2016

NATIONAL ENERGY TECHNOLOGY LABORATORY

ANNUAL REPORT

Discovering, integrating, and maturing technology solutions

U.S. DEPARTMENT OF ENERGY

Contents

Director's Message

Researchers and inventors are in an innovation race to develop the technologies that will enable nations around the world to access reliable, affordable energy to fuel development and power prosperity, while, at the same time, ushering in a robust, vital age of environmental stewardship. The United States is at the forefront of this evolution. The National Energy Technology Laboratory (NETL) is playing a significant role in ensuring the nation's energy security by innovating safe, affordable, and increasingly sustainable ways to use our domestic fossil energy resources.

For the foreseeable future, coal, oil, and natural gas will continue to shoulder the bulk of our energy demands, providing reliable, affordable power for our businesses, homes, industries, and transportation. Through in-house research and strategic partnerships with industry and academia, NETL, the only U.S. Department of Energy (DOE) National Laboratory dedicated to fossil energy research, is working to eliminate the environmental impacts of fossil fuels. Our research is focused on energy challenges such as reducing greenhouse gas emissions through capturing and storing carbon dioxide (CO_2), developing more efficient energy conversion processes, and demonstrating novel advanced energy systems. As evidenced in this report, we have a solid record of success.

The 2016 fiscal year was a period of productivity and positive transition for NETL. We continued to cultivate a well-trained, dynamic workforce to accelerate technology advancements and reach our Lab's energy, economic, and environmental goals. We placed a new emphasis on diversity to foster collaboration, fresh ideas, and new perspectives. We also undertook a strategic reorganization designed to maximize our Lab's productivity around six core competencies, discussed in detail in the following pages, which are driving our researchers to develop technology solutions for today and options for tomorrow. NETL's ongoing portfolio of responsibility 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, with a total award value of more than $15 billion and a nearly $10 billion performer cost-share. 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 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, and environmentally sound 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 that appear on the following pages.

Dr. Grace M. Bochenek
Director, NETL

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 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.

Pictured: Nanotech goniometer, used to measure contact angle and surface tension of liquids

FY16 Employment and Funding

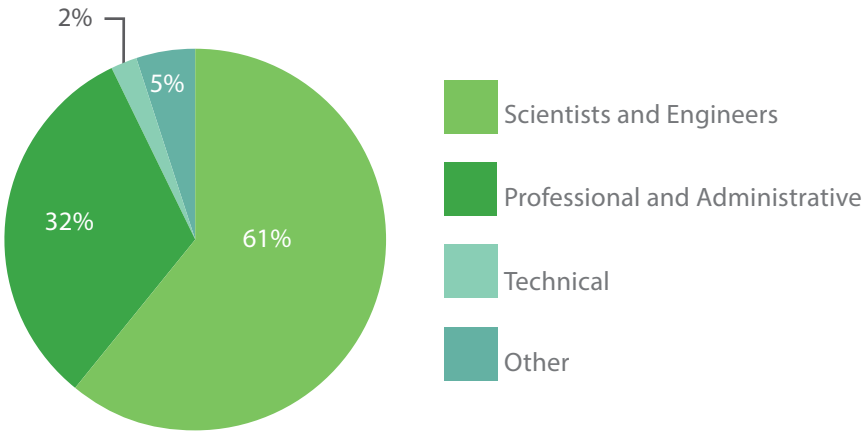
NETL's FY16 federal budget funding was $899 million, with a majority of that funding supporting mission work for the Office of Fossil Energy. In addition, NETL maintains financial oversight of $1.1 billion for the DOE Office of Energy Efficiency and Renewable Energy (EERE).

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. Nearly 1,400 employees work at NETL—a workforce of 525 highly skilled federal and 814 contract staff.

Employment

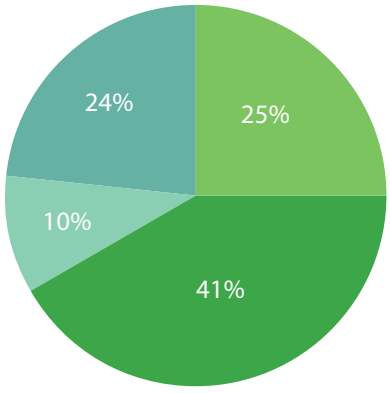
Federal Employees

Total: 525



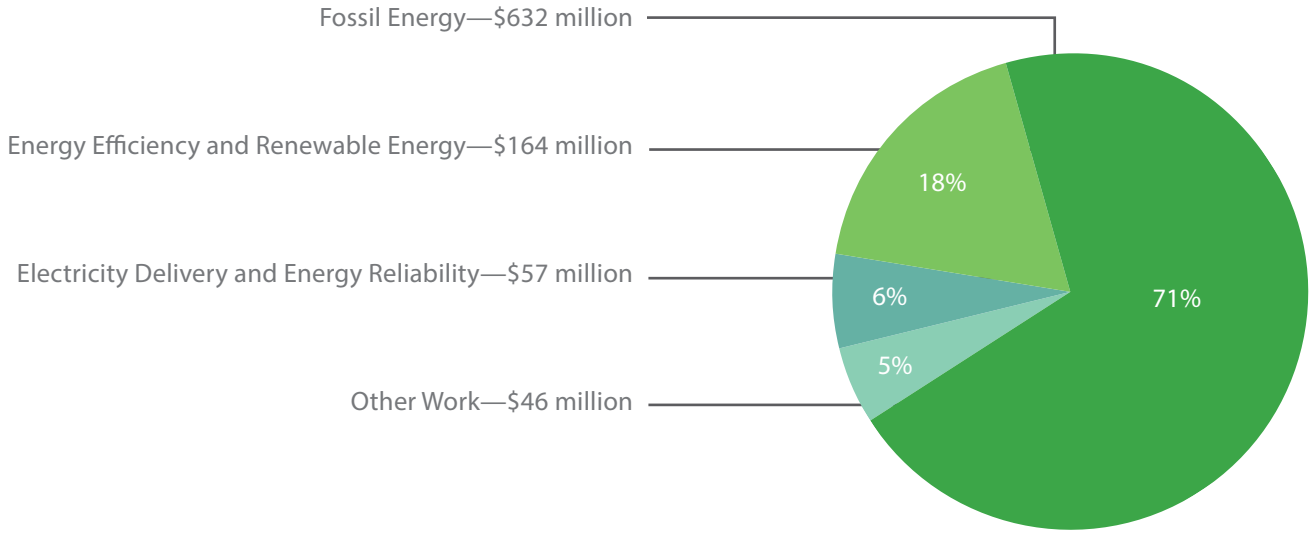
Site-Support Contractors

Total: 814



Funding

Total NETL Budget: $899 Million



Core Competencies

TOOLS TO TACKLE FOSSIL ENERGY RESEARCH

Because of NETL expertise in energy innovation, Americans will continue to enjoy the comfort and prosperity they have grown to expect, even as the demand for energy continuously rises. Today, the Laboratory is accomplishing its mission—to discover, integrate, and mature technology solutions to enhance the nation's energy foundation and protect the environment for future generations—by developing a tightly focused set of core competencies critical for mission success. Individually, these competencies represent some of the most advanced fossil fuel research being conducted in the world, but together they leverage NETL as a comprehensive science and engineering facility capable of delivering world-class technology solutions today and tomorrow.

ENERGY CONVERSION ENGINEERING

NETL has developed energy conversion systems for many years, and the resulting power, fuels, and chemicals have been historically derived from coal and natural gas, but recent advances have also featured integrated fuel and renewable generation.

As interests emerge that include district heating and cooling, smaller grids, energy storage, and further renewable integration, flexible power generation at many scales will be needed to meet the unique challenges of future energy demands.

NETL drives technological advancements by pioneering new technologies that enable low-carbon power production while optimizing environmental performance, water use, efficiency, and waste minimization. Using fundamental and applied modeling tools coupled with experimental testing, NETL researchers are accelerating the development of technologies by reducing the time, cost, and technical risk associated with bringing advanced technologies from concept to market.

MATERIALS ENGINEERING AND MANUFACTURING

The environments of advance energy systems are among the harshest in the world, so materials used to build them must withstand high pressure, high temperature, corrosion, and other demanding conditions. NETL specializes in the design, development, and deployment of these materials.

From atomic-level design to pilot-scale evaluations, researchers accelerate the development of enabling materials using a combination of computational and experimental techniques. NETL researchers access advanced tools, unique facilities, and broad expertise to design, synthesize, and process a variety of material classes. Functional materials, which include polymers and polymer-composites, ceramics and electroceramics, and nano-engineered materials, drive improved performance of technologies such as carbon capture, chemical looping combustion, and solid oxide fuel cells. Structural materials, which are fabricated from materials such as stainless steels, superalloys, and ceramics, have engineered chemistries and microstructures for enhanced strength, corrosion, and erosion properties. Structural materials enable advanced turbines, gasification, drilling, and other energy applications to push the boundaries of traditional operating parameters.

GEOLOGICAL AND ENVIRONMENTAL SYSTEMS

Fossil fuel resources must be recovered in an environmentally safe manner, but the unique nature and challenging locations of these resources requires the development and application of new technologies. Research in this area is catalyzing technological development, providing objective data to quantify the environmental and safety risks of oil and gas development, and characterizing emerging resources like gas hydrates.

NETL is addressing the challenges associated with engineered natural systems such as geological CO_2 storage, unconventional tight gas resources, hydrates, offshore oil and gas production, and geothermal systems by refining expertise in geo-materials science, biogeochemistry, field emission monitoring, geomechanics, risk and impact assessment, reservoir fluid characterization, and numerical modeling.

SYSTEMS ENGINEERING AND ANALYSIS

The discovery, design, and operation of energy systems benefit from systematic decision-making techniques that strike a balance among the often-competing goals of maximizing profits, minimizing costs, addressing market and policy drivers, and meeting environmental and technical restraints. One way NETL is achieving this balance is by developing and using advanced models coupled with optimization and uncertainty quantification to support decision making.

Methodologies based in the fundamental disciplines of mathematics, operations research, and computer science are complemented by experimental capabilities in chemistry, physics, and biology, as well as pilot-scale evaluation at locations such as the National Carbon Capture Center in Wilsonville, AL. Integration of computational and applied research provides insight into new technology; identifies new energy concepts; and analyzes energy system interaction at plant, regional, national, and global scales.

COMPUTATIONAL SCIENCES AND ENGINEERING

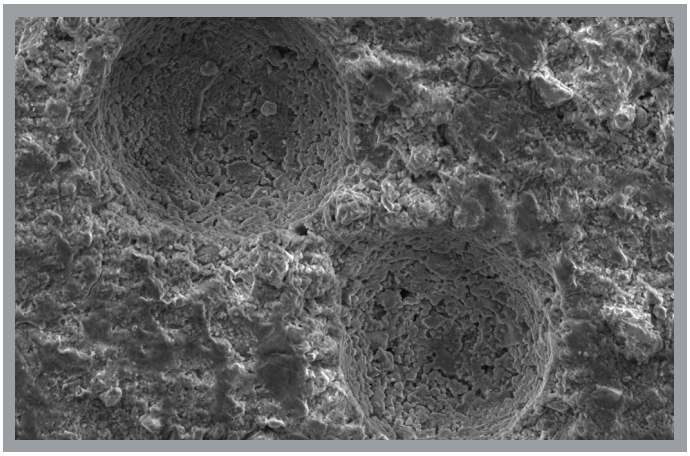
To keep pace with growing energy demand, scientists increasingly depend on shared simulations and data, analysis tools, and research collaborations, all of which require high-speed information access and high-performance computational infrastructure. State-of-the-art computing facilities enable the advanced computational capacities and collaborative workspaces used at NETL to create cutting-edge modeling tools to facilitate rapid technology development and understanding. Scientists from all over the country connect to use NETL's advanced visualization center and statistical and analytical software packages to address risk reduction, identify knowledge gaps, and evaluate environmental risks.

PROGRAM EXECUTION AND INTEGRATION

NETL is renowned as the nation's fossil-energy science and engineering resource, but a successful research portfolio is built upon a foundation that includes (1) a thorough understanding of the economic, environmental, technological, regulatory, and political landscape; (2) science-based strategic planning for programs and activities; (3) collaboration with strategic partners to develop and test technology over a variety of maturity levels; and (4) effective project management.

NETL's Program Execution and Integration functions are powered by highly trained management experts that excel as effective technical managers, communicators, and quality assurance analysts able to assess technical risks, assist with technical problem solving, and evaluate and manage project risk. Through integrated technical and business teams, NETL defines, solicits, negotiates, awards, manages, and delivers federally sponsored research and development benefits to the nation.

Applying these assets, NETL has guided a range of successful research, development, and demonstration projects involving technologies related to efficient energy conversion, effective resource development, and environmental sustainability, including technologies focused on power generation, resource extraction, vehicles, buildings and solid-state lighting, grid technology, and energy delivery.



NETL Foamed Cement Research is Changing Oil and Gas Industries

NETL played a key role in updating a 25-year-old testing standard that helps ensure quality, reduce cost, decrease waste, and support safer oil and gas operations around the world.

The research into foamed cement was conducted by NETL scientists using the Laboratory's CT scanning equipment and subsurface geomechanics facilities and was part of the Laboratory's collaboration with the American Petroleum Institute.

Safe and environmentally sustainable oil and gas operations require isolation between the wellbore and the surrounding formation. Foamed cement, created when gases are injected into cement slurry to form microscopic bubbles, is used to seal the gap between the rock face and a well's outer casing.

The cement must have consistent density and uniform distribution of bubbles to protect against leaks and spills for the life of the well. NETL research is helping to make sure the right characteristics are incorporated into the cement. The work showed that lab samples have not matched foam generated in the field, resulting in inconsistent assessments of cement capabilities. It also showed that the equipment used to generate foamed cement can have a major impact on the properties of the cement. These findings will help update the 25-year-old foamed cement testing standard for improved safety and efficiency.

NETL-Led Research Team Makes Significant Rare Earth Discovery

A team of DOE researchers found that rare earth elements (REEs) can be removed from two coal byproduct materials through an ion-exchange process—a discovery that could expand the U.S. resource base of these critical elements.

The findings, published in a peer-reviewed paper titled "A Study on Removal of Rare Earth Elements from U.S. Coal Byproducts by Ion Exchange," also indicates that removal of REEs through an ion-exchange process can offer significant cost and environmental advantages compared to extraction from conventional ores.

REEs are used in hybrid vehicles, wind turbines, fluorescent lights, catalysts, and consumer products such as computer hard drives and mobile phones.

The United States is heavily dependent on REE imports that are commonly produced from ores that are difficult to break down for element extraction. Extraction requires temperatures of more than 500°F and exposure to concentrated acids—a process known as roasting. Emissions concerns, including CO_2 emissions, are also associated with roasting.

The research team found that, for two coal byproducts associated with a coal bed in Pennsylvania, REEs can be removed with an ammonium sulfate solution that is used commercially for REE recovery outside the United States.

These findings—the result of a collaboration between DOE's Office of Fossil Energy and NETL, and Penn State's College of Earth and Mineral Sciences—appeared in *Metallurgical and Materials Transactions E*, published by ASM International and The Minerals, Metals and Materials Society.

Computational Toolset for Carbon-Capture Technology Development Readied for Commercial Use

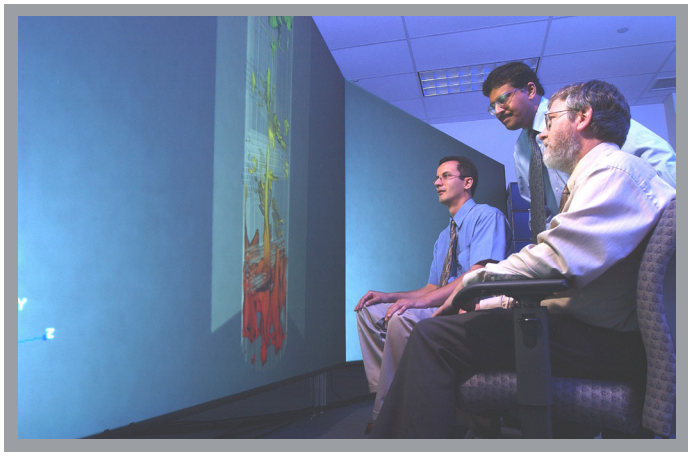
The NETL-supported Carbon Capture Simulation Initiative (CCSI) Computational Toolset was officially ready for commercial use to support carbon-capture technology development and unveiled at the 2016 Carbon Capture Technology Project Review Meeting.

The CCSI Toolset is a comprehensive, integrated suite of validated, multi-scale computational models and simulation tools that provide new capabilities for rapid deployment of carbon-capture concepts with reduced risks compared to what would be accomplished by traditional research and development pathways.

The toolset is the only suite of computational tools and models tailored to reduce risk—important because pilot projects are traditionally expensive and offer limited opportunities to collect data needed to move to commercial scales. The toolset can also be used in related industries for faster, more cost-effective scale-up of additional technologies.

The final fourth-generation toolset release was the culmination of nearly 5 years of development and lays the foundation for the new CCSI^2—Carbon Capture for Industry Impact—which will use the CCSI Toolset to create additional partnerships with technology developers to accelerate next-generation carbon-capture technologies.

CCSI^2 builds on the momentum of CCSI, which was an unprecedented success and pushed the limits of what is possible with commercial simulation tools. CCSI^2 is establishing multiple cooperative research and development agreements to examine several challenging carbon capture technology issues.

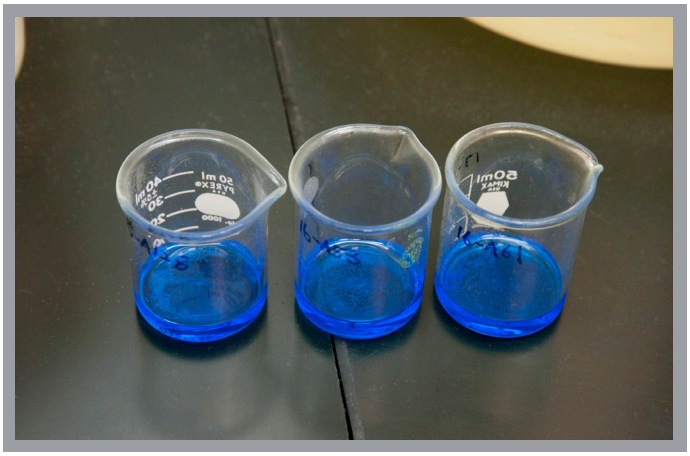


Multiphase Modeling Gets Faster

NETL has improved the time to solution of its Multiphase Flow with Interphase eXchanges (MFIX) code by a factor of ten. This represents a remarkable increase in speed that is adding value to this high-fidelity simulation tool. The tool can more effectively aid in the development of advanced gasification technologies that are highly efficient, environmentally superior, and more cost-competitive with other fossil fuel power generation technologies currently available.

MFIX is NETL's internationally acclaimed suite of specialized computational fluid dynamic codes. Researchers use MFIX to create detailed computer models of multiphase systems—such as the flow of coal ash and flue gas. These computer models drastically shorten the time and cost associated with developing new power generation technologies, allowing the public to benefit from clean, affordable, and more reliable power in less time.

NETL will continue to release improved versions of the code to the public on its Multiphase Flow Science website. The MFIX suite of multiphase software is accessed by more than 4,000 registered users worldwide, including those from industry, academia, and other national labs.



NETL Uncovers Copper's Potential for Reducing CO_2 Emissions in Chemical Looping

NETL determined that copper can be used in a coal combustion technology known as chemical looping, thus helping to economically remove CO_2 from fossil fuel emissions.

In power plants, coal is burned in air to create the steam that powers electricity-producing turbines. In chemical looping, pulverized coal or natural gas is combusted through reaction with oxygen-bearing materials called oxygen carriers. After combustion, the oxygen-depleted carrier circulates to an air reactor, where it is again oxidized and transported back to the fuel reactor for combustion. The process is similar to how blood circulates through animal bodies, carrying oxygen to the heart, out to the muscles, and then looping back to the heart again for new oxygen.

The process produces a nearly pure exhaust stream of CO_2 that can be easily captured to produce other products, or permanently stored underground.

More efficient oxygen carriers are needed. NETL discovered that when copper is used as a key ingredient in oxygen carriers, it improves the efficiency of chemical looping.

Researchers designed a mixed metal oxygen carrier containing iron oxide and a high concentration of copper oxide to create a highly reactive oxygen carrier that can withstand high temperatures.

Texas CO_2 Capture Demonstration Project Hits 3 Million Metric Ton Milestone

Allentown, PA-based Air Products successfully captured and transported, via pipeline, its 3 millionth metric ton of CO_2 to be used for enhanced oil recovery on June 30, 2016—an achievement that highlights the ongoing success of carbon capture and storage projects managed by NETL.

The project demonstrates how a gas separation technology called vacuum swing adsorption can be implemented into an operating facility. The technology is being used at a hydrogen production facility in Port Arthur, Texas, to capture more than 90 percent of the CO_2 from the product streams of two commercial-scale steam methane reformers, preventing its release into the atmosphere.

In addition to demonstrating the integration of Air Products' vacuum swing adsorption technology, the project is also helping to verify that CO_2-enhanced oil recovery (CO_2-EOR) is an effective method for permanently storing CO_2. CO_2-EOR allows CO_2 to be stored safely and permanently in geologic formations, while increasing oil production from fields once thought to be exhausted.

The CO_2 captured from the Port Arthur facility is being used for EOR at the West Hastings Unit (oilfield) in southeast Texas. Injected CO_2 can dissolve and displace oil residue that is trapped in rock pores. It is estimated that the West Hastings Unit could produce between 60 and 90 million additional barrels of oil using CO_2 injection.

In total, DOE-sponsored projects have captured and securely stored more than 12 million metric tons of CO_2, equivalent to taking more than 2 million cars off the road for a year. Investing in projects and technologies, such as Air Products', are critical to paving the way for more widespread use of carbon capture and storage technologies.

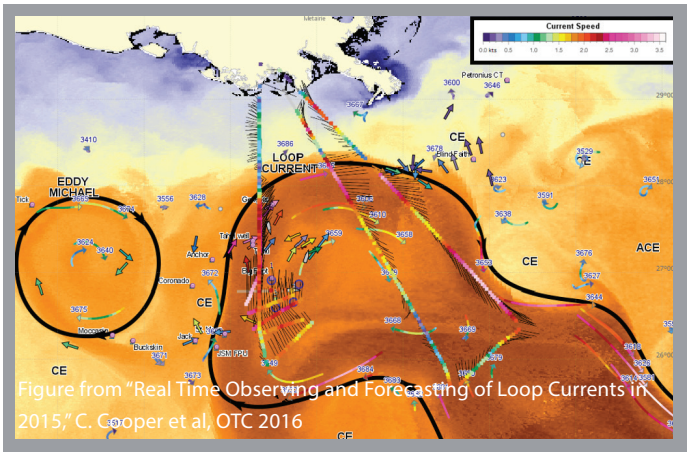


Figure from "Real Time Observing and Forecasting of Loop Currents in 2015," C. Cooper et al, OTC 2016

Airborne Ocean Current Measurement Technology Used for Energy and Rescue Missions

A project sponsored by NETL with partners Fugro (Houston, TX) and Areté Associates (Arlington, VA), developed, commercialized, and sold a system that can monitor offshore current conditions from the air, providing critical information in record time for oceanographic research and emergency situations such as oil spills and search and rescue missions.

The Remote Ocean Current Imaging System (ROCIS), measures ocean surface current velocities from an airplane in near real time over a broad area.

ROCIS is the first commercially available system for mapping surface current conditions over a wide area of ocean. In just 4 hours, the system can survey ocean currents at 800-foot intervals over a track of 500–680 miles. Traditional methods would take a combination of 4 vessels 24 hours to cover the same area.

ROCIS was developed using digital camera technology, highly accurate positioning systems, and advanced image processing algorithms to derive surface currents from wave measurements. The technology can be installed on survey aircraft equipped with a navigation system augmented by Fugro's Starfix© satellite positioning system.

Using ROCIS, data is reviewed in real time on board the aircraft. Within an hour after the aircraft lands, the system produces a "quick-look" map of the currents over the surveyed area. Processed data files are available a few hours later.

Project Captures First Comprehensive Hydraulic Fracturing Research Data from 1.5 Miles Underground

NETL, with the Gas Technology Institute (Des Plaines, IL), Laredo Petroleum (Tulsa, OK), and other industry partners, collected the world's most comprehensive hydraulic-fracturing research dataset in unconventional shale.

The data provides a first-ever look at how induced underground fractures spread within horizontal wellbores. It will be used to help reduce potential environmental impacts, improve efficiency, and demonstrate safe and reliable hydraulic fracturing operations.

Hydraulic fracturing is a complex process with many variables affecting exactly where fractures propagate, their dimensions, and their ability to enhance production of hydrocarbons. Because fractures are underground, they are unseen and operators rely on indirect measurements to calculate dimensions.

By improving the design and execution of hydraulic fracturing, the number of future wells drilled can be reduced along with the amount of water and energy needed in hydraulic fracturing operations. A smaller environmental footprint can result.

At a test site in the Permian Basin of Texas, 11 new 10,000-foot-long horizontal wells were drilled and stimulated in the upper and middle Wolfcamp formations, and approximately 600 feet of unique core was obtained by drilling a one-of-a-kind core well through created hydraulic fractures. The process allowed researchers to obtain phenomenal quality core samples for further study.

Super Truck Project Reaches New Performance Milestones

An NETL-managed project under DOE's Super Truck program, which successfully developed four long-haul freight vehicles capable of exceeding 50 percent brake thermal efficiency and greater than 50 percent freight efficiency, achieved new performance milestones in 2016 compared to their 2009 base model truck standards.

The Super Trucks feature advances such as a highly efficient and clean diesel engine, an advanced waste heat recovery system, an aerodynamic tractor-trailer combination, advanced material lightweighting and engine idle reduction technologies and strategies. The four trucks tested achieved the following successes in 2016:

- A Cummins-Peterbilt Super Truck achieved an 86 percent improvement in freight efficiency over a 2-day, 500-mile highway test route
- A Daimler test truck attained 115 percent freight efficiency improvement based on on-road vehicle testing over a 5-day, 312-mile round trip
- A Volvo truck test attained 88 percent freight efficiency improvement over a customer drive cycle
- A Navistar truck attained 104 percent freight efficiency improvement

The increase in fuel economy for the Super Truck could save thousands of dollars annually per truck based on today's diesel fuel prices for long-haul trucks. According to the American Trucking Associations, about 2 million registered tractor-trailers travel U.S. roads today.

New Carbon Storage Risk Monitoring Tools Released for Testing

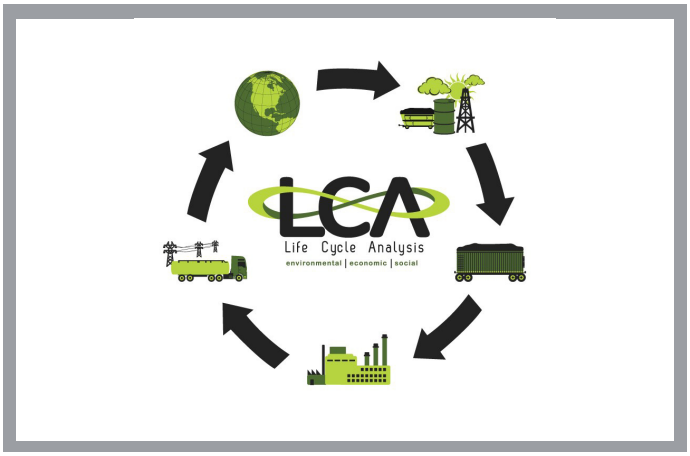
Seven new high-technology tools that can help predict long-term risks of large-scale carbon storage operations were developed by the NETL-led National Risk Assessment Partnership (NRAP), and released to carbon capture and storage researchers and the industrial community for beta testing.

The simulation tools are designed to help evaluate environmental risks of carbon storage containment systems. Deployment will enable users to predict the safety and permanence of carbon storage systems based on two major types of environmental risks: leakage and induced seismicity.

The tools were specifically designed by national experts who are a part of the NRAP team to be useful in exploring the behavior of several key components of the carbon storage system, including storage reservoirs, seals, wells, and groundwater aquifers. NRAP applies DOE's core competency in science-based prediction for engineered–natural systems to the long-term storage of CO_2.

The NRAP program receives input from industry, government, non-government organizations, and academia regarding research needs for large-scale CO_2 storage deployment.

The NRAP project team will implement improvements based on feedback from beta-testers made up of members from industry, regulatory agencies, universities, and other research organizations prior to wider release.



NETL Life Cycle Analysis Work Sets the Standard for Evaluating Energy Technology Options

Life Cycle Analysis (LCA) evaluates the environmental, economic, and social attributes of energy systems ranging from the extraction of raw materials from the ground to the use of the energy carrier to perform work. Throughout FY16, NETL's LCA resources and leadership provided a high-value impact to the following entities:

- The Secretary of Energy, to determine the export authority for liquefied natural gas facilities
- The U.S. Environmental Protection Agency, to improve the accuracy of the Greenhouse Gas Inventory for natural gas systems
- The U.S. Department of Agriculture's Forest Service, to determine the life cycle environmental impacts of proposed rulemaking
- The Wyoming Infrastructure Authority, to evaluate the life cycle environmental footprint of international options for exporting U.S. coal resources
- The Environmental Defense Fund, to synthesize the current state of science on methane emissions from the natural gas sector

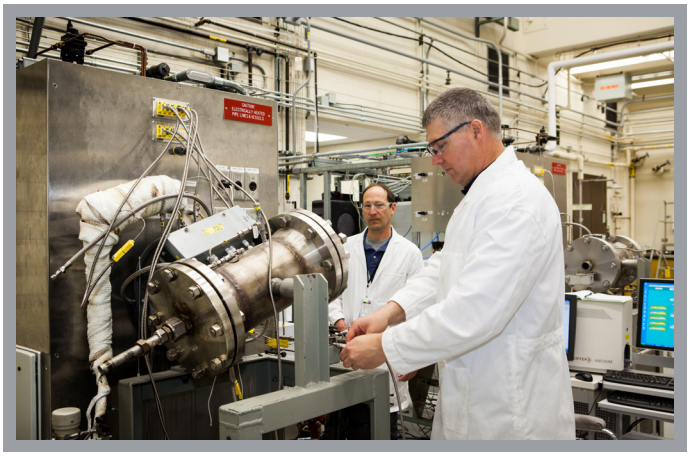
LCA provides strategic guidance in identifying opportunities for research and development for advancing energy options that fuel the nation's economy, strengthen its security, and improve its environment.

NETL Research Team Improves Chemical Looping Reactor Performance

NETL researchers developed 3D simulations for use in the Laboratory's chemical looping combustor, providing first-of-its-kind views of how centrifugal force can efficiently separate coal ash from the metal oxygen carrier in a chemical looping combustion reactor—increasing the efficiency of a technology poised to have a positive impact on fossil fuel power generation.

Chemical looping combusts fossil fuel in nearly pure oxygen rather than air and operates at conditions similar to today's power plants. Energy systems using conventional construction materials and techniques can accommodate chemical looping combustion, decreasing costs. In addition, combustion in one part of a chemical looping reactor produces highly concentrated CO_2 and water that can be purified, compressed, and sent for storage or reuse. As a result, a separate and expensive CO_2 separation process is unnecessary.

The team's success highlights NETL's strength in forming strategic partnerships to leverage resources and conduct world-class research.



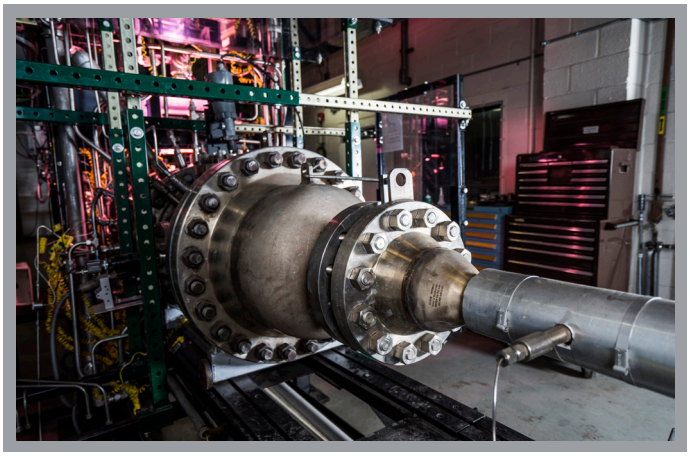
Carbon Capture Technologies Used for Biomass-to-Biofuel Conversion and Power Generation

NETL granted a license for two patented sorbent technologies that capture CO_2 from streams of mixed gases enabling cleaner, more-efficient energy production from renewable fuels. The license was granted to renewable energy systems developer CogniTek Management Systems (Northbrook, IL) through the company's MG Fuels.

Sorbents absorb gases, such as CO_2. CogniTek plans to incorporate these sorbent technologies into its integrated biomass-to-biofuels conversion process with power generation. This innovative process includes carbon capture and represents a sustainable solution for distributed power. The liquid biofuels produced by the process can also be used as transportation fuels.

Biofuels are usually derived from corn, but CogniTek plans to use a wide range of plant matter for feedstock, including quick-growing grasses and trees, nuisance crops, and agricultural and commercial waste. Biomass is an abundant domestic resource and may significantly contribute to the renewable fuel market within the next decade.

The CogniTek process will have naturally low carbon emissions because the plants used as feedstock consume CO_2 from the atmosphere as part of their growth process. Incorporating the NETL technologies, which employ a regenerable magnesium hydroxide sorbent to capture CO_2, makes an inherently green process even greener and will result in a near 100 percent "carbon negative" process.



Breakthrough Could Improve Turbine Performance and Reduce Carbon Emissions from Power Plants

Research supported by NETL could significantly increase the efficiency of turbines in fossil fuel electricity generation, reducing CO_2 emissions from power plants.

Gas turbines are the main electricity-generating components in most power plants. When they operate at high temperatures, they use less fuel, operate more efficiently, and enable carbon capture technologies to more effectively reduce greenhouse gas emissions.

The materials that protect the turbines from high heat degrade and fail when exposed to temperatures that exceed 1,200°C, which is required for efficient operations and greenhouse gas capture.

Researchers from HiFunda LLC (Salt Lake City, UT) and the University of Connecticut successfully demonstrated that an oxide called yttrium aluminum garnet deposited by the relatively new process called a "solution precursor plasma spray" provides a thermal barrier coating that can be used at 1,500°C—a temperature advantage of 300°C compared to current state-of-the-art air plasma-sprayed coatings.

A new spin-off company—Solution Spray Technologies LLC (Storrs-Mansfield, CT)—was created to be a thermal barrier coating service provider for the new technology.

If adopted throughout the gas turbine industry, the technology could significantly increase turbine efficiency and reduce overall fuel consumption. It may also enable development of technologies for next-generation, high-temperature, high-efficiency systems and lay the groundwork for more effective carbon capture in power plants.

Innovation That Improves Safety, Efficiency of Energy Plans Nets R&D 100

Virtual reality–based software, developed by a team of experts from NETL, West Virginia University, and Schneider Electric, that provides energy industry decision makers with an unprecedented high-tech look inside the operation of power plants received a prestigious R&D 100 Award. The software can help lower costs and increase safety and efficiency.

The R&D 100 awards, given by R&D Magazine and known as the "Oscars of Invention," celebrate the top technology products of the year.

The R&D team created the 3D, immersive, virtual reality software technology, known as EYESIM, to give engineers and operators of energy plants a clearer vision of conditions inside plant equipment while in operation so that greater, more-informed efficiency and safety decisions can be made faster and more effectively, saving time and money.

EYESIM recreates the look and feel and sounds of an actual operating plant, enabling hands-on interaction with process equipment. EYESIM enables users to master and optimize plant operations, control, and maintenance, and follow safety procedures for process malfunctions and abnormal situations.

Users of the new product include plant control room workers, field, and maintenance operators, and engineers and managers from electric utilities, fossil energy producers, renewable energy companies, engineering and construction firms, and equipment vendors.

Light-Duty Advanced Technology Powertrain Project Achieves Improved Fuel Economy

Research financially supported by NETL for DOE's Office of Energy Efficiency and Renewable Energy (EERE) improved the fuel economy of a vehicle similar to a minivan by more than 25 percent while meeting the U.S. Environmental Protection Agency's most stringent emissions standards.

Automaker FCA, Argonne National Laboratory, Bosch, Delphi, and Ohio State University designed, built, and tested a dual-fuel advanced combustion 2.4-liter engine with a number of extremely efficient features.

For example, the engine features a high compression ratio; a gasoline direct injection system; two-stage turbochargers allowing the engine to access extra power; and a cooled exhaust gas recirculation technology lowering the combustion temperature and decreasing pollutants produced by the engine.

An electrical mode management strategy enables the car to maintain the same state of battery charge as a conventional vehicle with less fuel, and an innovative heat management system cools the engine more efficiently. The vehicle also uses alternative fuels.

EERE's Vehicle Technologies Office develops and deploys efficient and environmentally friendly highway transportation technologies that will enable America to use less petroleum. These technologies will provide Americans with greater freedom of mobility and energy security, while lowering costs and reducing impacts on the environment.

More Efficient Method of Water Desalination Developed in NETL-Managed Project

In a project managed by NETL, General Electric (GE) developed a method to lower the energy requirement and cost of recovering usable water from high-salinity brines that are expensive to treat with currently available technologies. The new technology involves freezing the brine by expansion of a compressed propane and brine stream in a turbo-expander to yield solid ice and salt crystal. This method offers a lower cost way to turn a potential waste product into a usable source of water and minerals, while helping to facilitate CO_2 mitigation efforts.

NETL research has shown that deep saline formations hold great potential for CO_2 storage, but these deep geologic formations are already filled with brine, which limits the amount of CO_2 that can be injected. Removing some of this brine increases the storage capacity of the aquifer and enables operators to manage the reservoir pressure and steer the plume of injected CO_2.

GE's method demonstrated 100 percent water recovery and a 58 percent cost of water treatment reduction compared to a thermal crystallizer.

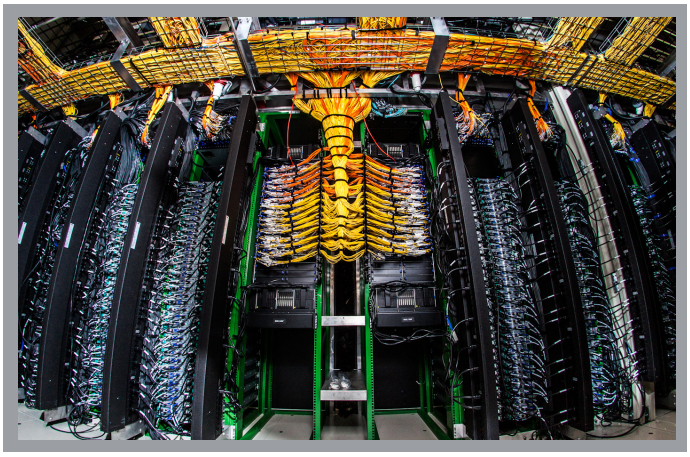
Enhanced NETL Knowledge-Sharing Tool Reaches New Users

NETL developed a series of 12 enhancements to its knowledge-sharing network, the Energy Data Exchange (EDX), to provide a more efficient and effective data management tool that now spans all DOE.

The EDX improvements enabled DOE's Office of Fossil Energy and the DOE Subsurface Technology and Engineering Research, Development, and Demonstration Crosscut to use EDX as a key data management system. EDX was also enhanced to connect users more efficiently to authoritative and relevant data resources. Based on the success of the upgrades, two additional national labs are developing collaborations centered on EDX.

In addition, NETL's Knowledge Management Database (KMD) was integrated into EDX, to enhance discoverability of oil and gas products while helping users connect more effectively to datasets and tools that promote research. The KMD is a collection of over 10,000 NETL oil and gas research program–affiliated reports and products that were previously only available on NETL's website.

Beyond DOE, EDX is at the core of a Department of Interior-Bureau of Safety and Environmental Enforcement project that supports oil spill worst-case discharge evaluations. The EDX development team was also awarded a cooperative research and development agreement through the Environmental Defense Fund to add to EDX key data and search capabilities leveraging custom big data computing capabilities related to methane emitting infrastructures worldwide.



Institute for the Design of Advanced Energy Systems Founded

A new initiative led by NETL has attracted industry attention for its new multi-scale computational approach for developing new energy systems concepts.

NETL launched its Institute for the Design of Advanced Energy Systems (IDAES) in FY16 to be the premier resource for the identification, synthesis, optimization, and analysis of advanced energy systems for supporting DOE's strategic objectives of improving the nation's energy security, economic competitiveness, and environmental responsibility.

IDAES is focused on innovative processes that overcome existing constraints and support technology maturation. For example, the initiative has developed initial models for solid and solvent-based CO_2 capture, chemical looping, and advanced combustion that go beyond the capabilities of current commercial simulation tools. Several companies have already expressed interest in participating in the IDAES program and using the computational tools and models under development.

Aggressive innovation is required to meet carbon reduction goals while simultaneously addressing other environmental objectives such as water-energy-food challenges. IDAES aims to overcome the challenge of determining which technologies to pursue and how to optimally integrate them while considering their full life cycle environmental footprint and determining market potential.

NETL Leads Discussion on Ways to Tap the Earth's Heat for Geothermal Possibilities

NETL and EERE's Geothermal Technologies Office brought together industry, academia, and government stakeholders to exchange information and make recommendations for the use of geothermal energy in the Appalachian Basin including New York, Pennsylvania, and West Virginia.

Geothermal energy is derived from the Earth's heat, which can supply clean, renewable, and continuous energy with very low greenhouse gas emissions. Direct use, low-temperature geothermal energy applications, such as residential heating and cooling, can diversify U.S. energy supplies and contribute to the goal of doubling renewable energy generation by 2020.

At the workshop, internationally recognized geothermal experts led discussions on a variety of topics including location and characterization of geothermal resources, low-temperature direct-use applications, and the economics and market potential for geothermal energy.

The Geothermal Energy Association estimates that less than 7 percent of the world's geothermal capacity has been tapped thus far. Geothermal resources represent an opportunity for a relatively low-cost energy source and for development as an essential part of a more diverse energy portfolio. Geothermal reservoirs are systems of hot rock and water at temperatures that generally increase with depth below the Earth's surface.

Game-Changing Process Mitigates CO_2 Emissions Using Gold Nanoparticles

Gold nanoparticles are part of a new process developed by NETL that can efficiently convert CO_2 into usable chemicals and fuels—a breakthrough that could lead to an effective way to reduce CO_2 emissions.

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. Most fossil fuel-powered CO_2 conversion processes are currently "carbon positive" and do not help mitigate CO_2 emissions. The new NETL approach is a "carbon neutral" energy cycle, using renewable energy sources to recycle waste CO_2 into chemicals and fuels without generating new CO_2 emissions.

Researchers developed a special form of gold nanoparticle that contains exactly 25 gold atoms to convert CO_2. This "Au25" catalyst is highly efficient. Researchers powered a small CO_2 reactor with inexpensive renewable energy sources, such as solar panels and solar-rechargeable batteries.

Data obtained from the study is used in critical performance estimates needed to move the carbon-neutral energy cycle out of the lab and into industrially relevant applications.

Reaching Out to Expand Core Competencies and Engage Stakeholders Internationally

In FY16, NETL engaged old and new stakeholders, joined forces with influential consortia, was awarded funding for specific new research projects, and hosted international visitors for shared learning experiences.

- NETL participated in the Coal Utilization Research Council (CURC) Technology Showcase on Capitol Hill. CURC represents technology consumers, developers and manufacturers, and government research organizations. Membership organizations participate in research projects with NETL at a level that represents nearly 25 percent of NETL's DOE research budget.
- In the advanced and additive manufacturing area, NETL joined two important consortia in FY16—America Makes and Carnegie Mellon University's NextManufacturing Consortium—and pursued a range of other, additive manufacturing and 3D printing activities.
- NETL broadened its core competencies by winning 25 awards representing $7.6 million. Highlights include a $1.3 million award from the DOE Office of Advanced Scientific Computing Research to develop the capability for exascale simulation of multiphase energy devices; and a $1.08 million award from DOE in partnership with the Universidad del Turabo (Puerto Rico) to provide opportunities for students and faculty participating in the Consortium for Integrating Energy Systems in Engineering and Science Education (CIESESE) to conduct energy-related research at campuses across the United States.
- The Laboratory hosted 30 delegates from the Shanxi Province in China for discussions about unconventional oil and gas development. The engagement resulted in opportunities to further strengthen collaboration between NETL and China.

Multi-Material Lightweight Vehicle Helps Bring Technologies to Market

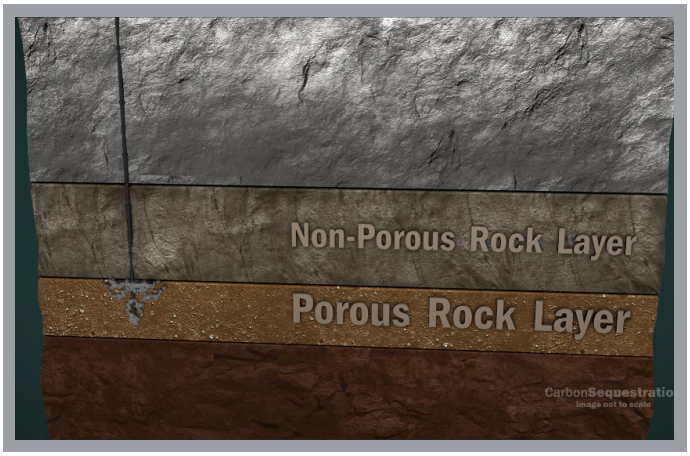
NETL provided financial management for a Multi-Material Lightweight Vehicle (MMLV) project built by Vehma International (Troy, MI) and Ford (Dearborn, MI), with support from EERE that demonstrated the feasibility of integrating lightweight materials and joining technologies into current production vehicles.

The MMLV concept car weighs 23.5 percent less than the 2013 Ford Fusion, a similar mid-size sedan. Reducing a vehicle's weight by 10 percent can increase its fuel economy by 6 to 8 percent, so the technology offers huge potential for increasing vehicle efficiency.

To assess its safety, Ford ran the MMLV through its durability test track and four standard safety tests. The MMLV passed all the tests.

Seven vacuum die casting facilities to manufacture cast aluminum structural components were established. Two of those facilities are in the United States.

These technologies will increase Americans' energy security, lower costs, and reduce environmental impacts.



Virginia Tech–NETL Research Targets Underground CO_2 Storage, Natural Gas Recovery

Researchers from Virginia Tech teamed with NETL on a multi-part project to investigate the feasibility of injecting captured CO_2 into organic-rich rocks, deep underground, to permanently store the greenhouse gas while simultaneously recovering natural gas.

Organic-rich sedimentary rocks, such as shale and coal, consist of nondecayed organic tissue from plants and animals preserved in underground deposits. Over time, natural gas becomes trapped in their pores. This large-scale research tested the use of CO_2 captured from fossil fuel power plants and industrial facilities to force the natural gas out of the rock pores and to the surface, while keeping the injected CO_2 stored safely underground and out of the atmosphere.

The resulting natural gas could find its way to market for traditional uses.

As part of its research with NETL, Virginia Tech's Virginia Center for Coal and Energy Research initiated the injection of up to 20,000 tons of CO_2 into a coalbed methane field in Buchanan County, VA. The research team will use a state-of-the-art monitoring, verification, and accounting program to monitor the site and collect data as CO_2 is injected into the coal seams.

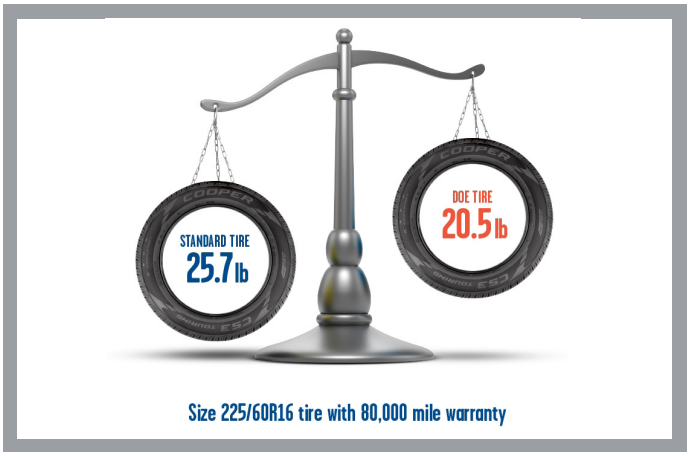
Pittsburgh Start-Up Licenses NETL Technology for Safer, Cleaner Corrosion-Protecting Metal Coatings

Because corrosion-related issues cost the U.S. economy $276 billion a year, NETL teamed up with Carnegie Mellon University (CMU) to create a revolutionary, cost-effective technology to address the issue, which resulted in positive results and a new CMU-based spin-off company.

The new process, which electrodeposits aluminum using standard equipment available in most electroplating shops, can replace coatings based on heavy metals, such as cadmium and chromium, which are expensive and toxic. Electroplating is the process of depositing a metal coating onto an object by putting a negative charge on it and immersing it in a solution.

Called the "Ionic Liquid Solvent for aluminum Electroplating Process," the innovation has been licensed by LumiShield, a Pittsburgh-based CMU spin-off company. LumiShield specializes in corrosion-resistant metal products that are less expensive and less environmentally harmful than existing approaches.

The new electroplating technology uses a plating solution containing ionic liquids (salts in liquid state) in open vessels without creating toxic vapors. The result is a more cost-efficient, environmentally responsible process. In addition, the process can be altered to produce a variety of properties and finishes that meet specifications for a range of applications.



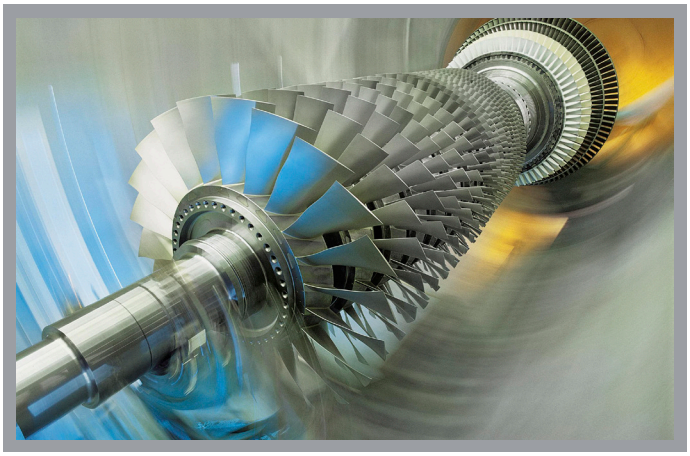
New Tire Technologies Can Improve Fuel Efficiency

NETL financially managed an EERE Vehicle Technologies Office project that enabled Cooper Tire & Rubber Company (Findlay, OH) to develop concept tires that can improve fuel efficiency by 5.5 percent.

In addition, the new tires are more than 23 percent (5 to 6 pounds) lighter than current tires and reduce rolling resistance by more than 30 percent while meeting performance and durability goals.

The new technologies, including substituted materials, ultra-long wearing and ultra-fuel efficient tread compounds, and low-rolling resistance tire profiles, are so promising that Cooper is already planning to transfer some of them to new, commercialized tire designs.

To reduce weight, the Cooper team replaced the standard steel belt with alternate lightweight materials. Other efforts focused on reducing energy loss (heat dissipation) when a tire rolls on the road. Because different materials have different properties, the concept tires replaced commonly used carbon black and silica fillers (used in current tire compounds for reinforcement) with innovative, highly reinforcing fillers such as nano-fibers that minimize energy losses.



Sensor Technology Transitions to Commercial Use

NETL-funded research led to the development of a sensor technology called Additive Topology Optimized Manufacturing with embedded Sensing (ATOMeS) that is being transitioned for commercial use. Sensor technologies like ATOMeS play a vital role in the success of advanced turbine technologies, which have the potential to provide cheaper and more reliable power.

ATOMeS uses an additive manufacturing process (building objects by adding layer upon layer of material) to seamlessly embed commercial off-the-shelf sensors onto the airfoils of a gas turbine. The embedded sensors maintained their structural integrity in the harsh environments of power generation while still being remotely powered and able to deliver detailed sensory information such as temperature, position, and vibration to operators. This information allows engineers to increase the reliability of the turbines, reduce downtime for maintenance, and increase fossil fuel use.

NETL is working with the developers of the technology, United Technologies Research Center (East Hartford, CT), to transition the technologies to commercial use.

Coal-based Transport Gasifier Project Achieves Syngas Production Milestone

Mississippi Power, a subsidiary of Southern Company, successfully demonstrated power generation via coal-derived syngas (a fuel mixture produced during gasification) at the company's Kemper County energy facility. The project was funded through the DOE's Clean Coal Power Initiative and managed by NETL.

The advanced power generating facility used a specially designed coal gasifier called TRIG™ to produce electricity at commercial scale for the first time ever. A unique feature of TRIG™ technology is the high rate of lignite-to-gas conversion that is achieved at a lower operating temperature than other gasifiers, ultimately resulting in lower operating costs. The TRIG™ technology was developed jointly by Southern Company, KBR, and NETL.

Once fully operational, the power plant will produce 582 megawatts of electricity—enough to power over half a million homes for a year. The facility is equipped with carbon capture technology capable of preventing approximately 67 percent of its CO_2 emissions from being released into the atmosphere. The captured CO_2 will be used for enhanced oil recovery operations at depleted oil fields in Mississippi. It is estimated that the captured CO_2 from the Kemper County facility will increase U.S. oil output by 2 million barrels per year, playing an important role in reducing America's dependency on foreign oil imports.

Awards

Carnegie Science Awards
The Carnegie Science Center's awards recognize and promote outstanding science and technology achievements in the Pittsburgh region.

- Shiwoo Lee, Innovation Award, for his work on critical efficiency improvements that will make solid oxide fuel cells economically attractive for widespread and industry use.
- Natalie Pekney, Environmental Award, for her innovative approach to quantifying the air quality impacts associated with fugitive methane emissions in western Pennsylvania.

Excellence in Government Awards
The Pittsburgh Federal Executive Board's Excellence in Government Awards recognize outstanding federal employees for their efforts, leadership, and initiative.

- Colleen Butcher, Heroic Act Award—Gold, for serving as a living organ donor for a fellow employee.
- Yuhua Duan, Outstanding Contribution to Science Award—Silver, for his work in theoretical modeling of CO_2 capture technologies, high-temperature gas sensors, and solid oxide fuel cells.
- Jessica Mullen, Rookie of the Year Award—Gold, for discovering improved water treatment processes, increasing water use and efficiency, and creating partnerships that change the way we view and use all types of water.

Hispanic Achievement Award
The Pittsburgh Federal Executive Board's Hispanic Achievement Awards recognize Hispanic and non-Hispanic federal employees who have contributed substantially to the Federal Government and the Hispanic community.

- Alexandra Hakala for her leadership in environmental research toward a clean and safe energy future, her professional commitment, and outstanding mentorship.
- Nicolas Huerta for his exceptional leadership and scientific contributions on subsurface geomechanics and well integrity, and his commitment to mentoring aspiring energy researchers.

Outstanding Service Awards
The American Society of Mechanical Engineers International Gas Turbine Institute's Outstanding Service Awards honor individuals who performed outstanding service work in their divisions.

- Richard Dennis for his outstanding contribution, commitment, and service to the Supercritical CO_2 Power Cycles Committee.

President's Early Career Award for Scientists and Engineers
The Office of Science and Technology's PECASE Award is the highest honor the U.S. government can bestow on scientists or engineers in the early stages of their research careers.

- Paul Ohodnicki for his outstanding innovation and technical leadership, which have advanced foundational materials science and led to the development of new applications and inventions in materials technology.

R&D 100 Award
The R&D 100 Awards celebrate the top technology products of the year and have become known as the "Oscars of Invention."

- Steve Zitney for EYESIM v2.3 virtual reality software that provides energy industry decision-makers with an unprecedented high-tech look inside the operation of power plants, helping to lower costs and increase safety and efficiency.

Women of the Year Award
The Pittsburgh Federal Women's Committee Women of the Year Awards recognize female federal employees who have made significant contributions to the goals and missions of their organizations.

- Circe Verba, Gold Award, for leading collaborations in cutting-edge analysis to better detect trace elements through electron microscopy, and for her prolific advocacy of STEM education.
- Barbara Kutchko, Silver Award, for world-renowned expertise in the area of foamed cement research, as well as her STEM mentorship.
- Alexandra Hakala, Bronze Award, for facilitating a collaborative work environment and her active involvement in growing NETL's Diversity in the Workplace initiative.
- Natalie Pekney, Bronze Award, for developing an air quality monitoring and analysis competency at NETL, including a mobile air quality monitoring laboratory that can be taken to remote oil and gas production locations.

Patents and Licenses

Patents

Method of CO and/or CO_2 Hydrogenation Using Doped Mixed-Metal Oxides; David A. Berry, Dushyant Shekhawat (DOE/NETL), James Jerry Spivey (ORISE), Mark Smith (URS), Daniel J. Haynes (DOE/NETL), Victor Abdelsayed (URS); 9,150,476; issued October 6, 2015.

Creep Resistant High-Temperature Martensitic Steel; Paul D. Jablonski, Jeffrey Hawk, Christopher Cowen (DOE/NETL); 9,181,597; issued November 10, 2015.

Method of Fabrication of Supported Liquid Membranes; David Luebke (DOE/NETL), Christina R. Myers, Lei Hong (Global Energy Services); 9,186,854; issued November 17, 2015.

Poly(Hydroxyl Urethane) Composites and Methods of Making and Using the Same; David Luebke (DOE/NETL), Hunaid Nulwala (Carnegie Mellon University), Chau Tang (ORISE); 9,243,174; issued January 26, 2016.

Laser Based Analysis Using a Passively Q-Switched Laser; Steven D. Woodruff, Dustin McIntyre (DOE/NETL); 9,297,696; issued March 29, 2016.

MCrAlY Bond Coat with Enhanced Yttrium; Paul D. Jablonski, Jeffrey Hawk (DOE/NETL); 9,428,825; issued August 30, 2016.

Licenses

Liquid Ion Solutions (Pittsburgh, PA), exclusive license for four patented technologies:

- 1,2,3-Triazolium Ionic Liquids
- Method of Purifying a Gas Stream Using 1,2,3-Triazolium Ionic Liquids
- Synthesis and Polymerization of Vinyl Triazolium Ionic Liquids
- Ionic 1,2,3,-Triazolium-Based, Cross-Linked Polymerica Films for Gas Separation

All issued February 19, 2016.

Lawrence Sim (Oakland, CA), non-exclusive license for BLOSOM—Blowout and Spill Occurrence Model Software, issued August 23, 2016

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