the link between increased seismic activity and wastewater disposal. Over the course of the study, more than 95 percent of the earthquakes in Oklahoma occurred in a small portion of the state, where about 70 percent of wastewater was injected.

Researchers found that seismic events increased between July 1, 2014, and the end of 2015, but have decreased since then. Similarly, earthquakes of magnitude greater than 3.0 increased from 579 in 2014 to 903 in 2015, then decreased to 623 in 2016. The decrease in earthquakes correlated to a decrease in water injection during that same period.

The team also applied a novel simulation approach to estimate pressure increases that could trigger seismic events, which could be used to help identify safe injection rates and safe distances from injection wells to faults.

NETL employees with hosts at Technology Centre Mongstad, February 2017.

Tested Novel Carbon Capture System

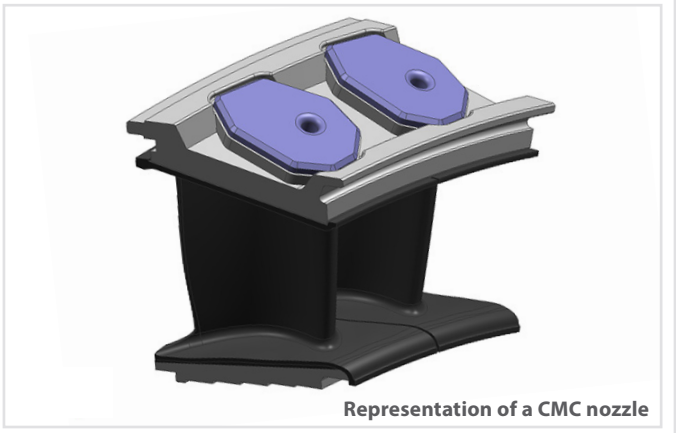
A project conducted by ION Engineering and supported by NETL successfully concluded a six-month testing campaign at the Technology Centre Mongstad (TCM) in western Norway, the world's largest facility for testing and improving carbon capture. The testing of ION's novel carbon-capture system successfully achieved all research objectives and represents significant progress toward commercialization.

ION began evaluating its proprietary Advanced Liquid Absorbent System in October 2016. Compared to conventional liquid CO_2 absorption technologies, ION's novel system provides a more energy-efficient process with high CO_2 capture capacity and reduced water usage. ION's system successfully captured more than 90 percent of CO_2 from the flue gas during steady-state testing with CO_2 product purity greater than 99 percent.

The ION project is the first from DOE's Carbon Capture Program to conduct testing at an international host site.

ION Engineering's post-combustion CO_2 capture work with NETL began in 2010 through the Small Business Innovation Research/Small Business Technology Transfer programs.

This project is supported by significant contributions from DOE and TCM, and other project partners: SINTEF Materials and Chemistry, the Nebraska Public Power District, Sulzer Chemtech USA, the Colorado Office of Economic Development and International Trade, the University of Alabama, Optimized Gas Treating, and ION Engineering.



Representation of a CMC nozzle

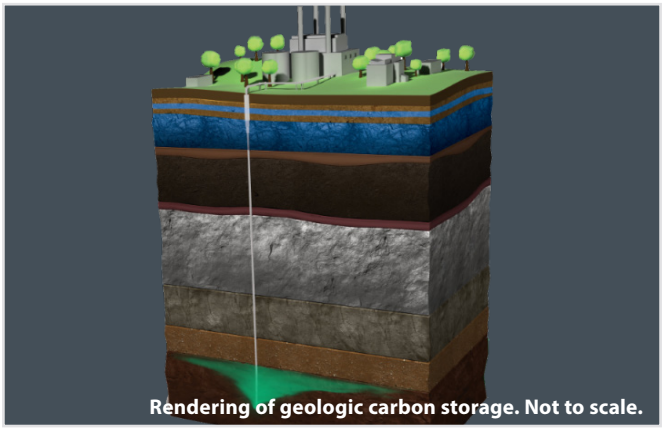
Advanced Ceramic Matrix Composites Research for Application in Gas Turbines

Working with experts in the private sector, NETL continued its efforts to increase the efficiency and durability of advanced gas turbines using ceramic matrix composites (CMCs)—an objective that could help meet the nation's increasing demand for energy.

CMCs represent a major step forward in developing material capabilities for gas turbines because they have the strength of metals and the temperature capability of ceramics. CMCs are made up of ceramic fibers that are embedded in a ceramic matrix.

As gas turbine performance and efficiency goals increase, the resulting temperatures are increasingly higher than the melting temperatures of the super alloys traditionally used in turbines. For metal parts to survive at these temperatures, they are cooled with air. The high-temperature capabilities of CMCs reduce the amount of air needed for cooling, which delivers benefits in output and efficiency.

High-strength CMC material is a uniquely U.S.-based technology enabling gas turbine parts to operate 500 degrees Fahrenheit hotter than turbine parts made with exotic metal alloys. According to researchers, the efficiency benefit of CMCs in a single set of nozzles in a gas turbine is equivalent to the energy needed to power 3,700 typical U.S. homes.


Rendering of geologic carbon storage. Not to scale.

Earned Recognition for Geologic Carbon Storage Risk Assessment Tools

The Carbon Sequestration Leadership Forum (CSLF), an international, ministerial-level organization focused on the development of carbon capture and storage technology, selected the National Risk Assessment Partnership (NRAP), led by NETL, as a CSLF-recognized project. The CSLF chooses projects that contribute significantly to advancing carbon capture and storage technology deployment. The organization has only recognized about 50 projects worldwide over the past decade.

NRAP is a multi-lab partnership developing a defensible, science-based methodology and platform for quantifying risk at CO_2 storage sites to guide decision-making and risk management. One of the drivers behind the nomination and selection of NRAP as a CSLF-recognized project is the internationally used NRAP toolset, which is designed to help evaluate the performance of geologic carbon storage sites related to CO_2 or brine leakage and induced seismicity.

The toolset's flagship product is the NRAP Integrated Assessment Model–Carbon Storage, which enables prediction of long-term risk-related behavior of a storage site from the reservoir to the atmosphere, assists in uncertainty quantification, and supports identification and ranking of factors that contribute to leakage risk. Additional tools enable stakeholders to rapidly explore the behavior of different system components, including reservoir performance, well and seal leakage, groundwater impacts, and induced seismicity behavior.

Released Latest Best Practice Manuals for Geological Storage

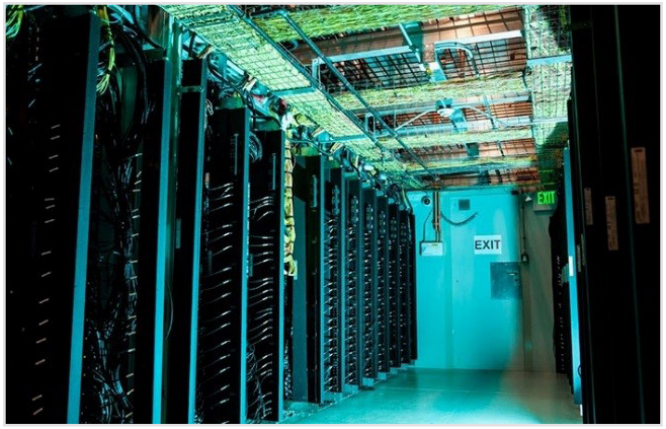
NETL released five 2017 revised edition best practice manuals for geologic storage projects. Together, the interconnected manuals provide a holistic approach to carrying out a geologic storage project, from inception to completion.

Experts from DOE and the NETL-managed Regional Carbon Sequestration Partnership (RCSP) Initiative worked together on the latest update to the best practice manuals, which incorporate knowledge gained through each of the partnership projects.

The 2017 revisions include new information learned as the RCSPs progressed to large-scale field development projects. The latest manuals include a variety of carbon storage scenarios at different geologic and geographic settings across the United States. Along with updated content, the manuals have integrated and color-coded case studies from the RCSPs on various topics.

The five 2017 revised edition best practice manuals, which are available for download on NETL.DOE.GOV, are—

- Public Outreach and Education for Geologic Storage Projects (June 2017)
- Risk Management and Simulation for Geologic Storage Projects (June 2017)
- Site Screening, Site Selection, and Site Characterization for Geologic Storage Projects (June 2017)
- Operations for Geologic Storage Projects (August 2017)
- Monitoring, Verification, and Accounting (MVA) for Geologic Storage Projects (August 2017)

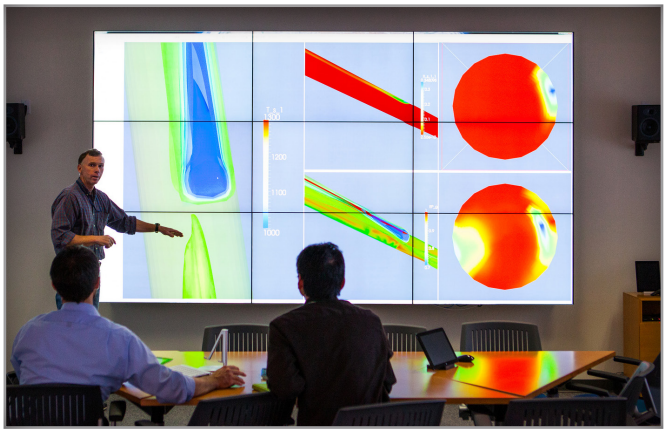


Advanced Multiphase Flow Research Using Next Generation of Supercomputers

NETL collaborated with Lawrence Berkley National Laboratory and the University of Colorado Boulder to develop MFIX-Exa, the next generation of NETL's internationally acclaimed Multiphase Flow with Interphase Exchanges (MFIX)—a suite of specialized computational fluid dynamic codes that help researchers study the simultaneous flow of gases, liquids, or solid materials.

The work is ongoing because computational science evolves rapidly. Today's supercomputers will soon be replaced by systems operating at the exascale (10^{18} calculations each second)—a thousand-fold increase. This surge of processing power will open the doors to breakthroughs across the scientific community, including fossil energy research into advanced power generation systems that are more efficient and release less CO_2 into the atmosphere.

Currently, MFIX-DEM (the discrete element model) can track millions of particles, accounting for the mass, momentum, and energy transfer between the particles and gas phase. The MFIX-Exa project will advance this capability so that billions of reacting particles can be tracked. This kind of simulation will allow researchers to affect the design of systems early enough in the development process to help control costs and reduce risks.



Improved Optimization Process for Chemical Reactors

Understanding the reactions and designing optimized chemical reactors requires intricate modeling and simulation, and a new toolset developed by NETL multiphase flow science experts made the optimization process faster and more efficient. The new toolset will enable more efficient creation of new technologies to reduce costs and increase efficiency of coal-based power generation systems.

The NETL research team's user-friendly simulation tool allows the user to test variables—such as flow rates, temperatures, pressures, injector positions, and others—across a range of conditions. A big advantage to the new approach is that several simulations can be run in parallel and then analyzed to discover if the conditions tested are optimal for specific reactor scenarios.

Optimizing the design and operation of chemical reactors involves many inter-related variables, and using computational tools to investigate various reactor designs enables researchers to investigate more options in less time.

The toolset resides within NETL's open-source Multiphase Flow with Interphase Exchanges (MFIX) system, which allows users to quickly set-up computational fluid dynamics models and create computer models of reacting multiphase systems. In addition, the new toolset commands MFIX to run a broad sweep of conditions, allowing users to investigate the design space and choose the best conditions and optimal geometries.

NETL's Rob Gross with Secretary Rick Perry at the Texas Emergency Operations Center in Austin.

Helped Communities in Hurricane Ravaged Regions

In support of DOE's Office of Electricity Delivery and Energy Reliability, NETL's Emergency Support Function #12 Team continued to work to ensure a resilient, reliable, and flexible electricity system. The NETL team traveled to the Texas Emergency Operations Center in Austin to help facilitate recovery efforts for Hurricane Harvey.

In their day-to-day jobs, the NETL team of experts work on issues related to improving the nation's power grid, increasing cyber and physical security of the grid, updating technologies for electric transformers, and dozens of other critical power topics. But, when tragedies strike, the team packs up and heads to where their specific skills can best assist the Federal Emergency Management Agency with disaster response.

In addition to the devastation from Hurricane Harvey, NETL's Emergency Support Function team assisted with recovery efforts from Hurricane Irma in Florida, Georgia, and the U.S. Virgin Islands (USVI). The team also assisted in recovery efforts from Hurricane Maria in the USVI and Puerto Rico.

U.S. Secretary of Energy Rick Perry applauded the public and private sector cooperation that makes the recovery achievable.

Investigated Carbon Storage in Shale

NETL researchers used complex experiments to determine if fractured shale formations can accommodate a new role as a reservoir for CO_2 captured from fossil fuel burning power plants and other industries. The research showed that injected CO_2 may change rock porosity and permeability. Understanding these and other effects is key to developing successful carbon storage techniques and achieving more accurate predictions of the formations' storage potential.

The results of the study showed, contrary to current literature, that even dry CO_2 injection can cause etching in the rock. That's significant because etching has the potential to alter the physical characteristics of the rock over time, affecting the storage potential of the formation.

The study also found that shales with a higher content of kerogen and certain clays would be expected to have the highest CO_2 storage capacity provided these constituents were accessible for interaction. Researchers are optimistic about the research and its implications not only for carbon storage, but also for determining if CO_2 can be effectively used as a fracturing fluid in future hydraulic fracturing operations.

Flue gas duct at Petra Nova. Photo courtesy of NRG Energy.

Supported Project Named as 2017 Power Plant of the Year

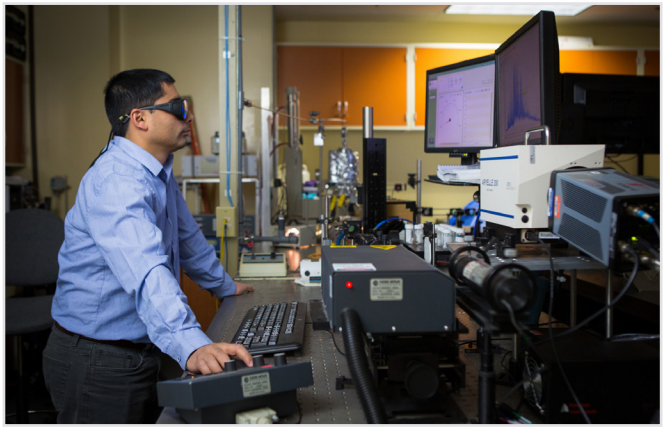
The NETL-supported Petra Nova project, the world's largest post-combustion carbon capture system, was selected by *POWER* magazine as its 2017 Power Plant of the Year.

POWER recognized the project, a joint venture between NRG Energy and JX Nippon Oil and Gas Exploration, because "it was brought online on time, and on budget, and despite its unprecedented scale, it was completed in roughly 1.78 million man-hours without a single lost-time incident during construction."

The project is designed to capture and store 1.4 million metric tons of CO_2 per year. At 240 MWe, the project is the largest post-combustion retrofit of an existing coal-fueled power plant with a CO_2 capture plant and has the potential to enhance the long-term viability and sustainability of coal-fueled power plants across the United States and throughout the world.

The captured CO_2 is being used to enhance oil production at the West Ranch Oil Field, where it will remain stored underground as a result of enhanced oil recovery operations. The project is expected to boost production at West Ranch from 500 barrels per day to approximately 15,000 barrels per day.

As of the end of FY17, the project resulted in 926,704 tons of CO_2 captured and injected, and 607,693 barrels of oil produced by enhanced oil recovery.



Identified Rare Earth Elements in Coal & Coal Byproducts

NETL researchers used laser induced breakdown spectroscopy as one of several techniques to identify rare earth elements (REEs) present in coal and coal byproducts. REEs are used in high-tech products, including cell phones, computers, batteries, and lasers, and are of significant value to national security, energy dominance, and the country's economic growth. The United States currently imports most of its REE supply from offshore countries.

REEs are not that rare; however, it is unusual to find them in large concentrations. A promising new way of obtaining REEs domestically begins by analyzing and characterizing the nation's supply of coal. NETL has developed techniques for characterizing samples both in the field and in the lab, assisting in the demonstration that REE extraction from coal and coal byproducts can be technically and economically feasible.

More than 800 field samples have been collected since June 30, 2015, by NETL researchers and personnel from the DOE Office of Fossil Energy. The United States Geological Survey and the Electric Power Research Institute have both signed memorandums of agreement with NETL calling for additional collaborative field sampling activity.

NETL's REE characterization efforts are among the most advanced in the world and are forging a path toward establishing a reliable domestic supply of REEs.

Celebrated Anniversary, Progress with City of Pittsburgh

NETL celebrated the two-year anniversary of a fruitful collaboration with the City of Pittsburgh in July. Since 2015, NETL has been assisting Pittsburgh on plans for efficient distributed energy systems in specific neighborhoods and ways to use new investments to increase resilience, reduce consumers' energy costs, and encourage workforce development.

A recent survey by the American Council for an Energy-Efficient Economy (ACEEE) showed that energy efficiency has improved in the city since the collaboration began. According to ACEE, Pittsburgh ranked 17th out of 51 cities on its City Energy Efficiency Scorecard. Scoring was based on metrics reflecting the adoption and implementation of specific government policies, actions, or public services that can improve energy efficiency.

Contributed to Safer Offshore Technologies with Offshore Risk Modeling Tools & Capabilities

A collaborative project between Pacific Northwest National Lab and NETL, funded by the Bureau of Safety and Environmental Enforcement (BSEE), resulted in the first open-source 4D blowout and oil spill occurrence model capable of simulating the application of dispersant at any location, including the blowout. The enhancement makes the model, called BLOSOM (Blowout and Spill Occurrence Model) useful for spill prevention related simulations, and improves BLOSOM's capabilities for rapid response and response preparedness.

BLOSOM is part of NETL's full Offshore Risk Modeling suite, which comprises custom big data and machine learning tools, data and models to assess risks and potential impacts of offshore oil and gas operations. In FY17 the Offshore Risk Modeling suite was adapted into an online custom modeling package for BSEE, which had funded NETL to adapt the Offshore Risk Modeling suite and tailor it for evaluation of offshore worst-case discharge applications from industry. NETL's team built a custom, online user interface, data, modeling and analytical suite via the Energy Data eXchange, or EDX.

Patents & Licenses

NETL's technology leadership was reaffirmed this year by the patenting of many novel and new inventions. A list of these inventions follows.

Regenerable Mixed Copper-Iron-Inert Support Oxygen Carriers for Solid Fuel Chemical Looping Combustion Process; Ranjani V. Siriwardane (DOE/NETL), Hanjing Tian (URS); 9,523,499; issued December 20, 2016.

Multi-point Laser Ignition Device; Steven D. Woodruff, Dustin McIntyre (DOE/NETL); 9,548,585; issued January 17, 2017.

Metal Ferrite Oxygen Carriers for Chemical Looping Combustion of Solid Fuels; Ranjani V. Siriwardane (DOE/NETL), Yueying Fan (URS); 9,557,053; issued January 31, 2017.

Creep Resistant High Temperature Martensitic Steel; Jeffrey Hawk (DOE/NETL), Paul D. Jablonski (DOE/NETL), Christopher Cowen (DOE/NETL); 9,556,503; issued January 31, 2017.

Methane-Rich Syngas Production from Hydrocarbon Fuels Using Multi-Functional Catalyst/Capture Agent; David A. Berry (DOE/NETL), Dushyant Shekhawat (DOE/NETL), Nicholas Siefert (DOE/NETL), Wayne Surdoval (DOE/NETL); 9,562,203; issued February 7, 2017.

Nanocomposite Thin Films for Optical Temperature Sensing; Thomas Brown (DOE/NETL), Christopher Matranga (DOE/NETL), Paul Ohodnicki Jr. (DOE/NETL), Michael P. Buric (DOE/NETL); 9,568,377; issued February 14, 2017.

Method of Making an Apparatus for Transpiration Cooling of Substrates Such as Turbine Airfoils; Mary Anne Alvin (DOE/NETL), Iver Anderson (Ames Laboratory), Andy Heidlof (Ames Laboratory), Emma White (Ames Laboratory), Bruce McMordie (Coatings for Industry); 9,579,722; issued February 28, 2017.

Surface Functionalization of Metal Organic Frameworks for Mixed Matrix Membranes; David Luebke (DOE/NETL), Hunaid Nulwala (Carnegie Mellon), Erik Albenze (URS), Surendar Reddy Venna (West Virginia University), Michael Lartey (ORISE), Tao Li (University of Pittsburgh), Nathaniel Rosi (University of Pittsburgh); 9,597,643; issued March 21, 2017.

Chromia Refractory Brick with Carbon Treatment; James Bennett (DOE/NETL), Keyi-Sing Kwong (DOE/NETL); 9,598,318; issued March 21, 2017.

Method of CO and/or CO_2 Hydrogenation to Higher Hydrocarbons Using Doped Mixed-Metal Oxides; Daniel J. Haynes (DOE/NETL), Mark Smith (URS), Victor Abdelsayed (URS), David A. Berry (DOE/NETL), Dushyant Shekhawat (DOE/NETL), James J. Spivey (ORISE); 9,598,644; issued March 21, 2017.

Mechanical Membrane for the Separation of a Paramagnetic Constituent from a Fluid; David Maurice (DOE/NETL); 9,636,631; issued May 2, 2017.

High Performance Hydrophobic Solvent for CO_2 Capture; David Luebke (DOE/NETL), Hunaid Nulwala (Carnegie Mellon); 9,643,123; issued May 9, 2017.

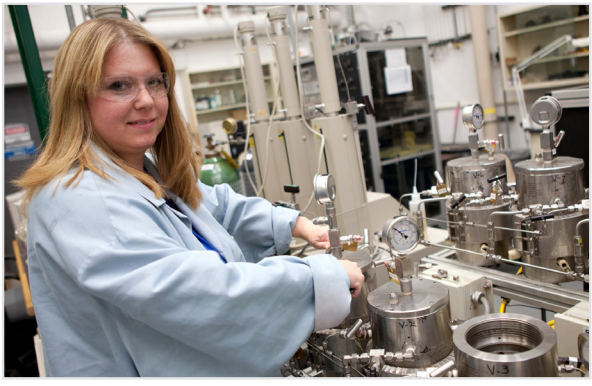
An exclusive license for *Variable Grid Method for Simultaneously Visualizing Uncertainty and Attribute Trends Associated with Spatial Data*; issued to VariGrid Explorations LLC (Texas); February 3, 2017.

Awards

Alexandra Hakala was named a recipient of the Presidential Early Career Award for Scientists and Engineers (PECASE)—the highest honor the U.S. government can bestow on scientists or engineers in the early stages of their research careers. Hakala was selected for her technical leadership and her work toward increasing the efficiency of domestic energy production while minimizing the environmental impacts associated with the use of fossil fuels.

Kelly Rose was recognized as an Innovative R&D winner at the Sixth Annual Shale Gas Innovation Contest for her kick-detection technology, which provides a cost-effective early warning of oil or gas well destabilization that could result in a blowout gusher event or "kick."

NETL's **Equation of State Water Management Team** earned a Pittsburgh Federal Executive Board Excellence in Government Award as an Outstanding Team for their work toward innovations that can help save millions of dollars in the event of an ultra-deepwater oil leak or an uncontrolled flow rate from ultra-deep wells and reservoirs. Awarded to NETL Team Members **Isaac Gamwo, Bryan Morreale, Roy Long, Jamie Brown, Kelly Rose,** and **David Berry**.



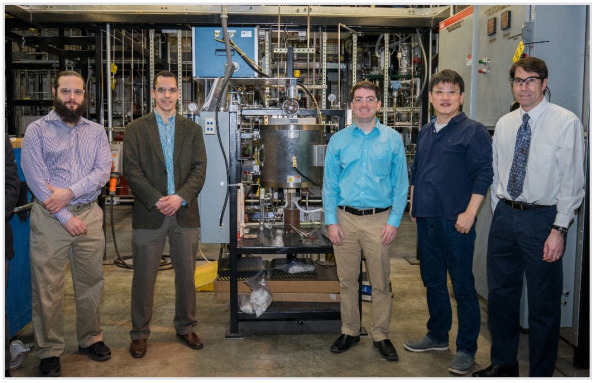
Barbara Kutchko received a Women in Energy Leadership Award from the Pittsburgh Business Times (PBT) for her involvement as a third-party analyst during the Deepwater Horizon Oil Spill. PBT officials said the magnitude of Kutchko's success made her an "obvious choice."

NETL Metallurgist **Paul Jablonski** was elected as Fellow of ASM International, the world's largest and most distinguished association for materials science professionals. ASM cited Jablonski for sustained excellence in materials processing and heat treatment.

Shiwoo Lee was awarded a prestigious AECOM Excellence Award in recognition of his exceptional and innovative research, which is improving solid oxide fuel cell performance, with significant environmental and commercial benefits.

Jessica Mullen received recognition from the Pittsburgh Federal Executive Board as an Outstanding Professional Employee. Mullen is a project manager at NETL and works with NETL research teams in water management and sensors and controls.

Anna Nakano received the Best Poster Award by a Young Professional in the Functional Materials Division at The Minerals, Metals & Materials Society Annual Meeting and Exhibition. Co-authored by **Jinichiro Nakano** and **James Bennett**, the poster reported thermodynamic and kinetic aspects of high-temperature thermocouple sensor alloy failure controlled by distinct diffusion processes.



NETL's **Material Science Functional Materials Team** received a Carnegie Science Award in recognition of the ways their work has serviced manufacturing and materials science in the western Pennsylvania region. The team develops high-performance optical sensors capable of operating in harsh environments, such as those found in fossil-fuel power generation systems. Awarded to NETL team members (pictured L-R) **Michael Buric, Paul Ohodnicki, Gregory Hackett, Shiwoo Lee, Benjamin Chorpening;** (not pictured) **Aidong Yan, Zsolt Poole, Thomas Brown, Kirk Gerdes,** and **John Baltrus.**

NETL's patent attorney **Lisa Baker** was inducted into the West Virginia University Department of Chemical Engineering Academy of Chemical Engineers for having "brought honor upon the department and her profession."

NETL's **Steve Zitney** and **Eric Liese** with co-authors Fabio Lambruschini and Alberto Traverso of the University of Genoa received a Best Paper Award from the American Society of Mechanical Engineers, for their paper, "Dynamic Model of a 10 MW Supercritical CO_2 Recompression Brayton Cycle."

Angela Goodman received a Division of Environmental Geosciences Award from the American Association of Petroleum Geologists (AAPG) for her work on carbon storage, which the AAPG cited as an invaluable resource for determining how much CO_2 can be stored at sites around the nation and the world, ensuring a safer environment for generations. Goodman was also honored with an Excellence in Government Award for Outstanding Contribution to Science by the Pittsburgh Federal Executive Board.

A cost-effective coating process to protect metal products from corrosion, developed by NETL researchers and Carnegie Mellon University, was recognized with a prestigious Excellence in Technology Transfer Award from the Federal Laboratory Consortium for Technology Transfer. Lumishield Technologies, a Pittsburgh-based startup company, was established to advance the technology into a commercial process.

NETL was the recipient of three **R&D 100 Awards**, which recognize the 100 most technologically significant products introduced into the commercial marketplace within the past year. The following NETL technologies were awarded:

- Carbon Capture Simulation Initiative (CCSI) Toolset—the only suite of computational tools and models specifically tailored to help maximize learning and reduce risk during the scale-up process for carbon capture technologies. Awarded to **David Miller.**

- Computationally Optimized Heat Treatment of Metal Alloys—a novel process that provides an easy method to optimize heat treatment to achieve the desired degree of homogenization with a minimum of furnace time. Awarded to **Paul Jablonski** and **Jeffrey Hawk.**

- HVAC Load Reduction Technology for Commercial Buildings—unique multi-functional sorbents that can capture CO_2 and volatile organic compounds at ambient temperatures and regenerate below 60 degrees Celsius. Awarded to **Ranjani Siriwardane.**

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Program staff are also located in **Houston, TX** and **Anchorage, AK**.

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