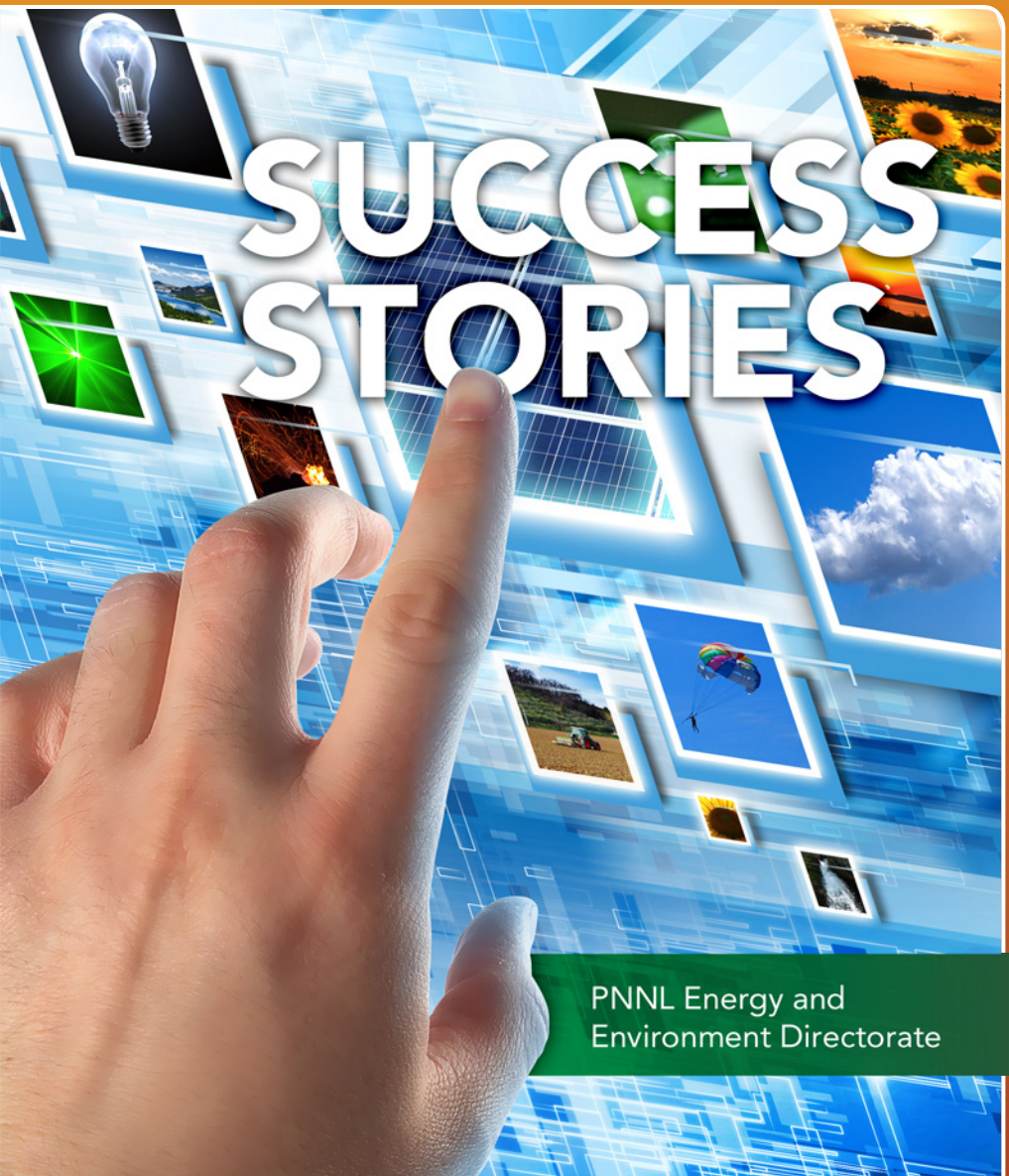
Pacific Northwest
NATIONAL LABORATORY

*Proudly Operated by* Battelle *Since 1965*

# SUCCESS STORIES



PNNL Energy and Environment Directorate

# CONTENTS

Introduction ..... 3

**ON THE HORIZON: Promising Research Efforts Currently Underway**

A Smarter Charge ..... 4
Unlocking Fire Ice ..... 5
CRISP Crunches Cyber Threats ..... 6
Gel Zeroes in on Cancer ..... 7
Liquid Solvent: A Solid Solution for $CO_2$ ..... 8
Real-time Grid Stability ..... 9
Biofuels Take Flight for Aviation Industry ..... 10
Nanostructures Pack It In ..... 11

**SUCCESS STORIES**

A Different Kind of Sponge ..... 12
Green PG—Rated Good for All Audiences ..... 13
Maximizing Megawatts for America ..... 14
Idle Time Solution ..... 15
Weight Loss Program for Autos ..... 16
Salmon Savers ..... 17
Faster, Cleaner, More Flexible Energy Storage ..... 18
Shining a Light on Radiation ..... 19
CFLs Shine with the Right Touch ..... 20
Paving the Way for Fuel-Efficient Diesel Trucks ..... 21
A New Way of Looking at Waste ..... 22
It's in the Code ..... 23

# Hello.

I invite you to take a moment and browse through this updated booklet, where we've captured just a few examples of how energy and environment innovations at Pacific Northwest National Laboratory are improving the world in which we live. You'll learn about new materials forming processes that we've developed to reduce the weight of cars and trucks, innovative approaches for protecting fish as they navigate power-producing dams, and a discovery that makes it possible to turn food crops into a useful chemical. Our work at PNNL—in partnership with the Department of Energy, industry, and other clients—is supporting America's energy future, environment, and economy as we put discoveries into action.

*Jud*

**Jud Virden**
Associate Laboratory Director
Energy & Environment Directorate

## ON THE HORIZON:
*Promising Research Efforts Currently Underway*

# A Smarter Charge

**This technology detects the load on the electricity grid and make "smart" decisions about when to charge electric cars—saving owners money and reducing strain on the system.**

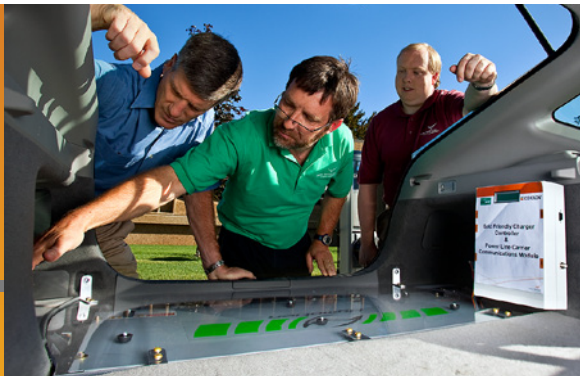
As electric cars become more popular, demand for electricity to keep them charged also will grow. Consumers trying to be more environmentally friendly or looking for less expensive alternatives to gasoline may see the opposite effects if the combined demand created from electric cars puts additional strain on the nation's electricity system or results in the need for more power plants.

PNNL researchers have developed a Smart Charger Controller that can help manage when electricity flows to plugged-in vehicles waiting for a charge—using the strain on the grid as its guide and varying electric rates accordingly. The technology allows the cars, and their owners, to be partners in managing the electric grid. Without the need for any Internet connection or other communications, the device detects stress on the grid by sensing changes in frequency or voltage at the receptacle. It temporarily stops charging the vehicle until the stress subsides, instantly reducing demand and serving as a large-scale shock absorber that could prevent blackouts. If the utility can communicate with the device, it can defer when cars are charged so that consumers can pay less for electricity when demand is low or be rewarded for avoiding use when demand is high if their utility's rate structures include those kinds of incentives.

The technology and approach are being demonstrated on PNNL's campus where the device has been deployed in a Toyota Prius electric test vehicle. AeroVironment, a California company specializing in electric vehicle charging solutions, has licensed the technology and is beta testing adaptive chargers based on PNNL's patents.

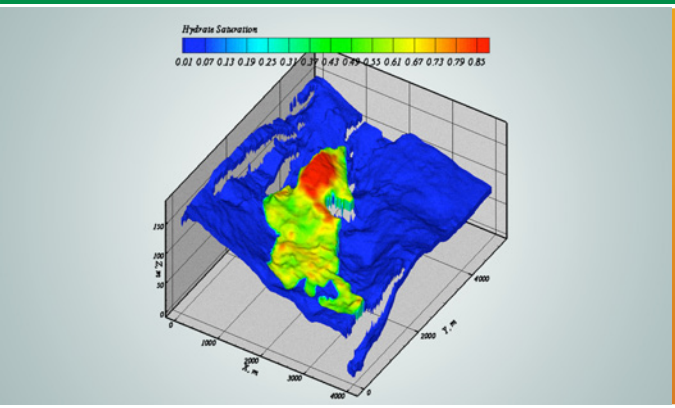
FUNDING PROVIDED BY: U.S. DEPARTMENT OF ENERGY | Electricity Delivery and Energy Reliability | Energy Efficiency and Renewable Energy

Using the ebbs and flows in the demand for electricity as its guide, PNNL's Smart Charger Controller manages when electric vehicles are charged to minimize stress on the grid—and some utilities may even reward vehicle owners for doing so.



ON THE HORIZON:
*Promising Research Efforts Currently Underway*

# Unlocking Fire Ice




PNNL is using STOMP to model a recent DOE experiment in Alaska to improve understanding of how the guest-molecule exchange process works to produce methane hydrate gas.

**PNNL is using its STOMP simulator to study a promising approach to producing methane hydrates—a massive and largely untapped potential source of natural gas.**

Methane hydrates are cage-like ice structures on the ocean floor and under Arctic permafrost that hold a massive supply of natural gas. They are called "fire ice" because the methane will burn while it's in the ice. However, questions about how to produce natural gas hydrates in a cost-effective and environmentally friendly way has put commercial use on hold. PNNL is using its Subsurface Transport Over Multiple Phases (STOMP) simulator to study a guest-molecule exchange process that could provide an environmentally sound alternative to unlocking ice cages and opening up this immense source of potential energy. The guest-molecule exchange process works by injecting a mixture of carbon dioxide and nitrogen into a natural gas hydrate bearing formation, releasing the methane and replacing it with either carbon dioxide or nitrogen, which maintains the ice cage structure and protects the formation. Many questions exist about reactions that take place inside the formation after injection, the right mixture of carbon dioxide and nitrogen, and the amount that can be injected. By accurately predicting the processes inside the formation, STOMP can answer these and other key questions holding the technology back. As a first step, PNNL is using STOMP to model a recent DOE experiment on the North Slope of Alaska that used the guest-molecule exchange method. STOMP's predictions will be compared to DOE's actual results, and if they match well, it will set the stage for supporting actual production operations.

FUNDING PROVIDED BY: U.S. DEPARTMENT OF ENERGY | Fossil Energy

## ON THE HORIZON:
*Promising Research Efforts Currently Underway*

# CRISP Crunches Cyber Threats

**A novel PNNL information-sharing program bridges the gap between government intelligence and private utilities to protect the U.S. electric infrastructure against cyber attacks.**

As our electric power systems become more integrated and complex, cyber security vigilance becomes equally complex. PNNL conceived, built and implemented the Cybersecurity Risk Information Sharing Program (CRISP) to detect signs of malware, including nation-state generated malware, that might impact the national electric grid or specific locations on the grid. CRISP fosters collaboration with private electric sector partners to facilitate the timely sharing of unclassified and classified threat information. Working together, we are enhancing our collective ability to protect our critical infrastructure.

CRISP begins with an information sharing device at the utility, which allows PNNL experts to determine whether malevolent actors (malware) are entering or leaving the utility or performing reconnaissance. Once PNNL receives the data, parallel analysis efforts begin—one focused on cyber security risks to the utility and a second on using government-based information to discover potential threats to the U.S. electric grid that also further enhance utility protection. Currently five government-based power companies and four large private utilities are participating in the pilot project.

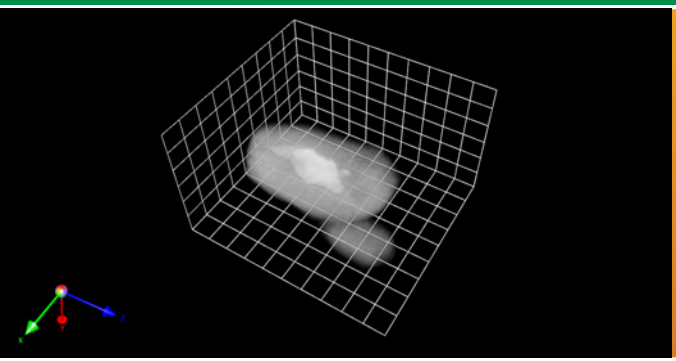
CRISP in action: Upon discovery of a sophisticated attack that compromised several PNNL computers, network signatures were developed to identify the attack's behavior. Using these signatures, CRISP data were searched to determine if systems at other institutions showed signs of compromise. The search found information consistent with the signatures at a partner site. Information was quickly shared with the affected site, enabling it to mitigate the compromised systems. Staff at the site noted it would have been extremely difficult, if not impossible, to identify the intrusion without the information provided by CRISP.

FUNDING PROVIDED BY: U.S. DEPARTMENT OF ENERGY | Electricity Delivery and Energy Reliability

PNNL is developing situational awareness tools that enhance the collective ability of government and private utilities to identify, prioritize, and coordinate protection of the U.S. electric grid.

ON THE HORIZON:
*Promising Research Efforts Currently Underway*

# Gel Zeroes in on Cancer



In this CT scan-derived image, the radiogel is the solid mass, holding yttrium-90 particles in place within the tumor.

**An injectable radiogel technology developed by PNNL delivers the yttrium-90 medical isotope to a precise location in the body for targeted radiation therapy, while minimizing exposure to surrounding healthy tissue.**

Longstanding PNNL capabilities in radiochemistry, radiation physics and materials chemistry gave rise to the radiogel technology. Since 2010, PNNL has been working with Advanced Medical Isotope Corporation (AMIC) to move radiogels toward commercial application. Safe, effective and relatively low-cost cancer treatments are needed for solid tumors that can't be surgically removed. PNNL's innovation—a non-toxic, injectable liquid polymer—is infused with tiny radioactive yttrium-90 particles. In the body, the liquid solution quickly warms and forms a gel that holds the yttrium-90 particles in place at the target site, maximizing the overall radiation dose to cancer cells and minimizing radiation exposure and associated side effects in nearby normal tissues. Once the yttrium-90 decays, the gel resorbs naturally—in contrast to treatments that remain in the body indefinitely. AMIC's next steps in commercializing the technology involve further product testing and characterization, and obtaining regulatory approval. Toward this objective, PNNL has provided follow-on assistance in several areas, and these subsequent efforts have also helped determine that it will be possible to further optimize the technology's effectiveness. In addition, PNNL and AMIC, in collaboration with the University of Washington Department of Radiology, were awarded a nearly $150,000 Washington State Life Sciences Discovery Fund grant in 2012 for additional assessment and testing of the technology. The PNNL-AMIC radiogel commercialization efforts received a 2013 Federal Laboratory Consortium Award for Excellence in Technology Transfer.

FUNDING PROVIDED BY: U.S. DEPARTMENT OF ENERGY | Office of Science

ON THE HORIZON:
*Promising Research Efforts Currently Underway*

# Liquid Solvent: A Solid Solution for $CO_2$?

**Scientists at PNNL—along with industry and university partners—are advancing a process that employs a reusable liquid to efficiently remove carbon dioxide ($CO_2$) from coal-fired power plant emissions.**

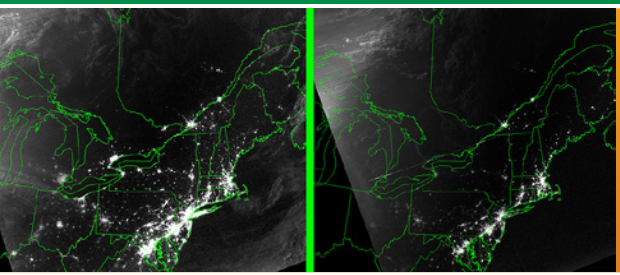
According to government statistics, coal generates nearly half of the nation's electricity. It also accounts for about one-third of the energy-related carbon dioxide emissions. Removing carbon from coal-fired power plant emissions is a complex, expensive challenge, but researchers at PNNL may have a solution. They're finding that by changing the polarity of an innovative gas scrubbing solvent known as $CO_2$ Binding Organic Liquids—or $CO_2$BOLS—they create a highly efficient treatment system. Compared to carbon capture methods currently in development, the $CO_2$BOLS technology can be regenerated for reuse at much lower temperatures, resulting in substantial projected energy savings. This approach translates not only to significant environmental benefits, but potential economic advantages, as power plants would spend less of the electricity they generate on carbon removal. In fact, it is estimated that the technology's energy requirements for $CO_2$ removal, compared to current treatment options, could be two-thirds less. The U.S. Department of Energy has funded a project aimed at validating and advancing the technology. Battelle, operator of PNNL, leads the project, which includes collaborators Fluor Corporation—a global leader in carbon capture technology—and Queen's University. Project efforts have focused on completing a detailed analysis of $CO_2$BOLS's chemical behavior and establishing a framework for confirming the technology meets its economic performance projections.

FUNDING PROVIDED BY: U.S. DEPARTMENT OF ENERGY | Fossil Energy

$CO_2$BOLS shows promise in efficiently removing carbon dioxide from emissions.

ON THE HORIZON:
*Promising Research Efforts Currently Underway*

# Real-time Grid Stability



NASA satellite imagery depicts the northeastern U.S. before (left) and after (right) the major blackout of 2003, impacting an estimated 55 million people with an estimated cost of $6-8 billion.

*Image courtesy NASA*

**A new grid disturbance detection tool enables electricity operators to see growing problems before they create a cascading failure—potentially saving billions of dollars lost in major outages.**

Researchers at PNNL, Montana Tech and the University of Wyoming have developed a unique grid oscillation detection system that uses real-time data combined with new analytic methods to give operators powerful information and enable real-time decision making for grid reliability. Small oscillations—or swings in power—in the nation's alternating current power systems are the result of different devices on the system interacting with each other. While oscillations can begin as minor disturbances, they quickly can escalate into very large grid events. Oscillations led to the major blackout on the West Coast in August 1996 with its estimated cost of $2 billion. PNNL researchers are combining newly available real-time phasor data with advanced signal analysis algorithms to create tools that enable operators to see destructive oscillations in the system long before they could lead to a blackout. PNNL's proprietary "Mode Meter" detects oscillations and reports them to operators with an easy-to-read visualization tool. In addition to allowing preventive actions to be taken quickly, this real-time, more precise view of grid oscillations may allow operators to manage and operate the system assets with fewer constraints. The PNNL-developed mode meter technology has been tested by the Bonneville Power Administration (BPA) and will be evaluated in the Western Electricity Coordinating Council control center as part of the Western Interconnection Syncrophasor Project. The Mode Meter software is being licensed to commercial energy management system (EMS) providers for incorporation in the next generation of EMS software used by utilities.

In addition to primary funding from DOE, Mode Meter development was supported by BPA and the California Energy Commission. Researchers at Montana Tech and the University of Wyoming continue to collaborate to advance the functionality of the Mode Meter, including adding the ability to distinguish between natural and forced oscillations.

FUNDING PROVIDED BY: U.S. DEPARTMENT OF ENERGY | Electricity Delivery and Energy Reliability

ON THE HORIZON:
*Promising Research Efforts Currently Underway*

# Biofuels Take Flight for Aviation Industry

**A leader in bioproducts development, PNNL is creating aviation biofuel options that are cost-effective and compatible with the nation's existing transportation infrastructure.**

In recent years, price volatility of the petroleum-based fuel used in aircraft has threatened the financial viability of the aviation industry, which contributes more than $1 trillion annually in estimated national economic impact. The price situation, as well as the industry's desire to reduce its greenhouse gas footprint, has prompted interest in alternative fuel sources. Biomass, or plant-derived material, is one such source that can address both cost stability and greenhouse gas issues.

PNNL and its partners are improving and expanding the use of cost-effective, bio-based aviation fuels in several ways, including advancements in the conversion of biomass-derived alcohol to jet fuel. Additionally, research is focused on the use of pyrolysis or hydrothermal liquefaction techniques to turn biomass into a low quality oil for upgrading into jet fuel, gasoline and diesel. PNNL also possesses wide-ranging analytical capabilities that drive to the bottom line—assessing factors such as marketplace viability and life cycle costs.

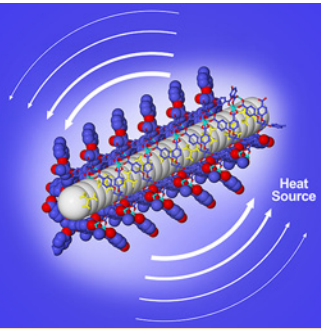
An example of PNNL's pioneering work includes a unique milestone achieved in partnership with UOP, Boeing, DOE and others. Upgraded pyrolysis oil, used in combination with synthetic paraffinic kerosene, produced the world's first biomass-derived jet fuel that was demonstrated in a hydroplane at Seattle's Seafair race. PNNL also partnered with Imperium Aviation Fuels to produce samples of alcohol-to-jet aviation fuels that were provided to the Air Force Research Laboratory in 2012 for testing.

FUNDING PROVIDED BY: U.S. DEPARTMENT OF ENERGY | Energy Efficiency and Renewable Energy

PNNL is focusing its bio-based products and fuels expertise on solutions for today's airline industry.

ON THE HORIZON:
*Promising Research Efforts Currently Underway*

# Nanostructures Pack It In




PNNL-designed, cagelike nanostructures increase the efficiency of heat exchange.

**A new class of materials designed by PNNL offers significant energy savings in various applications, from cooling commercial buildings to increasing the efficiency of low-temperature geothermal power.**

The innovative material is being used to design a new type of adsorption chiller for commercial buildings that will double chiller performance, shrink its size by a factor of three, and reduce cost. The result? Chillers that are affordable enough to be used more frequently in commercial buildings, introduced into residential markets—and set up at field military bases. Adsorption chillers are air conditioners that are powered by waste heat, have few moving parts and need almost no electricity to operate. The PNNL material is a metal organic framework, or MOF, that can be molecularly engineered to capture—and release—refrigerants, such as water or fluorocarbons. PNNL is adapting its MOFs adsoprtion chiller system for use on the battlefield. The military system will run off of waste heat from a diesel engine. By using up to 50 percent less diesel than current air-chilling technologies, the system could save soldiers' lives by reducing the need for fuel supply convoys.

MOFs can be tweaked to selectively capture and release refrigerants not just with heat but potentially with electricity. PNNL is developing a five-pound molecular heat pump, about the size of a two-liter bottle, for heating and cooling electric cars. The PNNL heat pump relies on a new type of MOF that responds to electricity to pump refrigerants much more efficiently than conventional heating/AC units, which rely on engine heat or mechanical compressors. The molecular heat pump could increase electric cars' driving range by 50 percent. PNNL-developed MOFs are also being used to increase power production from low-temperature geothermal sources by 15 to 20 percent, making geothermal power a safer, economical clean energy alternative. This work involves suspending nano-sized MOF particles in working fluids so they extract heat with greater efficiency.

FUNDING PROVIDED BY: U.S. DEPARTMENT OF ENERGY | Energy Efficiency and Renewable Energy arpa·e

# A Different Kind of Sponge

**A sponge-like sorbent material developed by PNNL to remove mercury from a wide variety of waste streams has been licensed to Steward Advanced Materials of Chattanooga, Tenn.**

Steward has been producing SAMMS® on an industrial scale since 2006 to selectively remove mercury from industrial process streams and emissions, such as stack emissions from coal-fired power plants. SAMMS, short for Self-Assembled Monolayers on Mesoporous Supports, is an ordinary-looking white powder engineered to latch onto and bind mercury, creating a harmless powder that is stable enough to be disposed of in landfills. It has a very high surface area. One tablespoon contains approximately the same surface area as a football field, so it is extremely efficient and cost effective, as well as environmentally safe. SAMMS is highly adaptable for removing other contaminants from soil and water, and it has numerous applications, including water treatment, waste stabilization, and metal processing and finishing.

PNNL has collaborated with the U.S. Navy to develop an application of SAMMS that captures $CO_2$ directly from the atmosphere and subsequently releases it when triggered. This collaborative effort expanded the SAMMS product line and Steward is currently producing this version of SAMMS, which will be used to significantly improve air quality on board submarines. In addition, PNNL is developing a pharmaceutical version of SAMMS that can be delivered orally to absorb radionuclides and heavy metals from the body. SAMMS received an R&D 100 award in 1998 and a Federal Laboratory Consortium Award for Excellence in Technology Transfer in 2006. In 2012, the creators of SAMMS were recognized with the FLC's Interagency Partnership Award.

FUNDING PROVIDED BY: U.S. DEPARTMENT OF ENERGY | Office of Science

SAMMS, Self-Assembled Monolayers on Mesoporous Supports, can strip pollutants from toxic wastes and even render hazardous wastewater clean enough to drink. The image at right is a representation of SAMMS.

# Green PG—Rated Good for All Audiences

Catalysis research at PNNL led to a breakthrough discovery for economically producing propylene glycol from renewable sources.

**With PNNL technology at its foundation, a facility in Illinois is capable of annually producing up to 100,000 metric tons of propylene glycol, or PG, from plant-derived materials.**

At the heart of the plant's operations is a PNNL-developed chemical catalyst. The catalyst makes it possible to economically convert glycerol—a byproduct from the processing of biodiesel or crops such as corn, soybeans or canola—into propylene glycol. PG is a versatile chemical. The industrial grade of PG is an ingredient in products such as anti-freeze and fiberglass used in bathtubs, showers and boat hulls, and the pharmaceutical grade is found in many personal care products. Petroleum has typically been the cheapest source of the chemical, but PNNL's catalyst has made it possible to create propylene glycol from renewable sources in a cost-competitive fashion. The production facility in Illinois, established by Archer Daniels Midland Company (ADM), reached full-scale operations in 2011, producing bio-based propylene glycol that meets standards for industrial and United States Pharmacopeial Convention specifications. (USP sets standards for medicines, food ingredients and dietary supplements). The ADM facility benefited from PNNL's early stage fundamental catalysis expertise and ADM's process development and scale-up capabilities. ADM is the exclusive licensee for the PNNL-developed technology. The innovation and its deployment have been recognized with a number of prestigious honors, including R&D 100 and Federal Laboratory Consortium awards.

FUNDING PROVIDED BY: U.S. DEPARTMENT OF ENERGY | Energy Efficiency and Renewable Energy

# Maximizing Megawatts for America

**From 2000 to 2012, PNNL license renewal support to the U.S. Nuclear Regulatory Commission helped extend the life of 36 reactors in America's nuclear fleet by 20 years. As a result, the nation continues to benefit from the production of millions of megawatt hours of electricity annually.**

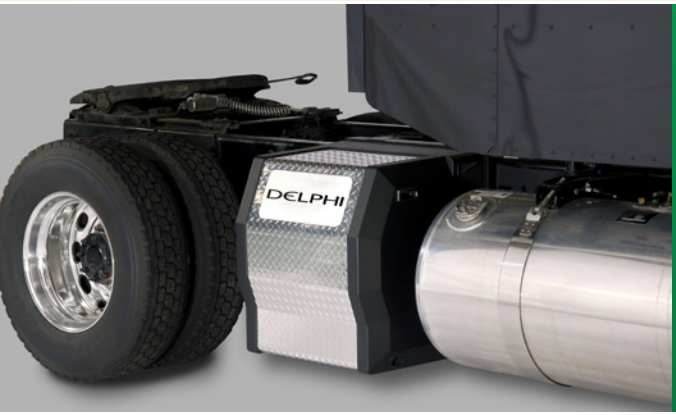
PNNL provides the NRC with integrated nuclear and environmental capabilities, a vital contribution in advancing nuclear energy as a viable and safe component of America's energy portfolio. Today in the United States, nuclear power generates about 20 percent of the U.S. electricity supply—while emitting no carbon dioxide or other harmful air pollutants. To help preserve this crucial energy resource, PNNL offers a range of expertise to the NRC, including environmental impact reviews for both existing plants seeking license renewal and proposed new reactors. From 2000 to 2012, PNNL's significant contributions to environmental and other reviews supported the NRC in approving license renewals for 36 reactors at 21 sites nationwide. These reactors represent an estimated 250 million megawatt hours of electricity production annually. Additionally, in recent years, PNNL has helped deliver environmental impact statements to the NRC for four U.S. plant sites seeking to install a total of seven new reactors—an effort that has set the stage for the first new nuclear power plants to be constructed in the United States in more than 30 years. As of spring 2013, the NRC has approved construction permits for four reactors at two of the sites. PNNL also provides the NRC with science and technology solutions to improve nuclear plant operations and safety, and is assisting the NRC as the agency evaluates the feasibility of allowing nuclear plants in the U.S. to operate beyond 60 years.

FUNDING PROVIDED BY: U.S.NRC United States Nuclear Regulatory Commission *Protecting People and the Environment*

Witnesses are sworn in at a historic September 2011 NRC mandatory hearing on the application for two new reactors at a site in Georgia—the first such hearing since the 1970s, which led to NRC issuance of the reactor licenses in February 2012. PNNL conducted the environmental review for the reactors.

*Image courtesy U.S. Nuclear Regulatory Commission*

# Idle Time Solution




Today, long-haul truckers can power electronics without idling engines through use of auxiliary power units developed by PNNL and Delphi.

**PNNL and Delphi leveraged decades of fuel cell research to develop an efficient auxiliary power unit for long-haul truck, military transport and recreational vehicle markets.**

The five-kilowatt solid oxide fuel cell converts chemical energy directly to electrical energy, greatly reducing emissions that would be produced if the diesel engine was running to power the truck's air conditioning, refrigeration, stereo, GPS and other accessories. The effort to move this technology to market was recognized with a Federal Laboratory Consortium Award for Excellence in Technology Transfer in 2009.

PNNL researchers have been applying their expertise in materials and manufacturing, modeling and simulation, fuel reformation and thermal management to advance solid oxide fuel cell technology for government and industry clients since the late 1980s. Solid oxide fuel cells are cleaner, quieter and more efficient than today's internal combustion engines or combustion-based electricity generation, such as coal-fueled power plants. They can be engineered to use many types of fuels, including natural gas, diesel, bio-diesel, propane, gasoline, coal-derived fuel and military logistics fuels. This flexibility makes them suitable for multiple applications, including residential, military and stationary power. Also, PNNL co-leads the Department of Energy's Solid State Energy Conversion Alliance (SECA) with the National Energy Technology Laboratory. SECA bring together universities, national laboratories and industry with a common goal of accelerating the commercialization of clean, efficient and low-cost solid oxide fuel cell technologies.

FUNDING PROVIDED BY: U.S. DEPARTMENT OF ENERGY | Fossil Energy | Energy Efficiency and Renewable Energy

# Weight Loss Program for Autos

**PNNL's understanding and optimization of superplastic forming processes for vehicle components can be found in General Motors' Cadillac STS and other cars, trucks, and semis today.**

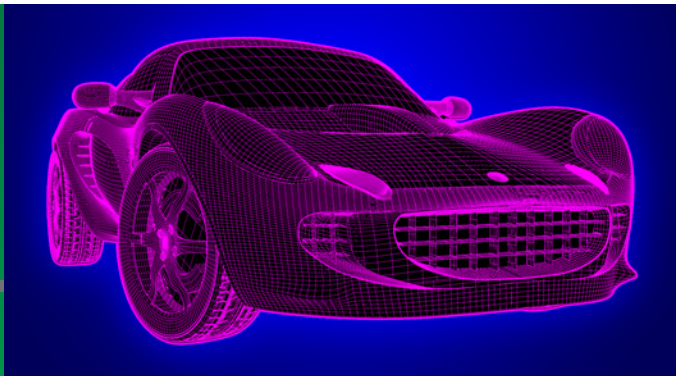
In contrast to conventional metal-forming methods, superplastic forming reduces the weight and cost of automotive and other structural components by forming unique structures in a single step. This simplifies assembly operations, significantly reduces the number of required fasteners and parts and enables cost-competitive use of lighter-weight aluminum in place of steel.

Prior to PNNL's forming advancements, SPF was not viable for automakers because it was too slow to meet the industry's high-production-rate demands, and materials required for SPF were three times more expensive than a standard sheet of non-SPF material. PNNL, in partnership with the Department of Energy, General Motors Corporation and others, provided a cost-effective forming technology for aluminum sheet materials that cut forming time from 35 to 3 minutes while providing the ability to predict the configuration of complex parts. This made SPF a practical and attractive process for higher-volume auto manufacturing, resulting in improved auto fuel efficiency and reduced emissions while still meeting design and safety requirements. GM leveraged PNNL's optimized SPF approach to produce complex components with an order-of-magnitude reduction in cycle time. The process was used to produce the hatchback on GM's former Chevy Malibu Maxx, reducing the component weight by nearly half, as well as for the Oldsmobile Aurora and the Cadillac STS.

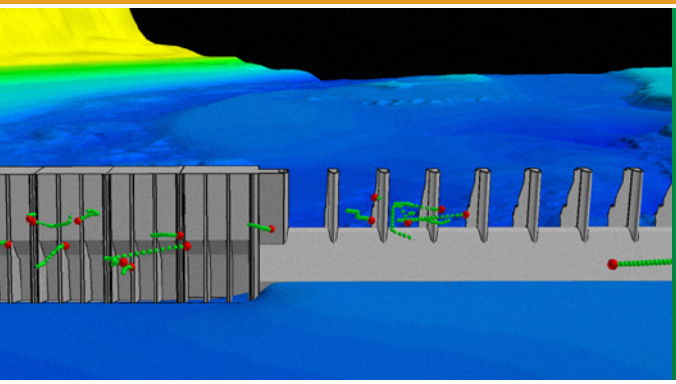
Kaiser Aluminum has applied the PNNL technology as the basis for a new alloy that delivers 40 percent weight savings on a typical mid-sized car. PNNL also has developed SPF for heavy duty truck applications, providing the ability to replace steel and heavier fiberglass parts with lightweight SPF aluminum panels.

FUNDING PROVIDED BY: U.S. DEPARTMENT OF ENERGY | Energy Efficiency and Renewable Energy | Office of Science

PNNL's SPF technology has helped enable the cost-effective manufacture of lightweight parts used throughout the automotive and other manufacturing industries today.



# Salmon Savers



JSATS provides three-dimensional monitoring of fish movement and behavior. This visualization depicts juvenile Chinook salmon passing through a dam on the Columbia River.

**PNNL technologies are helping to build salmon populations and maintain use of the Pacific Northwest's hydroelectric dams that provide about 60 percent of the region's electricity.**

Researchers are developing and deploying technologies to understand the potential hazards—including dams—that migrating fish encounter as they travel to and from the ocean. Two approaches are providing data to help boost fish survival rates, an environmental priority that directly impacts dam operations. Together, these technologies provide the foundation to assess whether dams are complying with federal standards for fish survival as outlined in the Endangered Species Act. For example, a 96% survival rate is required for juvenile salmon passing each dam on their way downstream during the spring. Dams that fail to meet standards must be modified or could even be considered for removal.

In one approach, PNNL researchers helped develop and test tiny acoustic transmitters implanted in salmon that migrate past dams. The Juvenile Salmon Acoustic Telemetry System, or JSATS, provides data on the behavior, movement and habitat use of juvenile salmon as they pass through rivers, reservoirs and dams. Each transmitter, smaller than a pencil eraser, transmits a unique code that enables individual fish to be tracked. JSATS has been used to monitor other fresh and salt water species as well.

PNNL's "Sensor Fish" is providing first-ever data on actual conditions experienced by fish as they travel through turbines, spillways and other passage routes at dams. The current design collects temperature, pressure, linear acceleration and angular velocity data simultaneously at a rate of 2,000 sample points per second. Following dam passage, Sensor Fish are collected and data are downloaded and analyzed. Results help identify where fish are most vulnerable, enabling engineers to design safer, fish-friendly turbines and dam operators to adjust spill patterns and turbine operations to increase fish survival rates.

FUNDING PROVIDED BY: U.S. DEPARTMENT OF ENERGY | Energy Efficiency and Renewable Energy

US Army Corps of Engineers®

# Faster, Cleaner, More Flexible Energy Storage

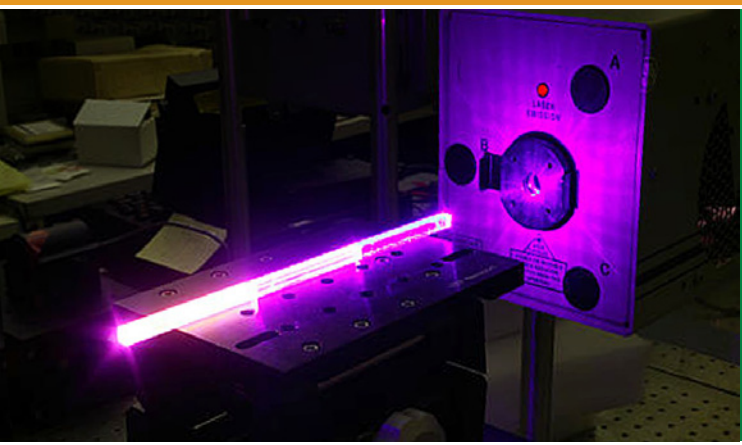
**PNNL researchers have developed a commercially viable, next-generation vanadium redox flow battery technology capable of storing 70% more energy and operating in an 83% wider temperature window than traditional redox flow batteries.**

PNNL's Mixed-Acid Vanadium Redox Flow Battery (MAV-RFB) is the first commercially viable redox flow battery capable of grid-scale deployment. Compared to traditional vanadium flow batteries, the MAV-RFB stores more energy, operates at a wider temperature range, and charges and discharges at a faster rate, which enables the system to be smaller, faster, tougher, and cheaper for utility applications such as renewable integration and grid distribution. The technology has been licensed to four U.S. companies for commercial production. As a unique solution for large-scale energy storage, the redox flow battery offers many advantages over other energy storage options because its working mechanism involves storing energy in aqueous electrolytes in separate external tanks. The non-flammability and physical separation of energy-bearing electrolytes make flow batteries intrinsically safer than traditional solid-state batteries. Compared to turbines, the flow battery is also faster, cleaner, and more flexible. It takes milliseconds, not minutes, to respond to energy contingencies, has zero greenhouse gas emissions, and enables energy and power to be easily and independently adjusted for specific storage applications. The MAV-RFB received a Federal Laboratory Consortium Award for Excellence in Technology Transfer in 2013.

FUNDING PROVIDED BY: U.S. DEPARTMENT OF ENERGY | Electricity Delivery and Energy Reliability

PNNL researchers are improving the performance of redox flow batteries, which hold promise for storing large amounts of renewable energy and providing greater stability to the energy grid.

# Shining a Light on Radiation



A laser excites Optically Stimulated Luminescence crystals, revealing radiation exposure.

**A PNNL technology, Optically Stimulated Luminescence (OSL), forms the basis for a breakthrough radiation measurement product that's protecting workers and improving health and safety worldwide.**

For people who work in radiation environments, dosimeters—or devices worn on the body to measure radiation exposure—are necessities. PNNL began exploring improved dosimetry techniques in the mid-1980s and discovered the novel Optically Stimulated Luminescence (OSL) technology. OSL dosimeters contain special materials that reveal radiation exposure information quickly when exposed to light. Compared to other methods, OSL is more sensitive, less expensive, faster, and it uniquely maintains dosimeter data for cumulative dose readings and re-analysis of questionable results. PNNL's partnership with Landauer Inc., a global leader in radiation monitoring services, was key to moving OSL to market. Landauer began funding research at PNNL in 1990 to further develop the base technology, and took the breakthrough to market in 1997. In addition to worker health and safety, OSL-based dosimeters and associated services are being used in environmental monitoring, the monitoring of radiation dose during medical procedures and treatments, and the detection of ionizing radiation dose to U.S. troops. DOE has continued to fund research at PNNL for innovative outgrowth applications of the original OSL discoveries. The OSL technology received R&D 100 awards in 1992 and 2000 (for high-dose dosimetry), and a Federal Laboratory Consortium Award for Excellence in Technology Transfer in 1994.

FUNDING PROVIDED BY: U.S. DEPARTMENT OF ENERGY | Health, Safety and Security

# CFLs Shine with the Right Touch

**PNNL's innovative market transformation program led to sales of three million energy-efficient sub-compact fluorescent lamps (CFLs) and netted $22 million in savings its first year.**

According to PNNL market research, the price and size of early CFLs were the main barriers to wide distribution. PNNL developed size and performance specifications based on these needs and worked with manufacturers to facilitate the development of smaller lamps, or "sub-CFLs." PNNL also lined up large-volume buyers interested in purchasing the sub-CFLs at a good price. Later, PNNL designed a second market transformation program for recessed compact fluorescent lights, or R-CFLs. Recessed downlights are among the most popular lighting fixtures with hundreds of millions installed in U.S. homes, but prior to 2001, R-CFLs burned out prematurely due to high heat buildup in recessed fixtures. PNNL developed lamp specifications, organized a competition for manufacturers to produce bulbs at volume prices and tested the resulting lamps. Sixteen new R-CFL models that met the demanding specifications were developed through PNNL's program. The new models provided comparable light output to incandescent bulbs, but used one-third the energy. PNNL was recognized with a 2008 Federal Laboratory Consortium Award for Excellence in Technology Transfer for its success with R-CFLs. Technical specifications developed by PNNL for both sub-CFLs and R-CFLS were adopted by DOE's ENERGY STAR program. PNNL is now leading DOE's market transformation efforts for a lighting technology that promises even more energy savings—solid state lighting.

FUNDING PROVIDED BY: U.S. DEPARTMENT OF ENERGY | Energy Efficiency and Renewable Energy

CFLs are now commonplace lighting due in large part to insights gained through PNNL's market transformation program.

# Paving the Way for Fuel-Efficient Diesel Trucks

Today's fuel-efficient diesel passenger vehicles, such as the Volkswagen Jetta TDI, are using next-generation catalytic exhaust after-treatment systems based on PNNL's original technology.

**A PNNL-enabled catalytic exhaust after-treatment improved fuel efficiency of diesel engines 25% and allowed the engines to meet 2010 EPA emissions standards.**

Many of today's fuel-efficient diesel trucks produce significantly less harmful emissions due to catalysis research at PNNL. Lean-burn diesel engines operate at very high air-to-fuel ratios, and in this way, improve fuel efficiency by more than 25 percent over standard gasoline engines. However, in the early 2000s, these higher ratios meant that emission control devices developed for standard gasoline engines were not effective at removing NOx, a mixture of nitric oxide and nitrogen dioxide, from lean-burn engines. So the engines did not meet emission standards for diesel vehicles. In 2003, PNNL and engine manufacturer Cummins, Inc., began a collaborative, multi-year Cooperative Research and Development Agreement—or CRADA—to explore failures in the Lean-NOx Trap catalysts that Cummins had been studying. Using ultra-high field NMR spectroscopy and a history of expertise in chemistry and chemical engineering, PNNL researchers provided the foundational understanding of catalyst structure and performance necessary for converting harmful NOx emissions to benign molecules, and ultimately, for improving catalytic converters for lean-burn diesel trucks. The NMR spectrometer was accessed at the Environmental Molecular Sciences Laboratory, a Department of Energy national scientific user facility located at PNNL.

Armed with this understanding of the important materials interactions in the Lean-NOx Trap catalysts from PNNL research, Cummins and catalyst supplier Johnson Matthey developed improved materials and new ways of operating the diesel engines that minimized the harmful catalyst changes PNNL had discovered in the Lean-NOx system. Lean-Nox Trap catalytic exhaust after-treatment was first used in the 2007 Dodge Ram pickup and is now being used on other fuel efficient diesel vehicles in the U.S. market, including the Volkswagen Jetta TDI.

FUNDING PROVIDED BY: U.S. DEPARTMENT OF ENERGY | Office of Science | Energy Efficiency and Renewable Energy

# A New Way of Looking at Waste

**A PNNL technology is providing the first remote characterization of residual tank waste, with potential to improve worker safety and save millions in sampling analysis costs.**

PNNL and contractors at the Hanford Site in eastern Washington are deploying—for the first time—telescopic Raman spectrometer capabilities to determine the type of radioactive waste left at the bottom of Hanford storage tanks. Raman sensors are installed on the top of the tank to probe the composition of the solid waste remaining on the tank bottom and transmit the signal to a computer located outside the tank area. The technology remotely identifies Raman-active mineral and chemical compounds in radioactive waste after liquid waste has been pumped out. Determining the composition of residual waste—called "hardpan"—is important because scientists need to identify and study the material to determine the best approach for its removal. As part of a regulatory agreement for Hanford Site cleanup, workers must remove at least 99 percent of the material in every waste storage tank on the site, or as much waste that can be removed based on the best available technology. Raman spectroscopy provides information on molecular structure, which can be used to identify minerals and chemicals present in samples. PNNL scientists and contractors are deploying this technology to evaluate hardpan in support of sampling activities for the Hanford Tank Waste Treatment and Immobilization Plant in Richland, Washington, which will retrieve, process and prepare waste for long-term storage.

FUNDING PROVIDED BY: U.S. DEPARTMENT OF ENERGY | Environmental Management

PNNL scientists collect real-time Raman spectroscopic data for remote sensing of tank waste.

# It's in the Code

Staff at PNNL are key to DOE's ongoing efforts to improve buildings energy efficiency through adoption and implementation of progressive building energy codes.

**Approximately $3 billion in energy cost savings per year are attributable to successes within DOE's Building Energy Codes Program, for which PNNL staff play a critical role.**

Residential and commercial buildings account for more than 70 percent of the electricity consumed in the U.S., which offers a tremendous opportunity to reduce the nation's energy use by improving how our buildings operate. For the better part of 30 years, Pacific Northwest National Laboratory has helped our nation "build better buildings" by leading collaborative research programs that include materials research, building performance measurement, and codes and standards energy analysis. The result is significant efficiency improvements to the actual built environment; to the appliances, fixtures, and systems in the structure; as well as the way in which owners and occupants use the building. For example, the Department of Energy's Building Energy Codes Program (BECP), managed by PNNL, has delivered transformational changes in building energy consumption. In 2010, energy savings of over 300 trillion BTUs and cost savings of $3 billion per year were attributable to BECP efforts. By 2030, continuing efforts by BECP are projected to result in annual primary energy savings of 2.4 quadrillion BTUs and annual cost savings of $9 billion.

FUNDING PROVIDED BY: U.S. DEPARTMENT OF ENERGY | Energy Efficiency and Renewable Energy

DISCOVERY *in Action*

# ABOUT
## Pacific Northwest National Laboratory

The Pacific Northwest National Laboratory, located in southeastern Washington State, is a U.S. Department of Energy Office of Science laboratory that solves complex problems in energy, national security, and the environment and advances scientific frontiers in the chemical, biological, materials, environmental, and computational sciences. PNNL employs 4,500 staff members, has an annual budget of nearly $1 billion, and has been managed by Ohio-based Battelle since 1965.

Pacific Northwest
NATIONAL LABORATORY

*Proudly Operated by* Battelle *Since 1965*

www.pnnl.gov

*For more information, contact:*

**Jud Virden**
Associate Laboratory Director
Energy & Environment Directorate
Pacific Northwest National Laboratory
(509) 375-6512
jud.virden@pnnl.gov
http://energyenvironment.pnnl.gov

October 2013
PNNL-SA-98712