Pacific Northwest
NATIONAL LABORATORY

Proudly Operated by Battelle *Since 1965*

DISCOVERIES IN

ENERGY & ENVIRONMENT

U.S. DEPARTMENT OF
ENERGY

Compared to current vanadium redox flow batteries, this modular design incorporates PNNL's new electrolyte chemistry, delivering 80 percent increased power capacity and 90 percent increased efficiency with about half the operating cost – plus a greater operational temperature range.

Customer Focus. Exceptional People. National Impact.

The 1,000 scientists, engineers, and professional staff in the Energy and Environment Directorate at Pacific Northwest National Laboratory are intent in our pursuit of answers to the nation's most challenging problems. Our mission is unique in its diversity, from discovering efficient sources of renewable energy to providing scientifically defensible solutions for legacy nuclear waste at the Hanford Site.

Success for us means working with partners to drive remarkable results to the market. We do this is in service to the U.S. Department of Energy and in collaboration with government sponsors, industry customers, universities, research institutions, and our fellow national laboratories.

Rooted in a broad understanding of complex systems, our innovations provide crucial pieces to bigger puzzles. These accomplishments often are relatively invisible to the typical consumer, yet are key to products including the compact fluorescent light bulb that shines safely for years, the catalytic exhaust component that reduces a vehicle's carbon emissions, and the home appliance that meets higher energy efficiency standards.

Our strategically focused research, analysis, and technological contributions are saving the nation billions of dollars in energy costs. We are dedicated to a cleaner future, restored environment, and a stronger economy.

Jud W. Virden, Ph.D.

Associate Laboratory Director
Energy & Environment Directorate

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ON THE COVER: *Scientists at PNNL are exploring photosynthetic bacteria that can efficiently convert carbon dioxide, a potent greenhouse gas, into oxygen. Bacteria isolated from extreme environments, such as hot springs, provide insight on carbon cycling, which may help mitigate climate change.*

Energy Efficiency and Renewable Energy

Delivering distinctive science and technology solutions for efficient and sustainable energy

At PNNL, we believe that greater energy efficiency throughout buildings, improved technologies for enabling renewables – such as wind, water, solar, and biomass – and new vehicle technology, including storage systems for electric vehicles, can lead to timely solutions to our nation's energy challenges. We are a team of chemical, environmental, and materials scientists, economists, and engineers who are finding more efficient ways to use energy resources in transportation, buildings, and industry, and in advancing clean, renewable energy.

Our researchers are working to drive down the costs of clean energy technologies, overcome challenges to large-scale renewable energy deployment, and revolutionize buildings as energy assets. Science, engineering, and supporting analysis at PNNL enables the efficient and sustainable use of energy resources, reduces petroleum consumption and carbon emissions, and integrates renewable energy with the grid.

New, more efficient host materials for the blue phosphorescent organic light-emitting diode (OLED) – designed, developed, and tested by PNNL scientists – are improving their efficiency by at least 25 percent and leading to much more efficient white lights.

« *Building Energy Codes and Standards: The Foundation for Better Buildings*

Buildings account for about 40 percent of our nation's energy use and nearly 40 percent of our carbon dioxide emissions. As a leader in DOE's Building Energy Codes and Appliance Standards programs, our contributions helped DOE gain recognition by the White House as the only agency that met the nation's Climate Action Plan goals established for 2014.

In support of these goals, we submitted the final determination package for the Commercial Building Model Code (ASHRAE 90.1-2013), and the preliminary determination package for Residential Model Code (IECC 2015). These technical documents represent thousands of hours of experimentation, modeling, and analysis that lead to new efficiency and performance regulations that can save billions of dollars in energy costs each year.

Our analyses also enabled DOE to set the minimum energy efficiency standards for manufactured housing. Other 2014 rules in development, including the finalized metal halide lamp fixtures decision, are expected to result in a total of 1 quad of energy savings – the equivalent of 8.2 billion gallons of gasoline.

« *Enabling Development of a U.S. Offshore Wind Industry*

Off both U.S. coasts, PNNL scientists are exploring the immense potential that wind energy holds. In Fall 2014, two specialized 20,000 pound buoys arrived at the PNNL Marine Sciences Laboratory in Sequim Bay, north of Seattle, to further this research. Each buoy carries advanced instruments that measure wind speed and direction while recording air and sea surface temperature, barometric pressure, relative humidity, wave height and period, water conductivity, and subsurface ocean currents.

The buoys, valued at $1.3 million each, were purchased by the DOE Office of Energy Efficiency and Renewable Energy and are being operated and managed by PNNL. After a brief commissioning period in Sequim, the buoys are initially operating for up to a year at two offshore wind demonstration projects: one in the Pacific Ocean near Coos Bay, Oregon, and the other in the Atlantic Ocean near Virginia Beach, Virginia.

A National Offshore Wind Energy Grid Interconnection Study published in August 2014 estimated that the United States has enough offshore wind energy resources to power 17 million homes. Data from the newly commissioned buoys will help to validate the predicted success of this renewable energy resource, improve offshore turbine development, and reduce barriers to private investment in large-scale offshore wind energy development.

The Built Environment

We are committed to dramatically improving the energy efficiency of homes and buildings and to reducing their environmental footprint. From a foundation of research and analysis for new lighting designs and performance, energy codes, and appliance standards, to technology development, evaluation, and demonstration, multi-disciplinary teams at PNNL are leading the way in driving energy savings, enhancing whole building performance, and enabling grid-ready buildings through transactive controls, where two-way signals optimize energy use from source to sensor.

Renewable Power

The Columbia River is the nation's most important hydropower resource, producing 40 percent of the nation's hydroelectric generation and up to 70 percent of the power in the Pacific Northwest. At the same time, wind now produces enough electricity to power 17 million U.S. homes per year. From water and wind to solar and geothermal energy, we are drawing on our strong base of science, engineering, and computational modeling to advance the potential of these renewable energy sources, and work with stakeholders across the utility spectrum to resolve barriers to their use.

Transportation

Researchers at PNNL are developing the scientific and engineering foundations for converting biomass to biofuels that align with the current and future needs of a dynamic transportation energy sector. At the same time, we are improving the design and energy storage capacity of next-generation batteries and lowering the cost of hydrogen fuel cells, while making vehicles more efficient and environmentally friendly through lightweight materials and improved exhaust systems. These technologies address two of our country's most important energy challenges: reducing our dependence on petroleum imports and reducing greenhouse gas emissions.

Researchers in PNNL's Engine Emissions Laboratory investigate catalysts, particulate traps, and other methods for reducing diesel engine emissions.

« *Friction Stir Welding for Vehicle Components*

Federal regulatory requirements in the United States are driving the need to achieve automotive fuel efficiency greater than 35 miles per gallon by 2016 and 54 miles per gallon by 2025. To reduce the overall weight of vehicles, thus increasing fuel efficiency, steel could be swapped with lightweight aluminum alloy for components such as doors and other body panels. Traditional laser welding technologies, however, have been unsuccessful at producing quality joints, typically resulting in porosity and other defects.

PNNL has been working in friction stir welding for many years. We now partner with General Motors, TWB Company LLC, Alcoa Inc., and DOE's Office of Energy Efficiency and Renewable Energy to further develop and deploy this welding technology. The technology enables the joining of different thickness of aluminum sheets without melting the material, reducing the negative effects of high temperature.

The team successfully adapted stir welding technology for use in the automotive industry, and in June 2014 transferred the technology to TWB, who increased the production rate from 1 meter per minute to 3-6 meters per minute. With this throughput, friction welded parts can now join more than 250,000 automotive components on a single machine, reducing vehicle weight significantly.

« *Delivering a Sustainable and Affordable Supply of Jet Fuel*

The $1 trillion U.S. aviation economy is threatened by its inability to purchase jet fuels that are affordable, are not as harmful to the environment, and meet industry's rigorous requirements for aviation. Working with DOE's Bioenergy Technologies Office and industry, scientists and engineers at PNNL are developing catalytic processes that convert low-value, highly dispersed residues and waste materials into chemicals and fuels, like jet fuel, commonly used today.

To meet jet fuel specifications, PNNL researchers use a new hybrid process of lower temperature fermentation and catalysis. The result is a very high-quality, high-yield fuel produced from low-cost alcohols like ethanol. In this case, industry partner LanzaTech provided the ethanol, which was made from industrial waste gases captured from steel production. Fuel samples provided to the Air Force Research Laboratories in July 2014 passed even the most stringent tests – an important step for joining the ranks of renewable jet fuels that are certified for commercial use.

In addition to surpassing performance specifications, the new fuel can reduce greenhouse gas emissions by more than 60 percent compared to fossil-based jet fuel. With steady improvements demonstrated in the laboratory, engineers are building scaled systems that simulate industrial production, ultimately leading to transfer of the technology into commercial operation.

Electricity Infrastructure

Defining and delivering the 21st century grid

Even as buildings and appliances become increasingly efficient, demand for electricity in the United States is still expected to grow nearly 30 percent by 2040. To help DOE transform the aging power grid into one that is efficient, reliable, and secure – the "smart grid" of tomorrow – PNNL's system-wide approach to grid modernization uses information technology for greater sensing, communications, and control throughout the power system. In this not-too-distant future, energy technology meets information technology for a resilient grid architecture as big as the Internet, but faster – with unprecedented updates at all levels: generation, transmission, distribution, and end use.

Simultaneously, flexible grid-scale energy storage options are needed that can accommodate intermittent renewable power sources, smart assets, and increasing demand. Our strengths in material synthesis and characterization, systems engineering, and grid analytics are delivering new technologies for increased grid flexibility and storage to embrace all energy futures. And anticipating unprecedented consumer engagement, we are also identifying new market, regulatory, and system control approaches to meet the vital needs of our nation's energy future.

« *Energy Storage for a Resilient Grid*

Renewable energy is important to the future of our nation, but incorporating it onto the grid has proved challenging. Large-scale energy storage solutions can help solve this problem. The Vanadium Redox Flow Battery, developed by PNNL, increases energy density by 70 percent more than the previous technology, making it an attractive alternative for the power grid. This battery technology was licensed by UniEnergy Technologies and, thanks to $14 million in Clean Energy Fund grants from the State, is being deployed by a test group of Washington State utilities.

For two of the utilities, PNNL is providing analytical and technical support, including conducting benefits analyses, compiling field data for use cases, and designing acceptance testing plans. PNNL is also working with Avista and Washington State University to provide optimal control strategies for using the storage system at the Schweitzer Engineering Lab campus in Pullman, Wash.

PNNL scientists continue to enhance the battery technology, with a new vanadium prototype system already showing 50 percent increased density while maintaining more than 75 percent energy efficiency. This technology earned PNNL a 2014 Federal Laboratory Consortium Far West Region Award for Outstanding Technology Development.

« *High-Performance Computing Energizes Future Grid Efforts*

PNNL released version 2.0 of GridPACK™, a software framework designed to simplify the development of programs for simulating the power grid that can harness the capabilities of high-performance computing. GridPACK, or Grid Parallel Advanced Computational Kernels, is one of several software tools being developed at PNNL under the DOE Office of Electricity Delivery and Energy Reliability (DOE-OE) Advanced Grid Modeling program. GridPACK was started as part of PNNL's transformative Future Power Grid Initiative (FPGI) before being fully funded by DOE.

Since GridPACK's initial release in November 2013, DOE-OE funding has enabled new features that include:

» an interface that accommodates the popular Fortran programming language, broadening the base of potential users

» two additional applications that demonstrate how GridPACK can be used to create parallel power grid simulations. These include a massive contingency analysis code that can assess the effect of different failures in the system, and a state estimation program, which informs operational decisions by assessing how the grid is operating at any point in time

» modules and performance enhancements that support new types of calculations.

Continued investment by DOE in GridPACK over the next three years will support collaboration among other national laboratories to make additional high-performance libraries and algorithms available to the broader power grid community. GridPACK is one of the components in FPGI's GridOPTICS™ tool suite, which is advancing capabilities in support of grid operational and policy decision-making.

Environmental Health and Remediation

Reducing the cost and risk to resolve the most challenging legacy waste issues

Producing nuclear material to support America's war efforts — from World War II's Manhattan Project through the Cold War — now represents the most technologically challenging and costly mission facing the DOE: remediation of radioactive and hazardous waste contamination at former weapons production sites across the nation. Today, PNNL leverages 50 years of nuclear processing and chemical separations expertise, and integrates it with subsurface and predictive science to address this worldwide 21st century challenge.

In partnership with DOE and its contractors, PNNL plays a critical role in reducing the cost, risks, and timeline of cleanup at the Hanford Site. From waste immobilization and storage to contaminant monitoring and remediation, our scientists and engineers deliver safe and scientifically defensible systems-based approaches for solving environmental cleanup challenges, recovering environmental quality, and protecting human health. We also provide expertise to other national and international agencies and stakeholders faced with similar remediation challenges.

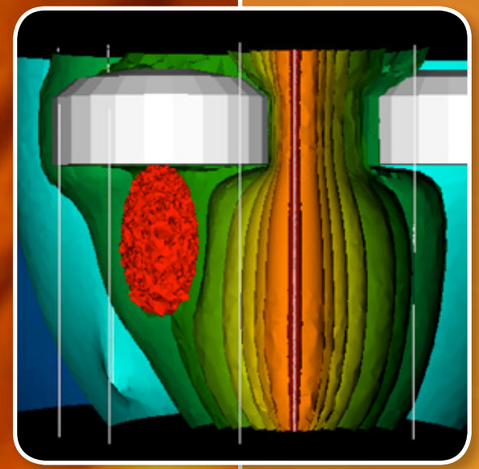
To study the efficiency of immobilizing nuclear waste into a durable glass waste form, scientists at PNNL use a laboratory-scale melter to process high-level waste simulant at high temperatures.

« *Safely Removing Stubborn Sludge from Waste Tanks*

The nation's legacy of nuclear waste poses unique challenges for environmental cleanup. Among the challenges are how to continue to store tank waste safely in double-shell tanks. In collaboration with Washington River Protection Solutions, PNNL is using simulants to evaluate existing theories on the retention of hydrogen gas in deep sludge layers.

Through a testing program ranging from laboratory-scale to large-scale pilot testing in a 45-foot tall column, research indicates that gas retention and release does not pose a flammable gas safety issue.

This safety basis for continued sludge retrieval and transfer will save taxpayers approximately $500 million in Hanford cleanup expenses.



« *Advancements in Electrical Imaging for Underground Tanks*

To detect leaks in waste storage tanks and track the movement of contaminants, electrical resistivity tomography (ERT) provides remote, cost-effective 3D characterization and monitoring. But Hanford's nuclear waste tank farms are dominated by a metallic infrastructure that interferes with ERT.

Scientists at PNNL developed the first – and currently the only – advanced high-performance computing code that models the metallic infrastructure. This allows metal objects to be removed from ERT images, giving the cleanup team unencumbered images of the subsurface contaminants.

Determining subsurface contamination and monitoring process performance has been one of the biggest technological challenges – and most costly expenditures – for remediating the subsurface environment. This technological advancement allows ERT to be effectively used in the tank farms to:

» locate, characterize, and monitor the migration of contaminant plumes in four-dimensions

» conduct modeling-based assessments of external tank leak detection system performance

» design external leak detection systems to meet specified criteria (e.g. low volume chronic leak detection)

» assist regulators and stakeholders with a visualization of subsurface contamination, empowering them with key information to decide on the remediation process.

Implementing and using this model code is projected to save DOE a total of $5 billion over the life of the tank waste project.

Clean Fossil Energy

Creating the future of emissions management

Despite global efforts to transition away from carbon-emitting energy sources like coal, oil, and natural gas, fossil fuels are projected to lead the global energy mix for the foreseeable future. Until the bridge to renewable energy is crossed, PNNL scientists and engineers are dedicated to reducing the impact of emissions — including greenhouse gases produced by fossil fuels — on Earth's atmosphere.

From fundamental process understanding to field-scale design and deployment, our researchers deliver advanced capabilities in subsurface science and simulation to enable safe and effective control of subsurface fluid injection and extraction. We also integrate chemistry, materials, and process engineering to develop technologies that more efficiently convert fossil hydrocarbons into power, fuels, and chemicals — all critical to environmentally and economically viable production and use of fossil energy.

« *First-Ever Class VI Permits for Carbon Sequestration*

This year, the U.S. Environmental Protection Agency (EPA) approved the first-ever Class VI permits for carbon sequestration in the United States, allowing the FutureGen Industrial Alliance to inject and store carbon dioxide in an underground facility in Morgan County, Illinois. Class VI refers to a type of permit specifically designed for long-term storage of carbon dioxide.

Researchers at PNNL led the preparation of the permit application for permanent geologic sequestration of carbon dioxide inside the saline aquifer within the Mt. Simon sandstone formation, more than 4,000 feet below the surface level. The storage site will also include a visitors center plus research and training facilities, and is expected to begin operation in 2017.

Submittal of the permit application culminated more than three years of research, starting with site selection and characterization and leading to the development of detailed numerical models of the site. Following the submittal, researchers addressed technical questions from the EPA for the next 12 months. The site is designed to accept 1.1 million metric tons of carbon dioxide every year for 20 years – the equivalent of eliminating carbon emissions from more than 200,000 cars, according to the EPA.

The FutureGen Industrial Alliance is a non-profit membership organization created to benefit the public interest and the interests of science through research, development, and demonstration of near-zero emissions coal technology. The project in Illinois also entails retrofitting a nearby coal power plant, and will capture and store more than 90 percent of its greenhouse gas emissions.

Nuclear

Mobilizing interdisciplinary teams to advance safe and reliable nuclear power

Through a long and unique history in research and regulatory support across the nuclear fuel cycle, PNNL is a key national resource to help ensure the energy security of a nuclear-powered future. We specialize in a range of distinguishing capabilities, from waste form development and structured materials science to probabilistic risk assessment and advanced instrumentation and prognostics.

Our researchers are helping DOE advance the fuel, materials, and control technologies that will make small modular and advanced reactors viable and safe. At the same time, PNNL's diverse subject matter expertise supports the Nuclear Regulatory Commission in licensing these new technologies toward reality as an American energy source.

« *Separating Uranium from Seawater to Fuel Nuclear Energy*

As nuclear power reactors are built worldwide, there is a growing concern over the availability of uranium, the primary natural resource used for nuclear energy production. Because most uranium is mined outside the United States, DOE's Office of Nuclear Energy is supporting efforts to improve domestic access to uranium.

Nearly 60 years ago, scientists recognized the potential of tapping the ocean to increase the world's uranium reserve by 1,000 times — if they could develop a high-performance absorbent to extract the uranium from seawater. A team of national laboratories, universities, and research institutes is tackling that challenge.

At our Marine Sciences Laboratory, PNNL tested a polymeric adsorbent material developed by Oak Ridge National Laboratory, with promising results. The adsorbent material, referred to as AF1, extracted five times the mass of uranium compared to the baseline technique currently used, and can extract even more at higher temperatures. Additional tests are planned at Woods Hole Oceanographic Institution and the University of Miami to compare results.

The estimated cost of producing uranium from seawater — $606 per kilogram — can be cut in half as the industry increasingly reuses adsorbent materials. Delivering a U.S. source of uranium limits the future cost of this material for the nuclear energy market.

Exceptional People

Bing Liu

Received ASHRAE's Distinguished Service Award for being an active member of ASHRAE and an internationally recognized technical expert in the area of building energy efficiency analysis and application.

Vrushali Mendon

Nominated as one of ASHRAE's Rising Stars for the 2014 New Face of Engineering for her cutting edge, impactful work in the buildings arena.

Reid Peterson

Served as the lead technical expert for the panel commissioned by the U.S.-Japan Bilateral Commission Working Group on Decommissioning and Environmental Management to review the Advanced Liquid Processing System at the Fukushima Daiichi nuclear power plant.

Sarah Widder and Cheryn Metzger

Honored in the 30th anniversary issue of "Home Energy" as part of the "30 under Thirty" for their noteworthy accomplishments in the home performance industry.

Jun Liu and Yuyan Shao

Recognized as highly cited researchers worldwide whose scientific reports were named in the top 1 percent as most referenced in their respective fields between 2002 and 2012, along with 3,200 of their peers.

Mikey Brady Rapp

Sworn in as the new president of the American Nuclear Society and featured on the front page of Nuclear News for her extensive knowledge in nuclear and criticality safety for spent fuel systems.

Jeff Dagle

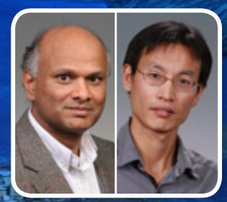
Invited to join a National Research Council Committee to provide recommendations on the analytic foundations of the next generation electric power grid.

Yousu Chen

Recognized for work on applying high-performance computing techniques to power system functions to enhance situational awareness and decision support by the IEEE Power & Energy Society governing board.

Alan Zacher and John Frye

Received the American Chemical Society's Green Chemistry Award for developing a sustainable, economic process to create the common industrial chemical propylene glycol from renewable sources rather than petroleum.



Srinivas Katipamula and Weimin Wang

Recognized for small commercial building roof top units design, content, and success in achieving overall communications effectiveness and excellence with the APEX award for publication excellence.

Aerial of the PNNL main campus, taken in 2010.

Pacific Northwest
NATIONAL LABORATORY

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ABOUT

Pacific Northwest National Laboratory

Pacific Northwest National Laboratory, located in southeastern Washington State, is transforming the world through courageous discovery and innovation.

PNNL's science and technology inspires and enables the world to live prosperously, safely, and securely. Our researchers collaborate to advance science and solve complex problems in energy, the environment, and national security — as well as move technology solutions to market.

PNNL employs more than 4,000 staff members with a $1 billion annual budget. Since 1965, PNNL has been operated by Battelle on behalf of the U.S. Department of Energy.

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