NREL: A YEAR IN CLEAN ENERGY INNOVATIONS

A Review of NREL's 2014 Feature Stories

NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Cover photo by Dennis Schroeder, NREL 28892

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INTRODUCTION

The U.S. Department of Energy's (DOE) National Renewable Energy Laboratory (NREL) is the nation's primary laboratory for renewable energy and energy efficiency research and development.

NREL's mission and strategy are focused on advancing DOE's and our nation's energy goals. The laboratory's scientists and researchers support critical market objectives to accelerate research from scientific innovations to market-viable alternative energy solutions. At the core of this strategic direction are NREL's research and technology development competencies. These areas span from understanding renewable resources for energy, to the conversion of these resources to renewable electricity and fuels, and ultimately to the use of renewable electricity and fuels in homes, commercial buildings, and vehicles.

What follows is a compilation of articles featuring NREL research and development, deployment, commercialization, and outreach activities in 2014. The feature stories can be found online at http://www.nrel.gov/features/.

Questions about these articles should be directed to NREL's Public Affairs Office by calling 303-275-4090 or sending an email to public.affairs@nrel.gov.

Photo by Dennis Schroeder, NREL 26217

Renewable
Hydrogen
Fueling
Station
U.S. Department of Energy
Energy Efficiency
and Renewable Energy
EPC

ADVANCED VEHICLES & FUELS

Working in partnership with public and private organizations, NREL researches, develops, and demonstrates innovative vehicle and fuel technologies that reduce the nation's dependence on imported oil and improve our energy security and air quality. *Photo by Dennis Schroeder, NREL 28217*

NREL Bolsters Batteries with Nanotubes

Researchers at the Energy Department's National Renewable Energy Laboratory (NREL) are turning to extremely tiny tubes and rods to boost power and durability in lithium-ion batteries, the energy sources for cell phones, laptops, and electric vehicles. If successful, the batteries will last longer and perform better, leading to a cost advantage for electric vehicles.

Transportation and communication around the world increasingly rely on lithium-ion batteries, with cell phones ubiquitous on six continents, and electric vehicles on pace to accelerate from a $1 billion worldwide market in 2009 to $14 billion by 2016, according to analysts Frost and Sullivan.

NREL's Energy Storage group is working with the Energy Department, automotive battery developers, and car manufacturers to enhance the performance and durability of advanced lithium-ion batteries for a cleaner, more secure transportation future, said Energy Storage Group Manager Ahmad Pesaran. "The nanotube approach represents an exciting opportunity—improving the performance of rechargeable lithium-ion batteries while make them last longer," Pesaran said. "Increasing the life and performance of rechargeable batteries will drive down overall electric vehicle costs and make us less reliant on foreign sources of energy."

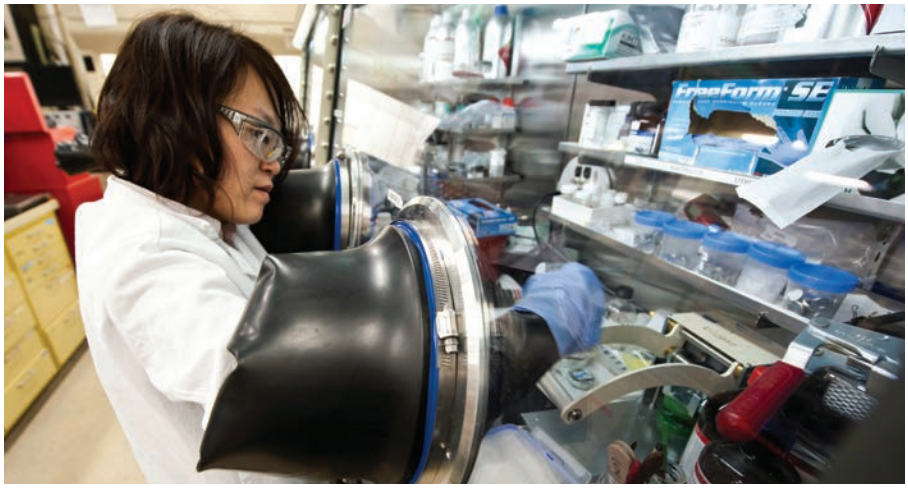
Scientists at NREL have created crystalline nanotubes and nanorods to attack the major challenges inherent in lithium-ion batteries: they can get too hot, weigh too much, and are less than stellar at conducting electricity and rapidly charging and discharging.

NREL's most recent contribution toward much-improved batteries are high-performance, binder-free, carbon-nanotube-based electrodes. The technology has quickly attracted interest from industry and is being licensed to NanoResearch, Inc., for volume production.

Nanotechnology refers to the manipulation of matter on an atomic or molecular scale. How small? A nanometer is one-billionth of a meter; it would take 1,000 of the nanotubes in NREL's project lined up next to each other to cross the width of a human hair.

Yet, scientists at NREL are able not only to create useful objects that small, but guide their formations into particular shapes. They've combined nanotubes and nanorods in such a way that they can aid battery charging while reducing swelling and shrinking that leads to electrodes with shortened lifetimes.

"Think of a lithium-ion battery as a bird's nest," NREL Scientist Chunmei Ban said. "The NREL approach uses nanorods to improve what is going on inside, while ensuring that the nest remains durable and resilient."



NREL Scientist Chunmei Ban assembles a lithium-ion battery in the materials lab at the Solar Energy Research Facility at NREL. *Photo by Dennis Schroeder, NREL 21998*

"We are changing the architecture, changing the chemistry somewhat," without changing the battery itself, she said.

NREL's work was supported by the Energy Department's Vehicle Technology Office under the Battery for Advanced Transportation Technologies (BATT) program, which focuses on reducing the cost and improving the performance and durability of the lithium-ion batteries that power electric vehicles.

Carbon Nanotubes Both Bind and Conduct

Typical lithium-ion batteries use separate materials for conducting electrons and binding active materials, but NREL's approach uses carbon nanotubes for both functions. "That improves our mass loading, which results in packing more energy into the same space, so better energy output for the battery," Ban said. "The NREL approach also helps with reversibility—the reversing of chemical reactions that allows the battery to be recharged with electric current during operation. If we can improve durability and reversibility, we definitely save money and reduce cost."

Single-wall carbon nanotubes (SWCNTs) are expensive, but scientists and engineers working in the field are confident that as the use of SWCNT-based electrodes grows wider, their price will fall to a point where they make economic sense in batteries, Ban said.

In a lithium-ion battery, lithium ions move back and forth in the graphite anode through an electrolyte; the ions are injected between the carbon layers of graphite, which is durable but unnecessarily dense. At the same time, electrons flow outside the battery through an electric load from the cathode to the anode. Electrolytes are essential in rechargeable batteries because they close the circuit inside the batteries by allowing ions to transfer; otherwise, the battery can't continue to conduct electricity from the positive to the negative poles and back again.

High-energy materials, such as metal oxides and silicon anodes, have massive volume changes when lithium ions are injected and extracted from the electrode material. They swell and shrink, gather into a cluster and touch each other, shrinking in unison, causing collapse and subsequent cracks that can harm performance, leading to destruction of the electrode and thus lower lifetime.

Certain metal oxides do a better job than graphite of teaming with the electrodes. But while they improve on the energy content and reversing functions, they still contribute to the large expansion in volume and the destruction of the internal structure.

The NREL team turned to iron oxide, which is abundant, safe, inexpensive, and shows great promise. Yet, to be effective, the size of the iron oxide nanoparticles had to be just right—and had to be maintained in a strong matrix that was both flexible and resilient to deal with large volume changes while optimally conducting electricity.

NREL tapped the unique properties of SWCNTs to address the challenges of heat, weight, and discharging all at once. "We use the carbon nanotube in this flexible network to make a conductive rope-like wrap," Ban said. So, when there is shrinkage, those wraps allow the electrons to reach the iron oxide and continue on the conductive path unabated. Using nanoparticles shortens diffusion length, enhancing the capability of fast charging and discharging. Using abundant inexpensive material means less need for such expensive metals as cobalt, currently used in lithium ion batteries' cathodes, lowering overall cost."

Building Better Anodes and Cathodes

The SWCNT with iron oxide solution produced a power density triple that of graphite, which means strong performance while eliminating much of the weight of a battery that depends on graphite. To get there, it was essential that the iron oxide particles be distributed uniformly within the encircling nanotubes.

Ban and NREL colleague Zhuangchun Wu used hydrothermal synthesis and vacuum filtration to build lithium-ion anodes that don't require the typical binders (the adhesion strength that allows the battery to endure charge-discharge cycling) yet have high capacity. The first step was to make iron oxide nanorods as precursors for making electrodes. Ban and her colleagues discovered that at 450°C, annealing the iron hydroxide nanorods with SWCNTs would produce iron oxide. And, the SWCNTs contributed just 5% to the weight. Not only did the SWCNTs actually facilitate the formation of the iron oxide particles, but they ensured excellent physical and electrical contact between the two materials.

> "Think of a lithium-ion battery as a bird's nest. The NREL approach uses nanorods to improve what is going on inside, while ensuring that the nest remains durable and resilient."
>
> —**CHUNMEI BAN**, *NREL Scientist*

For cathode electrodes, they embedded NMC—lithium nickel manganese cobalt oxide—in the nanotubes, causing the nanoparticles to become very conductive. The resulting nanocomposite retains 92% of its original capability to store and conduct electrical charges even after 500 cycles of charging and recharging.

Expertise in Wet-Chemistry Synthesis Guided the Ideal Shapes

It's not as easy as simply putting nanomaterials into batteries, Ban said. "You need a special process to make it work." Ban and her NREL colleagues Wu and Anne Dillon used a vacuum filtration process to combine inexpensive iron oxide with carbon nanotubes.

Ban brought her experience in wet-chemistry synthesis to the challenge of influencing the shapes of the nanomaterials to make them in the form of rods. "We know how to change the synthesis conditions to direct the design or realize the structure and shape of nanomaterials," Ban said.

They chose a rod shape because they thought that would integrate well with the nanowires and curvatures of nanotubes, wrapping around them to create a robust electrode. The unusually long and very flexible strands of the nanomaterials are crucial to the superior features of the electrodes. They attach intimately to the particles, and their porosity allows for ideal diffusion.

A Rechargeable Battery That Lasts

The innovative electrodes conceived by NREL can mean superior capacity, performance, and safety for lithium-ion batteries.

David Addie Noye, who founded NanoResearch, Inc., with a plan to commercialize proven nanoscience innovations, visited NREL, saw the process, and decided to license the technology. The nanomaterial chemistry innovation and manufacturing process innovation that results in binderless electrodes "is a game changer because it helps solve a fundamental problem the lithium-ion battery industry has not been able to solve for decades," he said.

The improvements in the lithium-ion batteries offered by NREL's approach also can make a difference in portable consumer electronics, such as laptops, tablets, cell phones, and portable media, as well as the stationary energy storage devices that will become increasingly important as more variable-generation renewable energy enters the grid.

"We aren't making a new battery, but we're changing the architecture somewhat by using SWCT wrapped metal oxide anodes," Ban said. "By so doing, we improve the mass loading, energy output per weight, and volume." The process ensures a faster charge, and that's what is most essential to manufacturers and their customers. That means fewer trips to the recharging station, and a battery that keeps going and going and going.

— Bill Scanlon (June 11, 2014)

NREL Driving Research on Hydrogen Fuel Cells

Hydrogen fuel cell electric vehicles (FCEVs) were the belles of the ball at recent auto shows in Los Angeles and Tokyo, and researchers at the Energy Department's National Renewable Energy Laboratory (NREL) continue to play a key part in improving performance and durability while driving down costs.

The driving public has long been tantalized by the allure of a vehicle that emits nothing but water from its tailpipe, but now that Toyota, Hyundai, and Honda have all committed to putting them on the market by 2015, the stakes have changed.

It's one thing for the automakers each to sell 1,000 or so cars the inaugural year, but quite another to ramp it up to 10,000 and beyond until these cars are an appreciable percentage of the marketplace.

Sunken engineering costs and the drive to improve economics through economies of scale are challenges for any new vehicles introduced to the market, including early internal-combustion hybrids, said Bryan Pivovar, fuel cell group manager in the Chemical and Materials Sciences Center located at NREL's Energy Systems Integration Facility (ESIF). But, no one doubts that the Prius is now a success—not just in being the best-selling hybrid on the market, but by enhancing Toyota's image as a green company and technology leader, he added.

Fuel cell electric vehicles could follow that same trajectory, but they have an extra hurdle to clear. They won't become commonplace until there's an infrastructure of fueling stations—and only a fraction of what is required has been built so far. "Nobody wants to have a hydrogen fueling station if there aren't enough fuel cell cars to support it," Pivovar said. Likewise, auto manufacturers are reluctant to go into full-scale production if there aren't enough places to fill up. "It's a chicken and egg scenario."

Cleaner Fuels a Research Priority at Energy Department

NREL hydrogen researchers are working with auto manufacturers, component vendors, and others to take a hard look at both the infrastructure and the cost challenges. NREL's new ESIF includes 7,000 square feet of lab space built for hydrogen and fuel cell research. Approximately 50 researchers contribute to hydrogen or fuel cell related tasks, including production, storage, codes and standards, technology validation, and analysis.

Researchers at NREL are examining the best ways to create hydrogen via electrolysis using wind and solar power. The most common way to produce hydrogen today is through steam reforming of natural gas—a tried-and-true approach, but one that generates greenhouse gases.

Just a few months ago, the Energy Department's Fuel Cell Technologies Office, within the Office of Energy Efficiency and Renewable Energy, which supports NREL's research at the ESIF, announced more than $7 million for projects in Georgia, Missouri, Pennsylvania, and Tennessee that will help bring cost-effective, advanced hydrogen and fuel cell technologies to market faster. In the past 5 years, fuel cell durability has doubled; since 2005, the amount of expensive platinum needed in fuel cells has fallen by 80%, according to the Energy Department.

Pivovar predicts that hydrogen fuel cell vehicles will take off first on islands such as Hawaii or Japan where a car can't get too far away from the nearest refueling station and fuel costs are often higher, and metropolises such as Los Angeles where smog provides an extra incentive for clean engines. "The motivations for cleaner engines often rise from local concerns, rather than global concerns."

NREL is analyzing the barriers and costs associated with installing enough hydrogen refueling stations to make fuel cell vehicles viable. One intriguing shortcut is to use existing natural gas lines to distribute hydrogen. Studies are exploring limiting hydrogen concentrations to less than 15% of the gas in the lines to avoid issues such as hydrogen embrittlement and to reduce the high capital costs of installing completely independent infrastructure.

> "Today's materials still need advances for large-scale deployment. Our role is to help enable the advances to allow them to become cheap enough and durable enough to get to manufacturing."
>
> — **BRYAN PIVOVAR**, *Fuel cell group manager in NREL's Chemical and Materials Sciences Center*

Lowering the Amount of Platinum Key to Lowering Cost

The NREL fuel cell group has a strong focus on helping lower the cost of fuel cells. One important avenue is to decrease the amount of the precious metal platinum used in the fuel cell. Platinum plays a key role as a catalyst for the electrochemical reactions that occur in a fuel cell that convert hydrogen and oxygen into electricity, heat, and water.

Fuel cells produce electricity directly and can lead to much higher efficiencies than are possible with combustion engines.

Internal combustion engines powered by gasoline burn the carbon-based fuel in the presence of oxygen, producing carbon dioxide and other pollutants such as nitrogen oxides (NOx) as byproducts. In fuel-cell vehicles, the only thing coming out of the tailpipe is water. In fact, they are so clean and efficient that they have provided both the electricity and water used by astronauts in space.

A typical FCEV uses polymer electrolyte membrane (PEM) fuel cells, which combine hundreds of single cells to make a fuel cell stack. The single cells consist of polymer membranes that are coated with catalysts, typically platinum supported on carbon. The high-pressure hydrogen gas cylinders on board release just enough hydrogen through the stack to produce the electricity needed to power the car. The vehicles use compressed hydrogen gas cylinders now, but could someday store the fuel in powder form.

"At NREL, we do a lot of work that is focused on enabling the materials science for the next generation of technologies for fuel cells," Pivovar said. The 2015 FCEVs will entice current and future customers, but the fuel cells will be using more platinum than will ultimately be cost competitive.

NREL scientists also have demonstrated activity and durability improvements for platinum if the surface is extended. "We're trying to make ultra-thin platinum films limited to a few atomic layers, while still making sure it covers the surface," Pivovar said. If platinum levels can be further dropped by two-thirds, hydrogen fuel cells could reach precious metal loadings on parity with catalytic converters in today's internal-combustion engines. The catalytic converters mandated for pollution concerns in conventional vehicles are not needed for the ultra-clean exhaust of fuel cell vehicles.

"We're getting very close to parity with the precious metals on the catalytic converter," he said. "Most of our projects focus on decreasing the platinum loading and making the performance of the cell higher and more durable, while lowering the cost. The key is addressing cost, performance, and durability at the same time."

NREL Analyzing Contaminants, Components

NREL is working with GM on improving the understanding of how contaminants affect fuel cells. Eventually, fuel cell systems will use inexpensive plastic, similar to the kind that is used to make containers, but without some of the added chemicals. NREL is examining which chemicals can be taken out of the plastic—and which need to stay in—in order to ensure reliable performance at a low price.

NREL is analyzing the components that will be needed to power hydrogen fuel cells. One approach is to put promising component materials in water, leach out potential contaminants, and carefully test for possible negative impact. "We perform analytical characterization of what's coming out in what I refer to as our CSI lab," Pivovar said, alluding to the popular Crime Scene Investigation TV series. Test results lead to recommendations for different materials or tweaks to current materials.

NREL's instruments can test efficiency while conditions change on catalyst-coated membranes, or while different contaminants are introduced. NREL also tests the electrochemical performance of the catalysts, a way to discover just how much platinum can be removed from the cell before it hampers efficiency. Considerations are also given for how materials can be recovered and recycled, particularly platinum. For fuel cell component manufacturing, NREL's unique web-line and quality-control diagnostic techniques are being employed to help manufacturers address costs and scale up issues associated with increased production volumes. Specifically, NREL is developing diagnostic techniques and applying them to roll-to-roll goods to ensure product quality requirements can be met at high production volumes.

Industry Demonstrates Commitment to Hydrogen

In the past 18 months, several auto manufacturers have formed partnerships to build platforms for fuel cell vehicles. So, when BMW comes out with its first hydrogen fuel cell vehicle, it will use the same platform as Toyota. Likewise, Nissan, Ford, and Daimler have formed a partnership for a fuel cell and drivetrain platform. Honda and GM also are working together. "They realize that if fuel cells are going to succeed, they can't succeed just for one manufacturer, but for all of them," Pivovar said. "Working together lowers research costs and risks. And having just a few platforms, rather than several, will help them get their volumes up much quicker. It shows a commitment that they are really going to do this."

NREL's data show that fuel cells made striking improvements between 2005 and 2013. An important benchmark will be when fuel cell vehicles cost about the same as other vehicles amortized over a lifetime.

"We look to perform an enabling role," Pivovar says of NREL's hydrogen R&D program, which has a budget of about $13 million a year. "Today's materials still need advances for large-scale deployment. Our role is to help enable the advances to allow them to become cheap enough and durable enough to get to manufacturing."

Robot Tests Resiliency of Hydrogen Refueling

A bright yellow robot the size of a power forward bends and twists a hydrogen fueling hose hundreds of times a day, testing the durability of the hoses that someday soon will refuel America's hydrogen vehicles.

The robot is the colorful keystone of the hose reliability project at the ESIF, the newest building at NREL.

With a long arm where its nose should be, the robot simulates the bending and twisting that humans do when they refill their gasoline engines today, and what they'll do in slightly different fashion in 2015 and beyond as car manufacturers bring vehicles powered by hydrogen fuel cells to market.

The robot has a twisty wrist that can turn the hose assembly deftly onto a pin to mate with the vehicle's exterior where the refueling will happen. The repetitive motion puts stress on the hose, so researchers can identify opportunities to increase the lifespan and reduce the cost of the hose assembly. The test also includes low-temperature and pressurized hydrogen gas conditions that will be part of the real-world refueling process.

NREL Senior Engineer Kevin Harrison notes that today's gas stations use the same hoses for thousands of fill-ups before they need to be replaced, and hydrogen fuel cell stations will need to reach that same level of reliability with their hose assembly. "This is a matter of adding value and working with industry to reduce the cost of the hose and the hydrogen infrastructure in general," Harrison said. "This facility [ESIF] allows industry to perform testing they can't do anywhere else in the world."

— Bill Scanlon (March 24, 2014)

Partnerships Drive New Transportation Solutions

Hybrid car sales have taken off in recent years, with a fuel-sipping combination of electric- and gas-powered technologies that simultaneously deliver energy efficiency, low emissions, and strong performance. The Energy Department's National Renewable Energy Laboratory (NREL)—which played a pivotal role in putting hybrids on the road—has applied a similar strategy to its talent base and partnerships, bringing together the best minds from the worlds of research and industry.

NREL's Transportation and Hydrogen Systems Center (THSC) provides just one example of how NREL partners with industry to address some of the toughest energy efficiency challenges. NREL's work with individual companies—from startups to established corporations—includes full collaboration, technical assistance, deployment guidance, research facility use, and technology licensing. The lab has also attracted national-caliber experts to its staff from the commercial sector, while continuing to bank on the intellectual capital of its research veterans.

For instance, THSC Director Chris Gearhart and Vehicle Technologies Laboratory Program Manager John Farrell joined NREL in 2013 after three collective decades in the automotive and fuels industries.

"We recruited Chris and John because we knew they could effectively steer our transportation team even further along in meeting the Energy Department's goals and the NREL mission," said Associate Lab Director for Mechanical and Thermal Systems Engineering Barbara Goodman. "Their ability to provide industry perspectives was essential for maintaining our relevance."

Gearhart led research and development (R&D) teams at Ford Motor Company for more than 16 years, as well as playing pivotal roles in product development, safety research, and quality assurance programs. Farrell came to NREL after 15 years at the ExxonMobil Corporate Strategic Research Lab, where he held R&D, technical, strategic planning, and program management positions, leading collaborations with Toyota, Caterpillar, and Ford.

"Even in my Ford days, reducing petroleum consumption and greenhouse gas production was my mantra," said Gearhart, who championed the company's fuel cell system, stack, and hydrogen storage research efforts. "Being able to focus 100% on sustainable transportation solutions was the logical next step."

Transportation and Hydrogen Systems Center Director Chris Gearhart, right, and Vehicle Technologies Laboratory Program Manager John Farrell joined NREL in 2013 after three collective decades in the automotive and fuels industries. These industries turn to NREL for support in addressing many of their energy efficiency challenges. *Photo by Dennis Schroeder, NREL 31863*

Farrell might have spent most of his career in private industry, but he also draws on considerable experience working with Sandia, Oak Ridge, and Argonne national labs on Energy Department projects. He carried this spirit of public-private partnership with him to NREL.

"The government, automakers, component manufacturers—they're all our partners," Farrell said. "We're an Energy Department lab, responsible for moving forward energy-efficient solutions with the potential for significant market impact. That means our work must deliver the greatest possible energy savings, while being informed by private-sector realities."

> "If we are going to accelerate the widespread adoption of sustainable transportation technologies, we need to pull with industry to identify the most viable solutions, break down market barriers, and increase the competitiveness of that technology."
>
> — **CHRIS GEARHART,** *Transportation and Hydrogen Systems Center Director*

A Long Track Record of Partnerships

"NREL's connection to the marketplace and deployment, its strong collaboration with industry—that's not a given at every organization," Farrell said when asked about the lab's reputation with the commercial sector.

This approach to transportation projects dates back to the Energy Department's launch of the Partnership for a New Generation of Vehicles project in 1993. NREL helped recruit General Motors (GM), Chrysler, and Ford as partners in this project that helped put the first of today's hybrid vehicles on the road. In the last year, NREL has collaborated on sustainable transportation projects with partners including General Electric, the U.S. Advanced Battery Consortium, and all of the Big Three automakers.

"Our primary concern is to find the best possible solution, which may or may not already be on industry's radar screen," said Senior Engineer Matt Keyser, who has been recognized with three R&D 100 awards, the most recent in 2013. "We engage with our industry partners nearly every step of the way, so that when that new technology reaches the commercialization stages, it addresses real-world market needs."

In 2013, NREL had 166 active cooperative research and development agreements (CRADAs), the largest number of any national laboratory. These partnerships have delivered tangible results and augmented resources. For example, NREL is leading 11 industry partners in the Energy Department-sponsored Computer-Aided Engineering for Electric-Drive Vehicle Batteries (CAEBAT) project. Partners have contributed $7 million to the project, effectively doubling funding, and the first design tools were released earlier this year.

"Over the last decade we've worked closely with Xcel Energy in exploring how wind power can be used to produce hydrogen for fuel cell vehicles," says Fuel Cell and Hydrogen Technologies Laboratory Program Manager Keith Wipke. "Teaming up on this is a win-win. Our research team benefits from Xcel's knowledge of large-scale utility operations, and we're able to explore and validate strategies that can reduce wind power's intermittency issues. Additional partnerships with electrolyzer companies help push the efficiency and reliability of the systems that use the wind electricity to split water."

NREL's Industry Growth Forum gives emerging clean energy and energy efficiency technology startups exposure to and feedback from investors, government agencies, and strategic partners. Collectively, the Forum's participating companies have raised more than $5 billion in financing since 2003.

NREL also works closely with other national laboratories, government agencies, and universities. Currently, NREL is collaborating with five other national laboratories on projects exploring the potential for integration of renewable energy sources, the electricity grid, buildings, and electric vehicles as part of the Energy Department's Integrated Network Testbed for Energy Grid Research and Technology (INTEGRATE) initiative.

Research Expertise Paired with Industry Savvy

NREL leverages partnerships to deepen its understanding of factors that impact industry and consumer adoption of sustainable transportation solutions.

NREL not only benefits from the savvy of industry partners, but also has a long track record of attracting and retaining top scientists, engineers, and analysts—both from other research institutions and from the private sector. The lab's 2,000-plus employees come from a range of backgrounds. What they have in common is a passion for renewable energy and energy efficiency research.

"The balance of staff members with both types of backgrounds really strengthens our capabilities," Gearhart said. "Many of our team members have actually moved back and forth between the research and private sectors, so they intimately understand priorities, concerns, and protocols on both sides. This gives us the critical mass of research expertise needed to tackle ambitious projects, while also knowing that the information, insights, and technology we're delivering are market viable."

The background of NREL's transportation staff is quite evenly divided, with approximately 45% of THSC's 84 researchers and managers coming from companies including Ford, GM, Chrysler, Volkswagen, Lockheed Martin, and Corning. The insights on development, manufacturing, scale-up, and operations provided by these former industry players complements the deep research expertise and institutional continuity supplied by staff members with decades of experience at the lab.

"While at GM, I helped lower emissions and meet fuel economy goals by designing and testing light-duty emission control systems," said Kevin Walkowicz, who now heads up NREL's transportation testing and analysis team. "For the past 13 years, I've continued to build on that, working with the commercial vehicle industry to green their fleets of heavy- and medium-duty trucks."

This industry know-how, in turn, is supplemented by the knowledge of staff members who come from other research institutions, such as national labs, government agencies, or academia. Veteran NREL researchers' commitment to innovation has netted the lab 57 R&D 100 awards, more than 200 royalty-bearing licenses, and in excess of 800 patents.

Although most of Gearhart's experience has been in hydrogen fuel cell and electric vehicle development, and Farrell's career has focused on fuels and combustion, they both recognize that a broad portfolio of solutions is needed to maximize energy savings and emissions reductions.

"Industry gets the need to explore renewable opportunities, but companies might not agree about the best way to get there," Farrell said. "Our unbiased research experts are able to identify and focus their efforts on the most promising R&D, pinpointing the technical, engineering, and scientific factors that determine whether a solution will be viable in terms of both mechanics and the marketplace."

In addition to established leadership in R&D related to electric-drive vehicle technology, Gearhart and Farrell point out that the lab is pursuing alternative fuel, engine combustion, climate control, and infrastructure advancements, as well as pushing into new areas of exploration, such as connected autonomous vehicles.

Integration of Perspectives

Just as integrated systems will be crucial in furthering the sustainable transportation mission, NREL sees the continued integration of industry and research perspectives as vital to the success of its R&D in this area.

"If we are going to accelerate the widespread adoption of sustainable transportation technologies, we need to pull with industry to identify the most viable solutions, break down market barriers, and increase the competitiveness of that technology," Gearhart said.

Farrell picked up the thread: "At the same time, without rigorous, independent research, those solutions aren't going to take us where we need to go."

NREL's sustainable transportation R&D will continue to bridge the worlds of scientific research, technology development, and the marketplace—in the form of the lab's approach to research, ongoing collaboration, and strategic hires.

— Anya Breitenbach (October 23, 2014)

Transportation Leader Roots Career in True Grit

In 1994, Wendy Dafoe clocked in as a temp at Energy Department's National Renewable Energy Laboratory (NREL) and began work on what would become the Energy Department's Clean Cities Alternative Fuels Data Center (AFDC). Twenty years later, Dafoe is still here, but in a full-time capacity as senior project leader helping steer the program. Some would call it commitment, some would point to a planetary alignment—but others might suspect it has something to do with the true grit Dafoe developed in her time with the mining industry.

Dafoe interprets it as kismet, saying: "Somehow, I lucked into connecting with Clean Cities, and the program has become an incredible success story for EERE. Since its inception, the leadership at Clean Cities has steered the program to build an impressive network of coalitions who establish public-private partnerships, leading to exponential growth."

In her current role, Dafoe works closely with the Energy Department's Office of Energy Efficiency and Renewable Energy (EERE) staff to advance the Clean Cities sustainable transportation mission. This June, the Energy Department recognized Dafoe with an award at the Annual Merit Review and Peer Evaluation Meetings for her long-lasting commitment to advancing the Clean Cities mission. The ceremony spotlighted her early efforts in establishing the AFDC as EERE's most popular website, building Clean Cities' national network of coalitions, and forging public-private partnerships. This was a follow-up to her 2009 Lifetime Appreciation Award from the Clean Cities program.

"I can't think of anyone who works with as much tireless dedication and professionalism as Wendy. In her role, she helps nearly 100 Clean Cities coalitions and countless numbers of stakeholders. I can't think of anyone more deserving of this award," National Clean Cities Co-Director Linda Bluestein said.

Turning Rough-and-Tumble Experiences into Pure Gold

Before joining NREL, Dafoe worked in the mining and sand and gravel industries, handling office management and purchasing responsibilities for field offices. She had originally planned on a career in oil and gas, but when the industry tanked, she took a job with a gold mining company and ended up working in rural Nevada, hundreds of miles north of Las Vegas, and 15 miles off any paved road.

Wendy Dafoe serves as the Clean Cities task leader at NREL, working closely with staff at the Energy Department's Office of Energy Efficiency and Renewable Energy (EERE) to advance the Clean Cities sustainable transportation mission. This June, the Energy Department recognized Dafoe with an award for her long-lasting commitment to advancing the Clean Cities mission. *Photo by Dennis Schroeder, NREL 30678*

> "Wendy has always been committed to the ultimate goal of greater impact on the nation's transportation energy use. She is constantly asking, 'How can we do things better? What should we be thinking about next?'"
>
> — **ANN BRENNAN**, *Dafoe's manager at NREL for 14 years*

Gold mining, as anyone can imagine, is fascinating for a number of reasons. Yes, miners are pulling precious metal from the ground that will eventually become coins, jewelry, or even manufacturing components. But the excavation is hard, dirty work.

Dafoe describes a rough-and-tumble existence as a female mining company employee in the 1980s. "You can't do that and be too attached to your identity as a girl," she said—while sitting at her desk in a pink sweater. "I was one of just three women in a workplace with 92 men. You had to have a pretty thick skin to succeed."

And it was an industry rife with hazards—heavy machinery, fire risks, people working long hours. As someone who was thrown into that world with next to no preparation, Dafoe was fortunate enough to connect with managers who wanted to help her succeed.

The experience also taught Dafoe to go toe-to-toe with staff members who didn't expect to take direction from a younger woman. To her surprise, that sense of assertion came naturally. "I'm pretty sure some people thought I was the city girl who would quickly sink," she said.

As the person responsible for standardizing practices across the office, including risk management policy, Dafoe found her time at the mining company drove home the importance of continuous organizational improvement—even if in the early stages of her career she wouldn't have called it that.

"Wendy has always been committed to the ultimate goal of greater impact on the nation's transportation energy use. She is constantly asking, 'How can we do things better? What should we be thinking about next?'" said Ann Brennan, who was Dafoe's manager at NREL for 14 years. "She maintains strong relationships throughout the industry and the broader community, and is constantly developing new ideas and approaches that take advantage of each group's capabilities and motivations to make change. She never cares who gets credit, just that things get done and we make a difference. This commitment to the goal and creative problem solving means Wendy is widely respected throughout the community."

Building a Rock-Solid Program

Dafoe has seen Clean Cities through many chapters in the last two decades. The program helps vehicle fleets and consumers reduce petroleum use by building partnerships with local and statewide organizations in the public and private sectors to adopt alternative and renewable fuels, idle-reduction measures, fuel economy improvements, and new vehicle technologies.

The program encompasses Clean Cities coalitions across the country and almost 18,000 stakeholders, including private companies, fuel suppliers, local governments, vehicle manufacturers, national laboratories, state and federal government agencies, and other organizations. In its first decade, Clean Cities centered its activities on the deployment of alternative fuels, and then expanded to include idle reduction, hybrid electric vehicles, and fuel economy.

In recent years, the program started the National Clean Fleets Partnership, an initiative to help the country's largest private-sector fleets incorporate alternative fuels, advanced vehicles, and efficiency measures into their operations. Clean Cities also partners with the National Park Service through the National Parks Initiative to support transportation projects that educate park visitors on the benefits of cutting petroleum use and vehicle emissions.

The AFDC was introduced in 1991 as a repository for alternative fuel vehicle performance data, and it expanded after it was suggested that alternative fueling locations should also be tracked.

"When we started the station locator on the AFDC, the information was literally a stack of papers on my desk paired with a telephone," Dafoe said. "The AFDC progressed to a 'sophisticated' dial-up computer network, and other data grew with it. Now it's evolved into a one-of-a-kind, publicly accessible website that provides robust, intuitive tools, data, and information."

Dafoe continued to manage a growing number of datasets and also became a main point of contact for Clean Cities coordinators by answering questions and pointing them to resources. Her early work on the AFDC and Clean Cities led to what are now some of the program's flagship projects.

Creating Ripples

Although Dafoe did not have much computer experience when she was hired as an NREL temp, her managers recognized she offered value well beyond that position. Dafoe found that even working as a part-time employee—which she continued to do for her first 5 years at NREL—she was still given abundant encouragement and support to develop professionally. In fact, she received an NREL Staff Award during this period. She credits her managers for much of her success, marveling at their willingness to teach her and help advance her career.

"If this was a place where you had to fit in a certain box and be in the office 40 hours a week, I'm not sure I could have fit in—or would've wanted to fit in," Dafoe said. "I am very fortunate to have worked for Bob Wooley, Kevin O'Connor, Ann Brennan, and Margo Melendez, who believe in job satisfaction and growing careers. They all made a major investment in not just helping me grow professionally, but making the job work for everyone. I can't believe how lucky I've been to have them all as mentors."

The flexibility and support Dafoe found in working for NREL has led to ever-increasing responsibility in helping determine Clean Cities priorities and strategy. It has also resulted in significant recognition from her colleagues. In 2011, Green Fleet magazine selected Dafoe as a Sustainability All Star based on her significant sustainability achievements and involvement in efforts to promote sustainable fleet transportation solutions.

Outside of work, Dafoe encourages other women. As a member of the Philanthropic Educational Organization (P.E.O.), she promotes educational opportunities for women through loans, grants, and awards at every stage of life. Not only is she involved in fundraising and selecting scholarship recipients for the local chapter of this 145-year-old organization, she continues to foster the awardees' successes through one-on-one contact.

"I think back on my career and the development opportunities I was presented with, and it's been a little bit like skipping stones," Dafoe said. "As you gain experiences, and as you come into contact with other people, it creates a ripple effect, and the culture, standards, and mindset can have such a positive impact beyond what you'd ever imagine. I consider myself very fortunate to work with such a great team."

— Anya Breitenbach (August 14, 2014)

Supply chain

ANALYSIS

Analysis at NREL aims to increase the understanding of the current and future interactions and roles of energy policies, markets, resources, technologies, environmental impacts, and infrastructure. These analyses are used to inform decisions as energy-efficient and renewable energy technologies advance from concepts to commercial applications. *Photo by Dennis Schroeder, NREL 30454*

Industry, Investors Count on NREL's Modeling Tools

Whenever installers attach solar panels to rooftops, utilities debate the merits of a wind farm, or investors mull the potential return on a concentrating solar power (CSP) plant, there's a good chance that the performance and risk models created by the Energy Department's National Renewable Energy Laboratory (NREL) come into play.

Can a rooftop photovoltaic (PV) system work for all the homeowners in a particular neighborhood, or only for the ones with a 40-degree pitch to their roofs? Will the wind resource that works in a west Texas county work as well one county over?

With accelerated interest in technologies that can provide energy while lowering carbon emissions, it becomes all the more crucial that manufacturers, installers, and their bankers can accurately predict the performance levels and financial risks associated with wind, solar, and other types of renewable energy. Precise, reliable models are also indispensable for those at universities and labs who are working to make incremental improvements to hardware and software.

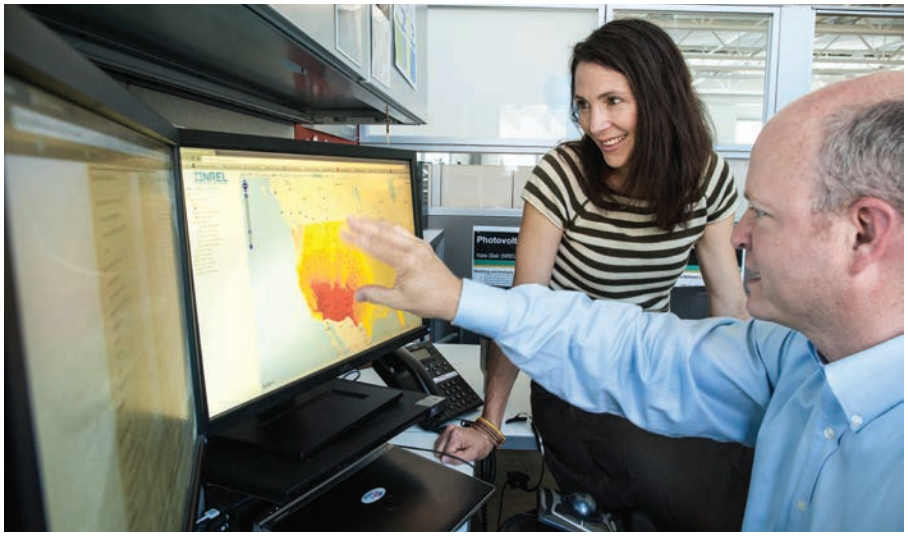
Modelers at NREL develop and constantly improve data and algorithms to enhance the accuracy of risk assessments and performance modeling of renewable energy projects. NREL makes its robust models available to various audiences, thereby improving the analysis of risk and performance associated with the projects, whether they're at the residential, commercial, or utility scale.

Hurrahs from Industry for Developing Tools for All

"NREL's models are a great service to the industry," said Gary Wayne, the principal for the solar design platform for Sunrun, which has installed 60,000 systems on rooftops nationwide. "NREL has been able to provide a standardized model that energy companies—and especially homeowners and bankers—can rely on. They've done great work on the design of the Solar Advisor Model [SAM]."

Wayne particularly likes that the NREL models are modular, which means Sunrun can put specific components of the SAM and other tools into its own systems. "We're able to incorporate them into our own production software, and that gives us great flexibility."

NREL's models are essential, he added. "Each individual solar company could not afford to invest in such a comprehensive national tool. By NREL taking that on, it frees all the other solar companies from having to duplicate that work."



NREL's Nate Blair and Suzanne Tegen take a look at NREL's Solar Prospector tool, which provides information about the sun's resource potential at any spot in the nation. Industry is using models created by NREL to plan for renewable energy installations.
Photo by Dennis Schroeder, NREL 30451

Excellent ideas for improvements in wind and solar energy systems come from all quarters—universities, startups, utilities, laboratories. The modelers at NREL make sure none of those ideas are shut out for lack of money or lack of name recognition. NREL's tools are just a few clicks away on a public platform, whether the user is a large corporation or a small startup.

Nate Blair, manager of NREL's Energy Forecasting and Modeling group, said: "Our goal is to really allow others to do complex analysis easily—from our own researchers here at NREL to academia to industry. That multiplies our efforts significantly."

PVWatts Estimates Solar Potential for Any U.S. Neighborhood

NREL's PVWatts tool allows anyone to enter a particular address —say, 1600 Pennsylvania Avenue in Washington, D.C. They'll find that the weather profile for that location is gathered from Reagan National Airport.

They'll find that solar panels are already on the White House, but the PVWatts tool invites users to play with the numbers. Increasing the existing system to a 35-kilowatt system kicks out 42,000 kilowatt hours a year, but what if the tilt or the angle was changed? April is the month in which the most electricity is produced, but how little is generated in the hazy summer months? At 12 cents per kilowatt-hour, what's the total value of the energy produced? How many years before that value exceeds the cost of the system?

Of course, PVWatts and SAM can be even more valuable before a system is installed. What happens if it is tilted a few degrees to the east, rather than due south? Installers can change the numbers, optimize the likely production, and tweak the system before the bolts and clamps are laid down. Utilities are particularly interested in PVWatts because they may pay subsidies based on the expected performance of the systems.

NREL tools such as SAM and PVWatts—plus the lab's analysis of others' tools—help companies and researchers examine their particular circumstances: the variables of their particular climate, the incentives in their state, the kilowatt-hour rate in their locales, the neighborhood bank's interest rate, and more. "By improving the characterization of risk, the models are improving the bankability of renewable projects," Blair said.

University researchers use the NREL tools to probe such issues as net metering, and how changes to it affect the economics. They need the best data and modeling to draw accurate conclusions. With the NREL tools, "they can get up to speed quickly. They can generate the output in days, rather than months," Blair said.

And there is always more work to do. NREL's modeling staff is developing new tools, including improved models for energy losses from components in a PV system, and a model that shows the effects of shading on overall energy production.

> "Our goal is to really allow others to do complex analysis easily—from our own researchers here at NREL to academia to industry. That multiplies our efforts significantly."
>
> — NATE BLAIR, *Manager of NREL's Energy Forecasting and Modeling group*

JEDI Estimates Economic Impact of Renewable Energy

NREL's Jobs and Economic Development Impact (JEDI) models are a suite of user-friendly tools that estimate the economic impacts of constructing and operating power plants, fuel production facilities, and other projects.

For example, a 500-megawatt wind project off the coast of Massachusetts, projected to begin construction in 2018, would include 167 turbines with capital costs of about $6,000 per kilowatt. One of JEDI's suite of tools, the offshore wind model, lists construction costs, including the percentage of dollars devoted to the nacelle, the blades, the tower, etc., and estimates annual operation costs in detail.

"It also estimates how many jobs are supported by the project, their wages, and the overall economic impact," said NREL's Suzanne Tegen, who manages the Market Transformation group at NREL's National Wind Technology Center. "For example, the land-based wind model incorporates things

like land lease benefits to farmers and projected property tax revenues to counties and states—even things like on-site construction operations and maintenance, or the sale of cement to build the roads and anchor the turbines."

The JEDI model includes the entire supply chain—the equipment to build the project, the fiberglass in the blades, the steel in the tower, the lawyer fees. This includes the induced impacts from the money spent by the crews that stay in the area for as long as the construction takes—the projected dollars they will spend at hotels, local restaurants, and the like.

JEDI is also an important tool for county commissioners, public utility commissions, project planners, and developers, Tegen said. And it's used frequently by academic researchers, nonprofits, and other government agencies, such as state energy offices.

Indispensable Tools for Securing Financing

Several states and utilities already require the NREL tools or similar models to be used if a utility, company, or homeowner wants to take advantage of renewable energy incentives.

For CSP, NREL's SAM tool is the only one available that can examine performance each hour of the year. For both CSP and PV, the NREL tools are the only ones that can tie together both detailed performance and detailed cash flow models.

Combining the NREL tools with a company's own proprietary software is a growing phenomenon, Blair said. "Companies want to use their own tools along with ours. They can download the engine for our tools and use it together with their own systems. We provide them with the library, and they can code it into their own online services."

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>
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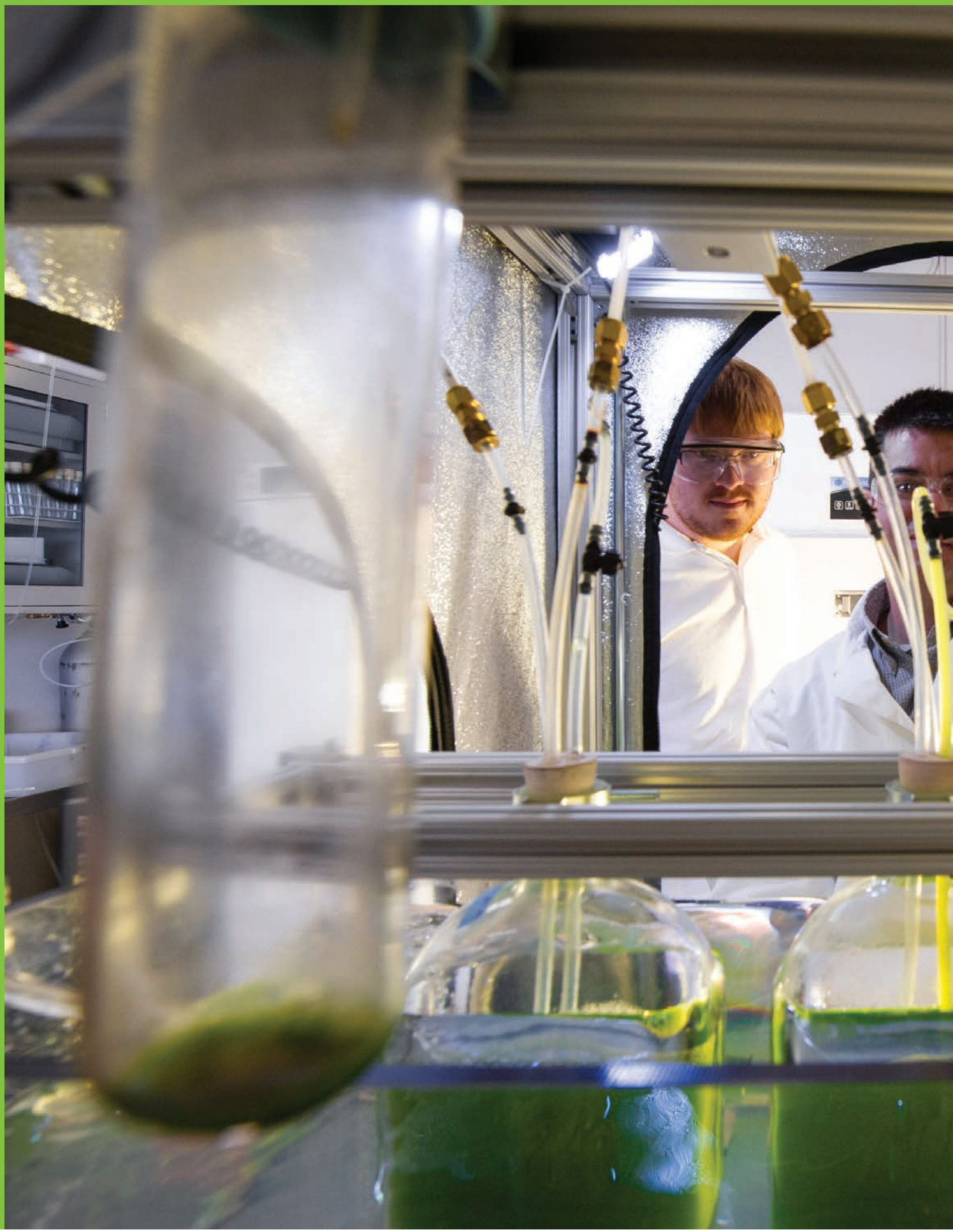
Blair and his colleagues take satisfaction in knowing that NREL's tools help accelerate the industry. Call up the model, input four or five variables, and voila, there on the screen is a robust estimate of the solar resource on a house or commercial building. "Both company representatives and university researchers tell us that putting it all into a useful package is a valuable service."

— Bill Scanlon (July 17, 2014)

Decisions about where to site solar arrays often rely on sophisticated modeling tools created at NREL. *Photo by Dennis Schroeder, NREL 26958*



BIOENERGY

Through bioenergy research, NREL is developing technologies to convert biomass—plant matter such as trees, grasses, agricultural residue, algae, and other biological material—to fuels, chemicals, and materials. These bioproducts will reduce our nation's dependence on foreign oil, improve our air quality, and support rural economies.

Photo by Dennis Schroeder, NREL 25522

NREL Working to Clean Air in Fracking Process

In the annals of impressive eating, there was The Cat That Swallowed the Canary and The Eggplant That Ate Chicago. Now, add The Microbe That Consumes the Methane.

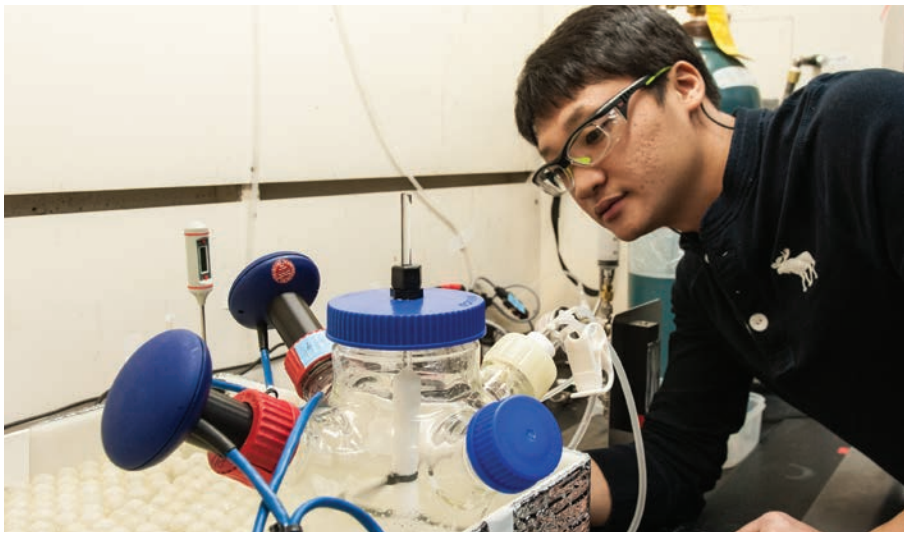
A microbe capable of digesting methane could save countless tons of greenhouse gas from reaching the atmosphere during the hydraulic fracturing process. Hydraulic fracturing, also known as fracking, uses pressurized water to fracture rock to release natural gas. It's been a boon to local economies and a source of inexpensive fuels—but if nothing is done to capture the byproduct methane, which is typically flared in the air, it can also contribute heftily to greenhouse gases in the atmosphere.

Scientists and engineers at the Energy Department's National Renewable Energy Laboratory (NREL) are working with colleagues at the University of Washington (UW), LanzaTech, and Johnson Matthey to develop microbes that convert the methane found in natural gas into liquid diesel fuel. If successful, the Biological Gas to Liquids (BioGTL) process could also lower our dependence on foreign oil.

The amount of natural gas simply flared or vented from oil wells globally is enormous—six trillion cubic feet, equal to one-third of the amount of petroleum used in the United States each year, which adds up to $12 billion in lost potential revenue annually. This adds greatly to global greenhouse gas emissions because every molecule of methane vented to the atmosphere in the fracking process has the global-warming capacity of 20 molecules of carbon dioxide.

"Fracking for oil has led to huge increases in the amount of natural gas that is flared or vented," said Philip Pienkos, principal manager of the Analytical Chemistry and Life Sciences Group of the National Bioenergy Center at NREL. "Look at nighttime satellite shots of the upper Midwest. You see Chicago, you see Minneapolis, and you see North Dakota, just as bright."

Today, with 600,000 fracking wells in the United States alone, pressure to use the technology to reach untapped petroleum reserves is greater than ever. The U.S. Energy Information Agency says that 209,439 million cubic feet of natural gas was vented or flared in the United States in 2011. That is roughly equivalent to 36 million barrels of oil per year wasted. If that stranded natural gas can be turned into a liquid, then it can be piped along with the petroleum to refineries where it can be turned into diesel suitable for trucks and cars, or even jet fuel for use in planes.



NREL scientist Qiang Fei examines a fermenter containing microbes that can consume methane at NREL's Integrated Biorefinery Research Facility. NREL is working with partners to see if the microbes can eat the methane vented or flared off gas wells in the fracking process. *Photo by Dennis Schroeder, NREL 28673*

Energy Department's ARPA-E Provided Funding

Backed by a $4.8-million Advanced Research Projects Agency – Energy (ARPA-E) award from the Energy Department, the scientists are making progress. The goal of the project is to transform the current landscape of the energy and raw materials markets by producing a scalable, low-cost, low-temperature, and low-environmental-impact way of converting that wasted methane into a transportation fuel.

Historically, oil wells have typically been situated in locations where the natural gas could be captured and sold as a chemical feedstock or as a fuel for heating and electricity generation. The amount of natural gas that was flared or vented was not considered to be such a concern. However, as we become more aware of the impact of greenhouse gas emissions, and as fracking has led to huge increases in domestic oil production in areas too remote for effective and economical natural gas capture and transport, natural gas flaring has become a dilemma for the domestic energy industry.

At the same time, fracking in other areas specifically for natural gas has increased the volumes produced and lowered prices so much that there is even less incentive to capture it at an oil well. But by happy accident, the average well is about the right size to accommodate a fermentation and conversion facility to grow the methane-eating bacterium (known as a methanotroph) and to convert the natural gas into liquid fuels. The microorganisms can be grown in fermenters with the help of nutrients such as nitrogen, phosphorous, and salts. The same water that comes out of the ground with the oil or that is available from nearby seawater can be used to operate these fermenters.

Microbe Has Novel Qualities; Can Use Methane as a Carbon Source

The scientists chose a novel microbe, *Methylomicrobium buryatense* 5GB1, which is one of just a few bacteria that have a high natural potential for producing lipids (a good biological feedstock for hydrocarbon-based fuels) from any carbon source. Within that small subset, 5GB1 is a rare species that can use methane to produce lipids—the precursor to fuel.

Scientists from NREL, UW, and LanzaTech have already shown at laboratory scale that the unique microbe growing in a simple mineral medium supplemented with a salt and carbonate buffer can double in three hours—twice as fast as other methanotrophs. Even with the faster growth, the lipid content comes in at an impressive 17% to 22%.

NREL's first major challenge was to demonstrate that the process can be done safely. In NREL's Integrated Biorefinery Research Facility, microbes consume the methane fed carefully into a fermenter, under the watchful eye of NREL Scientist Qiang Fei. "It's all about safety," Fei said, demonstrating how controls can combine methane and air in a safe way. He worked on the process for months, and in December, the continuous-feed system passed a safe work permit protocol. That marks a big step on the road to getting commercial-scale fermenters to well sites.

UW researchers are focusing on genetically modifying the microbes to both increase the amount of membrane lipids and get the microorganism to produce non-phosphorous-based lipids that are more readily converted to fuels. At the same time, the United Kingdom-based Johnson Matthey team is working to convert the phospholipids into diesel fuel. Combining the super microbe with the best methane oxidation machinery at the fracking wells could result in a bumper harvest of lipids and create conditions that will yield even higher liquid fuel outputs.

New Zealand-based LanzaTech, a pioneer in waste-to-fuels technology, has signed on to take the bench-scale plan to the commercial level if it is successful.

NREL in Charge of Fermentation; Will Analyze Economic Potential

NREL is in charge of fermentation to demonstrate the productivity of the microbes in batch cultures of both the native organism and the genetically altered varieties. NREL will also extract the lipids from the organisms and analyze the economic potential of the plan. Pienkos and his colleagues at NREL have been establishing a safe operating system to ensure there won't be any incidents with the experimental plan.

"We developed a great relationship with NREL's Environment, Health, and Safety Office, with all participants committed to both safety and the success of the project. We spent six months taking baby steps to grow the culture, but we've turned the corner," Pienkos said. "We're about to see a huge spike in

> “We are working with new feedstocks and producing new target molecules. We are absolutely committed to making sure that all the safety pieces are in place before we get started.”
>
> — PHILIP PIENKOS, *Principal Manager of the Analytical Chemistry and Life Sciences Group of the National Bioenergy Center at NREL*

progress. This is also serving as a new model for the research we do in the National Bioenergy Center. We are working with new feedstocks and producing new target molecules. We are absolutely committed to making sure that all the safety pieces are in place before we get started.”

Challenges remain. Using microbes to convert methane depends on the mass transfer of gaseous oxygen and methane, neither of which are very soluble in water. In addition, the heat generated by the rapid growth must be removed.

But interest in the process is high. An Energy Department Bioenergy Technologies Office workshop in Chicago on turning natural gas into liquids drew a large crowd of important industry players. In addition, ARPA-E has recently awarded winners in its REMOTE (Reducing Emissions using Methanotrophic Organisms for Transportation Energy) solicitation to identify additional technologies to convert methane to fuels.

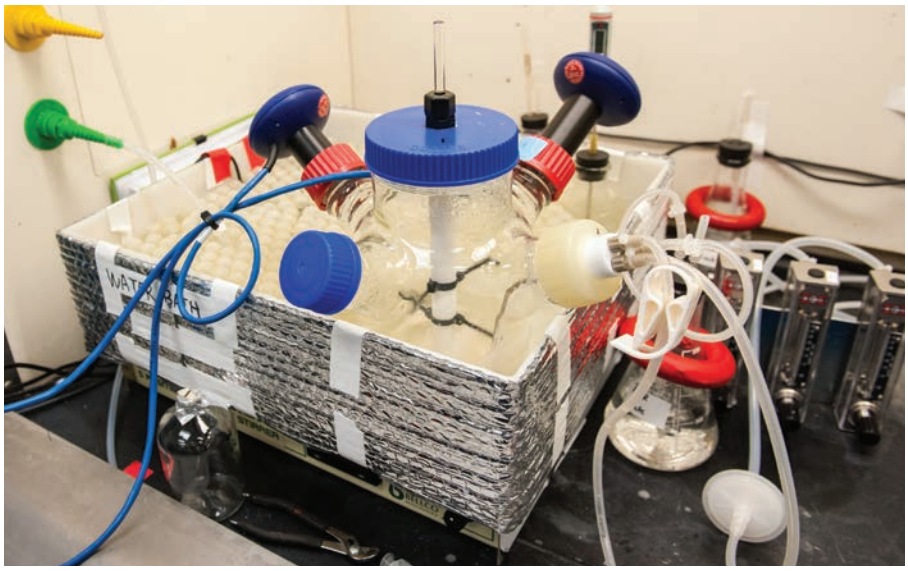
Potential to Disrupt the Transportation Fuel Paradigm

In its application to ARPA-E, the research team asserted that the process will simultaneously capture the energy lost by the stranded natural gas, provide a new source for liquid hydrocarbons, and mitigate greenhouse gas emissions—and the process will provide new jobs and new production capacity, while disrupting the current liquid fuel paradigm. That’s because the Bio-GTL diesel product can use the existing pipelines at extraction sites to travel to refiners where it will undergo processing. It could prove useful for petrochemicals, too.

One more potentially transformative benefit: the single-cell protein produced as a byproduct has been explored for more than 20 years as a source of nutrition for both humans and animals. Save trillions of tons of greenhouse gas; produce liquid diesel cheaply and safely; create a source of nutrition for livestock and people.

Not bad for an organism too small to see.

— Bill Scanlon (January 16, 2014)



This countertop experiment—which is feeding methane into a fermenter that contains microbes capable of consuming the methane—is a prototype of the fermenters that in the future may digest methane at many of the 600,000 fracking wells in the United States. *Photo by Dennis Schroeder, NREL 28668*

Reviving Algae from the (Almost) Dead

Tucked away in darkness and almost dead, algae can emerge from a frigid and foggy environment to live again—and perhaps even become the seeds for a new beginning that can provide biofuel for a clean energy future.

At the Energy Department's National Renewable Energy Laboratory (NREL), and at dozens of other labs nationwide, algae are like a junior high kid with great promise: slow to arise, but packed with energy for the long haul. It may take years, but eventually the great expectations can be reached.

A gallon of fuel made from algae currently costs about quadruple the cost of a gallon of conventional diesel. But looking long term, algae are an inexhaustible resource that if used as a substitute for fuels would slash the amount of carbon dioxide in the atmosphere—and costs are dropping.

Resurrecting Algae a Delicate Task

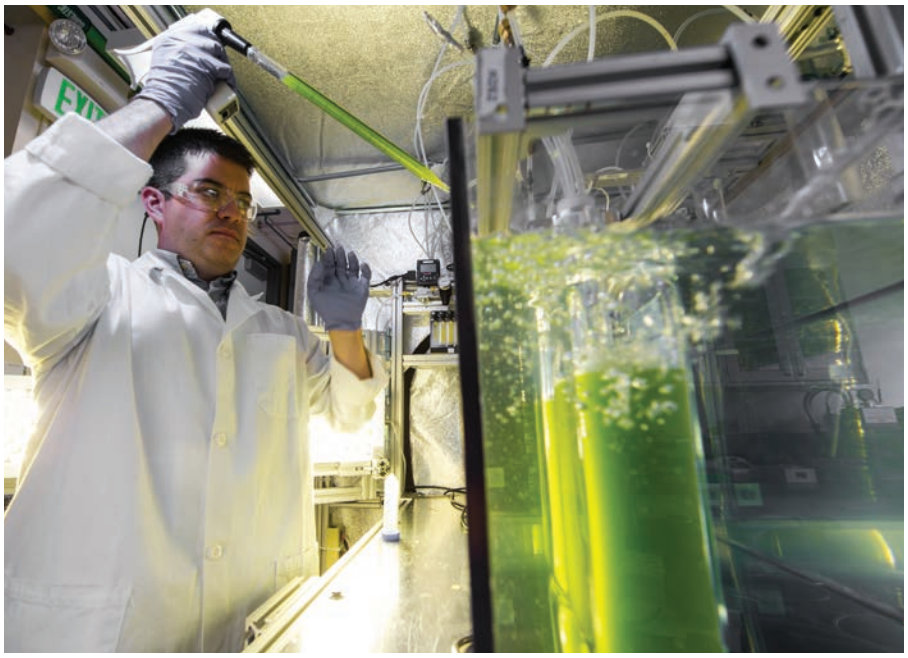
Unlike resurrecting zombies—or teens—awakening a dormant algae sample takes precision and care. At NREL, that task often falls to Research Technician Nick Sweeney.

"We do cryogenic resurrection of algae from our library of strains," Sweeney said. "We get calls from other labs, universities, private companies, or from our own researchers requesting a particular strain.

"It's not as simple as pulling something frozen out of the freezer; the protocol is to slowly bring it back to a state where its biology is going to start functioning normally."

"When we first started this, my boss used to tell people how hard it was to freeze algae," said Phil Pienkos, principal manager of the Bioprocess R&D group of the National Bioenergy Center at NREL. "I always corrected him: It's easy to freeze algae. The hard part is thawing them out without killing them."

The frozen algae samples are held in 2-milliliter vials in a 4-foot-high cryogenic tank, some frozen for as long as 5 years. A typical household freezer might operate at about -18°C, just a few degrees below freezing. By contrast, the cryogenic tank at NREL is set at -195°C. Liquid nitrogen provides the chill for the tank, which has a kind of 'Lazy Susan' inside to make it



NREL Research Technician Nick Sweeney inoculates algae being grown in a tent reactor. Algae brought back to active states from cryogenic tanks need aerobic environments to meet their full potential as biofuels. *Photo by Dennis Schroeder, NREL 25521*

easier to access the 500-plus strains. The algae stay alive, but dormant, despite the extreme cold thanks to a 5% solution of a cryogenic protectant solvent such as methanol. It's totally dark inside the tank.

Cells Are Like Coffee Grounds in the Deep Freeze

Sweeney looks up a strain's location—in the 15th position in the box on rack four, shelf five, for example—and opens the tank, releasing foggy vapors of liquid nitrogen. He carefully removes the vial.

The cells inside the vial are pelleted and look like coffee grounds. The first step is to separate the liquid from the solids, using a centrifuge to spin the pellets rapidly. When the water, salts, and cryogenic protectant solvents are removed, what remains are the green algae cells.

When reviving the cells, it is essential to keep them in the dark for the first several steps of the process. A paper towel around the vial can do the trick.

The aim is to slowly replicate the algae's natural environment, so a growth medium is introduced. Depending on where the strain came from, the growth medium could be brackish, salty, or mostly fresh water, or it could include numerous ingredients that replicate the natural water chemistry.

The samples are next put in a shaker to make sure the cells mix well with the growth medium. After the pellets are re-suspended in the growth medium, they're placed in a subdued lighting environment for 24 hours. They can be damaged if they're immediately hit with full light. Gradually, the light intensity is increased. The algae replicate on their own, and soon the population has doubled, quadrupled, and more.

NREL and Partners Exploiting Algae's Advantages

But why do we concern ourselves with freezing and thawing novel algal strains? Algae pose several advantages. They have much greater productivity—50 times greater—than their terrestrial cousins when measured by biofuel output per acre. Unlike corn and soybeans, they are a non-food resource. And they use otherwise nonproductive land, such as deserts, brackish lakes, and oceans. Plus, they often can be used in conjunction with wastewater treatment. Algae not only have the potential to produce the feedstock for transportation fuels, but in the future, algae offer an opportunity to recycle carbon dioxide from other sources of energy.

A unique bioreactor at NREL can reveal the intricate biochemical rearrangements that algae undergo when grown under different conditions, including the climatic differences found in locations throughout the United States. That capability is critical because it can pinpoint the ideal locations for farms to produce algae that could someday compete with renewable diesel, cellulosic ethanol, and other petroleum alternatives.

NREL researchers using this unique bioreactor also have shown that algae grown under the right conditions can produce not just lipids, but proteins and carbohydrates that can be turned into diesel, butanol, ethanol, and other fuels useful to industry. NREL has nearly doubled the fuel it can get out of the same amount of algae by using the additional components.

NREL's algae research has included collaborations with Cellana, Sapphire, and Algenol, as well as a partnership with Chevron Corp. to develop new technologies to accelerate the commercialization of algal biofuels. Most of NREL's funding in this area has come from the Energy Department's Bioenergy Technology Office, but the lab was recently awarded funding from the Office of Science for pathway engineering in algae.

A Happy Ending

The algae will live on after their prolonged near-death experience. They won't be used in some sort of mad scientist's scheme, but rather for the benign goal of evaluation for use as a biofuel production strain. And if algal cultivation for biofuel production can be successfully deployed, the result won't be world domination, but something a lot more positive—like reduced greenhouse gas production, energy security, and job creation.

— Bill Scanlon (October 31, 2014)

Unique Bioreactor Finds Algae's Sweet Spot

A unique bioreactor at the Energy Department's National Renewable Energy Laboratory (NREL) can help find the ideal locations for farms to produce algae that could someday compete with renewable diesel, cellulosic ethanol, and other petroleum alternatives as transportation fuel. It does so by revealing the intricate biochemical rearrangements that algae undergo when grown in different locations in the United States. The bioreactor has also demonstrated that algae grown in ideal climates and given the optimal amount of nutrients can produce not just lipids, but proteins and carbohydrates that can be turned into diesel, butanol, ethanol, and other fuels useful to industry.

"We've almost doubled the fuel we can get out of the same amount of biomass by using these additional components," said NREL Senior Scientist Lieve Laurens.

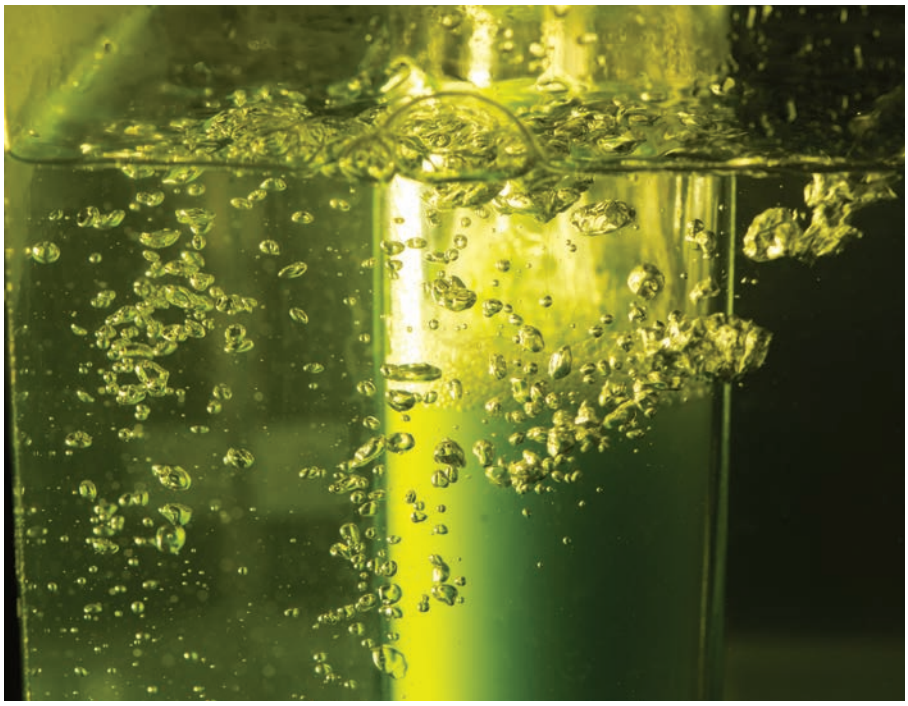
The Simulated Algal Growth Environment (SAGE) reactor resides in the Field Test Laboratory Building on NREL's campus in Golden, Colorado.

The reactor so precisely controls light, temperature, and delivery of carbon dioxide that it can mimic conditions anywhere. If scientists want to know how algae will grow in brackish water in the southwestern United States under mostly sunny skies, the dials can be set for that precise meteorology. NREL's bioreactor is unique because despite its large size and greatly increased capacity, it can replicate entire locations and climates—day, night, sunlight intensity, and temperature profiles. Light intensity is programmed, as is carbon dioxide delivery and uptake.

"We can model how a particular strain would grow in different locations around the United States, and how this impacts the oil productivity," as well as the general biochemical composition of the biomass, Laurens said.

"Feed and Starve" Approach Yields More Potential Fuel

Algae use the chlorophyll in their cells to turn sunlight into energy through photosynthesis. Add in nutrients and carbon dioxide, and the algae can produce sugars while rapidly reproducing.



Aeration helps algae grow and helps replicate real-life conditions in the Simulated Algal Growth Environment (SAGE) reactor at NREL. The reactor controls light and temperature, helping scientists determine not just what strain will grow the best, but where in the United States it may do so. Ideal strains can be harvested for their lipids, proteins, and sugars for use in biofuels. *Photo by Dennis Schroeder, NREL 25526*

Three "champion" strains of algae grow in the NREL reactor, which allows about five times the culture volume of other similar commercially available controlled-environment reactors. With its large size and ability to recreate real-world conditions, NREL's reactor allows researchers to grow dense cultures in far less time.

Optimal conditions—nutrients, carbon dioxide, and sunlight—lead to the extra energy capable of doubling the algae's productivity.

NREL has also come up with better and faster ways to analyze and characterize the components in the algae conversion process. "We harvest every other day," yielding maximum information about the changes in an algae population that can double in size twice a day, Laurens said.

Algal cells absorb the sunlight, which, together with carbon dioxide, grows the colony. For the strains being evaluated, the more humid air and warmer nights of Arizona look more conducive to optimal growth than the high desert climate and very cold nights of New Mexico. This makes sense because these strains have been cultivated extensively outdoors in Arizona. Algal strains adapted to New Mexico's climate may not grow as well in Arizona.

Laurens and NREL Bioconversion Engineer Nick Nagle can also trick the algae into doing more useful things than simply multiplying in number. For example, if they stint on the amount of nitrogen available, the algae go into storage mode, rather than multiplying mode. Some algae double in size a couple times a day when enough nutrients are available. When the nutrients run out, the algae stop growing so fast. But carbon dioxide and sunlight are still present, so in the interest of self-preservation, the algae store that carbon dioxide as high-energy organic molecules. It's a change that can be seen over the course of a few days.

"Once the algae run out of nitrogen, they turn into couch potatoes," Nagle said. "The cells start eating a lot of carbon and sitting around, putting on weight. That weight is literally in the form of carbohydrates and oils"—just what the biofuels industry needs from the little critters.

The "feed and starve" rotation is one useful pathway to getting more oils out of the algae.

> "Ultimately, it will come down to how many total gallons of biofuel we can make per acre of algal ponds per year. This is no different than our measure of corn productivity in terms of bushels per acre per year."
>
> — **LIEVE LAURENS,** *NREL Senior Scientist*

Industry Wants All Parts of the Algae Now

NREL is working with Arizona State University to examine how champion strains of algae convert sunlight into biomass, keep nutrients viable, and respond to light energy. Early on, the protein content is high; then carbohydrates have their day in the sun, followed later by lipids.

"From the feedstock, we get these different products—lipids, proteins, carbohydrates," Nagle said. A few years back, industry would approach research labs with a specific request—how to use algae to get diesel oil. Now, they want it all: protein to turn into butanol or methane; lipids to turn into diesel; carbohydrates to turn into a third fuel.

From 1978 to 1996, NREL embarked on a great search and cataloging of algae. "It's fun to think it's all coming back," said Nagle. "We're now working with industry partners and other universities, collaborating and really moving this forward."

NREL's contributions include using sunlight to drive growth, and using growing cells to convert solar energy to chemical energy by converting carbon dioxide to organic molecules, along with a comprehensive analysis of the different biomass components.

"We take these champion strains and put them into virtual environments, particular locations in the United States that lend themselves really well to algae cultivation," Laurens said. "We're working with partners in Florida, California, Arizona, Ohio, and Hawaii to quantify how the rain and temperature mix affect growth and composition of the biomass produced."

NREL is analyzing how to get the most out of the harvested biomass. A pretreatment with dilute acid yields fatty acids that can be used for diesel-like biofuels and carbohydrates that can be fermented to ethanol. That still leaves proteins that can be used for other kinds of fuel. Working with Sandia National Laboratories, NREL researchers are subjecting proteins from algae to a fermentation process to boost the production of short-chain alcohols such as butanol.

"We've been able to examine the fine variables and recommend the best tradeoffs in production of biomass, taking the biomass chemical composition into account. Like, 'this scenario won't yield as much biomass, but you would get much higher oil content,'" Laurens said. "Ultimately, it will come down to how many total gallons of biofuel we can make per acre of algal ponds per year. This is no different than our measure of corn productivity in terms of bushels per acre per year." Researchers ultimately place all the pieces together and advise on the process' economic viability through a techno-economic analysis.

In large-scale outdoor cultivation—for example, in large open ponds such as those in Columbus, New Mexico, or Phoenix, Arizona—a tweak here, an extra boost of nitrate there, more sunlight here, a little less nitrogen or a little higher temperature there, and a champion strain can produce oils and carbohydrates in a familiar setting. Wastewater facilities can be a prime setting for closing the loop—from the anaerobic digestion of the non-fuel components of the biomass, which generates the energy and the methane, to the nutrients that can be recycled to feed another generation of algae.

Industry Is Intrigued, and Wiser, About Algae

Nagle remembers the heady times in the 1980s when oil companies invested a lot of money in algae research. "It's like we put a message in a bottle and sent it out to sea," he said. "Now it's coming back, and that's pretty exciting."

After the first romance with algae, irrational exuberance ebbed, and oil companies became wiser and smarter, say Laurens and Nagle. These companies are investing dollars in algae research again, and funding from the Energy Department's Bioenergy Technologies Office has become more consistent.

Companies such as Exxon are looking for proof that algae can be important players in the biofuels landscape of the future. "They're investigating all the pathways," Laurens said.

Cost is falling steadily, and "you're not going to run out of algae" as production increases, Nagle said.

NREL will remain a key player, "a good neutral third party in the game, doing our own great research but also keeping our finger on the pulse of industry," Laurens said. "It allows us to gauge who is where. And we see that there's a lot going on, that they're starting to take this very seriously. We're seeing companies that are serious, that have significant plans for the commercialization of algae."

— Bill Scanlon (February 18, 2014)

A chlorella strain of algae grows in NREL's bioreactor. *Photo by Dennis Schroeder, NREL 25520*

BUILDINGS

NREL is a nationally recognized leader in buildings research, combining renewable energy with innovative technologies to significantly reduce energy consumption in buildings. *Photo by Dennis Schroeder, NREL 17825*

Campus Showcases High-Performance Buildings

Researchers at the Energy Department's National Renewable Energy Laboratory (NREL) are transforming the way the world uses energy—and those transformations become apparent the moment one sets foot on the NREL campus in Golden, Colorado. Here, research teams have applied their expertise to develop office and laboratory spaces that also serve as demonstrations for how high-performance, sustainable buildings and campuses should be designed, constructed, and operated.

The recent construction on the NREL campus was a significant undertaking, in which integrated project teams from a wide variety of disciplines—construction managers, sustainability professionals, and building research engineers, to name a few—focused on the design and construction of innovative facilities that would meet the needs of a growing laboratory while also meeting ambitious energy performance requirements.

"Energy has not been a foremost consideration on similar projects. They look at scope, schedule, and budget; then when the design is done, they determine how much power they need," said NREL Deputy Director for SITE Operations Drew Detamore, who led the campus development efforts.

"Here, we added energy to the decision-making process from the beginning. Every decision that was made along the way took into consideration the impacts it would have on the energy model for the building."

In order to ensure that energy performance goals could be met, NREL developed a unique performance-based design-build approach to partner with design, engineering, and construction industry leaders on the projects. The design-build approach incorporated rigorous project controls and methodologies to provide NREL with facilities that featured best-in-class energy efficiency and sustainability practices.

"The design-build approach with our project partners was critical to the process," Detamore said. "We came into it focused on what we wanted projects to do over what we wanted them to be, and the design-build approach allowed that line of thinking to work effectively. You have to place a priority on performance over design, and then you can do what we've done at NREL. You must have strong project-management people involved who understand the process and are willing to let go of the design. As a result, we have buildings that meet all of our performance goals, are well designed, and happen to be very attractive."

Showcasing the Right Way to Build Buildings

Developing a high-performance, sustainable campus at NREL to serve as a highly productive environment that would support the mission of the laboratory was important. NREL also wants its campus and buildings to serve as a model for how commercial buildings and campuses should be built and to be a tool to help show others how.

Aerial view of NREL's South Table Mountain campus with its six LEED Platinum buildings in view. NREL wants its campus and buildings to serve as a model for how the commercial buildings and campuses of the future should be built. *Photo by Dennis Schroeder, NREL 26954*

> “A project developer can take what we’ve done here and apply it in the marketplace. It performs as promised, is cost effective, maintainable, and marketable. These results combine to make energy-efficient buildings very approachable in any environment.”
>
> — **SHANTI PLESS**, *NREL Senior Energy Efficiency Research Engineer*

“Our goal is to provide leadership to both the public and private sectors to show that this can be done, it is being done, and here’s how you do it,” NREL Senior Energy Efficiency Research Engineer Shanti Pless said. “We’ve made these buildings as efficient as possible and have learned a lot along the way. We want to share those lessons learned and best practices with the buildings industry to facilitate the movement of this type of design and construction into the mainstream.”

All design and construction on the NREL campus used strategies and materials that are available to anyone. All products used are off-the-shelf and could be accessed for any building. Implementation of similar design-build techniques could be done on any project anywhere. The most important piece of the puzzle is to apply good technologies, along with a solid planning and design process, and integrate them effectively to work well together.

“These buildings are highly replicable,” Pless said. “A project developer can take what we’ve done here and apply it in the marketplace. It performs as promised, is cost effective, maintainable, and marketable. These results combine to make energy-efficient buildings very approachable in any environment.”

To facilitate the continued growth of energy-efficient and zero-energy building projects everywhere, NREL regularly hosts visits to its campus by project developers, architects, builders, and other commercial building industry professionals. These visits give NREL an opportunity to show firsthand what these buildings can do, how they perform, and how they can be replicated.

“When we show this to people they can quickly begin to visualize how they can replicate it, and by doing that we are having a meaningful impact on the commercial buildings industry,” Pless said. “Proving it can be done is an important step. It is one thing to say you can do it, another entirely to prove it and demonstrate it. Here at NREL we’ve done just that.”

A Living Laboratory

The campus also provides NREL research staff with opportunities to validate their research in a real-world environment with occupied, operational buildings in an effort to quantify and maximize building performance.

Researchers in NREL’s Commercial Buildings research program have installed meters in all new buildings and are collecting a massive amount of performance data. They are now developing tools that can put this data into action to the benefit of building developers and operators everywhere.

“We are trying to align building decision makers with the data that we are collecting,” Pless said. “By creating useful tools to help them take advantage of building data, we are providing them with the critical information that they need to make good decisions that will further enhance building performance and occupant comfort.”

NREL has developed a new tool called the “NREL Energy Story” that serves the dual purpose of telling the story of NREL’s sustainable campus to the public as well as serving as a management tool that allows NREL engineers to analyze campus energy performance in real time and identify problems quickly.

“We’ve essentially created an energy management tool for our campus with an education component layered into it,” said NREL Strategic Energy Analysis Center Principal Project Lead Mark Ruth. “It allows us to improve our story at the same time we are telling our story. It’s a one-of-a-kind tool that provides great benefit both internally and externally.”

The tool is a real-time visualization of energy production and consumption on the NREL campus. It includes modules for electricity, heating and cooling, and fuels. It provides a big-picture view of the entire campus, as well as detailed analysis

of specific areas such as lighting or plug loads within a section of a building. For the public, it compares NREL's campus energy use to that of a typical campus that lacks the type of high-performance buildings found at NREL. It also includes a series of infographics that can show users what the potential impacts and cost savings of energy efficiency applications could be for the nation, or for a home.

"This tool helps the public understand the impact of their energy choices, which will hopefully guide their decision making in the future to use energy more wisely," Ruth said. "We strive to be a 'living laboratory' here at NREL, and this tool helps to bring this to life in a way that everyone can understand. It clearly demonstrates how the lab improves its own energy use and the potential benefits others can realize if they to implement these strategies in their homes or communities."

> "Everyone looks to NREL to be a leader on these issues now and in the future. We have a responsibility within our basic mission to set the best possible example and to be a model for what a campus could be and should be."
>
> — **FRANK RUKAVINA,** *NREL Sustainability Program Director*

NREL Leads with Six LEED Platinum Buildings

Recently, at a dedication ceremony held on the NREL campus, the U.S. Green Building Council (USGBC) recognized NREL's efforts with Leadership in Energy & Environmental Design (LEED®) Platinum certification for three of its newest campus facilities, including the recently opened Energy Systems Integration Facility (ESIF).

The USGBC's LEED program is a green building certification that recognizes best-in-class building strategies and practices. Building projects must satisfy prerequisites and earn points to achieve different levels of certification. A Platinum certification is the highest level in the program.

In addition to the ESIF, the USGBC also recognized NREL's new Café and South Site Entrance Building for achieving Platinum status. With these new certifications, NREL can now lay claim to six LEED Platinum certified buildings on its Golden campus, including the award-winning Research Support Facility, which was recently verified to have performed for a full year as a net-zero energy building.

"We are extremely proud of the campus we have designed and built here at NREL and the recognition that we have received for our efforts," said NREL Deputy Director and Chief Operating Officer Ken Powers. "This campus will provide our world-class research staff with the resources and facilities they need to support our clean energy mission, as well as serve as an example of how these technologies and strategies can be effectively applied."

Sustainability as a Core Value

NREL is a recognized leader in sustainability, with practices that are incorporated into the mission and fully integrated into all facets of the operation of the laboratory. When planning the design of the NREL campus, it went without saying that sustainability would be a key consideration.

Sustainability professionals were part of all integrated project teams throughout the process, and efforts to make the NREL campus as sustainable as possible guided every decision. The use of sustainable building products, technologies, and practices helped to garner the points necessary to achieve the LEED Platinum certification for all new buildings.

"We underwent a lot of growth in a short period of time, and all of the people involved in making that happen adopted the mission and value system of the laboratory in regards to sustainability throughout the process and never lost focus on it," NREL Sustainability Program Director Frank Rukavina said. "It makes our job, as sustainability professionals, a lot easier when everyone involved understands the priority and is on board from the beginning to make these building projects as sustainable as possible."

Examples of sustainability practices incorporated into the new buildings are numerous. For the newly Platinum certified buildings, these include comprehensive recycling and composting programs, native and xeriscape vegetation,

> “We have a population here at NREL that takes energy efficiency and sustainability personally and seriously. This drives us to continued excellence and challenges us to always be as sustainable as we possibly can.”
>
> — **FRANK RUKAVINA,** *NREL Sustainability Program Director*

locally sourced food for the new cafeteria, water conservation efforts for the commercial kitchen in the new cafeteria, storm water recycling strategies, and building materials made of recycled materials.

“Everyone looks to NREL to be a leader on these issues now and in the future. We have a responsibility within our basic mission to set the best possible example and to be a model for what a campus could be and should be,” Rukavina said. “We’ve excelled because we’ve committed to it and we’ve created a campus that showcases our mission and our values as an organization. We have a population here at NREL that takes energy efficiency and sustainability personally and seriously. This drives us to continued excellence and challenges us to always be as sustainable as we possibly can.”

Beyond LEED — The Net-Zero Energy Research Support Facility

As NREL celebrates the certification of three new LEED Platinum buildings, bringing the total number of Platinum certified buildings on its campus to six, another important milestone on NREL’s sustainable campus was also achieved: NREL’s RSF recently completed a verified one year of performance as a net-zero energy building.

A net-zero energy building is one that, over the course of a full year, produces more energy than it consumes.

The RSF, a LEED Platinum certified 360,000-square-foot Class A office building that houses approximately 1,300 NREL and Energy Department staff as well as a data center, accomplished this through a combination of energy efficiency technologies used in the building, effective operations and management of the building, and onsite electricity generation from a 2.6-megawatt solar photovoltaic (PV) system on the roof of the building and adjacent parking areas.

“We made a commitment to design and build a building that could reach net zero in operations,” NREL Senior Energy Efficiency Research Engineer Shanti Pless said. “The design-build team delivered to us a well-designed, well-engineered, and well-constructed building that was able to support that goal. With the addition of the PV system we felt that we could successfully offset all of our annual energy use. Through active energy management and real-time benchmarking tools, we’re very proud that we were able to achieve this important milestone.”

Like the rest of the NREL campus, the RSF was designed and built with the intention of being a model for how building projects can incorporate energy efficiency strategies and technologies, and in the case of the RSF how projects can be made to be net-zero energy ready. The NREL researchers involved in the project made it accessible to anyone by compiling and documenting their experiences in energy performance-based commercial building acquisition and the adoption of energy-saving building technologies.

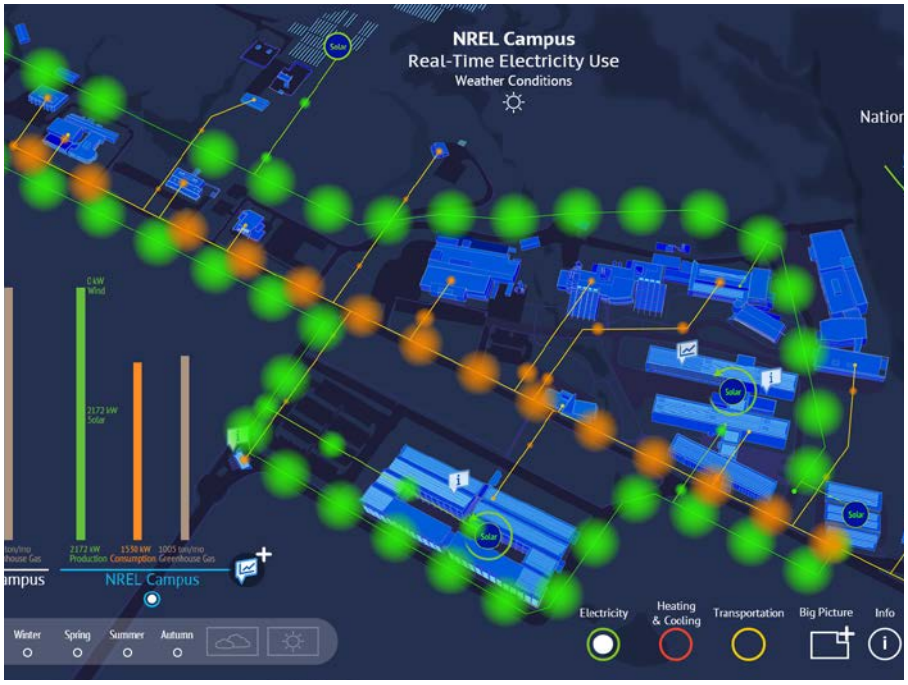
“There’s a growing interest in net-zero energy buildings now that it is getting more cost effective and the industry is beginning to understand it better,” Pless said. “The cost of PV and energy-efficient building materials like LED lighting have come down dramatically in the last few years, and that has made the idea of building for net zero much more approachable. As a result, there is an expanding level of expertise and capability out there for delivering buildings for net-zero energy operations. This is still cutting edge, but it is scaling up and heading toward the mainstream.”

NREL is a consistent leader in bringing high-performance, energy-efficient building projects to life on its campus. In 2006 NREL laid claim to having the only LEED Platinum federal building with its Science & Technology Facility. Today, LEED Platinum federal buildings are becoming commonplace,

including six on the NREL campus alone. Now, NREL again demonstrates its leadership by being the home of the very first federal building verified to achieve net-zero energy performance. However, unlike a green building certification that happens once, net-zero energy is something that is ongoing and must be achieved annually.

"One of the great things about net-zero energy is that it's an operations target, not a design target, that requires ongoing management to reach from year to year," said Pless. "This keeps our building managers, engineers, and occupants constantly thinking about how we use energy and seeking ways to improve our performance. We'll need to keep doing that to assure that the building meets net-zero energy operational goals year after year. We look forward to that opportunity."

— David Glickson (June 9, 2014)



NREL campus electricity activity can be viewed using the "NREL Energy Story" tool, a real-time visualization of the energy production and consumption on the NREL campus. The green dots represent energy production and the orange dots represent energy consumption. It allows for big-picture analysis of the entire NREL campus as well as detailed analysis for specific areas such as lighting or plug load within a section of a building. *Image courtesy of Marjorie Schott, NREL*

NREL Hosts Race to Zero-Energy Homes

The campus of the Energy Department's National Renewable Energy Laboratory (NREL) sprang to life on a late April weekend as 28 teams of university students and building industry experts converged at the lab for the Challenge Home Student Design Competition.

During the inaugural competition, funded by the Energy Department's Building Technologies Office, teams of students presented their zero-energy-ready home design and construction plans to juries of national experts including the leading high-performance builders in the industry, building science professionals, and researchers.

"Buildings are critically important when it comes to reducing U.S. energy use, as they represent more than 70% of our electricity consumption and about 40% of our carbon emissions," said NREL Center Director for Buildings and Thermal Systems Chuck Kutscher. "How we build in the future will determine how successful we are at addressing climate change. NREL is very pleased to host and support this design competition because it is a way for students to learn the techniques and strategies that will be necessary to make sure that the buildings of the future get designed and built properly."

Preparing the Sustainable Building Leaders of the Future

The Challenge Home Student Design Competition aims to inspire the next generation of architects, engineers, and construction managers to be able to design and construct zero-energy-ready homes that are affordable and market ready. Each team included students and their faculty advisors. Teams were encouraged to be multidisciplinary in makeup and to work as closely as possible with industry professionals to help inform their decision-making process.

On the Energy.gov blog, Chief Architect for the Building Technologies Office Sam Rashkin noted: "Each year, thousands of college and university students major in construction-related fields, including architecture, engineering, and construction management. These students enter into a competitive workforce that is increasingly demanding advanced knowledge and skills essential to delivering high-performance homes and buildings.

"The Challenge Home Student Design Competition will provide students with the skills and experience to start careers in clean energy and make them leaders in the movement to create truly sustainable homes."

Anya Barmina with the Utah Lab House team from the University of Utah School of Architecture carries her team's model to the next round of judging. *Photo by Dennis Schroeder, NREL 29904*

> "The Challenge Home Student Design Competition will provide students with the skills and experience to start careers in clean energy and make them leaders in the movement to create truly sustainable homes."
>
> — **SAM RASHKIN**, *Chief Architect for the Energy Department's Building Technologies Office*

Student teams were asked to develop cost-effective designs that mainstream homebuilders can start using and homebuyers can start buying today.

"As an engineer in this field, I only wish that there had been a program like this available to me when I was a student," said NREL Residential Buildings Research and Outreach Coordinator Cheryn Metzger. "The team concept has them working on a project, with different disciplines collaborating just as they will in the real world, all while working closely with experienced industry partners to help guide them through the process. The experience and knowledge gained by these students through their participation is priceless."

And the Winners Are

The team design presentations were followed by intense deliberation by the jurors. The industry experts judging the competition then presented two Grand Awards to the best overall designs.

The first award was given to the Montage Builders Northern Forest team. Montage Builders was a collaborative effort of students from three Syracuse, New York, area schools: Onondaga Community College, SUNY College of Environmental Science, and Syracuse University.

The Montage team developed an adaptable and accessible craftsman-style single-family detached home that embodied responsible development. The team demonstrated leadership in the sustainable redevelopment of a community in Syracuse by presenting an affordable design based on the median family household income for the area.

"We had an amazing experience participating in this competition," said team member Michelle Tinner, a graduate student in Sustainable Construction Management at SUNY College of Environmental Science. "It was a unique collaboration, building a team with diverse backgrounds from three different schools. But it was that diversity of experience and perspective that was the key to our success."

The Urban Harvest team from Ryerson University in Toronto, Ontario, was presented with the second Grand Award. The team developed a high-performance single-family attached townhome design that would fit well in any urban environment. The team addressed every aspect of the design requirements and integrated all systems artfully and effectively.

The Urban Harvest design was also recently selected to be a part of the Denver Super-Efficient Housing Challenge, and boasts a 90% reduction in annual energy consumption compared to an average Colorado residence. The design—along with homes by four other Challenge Home Student Design Competition teams—is slated to be constructed at the Denver Sustainability Park in Denver's Curtis Park neighborhood in late 2014.

"The opportunity to do this design in a real-world environment, on a building that is likely to actually be built, was an invaluable experience for us," said team member Antonio Cunha, a graduate student in Ryerson's Department of Architectural Science. "In academia, most projects stay in the conceptual realm and never progress beyond a poster or a model. This process required us to apply what we have learned in the classroom with a much more realistic approach where we had to consider the same challenges and implications that we will use throughout our careers."

In addition to the two Grand Awards, the judges presented 12 subject area awards as well as technical awards recognizing teams for best design solution, best technical integration, best production home adaptation, and best presentation.

More Than Just a Competition

A critical goal of the Challenge Home Student Design Competition is to facilitate the creation of a strong future workforce that can support the development of, and demand for, zero-energy-ready homes. To that end, students were provided with an opportunity to hear from industry thought leaders who presented their visions for the future of sustainable housing along with a series of technical presentations critical to advancing the students' knowledge of high-performance home design, engineering, and construction.

"This is the future of our industry," said Gene Myers, CEO of New Town Builders, a Denver-based builder of energy-efficient homes who served as a juror for the competition and also presented to the students. "It is important that we make this effort to develop a qualified workforce for the building industry. We need to nurture students who choose to engage in this topic, support the institutions that have made that possible, and encourage others to follow suit. A program such as this one is a great step in that direction."

The full attention and engaged participation of the students throughout the program indicated that their thirst for more knowledge continued even after having completed their designs and presentations.

"We may end up knowing more than our future employers do about green building design as a result of going through this process and the information we are receiving," said participant Martha Merzig, a graduate student in Integrated Design and Construction at Auburn University. "It's an exciting thing to be equipped with that knowledge at such an early stage in our careers, and I have high hopes for what we are going to be able to do with it going forward into the future."

NREL Provided a Perfect Setting

The student teams had the opportunity to present their concepts for zero-energy-ready homes inside the award-winning LEED Platinum and net-zero-energy Research Support Facility on NREL's sustainable campus. And they were supported by the world-class staff from NREL's buildings research teams who have dedicated their careers to energy-efficient and zero-energy buildings. This synergy provided an ideal backdrop for the competition, one that provided inspiration and motivation to the students and staff alike.

"Our campus is a showcase for the right way to build buildings, and there's no other place where we could have held this competition and have the students be as engaged as they have been here," said Metzger. "They've gotten to see this type of design in action, and their interest is piqued even further by that opportunity. They are truly excited to have the chance to be here."

While developing and preparing their designs, the student teams regularly used research published by the laboratory as well as NREL-developed tools. This connection further demonstrated the synergistic relationship between the work of the students in this competition and the buildings research being done at NREL.

"We've got huge energy challenges in front of us, and it is a great opportunity to be able to engage directly with the next generation who will be tasked with helping us to innovate the future solutions to those challenges," said NREL Senior Engineer for Residential Buildings Dane Christensen. "Hosting this event gave us the chance to show off the work that we are doing here, work that we are very proud of, and it also gave us an opportunity to hear from the students and see the very talented work that they are doing. It was very exciting to be able to witness their passion, dedication, and skill firsthand."

— David Glickson (May 12, 2014)

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COMMUNITY OUTREACH

NREL's involvement with the local community provides opportunities to learn about renewable energy, energy efficiency, and sustainability practices.

Photo by Dennis Schroeder, NREL 30215

2014 Science Bowl Adds New Rivals, New Friends

Winter paid a visit to this year's Colorado Science Bowl. As competitors battled snowy roads to get to the yearly contest, a new force came down from the north—12 northern Colorado high schools. The northern Colorado teams were formidable as they battled through the morning sessions, answering rapid-fire questions covering topics from physics to math to earth and space science. Six northern Colorado teams made it to the final 16. In the end, the Denver metro area teams held fast, with students from Boulder's Fairview High School beating out 47 other teams to claim victory.

This was the 24th Colorado Science Bowl hosted by the Energy Department's Golden Service Center and National Renewable Energy Laboratory (NREL). Second place went to Douglas County High School, and northern Colorado's Poudre High School rounded out the top finishers to take home the third-place trophy.

This competition marked the first year that northern Colorado teams from cities such as Fort Collins, Greeley, and Loveland competed against teams from Denver and southern Colorado. In the past, the Energy Department's Western Area Power Administration (WAPA) hosted a competition for the northern Colorado schools; this year, the Energy Department decided to organize one statewide competition.

"The Energy Department's goal is to try to get a regional science bowl competition in every state. With that goal in mind, Colorado consolidated to one high school science bowl, and WAPA added a statewide middle school science bowl," said NREL's Education Program Manager Linda Lung. "NREL is very excited about the middle school competition; it will be a nice addition and pipeline program for the high school event."

It's Off to D.C.

Fairview High School will represent Colorado at the Energy Department's National Science Bowl on April 24–28 in Washington, D.C., where the team will compete against more than 400 students from 70 high schools for the national title.

"We practiced two days a week, but the real secret to winning is Frappuccinos," shared Michael Chen, team captain for Fairview. Chen said the team will continue its regular practice schedule in preparation for D.C., where he said they expect harder questions, so they will hit the books—and, of course, drink more frappes.

Boulder's Fairview High School beat 47 other teams to win the 2014 Colorado Science Bowl. The Fairview team will represent Colorado at the Energy Department's National Science Bowl on April 24–28 in Washington, D.C. From left: Logan Garbarini, Chad Healy (coach), Michael Chen, Tammy Hearty (coach), Logan Collins, Siyang Sun, and Albert Soh. *Photo by Dennis Schroeder, NREL 29254*

DOE began the Science Bowl in 1991 as a way to encourage high school students to explore math and science. Each year, approximately 15,000 students from across the country compete for a chance to go to Washington, D.C., for the national finals.

"Fairview High School will be facing stiff competition at the National Science Bowl," Lung said. "Some of the competing teams eat, drink, and sleep Science Bowl, and are in it to win. But I don't have any concerns about our team. The National Science Bowl provides a great venue and recognition to students who excel in science and math. These students are amazing."

Despite facing what is sure to be tough competition, Fairview Team Member Logan Garbarini keeps it all in perspective: "We just enjoy learning. Last year we had a lunch table and talked scientific stuff. You just have to have fun with it and not focus too much on the competition, but more on learning."

Adults Love to Volunteer, Too

Learning is precisely what keeps parent Sylvia Artz involved with the Smoky Hill High School team, even after her own sons have graduated from college. "I love math and science, but I became a volunteer because I love these kids."

Artz hosts training sessions at her home, where she helps read test questions. She focuses on mentoring girls.

"The first year I was here, I looked around the whole auditorium and there were maybe five girls, and I thought, 'There is something wrong with this picture.' That's when I decided to start mentoring girls and tell them it's okay to be smart in math and science," Artz said.

In addition to helping girls become engaged in math and science, competing in Science Bowl also has a classroom benefit, according to Smoky Hill High School coach Mary Bartholomew.

"It inspires the kid to take on that extra challenge," Bartholomew said. "Our youngest team member is an engineering and computing kind of guy, but he's also in AP Biology right now, and he said to me, 'There's been a lot of biology questions; I didn't think that would pay off. Maybe I'll like biology a little bit better.' Science Bowl helps them understand that a breadth of knowledge is a good thing, too."

It's that kind of pull toward math and science that the Energy Department and national labs such as NREL hope to see pay off with more students pursuing the sciences through college and into their careers.

"Globally, innovation will drive the world's economy, and this takes more scientists and engineers. The demand is high and growing," NREL Deputy Director for Science and Technology Dana Christensen said. "Events such as the Science Bowl provide opportunities for students to discover just how fun science, math, and engineering can be—and will hopefully lead them into careers, such as those at NREL, where they might be asked to judge a future Science Bowl."

Shawn Ong, team captain for second-place finishers Douglas County High School, agrees. "It is really important to be studying sciences and new technology areas. By having these events and competing in the math and science fields, it helps prepare the next generation for the future."

— Heather Lammers (March 10, 2014)

Model Car Races Put Creativity on the Line

Emotions ran the gamut at the recent middle-school solar and lithium-ion car races hosted by the Energy Department's National Renewable Energy Laboratory (NREL). Nervous tension was heightened as the sun played an ornery game of peekaboo with the threatening rain clouds. The students' anxiety then gave way to grins of excitement—or grimaces of dismay—as their solar and lithium-ion battery cars raced (or crept) to the finish line.

"It was so stressful for me," Cullen Gillum of Lincoln Academy said. "If I don't catch the car at the finish line, it smashes—but I do have the magic touch."

This was the 24th year of the Junior Solar Sprint and Lithium-Ion Battery car competitions for Colorado's middle schoolers. Nearly 300 students on 74 teams from 21 Colorado schools were at Dakota Ridge High School in Littleton, Colorado, to vie for a spot in the final races. The middle schoolers raced solar and lithium-ion battery powered vehicles they designed and built themselves.

Each year, the Energy Department, NREL, and other local sponsors host the races to show middle-school students that science, engineering, and design can be rewarding—and to encourage them toward careers in STEM: science, technology, engineering, and math.

Linda Lung, NREL's Education Programs Coordinator, notes that teams often start competing in the sixth grade, and by the time the students are in the eighth grade they have learned the engineering principles to design and build a fast clean-energy model car.

"The car competition challenges students to use scientific know-how, creative thinking, experimentation, and teamwork to design and build high-performance model solar and lithium-ion battery vehicles," Lung said.

The batteries used in the lithium-ion competition are supplied by the Energy Department, and teams in the solar competition purchase authorized solar panels. Then, they design and build the rest of their cars themselves. Solar and lithium-ion battery power are highlighted at the competition because they are important research focuses for NREL and the Energy Department.

"This is a great learning experience coupled with a challenging engineering task," NREL's Associate Laboratory Director for Innovation, Partnering, and Outreach Bill Farris said. "The clean-energy future will need the attention of the next generation of scientists and engineers. This competition helps them get engaged in the energy challenges that lie ahead."

Students make last-minute adjustments to their vehicles as they compete in NREL's 24th Solar and Lithium-Ion Battery car competitions held at Dakota Ridge High School in Littleton, Colorado. *Photo by Dennis Schroeder, NREL 30153*

> “The car competitions are a great venue for these students to get recognized for their academic accomplishments. These students are the next generation of engineers and scientists who will find new technological energy and transportation solutions.”
>
> — **LINDA LUNG,** *NREL’s Education Programs Coordinator*

Small School, Big Win

The sun’s rays were in limited supply for the Junior Solar Sprint, forcing race judges to watch the rain clouds move on through and then be ready to start the moment the sun reappeared. But the students took it all in stride, focusing instead on the design of their cars.

“We went for lightweight and aerodynamic,” Matthew Heitmann with the “Green Team” from Calhan Middle School said. Calhan is a smaller school from the eastern plains of Colorado, and its team’s excitement was contagious when their car covered the track in a zippy 5.17 seconds for the first-place win.

While speed is important, the judges also recognize good design, and in the solar car competition the first-place design award went to Woodlands Academy and their car “Ring Ding the Fox.”

For some teams, getting the design right meant starting from scratch.

“We started building, and it was really fun, but we did mess up the first time,” Claire Stufflebeam of Ken Caryl Middle School said. “We had to start over, but it was a really good learning experience.”

“We copied our design from a dragster, but we measured it out and made it even so there was no tilt to the solar panels,” The Manning School’s Diana Santos said. “We learned about the solar panel and how it has silicon that helps collect the sun rays, and when the sun shines on the panel, the motor can use the energy.”

Even the fastest car on the track gave its team some headaches. “We destroyed one of our motors, so we learned to be more careful,” Heitmann said. “And to make sure your wheels are on tight—ours came off twice.”

First-Time Team Brings Fastest Battery Car

While clouds blocking the sun raised the level of tension for the solar racers, it didn’t matter to the students racing lithium-ion battery cars. What mattered most to the students from William Roberts E-8 School was getting a good feel for the competition.

“We’re here as part of our enrichment program to offer neat activities outside of the classroom,” said Assistant Principal Grant Varveris. “This is our first competition—we didn’t really know what to expect.”

Jon Havens, the eighth-grade science teacher for William Roberts, added: “We want to focus on engineering; it’s part of the Common Core and science standards. Plus, kids love competition. It’s engaging, and they are having a great time out here.”

Whatever the formula, the students from William Roberts had an impressive first showing. Their dinosaur-looking car “The Dinos” came in with a winning time of 5.58 seconds.

“Our framing was very precise,” team member Omar Sene said. “We also have foam on the car to protect it if the salt moves so it won’t break the car. We have rubber bands on the wheels for traction. And, we also learned how to wire.” Each lithium-ion battery powered car is required to carry an added payload of salt. This provides the students an extra engineering challenge.

But it was actually The Manning School and its car “Manning Battery 2” that took home the trophy for winning lithium-ion battery car design.

“The car competitions are a great venue for these students to get recognized for their academic accomplishments,” Lund said. “These students are the next generation of engineers and scientists who will find new technological energy and transportation solutions.”

The annual competition is sponsored by NREL, the Energy Department’s Office of Science, the Alliance for Sustainable Energy, Jefferson County Schools, Dakota Ridge High School, and the Energy Department’s Golden Service Center. Phil Long Ford of Denver, Whole Foods Market, Sam’s Club, and Mahnke Auto Body supported the event by providing lunches and trophies for the winning teams.

— Heather Lammers (May 30, 2014)

NREL Energizes Outreach at Education Center

Are you a student considering future opportunities in science and engineering—or a teacher seeking new and interesting ways to supplement the energy education in your science classroom? Perhaps you are a community organization looking to learn more about how emerging energy technologies can be beneficial on a local or global scale—or a small business or property owner wanting to better understand how these technologies might be applied to benefit your building or business in a very direct way?

If you fit into any of these categories—or if you have any other interest in renewable energy and energy efficiency technology—the Energy Department's National Renewable Energy Laboratory (NREL) is ready to help.

Guided by the belief that preparing future generations of scientists and engineers, along with nurturing an informed public to make empowered energy choices, are critical objectives as we move toward a clean energy future, NREL has upgraded its public education and outreach capabilities through an extensive rebranding and reprogramming effort at its Education Center.

Located just outside the main gate of NREL's sustainable campus in Golden, Colorado, the Education Center has repositioned itself using targeted programming to best serve the shifting needs around energy education for students and consumers alike.

"Our goal was to make NREL and our R&D innovations more accessible to the public and to create an experience that is appealing to a broad range of audiences," said NREL Community Affairs Manager Janice Rooney, who led the effort on the Education Center rebranding. "We're creating a more in-depth experience for visitors with the goal of encouraging students to be impassioned toward future study in science and technology disciplines, while at the same time providing the general public with the knowledge that they need to better apply these technologies in their homes and communities."

Educating the Scientists and Engineers of Tomorrow

Engaging students in renewable energy and energy efficiency topics opens doors for study and career opportunities in science, technology, engineering, and mathematics (STEM) disciplines. These backgrounds are critical in advancing workforce development objectives to assure that NREL and the nation have the sustained pipeline of highly trained STEM workers necessary to get us to a clean and sustainable energy future.

Fifth- and sixth-grade science students from Pioneer Charter School work on a wind turbine experiment during a field trip to NREL's Education Center to learn about renewable energy. *Photo by Dennis Schroeder, NREL 29156*

> “People can come here, either as part of a group or on their own, and learn about NREL, how we provide value, and how they can benefit from renewable energy and energy efficiency technologies. We’re reaching more people this way.”
>
> — **JANICE ROONEY,** *NREL Community Affairs Manager*

Energy education in schools is evolving rapidly. NREL, with its topical expertise and its revamped student programs at the Education Center, is in a unique position to supplement these efforts and provide a valuable experience for both students and educators.

Programs are aligned to Colorado’s core academic science standards in an effort to complement and support what is happening in local science classrooms. The result is new programming that brings a structured and focused approach to energy education and is calibrated to educators’ needs.

“We’ve made a significant effort to understand what teachers want and need from us when they visit, and we’ve incorporated that into our programs,” said NREL Education Programs Specialist Marcus Giron, who developed the new school programs at the Education Center. “We’ve developed content and activities that are customized to the age and experience of the classes, and we’ve made the programs much more hands-on and interactive in an effort to make learning about energy more fun and interesting for the students.”

Starting with ‘Watts Up with Electricity,’ a program for fourth- and fifth-graders that covers more basic concepts around electricity and includes hands-on activities with hand-crank generators as well as solar and wind power experiments, the programs advance to meet the needs of older students, exploring more complex renewable energy and energy efficiency concepts for middle-school students as well as the global impact of technologies and career opportunities for high-school classes.

Since October, the Education Center has hosted more than 30 classes and provided energy education opportunities to more than 1,100 students. The updated programs have been a hit with both the students and their teachers, many of whom will be returning year after year with their classes.

“We’re currently studying energy resources in our classroom, and I thought it would be beneficial for my students to hear directly from the experts at NREL,” said Pioneer Charter School Science Teacher Andrea Seymour. “This field trip was very beneficial for my students. The highlight was the opportunity for them to be actively engaged collecting data in hands-on activities.”

Energy Education Isn’t Just for Kids

In addition to offering exciting new opportunities for students, NREL’s Education Center continues to serve the needs of adult groups and the general public through a broad range of activities. Expanded offerings include a variety of programs designed to address renewable energy and energy efficiency innovations for both technical and non-technical interest, which introduce NREL and its work to a wide array of audiences and provide the public with opportunities for personalized interaction utilizing the Education Center’s experienced team of volunteers.

“We now have a variety of avenues for people to access NREL and our expertise,” Rooney said. “People can come here, either as part of a group or on their own, and learn about NREL, how we provide value, and how they can benefit from renewable energy and energy efficiency technologies. We’re reaching more people this way.”

One highlight is an ongoing ‘Power Lunch’ lecture series. Topics vary and appeal to both technically minded people looking for a deeper insight into NREL’s research as well as concerned consumers seeking ways to implement renewable energy and energy efficiency technologies into their homes and communities. During the summer months, this programming is supplemented by an after-hours lecture series that focuses on consumer-oriented approaches to common energy topics in addition to providing an introduction to NREL and its research.

Additionally, adult or youth community groups can make reservations in advance for on-demand group programs led by the Education Center's expert volunteer staff.

The community can also benefit from the new Education Center by taking advantage of the facility's updated exhibits and expert volunteers. Volunteers introduce each visitor to NREL, then provide direct, hands-on assistance to address topics of interest to the guest. A new walking tour for adults offers the public an up-close look at NREL's sustainable campus design.

"We are providing a facilitated introduction to NREL and renewable energy technologies to our visitors. This information is being delivered in an updated format to assure that we can always stay on top of current innovations for the public when they visit us," said NREL Public Affairs Specialist Sarah Barba, who manages the operations and programming at the Education Center. "We want to make sure that we are effectively communicating what NREL is doing, why it is important to them, and how these technologies are readily available to them and can improve their lives and their communities. This personalized and engaged approach is effective for getting these messages across in an impactful way."

Engaged Staff, Volunteers, and Exhibits Connect NREL to the Community

The programming and information delivered at NREL's Education Center would not be possible without a dedicated team of experts with a passion for getting the word out about renewable energy and energy efficiency. That team takes shape in the form of volunteers, along with significant contributions from NREL research staff to support the development of interactive exhibits.

"In addition to revamping our facility and our programs, we've been rethinking how we use our volunteer resources to maximize their value to our content and to our visitors," said Barba. "We align our volunteer responsibilities to their skill sets and interest areas. This creates more interesting and interactive opportunities for them, and they seem to find the experience rewarding."

An exhibit called the 'NREL Energy Story' allows visitors to get a virtual tour of the NREL campus and better understand how the lab generates and use energy. Developed by NREL researchers, the exhibit is part of a larger energy use analysis of NREL's campus, which is designed to innovate and develop cleaner and more efficient ways of harnessing and using energy. This allows the NREL campus to serve as a proving ground for these technologies—and the exhibit demonstrates how the strategies and lessons learned could be applied successfully elsewhere.

"It shows what we are doing here on our campus," said Barba. "But what we're really demonstrating, and what is really important to visitors, is what they can do at home, what their communities can do, and what the world can do as a whole."

Another new exhibit allows visitors an opportunity to see what life is like inside one of NREL's research laboratories and get to know the research community a bit better. 'Meet the Scientist' takes visitors behind the scenes, via video, into three distinct and different research laboratory environments where they get a chance to learn more about the scientists and their work, with a focus on the researchers' backgrounds and passion for science. Hoping to inspire the next generation of scientists toward STEM studies and careers, the NREL researchers take this responsibility seriously and enthusiastically support these types of efforts.

"What I am most proud of is all of the young scientists I have mentored over the years who are now making an impact themselves," said NREL Research Fellow David Ginley of the 'Meet the Scientist'. "Don't lose sight of the fact that science is a lot of fun. It's a chance to explore the world, learn more about it, and then do things differently and create things that are completely new that can make a difference in the lives of people all over the world."

A Model for Energy-Efficient Design

In addition to housing innovative new programs and exhibits to share the NREL story and information about renewable energy and energy efficiency, the Education Center building itself utilizes a variety of energy efficiency strategies that demonstrate the application of these technologies.

A 'Trombe Wall' is the building's most striking feature. The wall lights and heats a large portion of the facility using passive solar and daylighting technologies. A special insulation system improves the building's energy performance. A direct evaporative cooling system provides most of the cooling needs for the building in the summer. A computerized energy

management system monitors conditions and occupancy to determine the most efficient methods for meeting the energy needs of the building and also monitors the building's performance for future refinements.

These building features, along with the sustainable features of NREL's campus, serve as a testimonial to what is possible with renewable energy and energy efficiency technologies. This, combined with the new programming and exhibits that have been implemented inside the building to make education and information accessible to all audiences, truly makes the NREL Education Center a showcase for the public understanding of NREL's research and the application of clean energy technology in communities large and small.

"I'm really proud of what we've done at the Education Center," said Rooney. "We are showing off a broad range of innovations and technologies along with dramatically improving how we explain NREL's work and how these technologies can benefit our future. We've made a meaningful upgrade in the program offerings available for educators by aligning our efforts with NREL's education and outreach mission. The Center's transformation is a big win for everyone here at NREL, as well as for the public, who rely on us as an invaluable resource."

— David Glickson (March 4, 2014)

> "The Center's transformation is a big win for everyone here at NREL, as well as for the public, who rely on us as an invaluable resource."
>
> **— JANICE ROONEY,** *NREL Community Affairs Manager*

Children taking part in an educational field trip walk past an interactive display at NREL's Education Center. *Photo by Dennis Schroeder, NREL 29201*

NREL Interns Look Toward the Future

They come from diverse backgrounds and have varied plans for the future, but all have unique interests in renewable energy and energy efficiency—and a drive to leave the planet better than they found it. These common traits bring students from across the country to Colorado and the Energy Department's National Renewable Energy Laboratory (NREL) for internships in clean energy research.

"I'm really interested in solar energy and pursuing materials that can work with that," NREL intern Rekha Schnepf said. "Working here exposes me to a totally different research side from what I do at Carnegie Mellon University. It's just giving me more knowledge on what I can do in the solar cell field and how I can take my degree in different directions."

This summer, 44 interns arrived at NREL as part of the Energy Department's Science Undergraduate Laboratory Internship (SULI) program. These interns intend to pursue careers in science, technology, engineering, and math (STEM), and came to NREL with plans to research topics from genetic engineering to technologies for hydrokinetic turbines. The SULI program provides students opportunities to conduct research on a variety of projects at the Energy Department's cutting-edge facilities under the guidance of veteran scientists and researchers. Through this experience, interns and mentors alike gain invaluable knowledge and practice.

Schnepf is working toward a bachelor's degree in materials science and engineering. In her research at Carnegie Mellon, she works with transparent conductors; at NREL, she looked at a particular process used to cut silicon wafers for solar cells.

"The interns bring a fresh perspective and energy into the lab, and their research accomplishments are amazing for the short amount of time that they are here," NREL Education Programs Manager Linda Lung said. "The SULI experience changes academic and career goals for a lot of interns, and then some become advocates for renewable energy and energy efficiency."

Spencer Lindeman, a recent graduate of Brigham Young University with a bachelor's degree in biochemistry, came to NREL to work on biofuel conversion. Using the process of flash pyrolysis, Lindeman and colleagues can heat up materials like grass, grains, and wood chips in the absence of oxygen with the goal of creating fuel.

"We're still not close to where we need to be to make this an economically viable process," Lindeman said. "Once we actually understand what is happening on the molecular level, then we will be able to make significant leaps."

Intern Rekha Schnepf images the surface of a silicon wafer sample on an optical profilometer at the NREL's Science and Technology Facility. She was one of the 44 summer interns studying at NREL as part of the Science Undergraduate Laboratory Internship (SULI) program.
Photo by Dennis Schroeder, NREL 30687

Renewable energy has been, and will continue to be, a consistent theme throughout Lindeman's research. After he leaves NREL, Lindeman will take a year to work and apply for graduate programs to continue his studies in biochemistry.

For intern Emily Gasteyer, arriving in Colorado meant living out her dream. "I've been here for vacation a few times, and every time, I told my mom, 'One day I'm going to live in Colorado, and it's going to be great.' So I'm fulfilling my dream by living here, at least for the summer," she said.

Born and raised in the Midwest, Gasteyer studied chemical engineering at the University of Wisconsin in Madison. Along with her love of Colorado, her desire to make a difference led her to NREL.

"I think it's really important to work in a place where you're doing something good, something that will help future generations," Gasteyer said. "To me, that's the most important thing I'm doing here—working to allow future generations to live not only as well as we're currently living, but even better."

In her effort to leave the world better than she found it, Gasteyer is working with thermochemical conversion at NREL. This is the process of rapidly heating biomass to turn it into an oil that can potentially be used in to fuel vehicles. "That's the hope—to eventually replace at least some of our petroleum-derived fuels with fuels that are derived from biomass."

Like Gasteyer, intern Brandon Pereyra also understands the underlying implications of his work at NREL. Pereyra comes from Long Island, New York, and is a junior at Binghamton University working toward his bachelor's degree in mechanical engineering. His work at NREL's National Wind Technology Center near Boulder involves developing a model for a hydrokinetic turbine that can capture the energy of river currents.

"We need to start really investing and preparing for the future by developing these renewable technologies," said Pereyra. "We want to think of the future and where energy will come from in 100 years or so. We're not going to have the ability to just extract fossil fuels out of the ground, because they'll be depleted."

SULI Mentors Offer Guidance, Give Back

The SULI program is a chance for students to advance their academic and professional careers—and for their mentors, it is a chance to share their expertise and give back.

Todd Deutsch began at NREL as an intern researching photoelectrochemical water splitting and returned to become a senior scientist working in the same area. When the opportunity came to be a SULI mentor, he was happy to accept.

"It's been, for me at least, a life-changing experience that really provided me focus and showed me what I had to do to get to the next level," Deutsch said. "When I had my first internship it was like an epiphany for me, and I realized this is what I wanted to do with my life and career. I think it's a great program to expose young, enthusiastic, intelligent, and motivated interns to what a career in renewable energy looks like."

One thing Deutsch recommends for students looking to get into renewable energy is to get as much education as possible, saying: "You can never have too much education."

Deutsch isn't the only SULI mentor who is using this opportunity to give back. Michael Lawson, a research engineer at NREL, found his internship experiences as an undergrad so valuable that he's now helping others with similar goals.

"It's rewarding to work with the interns. You get to see them progress over the course of 10 weeks, typically pretty quickly," Lawson said. "It's really a valuable experience, and I think that when you bring in undergraduates who are fresh out of their classes, they bring a unique perspective on things."

As a SULI mentor, Lawson not only teaches the interns, but continues to learn in the process. "Just the act of having to describe something from a very basic perspective actually gives me a better understanding of what's going on and helps put the problem in better perspective for me," he said. "It's kind of like the saying, 'You don't really understand anything until you teach it.'"

— Shelby Wieman (September 19, 2014)

NREL Looks for Star Science Students

Barbara Hughes grew up and attended high school less than 20 miles from the Energy Department's National Renewable Energy Laboratory (NREL) and earned her doctorate at the nearby University of Colorado (CU) in Boulder—so it may not be too surprising that she has gravitated to the lab.

She's currently in NREL's Research Participant Program (RPP) pursuing battery research—her second stint at the lab. The RPP offers opportunities for undergraduates, graduate students, and postdoctoral researchers to work at the lab under the mentorship of experts in solar and wind energy, biofuels, building technologies, and other fields.

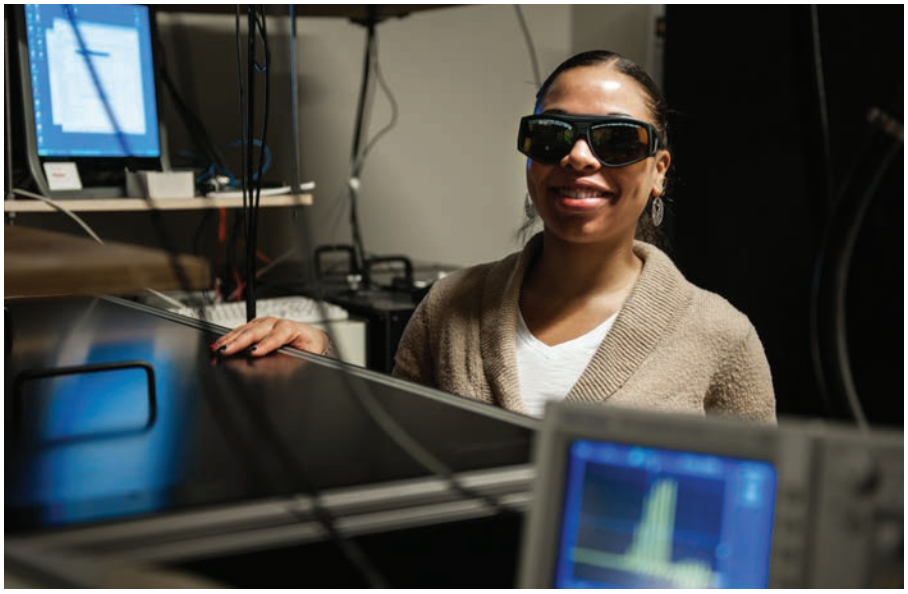
Earlier, while at CU, Hughes worked part time with renowned NREL scientist Art Nozik on quantum dots and an innovative approach to boosting the efficiency of photovoltaic solar cells. Realizing that the more she learned across disciplines, the more marketable she would be in her field, Hughes applied last year for a highly competitive RPP postdoc position that gave her the opportunity to join a lithium-ion battery project. She's investigating fundamental charge transfer in electrode materials and her postdoctoral research is supported by the U.S. Department of Energy, Office of Science, Basic Energy Sciences, Materials Sciences and Engineering Division.

"So far, the RPP program has provided an invaluable opportunity to work in a new research area beyond the scope of my graduate work," Hughes said. "NREL is a very friendly place," she added, "but when I was working with quantum dots, I didn't venture much out of that area. Now that I'm in batteries, I'm bridging the two fields, helping bring together scientists who otherwise wouldn't work together."

"People are very open if you come to them with ideas. The staff scientists here are so open to teaching you something new."

And those sorts of experiences are repeated again and again. From the lab's viewpoint, the RPP is a chance to bring in young scientists and engineers who:

- Show promise and are eager to learn
- Emerge from a competitive application process ready to contribute to an important project
- Can potentially propose a research project that intrigues NREL scientists or engineers.



NREL postdoctoral researcher Barbara Hughes works on time-resolved photoluminescence spectroscopy in the Laser Lab at NREL's Solar Energy Research Facility as part of the Research Participant Program. *Photo by Dennis Schroeder, NREL 29039*

"NREL recruits the brightest minds from university campuses through a competitive process," said Talent Management and Acquisition Manager Kim Gutierrez. "These students and recent graduates are able to work on cutting-edge research projects that will impact the world. They work hard for the opportunity to collaborate with world-renowned researchers at a national lab."

From the viewpoint of a young scientist or engineer, the RPP offers chances to:

- Work with world-class experts on ground breaking research that may yield patentable results
- Engage in innovative Energy Department initiatives
- Display their brainpower—and just as importantly, their collegiality and willingness to work as part of a team
- Work across disciplines, leveraging their skills in one area to become an important player in a bigger project
- Gain an edge for a job in industry or academia with access to more than 200 industry partners
- Potentially publish their work in peer-reviewed journals.

"The postdocs and interns may find career paths within NREL or build a career at other national laboratories, industry, or academia, carrying with them the advantage of having gained national lab experience," RPP and University Relations Coordinator Danelle Hutton said.

Internships are open to undergraduate and graduate students who are enrolled full-time in a U.S. college or university, have successfully completed at least the freshman year of school by May of the application year, and also plan to continue full-time enrollment the following fall term.

For postdoctoral researchers looking to participate in the laboratory's research and development programs, launch new areas of research, and even establish a base for ongoing collaborations, NREL's RPP can be an ideal fit. And both interns and postdocs can look for opportunities across the range of the lab's research centers, which include:

- National Bioenergy Center, a leading hub for biochemical engineering, microbiology, molecular biology, chemistry, and chemical engineering related to biomass and derived products
- National Center for Photovoltaic Research, recognized as a world leader in photovoltaic research, drawing upon physics, chemistry, materials science, and electrical and chemical engineering skills
- National Wind Technology Center, a primary global anchor for aerospace, mechanical and electrical engineering, and meteorology advancement
- Strategic Energy Analysis, which provides groundbreaking insights focused on technology, market, policy, and sustainability.

> "People are very open if you come to them with ideas. The staff scientists here are so open to teaching you something new."
>
> — **BARBARA HUGHES,** *NREL Postdoctoral Researcher*

Talent Shines at the Lab

NREL seeks to attract the best and brightest for the various RPP programs. RPPs are often students with great potential right from NREL's backyard. Robert Sebag was just a sophomore at Colorado School of Mines when he started working 18 to 20 hours a week at NREL.

It doesn't give him much free time, but he's having too much fun to notice. He has been using mass spectrometry to track changes in oil molecular composition when pretreating algae under very specific conditions to see if there can be a quicker and more efficient way to extract oil from algae when making biofuels.

"It's been great. Everyone is very cheerful and helpful and on board to help you out," Sebag said. "Over time, you learn so much on the job—operating advanced equipment, creating and optimizing lab procedures, how to properly work in a professional environment, the dos and don'ts of lab work."

"So many techniques and lessons I have learned at NREL can be applied to a wide range of careers I intend on pursuing as a

> "Over time, you learn so much on the job—operating advanced equipment, creating and optimizing lab procedures, how to properly work in a professional environment, the dos and don'ts of lab work."
>
> — **ROBERT SEBAG,** *NREL Postdoctoral Researcher*

chemical engineer. Everyone at NREL is on board with helping advance my career. I consider myself very fortunate to be working with such talented individuals while gaining valuable experience in the professional world."

Hughes has also had an enriching experience. "I don't feel like I have one mentor. I feel like I have six. The cross-disciplinary conversations you can have with experts are just fantastic. What I've learned here—it has been just amazing."

Working Together

Chad Hotimsky spent the summer of 2013 as a Science Undergraduate Laboratory Intern at NREL's National Wind Technology Center, where he impressed quite a few research engineers.

"Chad did a great job for us last summer, so when we needed someone to get into the details of one of our projects, we thought of him," NREL Research Engineer Yi-Hsiang Yu said. Yu, fellow research engineer Michael Lawson, and NREL Research Fellow Robert Thresher are triple-teaming Hotimsky's research—and Hotimsky appreciates the time from his mentors.

"Anytime I need anything, I can get my questions answered," said Hotimsky, who is working on marine hydrokinetics. "If I ever don't have enough to do, I can go to them and get more work. I'm learning things to further my own career." Hotimsky hopes to find a job in industry next summer, partly because he wants to see how it compares to working in a national laboratory. "But I really love it here. This is definitely an option for a career."

Hotimsky is a senior at CU, where he is a resident advisor and in charge of his dormitory's sustainability program. His enthusiasm for renewable energy combined with his love of big structures—wind turbines, ski lifts, the bigger the better—led him to apply for an RPP undergraduate internship.

A Continuing Tradition

NREL's RPP programs continue to allow experienced scientists to reach out to the next generation. NREL Senior Scientist Lieve Laurens, who herself was an RPP postdoc and is now making NREL her career, has mentored interns for several years and is now mentoring Sebag. "We're transferring knowledge to the students. They get that experience. But we get a lot in return."

Yu and Lawson remember when they were postdocs, counting on mentors to show them the ropes. "Mostly, I look at attitude" when deciding which candidates to bring into the RPP program, Yu said. "How do you approach a problem? Do you like to take on a challenge? Once they're here, I tell them to try to learn as much as possible when they're young. See what you like, and enjoy it."

Brainpower is important, but it's not the only requisite trait, said researcher Michael Lawson. "I don't think anyone wants a genius who is difficult to work with and has trouble communicating," he said. Instead, the lab seeks to bring in talented, well-rounded candidates who add to NREL's world-class standing. It's a win-win for both sides.

"The RPP gives us a lot of advantages, but it benefits recipients, too," Lawson said. "Even if they don't stay on, they've spent a year or two at a national lab. When they go on to industry or a university, they have that national lab perspective that benefits them."

— Bill Scanlon and Ernie Tucker (April 21, 2014)

Postdoctoral Fellows Bring Fresh Insights

A fresh pair of eyes can see things differently, which is one reason the Director's Postdoctoral Fellowships at the Energy Department's National Renewable Energy Laboratory (NREL) are already making an impact at the laboratory. Ph.D. graduates from across the country have come to NREL for mentorship and learning—and have enriched the lab in doing so.

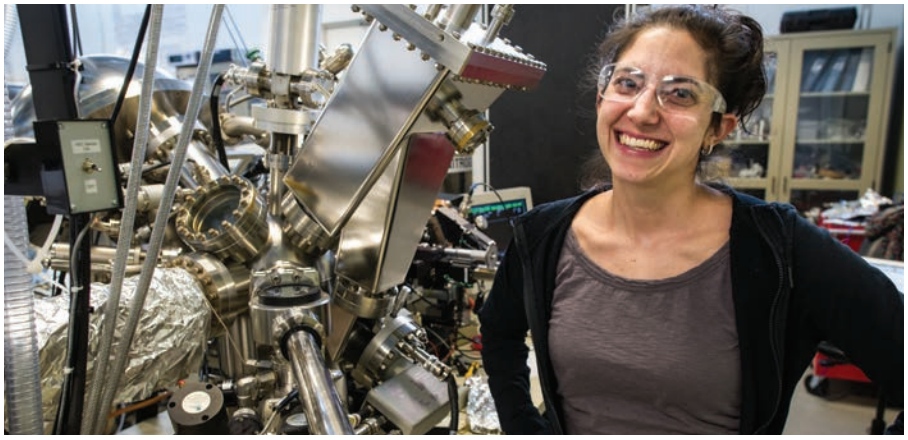
Elisa Miller, who began as an NREL Director's Postdoctoral Fellow in February 2013, brought her gas-phase photoelectron spectroscopy skills to condensed-phase spectroscopy experiments already in progress at the lab. Because of her basic research training, she asks different questions about how experiments impact solar cells, helping to refine the procedures and move the project forward. "So far, I've been lucky enough to contribute to two projects," Miller said.

Such moments are expected to multiply as the other NREL Director's Postdoctoral Fellowship awardees Brandon Knott, Xerxes Steirer, and Wei Xiong—along with the most recent honorees Eric Jankowski, Luis Reyes, and Giulia Gallo—continue to make contributions alongside Miller. Each year, NREL plans to award two new Director's Fellowships, supported by Laboratory Directed Research & Development (LDRD) program funding.

The NREL Director's Fellowships, one of NREL's Research Participant Programs (RPPs), are two-year awards—with a possible third year—designed to attract the next generation of exceptionally qualified scientists and engineers with outstanding talent and credentials in renewable energy research and related disciplines. Candidates must be recent Ph.D. graduates and demonstrate a promising career of leadership and research. "The program was created 3 years ago to compete with other national lab postdoctoral fellowships," Beverly Maestas of NREL's Human Resources Office said. The number of applicants continues to rise each year.

Brandon Knott was the pioneer of the program, joining in October 2012, shortly after earning his doctoral degree in chemical engineering from the University of California (UC) Santa Barbara. "NREL was on my radar," Knott said. His UC advisor was familiar with research at NREL's National Bioenergy Center, so Knott applied and was selected as the first NREL Director's Fellow. "I got in the door before the bar was raised," Knott joked. But in truth, his interest in biomass research was a natural fit, and he immediately jumped in to help expand research, coordinating with both his mentor, Gregg Beckham, and NREL researcher Michael Crowley. "My background allowed me to bring a new perspective on a number of projects."

Much of Knott's work involves molecular simulations, and he's tapped NREL's supercomputing capabilities in the Energy Systems Integration Facility (ESIF) to further his explorations. "We utilize advanced molecular simulation techniques to reveal the detailed molecular mechanism of cellulose breakdown by the enzyme," he said, explaining that the enzyme constitutes the cornerstone of modern industrial enzyme cocktails for biofuels processes.



NREL Director's Postdoctoral Fellow Elisa Miller works with a photo electron spectrometer in the surface analysis lab at NREL's Solar Energy Research Facility.
Photo by Dennis Schroeder, NREL 29022

And he's accomplishing what he set out to do as an NREL Director's Fellow. In December 2013, Knott, Beckham, Crowley, and other researchers published "The Mechanism of Cellulose Hydrolysis by a Two-Step, Retaining Cellobiohydrolase Elucidated by Structural and Transition Path Sampling Studies" in the Journal of the American Chemical Society. He's also given a presentation to the biomass staff, earning praise from his peers.

The bar, it seems, is already high.

Connecting through the Director's Fellowship

Xerxes Steirer first connected with the lab by collaborating with NREL while earning his Ph.D. in applied physics at Colorado School of Mines. Later, when he was a postdoc at the University of Arizona, he made a call to NREL's Craig Perkins, asking if Perkins would mentor him in his bid for an NREL Director's Fellowship—a key step in the process. Perkins agreed, and together, they found a winning path for his talent.

As Steirer can attest, the selection process was competitive. Successful applicants in the Director's Fellowship program must create proposals that spark interest in the NREL scientists who would work with the postdocs. Steirer's idea for working on junctions for earth-abundant materials in solar cells proved enticing enough for him to land one of the coveted fellowships.

Bringing to the lab his skills in spectroscopy, Steirer has expanded NREL's capabilities, according to Perkins, by "enhancing the measurement capabilities by addition of lock-in electronics that allow direct measurements of differential current." Perkins noted that Steirer obtained the first conduction band measurement of a cadmium-doped copper zinc tin selenide surface as part of semiconductor research, and that this result and others have allowed Steirer to be coauthor on two manuscripts in preparation. For his part, Steirer is pleased to be at the lab. "There's a great support group," he said. "Scientists' doors are open, and you can talk to anyone. I can contact a dozen scientists within 20 feet."

"Working in the surface analysis group at NREL has been amazing—the tools and the expertise of the people have brought my game up," said Steirer, whose goal is to someday manage his own research group. "I feel much more empowered, much more rounded. I have a much broader understanding of solar cells." Of the lab, he said: "There is a genuine curiosity here to solve scientific problems. They'll ask me, 'What are you trying to test? How can you define the problem you're trying to solve in one sentence?' Those kinds of interactions have really helped me get at the answers."

The Newest Director's Fellowship Awardees

The latest Director's Fellowship awardees arrived on campus this spring. Jankowski earned a Ph.D. in chemical engineering from the University of Michigan and then worked as a postdoc at the University of Colorado Boulder, where he applied some of his theoretical research into the self-assembly of polymers in organic solar cells. "I had a lot of overlap with people at NREL while I was there," he said, and when he heard about the Director's Fellowship, applying made sense. In his first round of outreach emails, however, Jankowski found all those he queried were already guiding candidates. "The good thing was being able to talk to people and see the projects they worked on." Eventually, he found his mentor, Dana Olson, in the Chemical and Materials Science Center.

"It is a really natural area for me to collaborate in because the work I'm doing allows me to look at the large-scale structure of molecules and ask questions about the experiments," His research fits in exactly with ongoing experiments and simulations in progress at NREL. Jankowski's only disappointment so far: losing out to super-cyclist Stuart Black in a competition for the longest commute to the lab. "I heard he altered his route to go longer," he said, laughing.

Gallo, who grew up in Genoa, Italy, was working in her native country when confirmation came that she was accepted to work in the Power Systems Engineering Center under mentors Bri-Mathias Hodge and Michael Milligan. "It was overwhelming," she said. "I had to leave my job and go outside." She called her family with the good news—her dream of returning to the United States was a reality. A year ago, she was working at Argonne National Laboratory for three months as a Ph.D. student. "My friends there were all thrilled."

She arrived in April to begin computational work on the future of electricity markets with growing renewable energy penetration. Her research aims at providing NREL with a software framework able to model new wholesale electricity markets, show what to expect in these market platforms, and provide policy guidelines for future integrated energy systems.

"Sometimes I cannot believe it," Gallo said—but she's adjusting. All she needs now is a good Neapolitan-style pizza in Denver, she joked.

For Reyes, the idea of leaving his hometown of Bucaramanga, Colombia, for the United States was never a thought growing up. After all, why leave a place known as the "most beautiful city in Colombia?" But after arriving at Texas A&M University 7 years ago in an exchange program with universities in Colombia, his thoughts changed. After he earned his Ph.D. in chemical engineering, his advisor alerted him to NREL's Director's Fellowship program.

His proposal—to expose microorganisms to "survival of the fittest" for biomass utilization and biofuels production—found a supporter in Katherine Chou of the lab's Biosciences Center. "It's pretty amazing to be accepted here," Reyes said of his time since at NREL arriving in March. "The research projects are top-notch, the people are nice—and my mentor has lots of patience."

Mentors Share the Enthusiasm

If so, Reyes's mentor is impressed as well. "The Director's Fellowship is a great channel to recruit talents to NREL from around the world, and it has been a joy for me to exchange, merge, and create ideas with Luis for scientific advancements," Chou said.

As with other RPP programs at NREL, the experienced scientists play key roles, helping to guide the postdocs' visions. The results can be impressive. Jianping Yu said of his mentee, Wei Xiong, that "Wei is among the most productive researchers I have worked with. He brought to NREL expertise in the measurement of carbon and energy flow in living organisms." He added that Xiong, who earned his Ph.D. in biology in 2010 from Tsing-Hua University in Beijing, "enables us to see the bigger picture of metabolism happening in our biofuel-producing microbes, analogous to real-time traffic reports we see on TV."

Yu explained that within half a year, Xiong developed NREL's capability to quantitatively analyze carbon metabolism by simultaneous measurement of dozens of metabolities. According to Yu, this accomplishment places NREL at the forefront of metabolic engineering of photosynthetic organisms, and the team is on track to publish high-impact papers during Xiong's fellowship.

Reaching Out as a Community

The gathering of postdocs across the lab is creating its own momentum. For example, the Director's Postdoctoral Fellowship awardees, who meet regularly with the support of NREL's Human Resources Office, decided to reach out to the general postdoc community at NREL. "We want to build a sense of community based on what postdocs go through," said Steirer. "It also involves helping each other." To that end, they've organized a number of gatherings, ranging from a presentation by a senior staffer about his postdoc experiences to an after-hours gathering with some of the 60 or so lab postdocs. Steirer sees all the postdocs at NREL reaching new levels of bonding, with a number of them already actively participating in group networking to expand their connections.

> "There is a genuine curiosity here to solve scientific problems. They'll ask me, 'What are you trying to test? How can you define the problem you're trying to solve in one sentence?' Those kinds of interactions have really helped me get at the answers."
>
> — **XERXES STEIRER,** *NREL Director's Postdoctoral Fellow*

The future looks bright for Director's Fellowship recipients as the next generation of scientific superstars shines at NREL, helping expand the laboratory's reach. Even as the newest awardees are getting established, they are looking ahead. And for those who have been on campus for a while, their goals are becoming clearer.

Miller plans to write papers on her own research, probably later this year. "I am going to contribute to the field," she said, and hopes that her work in basic energy science will lead to improvements in renewable energy technologies. Knott, too, is looking forward to achievement at the lab. "There's years of work ahead I could be part of," he said. "This [fellowship award] has been a huge blessing to me. Gregg and Mike have set me up for success."

Across the lab, the Director's Fellowship Program is repeating that successful result over and over, helping launch the next generation of science superstars.

— Ernie Tucker (August 1, 2014)

PEREGRINE
hp
Congratulations NREL!
Eric Monitz

COMPUTATIONAL SCIENCE

NREL is home to the largest high performance computing system in the world dedicated to advancing renewable energy and energy efficiency technologies.

Photo by Dennis Schroeder, NREL 31716

HP Supercomputer at NREL Garners Top Honor

A supercomputer created by Hewlett-Packard (HP) and the Energy Department's National Renewable Energy Laboratory (NREL) that uses warm water to cool its servers, and then re-uses that water to heat its building, has been honored as one of the top technological innovations of the year by R&D Magazine.

Supercomputers are hot—literally and figuratively.

The behemoths that can crunch a quadrillion calculations each second are needed to simulate and model everything from weather patterns to high finance to the movement of nanoparticles and celestial objects—and to analyze big data almost everywhere. All of these calculations heat things up. A typical supercomputing data center has rack after rack of servers, and each of those servers burns hot inside if not for a cooling mechanism—usually forced air driven by fans, which requires significant electricity.

When NREL outgrew its old data center and was drawing up plans for its Energy Systems Integration Facility (ESIF), ideas for a new data center were met with thoughts on how to live up to NREL's mission of being a living laboratory for energy efficiency and sustainability.

"Computers generate significant quantities of waste heat that is typically just thrown away," said Steve Hammond, director of the Computational Science Center at NREL. "Our vision was to build a showcase facility, to integrate the computer and data center with the building and do it with a holistic view toward energy efficiency.

"We spent a lot of time talking with people in the computer industry, telling them where we were headed," Hammond added. "'If we want to do this, you might want to consider the following…,' that type of thing."

NREL's Desire to Go Green Fit with HP's Plans for Liquid-Cooled Supercomputers

As planners were drafting specifications for the ESIF building, "some people from HP came to us saying they had an idea about how to cool supercomputers efficiently with liquid cooling," Hammond said.

Peregrine, the state-of-the-art liquid-cooled supercomputer at NREL, provides sufficient heat to meet the needs of the 182,500-square-foot ESIF, and combined with an energy-efficient data center is saving NREL about $1 million a year in energy costs. In all, the ESIF consumes 74% less energy than the national average for office buildings. *Photo by Dennis Schroeder, NREL 31716*

HP Distinguished Technologist Nic Dube picks up the timeline from there.

"At the same time that NREL was ramping up the effort to build a new facility that would be a world leader in energy efficiency, we at HP had been working on a project called Apollo—a liquid-cooled supercomputer platform," Dube said. "Availability was initially targeted for a year later than Steve's timeline, but we decided to accelerate the program to meet NREL's goals."

The NREL data center would be an ideal showcase for the technology HP was proposing. Key to NREL's mission is to be a model for energy efficiency, and HP wanted to demonstrate that there could be a broad market for liquid-cooled high performance computers. "We went very aggressively after the bid," Dube said.

The result is the high performance computer called Peregrine at the ESIF. Peregrine is the first installation of the HP Apollo 8000 platform, which uses more than 31,000 Intel Xeon processors providing a total capacity of 1.19 petaflops.

Peregrine provides sufficient heat to meet the needs of the 182,500-square-foot ESIF, and combined with an energy-efficient data center is saving NREL about $1 million a year in energy costs. In all, the ESIF consumes 74% less energy than the national average for office buildings. It has been designated a LEED® Platinum building and was named 2014 Laboratory of the Year by R&D Magazine.

There were plenty of hurdles to clear in designing the first system in the HP Apollo 8000 series, but the thermodynamic fundamentals are quite straightforward and easily replicable, Dube said. "The big picture is simple. You take heat from something that generates heat and send it to something that requires heat."

The challenge was to build liquid cooling not just in an exotic way, but in a way that was simple, reliable, and cost effective enough that it could work for a wide array of large computers—not just those in federal labs, but computers with a broad range of customers and applications.

The Apollo system, which uses liquid cooling rather than forced air, packs amazing computational capacity into a small space. "For heat exchange [e.g., cooling], liquids are orders of magnitude more effective than air, and the pump energy needed to circulate the liquid cooling is much less than the fan energy to move the equivalent amount of air," Dube and Hammond noted. Using liquid cooling allowed HP to pack the servers more densely and still keep them cool, rather than having to spread the servers out in a data center measured in acres in order to cool them sufficiently with air. Within a standard rack footprint of 2 feet by 4 feet, the HP Apollo 8000 platform can pack as many as 288 processors. That's four times the density of typical racks for high performance computers—and it means a much smaller footprint and lower cost.

> "Our vision was to build a showcase facility, to integrate the computer and data center with the building and do it with a holistic view toward energy efficiency."
>
> — **STEVE HAMMOND,** *Director of NREL's Computational Science Center*

Capturing Heat, Using It to Warm the Entire Building

Because the servers are cooled with warm water, rather than cold, the HP Apollo system doesn't need to be in a data center supported by compressor-based chillers, which are both energy hungry and expensive. Pipes carry the water right to the critical components, exploiting the thermal advantage of water over traditional air-cooled systems that force chilled air through heat sinks. If a supercomputer drawing a megawatt of power needs chillers for cooling, there may be an additional 500 kilowatts of energy needed to power the chillers, just to cool the supercomputer. The evaporative cooling used at the ESIF calls for about one-tenth of that cooling cost, because the water supplied for cooling can be 75°F, not 45°F or 50°F.

Water flowing to the servers is about 75°F. While it cools the servers, the servers in turn heat the water, so that by the time the liquid finishes a pass of the data center, its temperature has

risen to 95°F or warmer. That's a sufficient temperature to serve as the primary source of heat for the ESIF's office and lab spaces. The waste heat that warms the building via the hot water in the pipes circulates back to cool down the racks of servers, completing the loop. The HP Apollo system is designed so that maintenance on servers can be performed without opening any liquid connections. That's an important safety feature, as it keeps expensive electronics away from water.

But that's not all. The water heated by the data centers is also used under the front plaza and walkway outside the building to melt snow and ice. And that heat isn't just wasted in the summer—it's used to complete the loop for the cooling system that lowers the building's temperature during the hot days of June, July, and August.

Knowing Specs, Goals Helped Lower Cost

HP's goal was to demonstrate that liquid cooling can be simple; NREL's aim was to build an energy-efficient data center and integrate the supercomputer with the data center—and the potential energy savings—into the ESIF building as a whole. Before the pipes were routed, the team learned everything it needed to know about the dynamics of the building—the height of the ceilings, flow rates, supply and return temperatures, locations of the freight elevators, strength of the floor. Dube said the final product was enhanced because NREL knew exactly what it wanted, and that challenged HP to meet hard goals in a short timeline. "Because NREL was able to give us detailed specs like that, we were able to deliver a product far above our original target. Steve and NREL had really done some good analysis of where the industry needed to get."

One key time saver during installation was modular plumbing, 6-foot lengths with flanges on either end. The pipes were pre-assembled and pre-tested in the factory, and they employ quick-disconnect stainless connectors and flexible hoses. "That allowed us to put in 18 racks in four days, instead of four weeks," Hammond said.

The HP Apollo system has very sophisticated control systems as well; it's not actually as simple as treating the supercomputer as a furnace. The building requires a minimum temperature of water coming out of the data center for a heat source. High-tech engineering allows a varying flow rate within the servers, which maintains a constant water output temperature whether the computer is running at full load or idle, while also allowing for a range of temperature at the system's water inlet.

Collaboration Was Key, Say HP and NREL

Dube praised the collaboration. "You always encounter hurdles in a project like this, but we would sit down with the NREL team and work out the challenges—'This is the metric we need to meet; now how do we make that happen?'"

Hammond said NREL is very pleased with the system. "We took delivery of the first racks in August of 2013, had the ribbon-cutting with the Energy Secretary in late September, passed the acceptance test in November, and were in production in January. That's an impressive timeline considering this is a first-of-its-kind system.

"HP got to showcase its state-of-the-art platform, and NREL has an energy-efficient, showcase data center that cost less to build than if we had built something less energy efficient," Hammond said. "We didn't have to look at how many years it would take us to recoup our investment. It cost less to build and less to operate from day one."

— Bill Scanlon (October 13, 2014)

Supercomputer Exposes Enzyme's Secrets

Thanks to newer and faster supercomputers, today's computer simulations are opening hidden vistas to researchers in all areas of science. These powerful machines are used for everything from understanding how proteins work to answering questions about how galaxies began. Sometimes the data they create manage to surprise the very researchers staring back at the computer screen—that's what recently happened to a researcher at the Energy Department's National Renewable Energy Laboratory (NREL).

"What I saw was completely unexpected," NREL Engineer Gregg Beckham said.

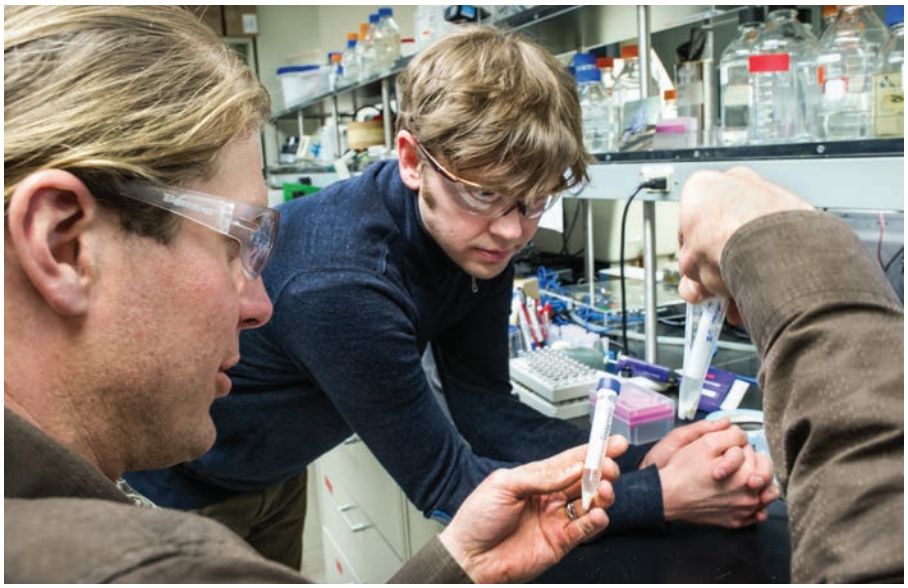
What startled Beckham was a computer simulation of an enzyme from the fungus *Trichoderma reesei* (Cel7A). The simulation showed that a part of an enzyme, the linker, may play a necessary role in breaking down biomass into the sugars used to make alternative transportation fuels.

"A couple of years ago we decided to run a really long—well, really long being a microsecond—simulation of the entire enzyme on the surface of cellulose," Beckham said. "We noticed the linker section of the enzyme started to bind to the cellulose—in fact, the entire linker binds to the surface of the cellulose."

Working Together in Ways We Don't Understand

The enzymes that the NREL researchers are examining have several different components that work together to break down biomass. The enzymes have a catalytic domain—which is the primary part of the enzyme that breaks down the material into the needed sugars. There is also a binding module, the sticky part that attaches the cellulose to the catalytic domain. The catalytic domain and the binding module are connected to each other by a linker.

"For decades, many people have thought these linkers are quite boring," Beckham said. "Indeed, we predicted that linkers alone act like wet noodles—they are really flexible, and unlike the catalytic domain or the binding module, they didn't have a known, well-defined structure. But the computer simulation suggests that the linker has some function other than connecting the binding module to the catalytic domain; namely, it may have some cellulose binding function as well."



NREL Biochemist Michael Resch, left, and NREL Engineer Gregg Beckham discuss results of vials containing an enzymatic digestion assay of cellulose.
Photo by Dennis Schroeder, NREL 28884

Cellulose is a long linear chain of glucose that makes up the main part of plant cell walls, but the bonds between the glucose molecules make it very tough to break apart. In fact, cellulose in fossilized leaves can remain intact for millions of years, but enzymes have evolved to break down this biomass into sugars by threading a single strand of cellulose up into the enzymes' catalytic domain and cleaving the bonds that connect glucose molecules together. Scientists are interested in the enzymes in fungi like *Trichoderma reesei* because they are quite effective at breaking down biomass—and fungi can make a lot of protein, which is also important for biomass conversion.

To make an alternative fuel like cellulosic ethanol or drop-in hydrocarbon fuels, biomass is pretreated with acid, hot water, or some other chemicals and heat to open up the plant cell wall. Next, enzymes are added to the biomass to break down the cellulose into glucose, which is then fermented and converted into fuel.

> "In terms of fuels, if you make even a small improvement in these enzymes, you could then lower the enzyme loadings. On a commodities scale, there is potential for dramatic savings that will help make renewable fuels competitive with fuels derived from fossil resource."
>
> — **GREG BECKHAM,** *NREL Engineer*

Seeing Isn't Always Believing

While Beckham and his colleagues were excited by what the simulation showed, there was also some trepidation.

"At first we didn't believe it, and we thought that it must be wrong, so a colleague, Christina Payne [formerly at NREL, now an assistant professor in chemical and materials engineering at the University of Kentucky], ran another simulation on the second most abundant enzyme in *Trichoderma reesei* (Cel6A)," Beckham explained. "And we found exactly the same thing.

"Many research teams have been engineering catalytic domains and binding modules, but this result perhaps suggests that we should also consider the functions of linkers. We now know they are important for binding, and we know binding is important for activity—but many unanswered questions remain that the team is working on now."

The NREL research team experimentally verified the computational predictions by working with researchers at the University of Colorado Boulder (CU Boulder), Swedish University of Agricultural Sciences, and Ghent University in Belgium. Using proteins made and characterized by the international project team, NREL's Michael Resch showed that by measuring the binding affinity of the binding module and then comparing it to the binding module with the linker added, the linker imparted an order of magnitude in binding affinity to cellulose. These results were published in a recent article in the *Proceedings of the National Academy of Sciences* (PNAS). In addition to Beckham, Payne, and Resch, co-authors on the study include: Liqun Chen and Zhongping Tan (CU Boulder); Michael F. Crowley, Michael E. Himmel, and Larry E. Taylor II (NREL); Mats Sandgren and Jerry Ståhlberg (Swedish University of Agricultural Sciences); and Ingeborg Stals (University College Ghent).

"In terms of fuels, if you make even a small improvement in these enzymes, you could then lower the enzyme loadings. On a commodities scale, there is potential for dramatic savings that will help make renewable fuels competitive with fuels derived from fossil resources," Beckham said.

According to Beckham, improving these enzymes is very challenging but incredibly important for cost-effective biofuels production, which the Energy Department has long recognized. "We are still unraveling a lot of the basic mechanisms about how they work. For instance, our recent paper suggests that this might be another facet of how these enzymes work and another target for improving them."

The research work at NREL is funded by the Energy Department's Bioenergy Technologies Office, and the computer time was provided by both the Energy Department and the National Science Foundation (NSF). The original simulation was run on a supercomputer named Athena at the National Institute for Computational Sciences, part of the NSF Extreme Science and Engineering Discovery Environment (XSEDE). The Energy

Department's Red Mesa supercomputer at Sandia National Laboratories was used for the subsequent simulations.

The research team has begun running other cellulase simulations on NREL's new Peregrine supercomputer.

"Peregrine will be incredibly useful for continuing this work because there are so many facets we are still trying to understand," Beckham said. "We are still trying to understand how the binding module sticks to cellulose in more detail, how the chemical reaction occurs in the catalytic domains of these enzymes, and how the chains thread through the enzymes—and that's all just for this one enzyme."

"We've recently published a paper on an enzyme from the wood-boring crustacean called the gribble with collaborators from the Universities of Portsmouth and York in the United Kingdom. The catalytic domain of the gribble is similar, but it has some key differences. Now we're using supercomputing and experiments together to understand the differences between a cellulase from an animal versus one from a fungus."

These types of results demonstrate that supercomputers are an essential research tool that will continue to open doors to discovery, and throw in a few surprises along the way.

"We didn't go into this with the hypothesis that the linkers would bind—we were simply looking to see how the enzyme behaves on the surface," Beckham said. "Our finding was completely serendipitous, but it really shows the value of these computer simulations. They allow us to look at things with a molecular microscope and understand how enzymes work, often by predicting new features that we hadn't even thought of before."

— Heather Lammers (January 23, 2014)

ENERGY SYSTEMS INTEGRATION

NREL's energy infrastructure research and development efforts involve developing technologies, systems, and methods to interconnect variable renewable energy at utility scale. *Photo by Dennis Schroeder, NREL 29576*

Climate Change Shifts Focus for Energy System

The U.S. National Climate Assessment report states bluntly that streets in coastal cities are flooding more readily, that hotter and drier weather in the West means earlier starts to wildfire seasons, and that every region of the nation already is seeing real effects of climate change.

"It's more vital than ever that the nation have a secure, reliable energy infrastructure that can respond to extreme weather events, integrate sustainable sources of energy onto the grid, and keep the lights on," said Bryan Hannegan, Associate Laboratory Director for Energy Systems Integration at the National Renewable Energy Laboratory (NREL). "Our existing electric system has served us well, but will it be up to the task of meeting our clean energy needs in a changing climate?"

And they're turning to the Energy Department's NREL and its newest building, the Energy Systems Integration Facility (ESIF), to test the latest concepts and devices that can intelligently manage energy from batteries, electric cars, wind, solar, and biofuels. It's the ideal testbed for the "microgrid," a system that can disconnect from the grid and continue to provide power, and then reconnect to the grid without disruption. As decision makers become more concerned about climate change and its effect on the resilience of America's energy infrastructure, microgrids become increasingly important components.

NREL Electrical Engineer Greg Martin, who works with microgrids, said the nation is moving toward "more mobile, more deployable, transportable" energy systems, which will be particularly useful for disaster relief and military applications.

Microgrids Integrate Fossil Fuels, Renewables, Battery Storage

"The catchword today is integration—how can we link together emerging consumer demands and clean energy resources without disrupting the grid," Hannegan said. "The plug-in vehicle in the garage, the appliance in the kitchen, the rooftop solar and battery storage—when they're all hooked together, how is it going to work? And can we get it to work in a way that is secure, reliable, and saves money?"

"Right now, we're a heavily centralized system," Martin said. "There is a lot of opportunity to implement these new technologies like rooftop solar and energy storage. Once you get rooftop solar with battery storage, and once you start viewing plug-in vehicles as both users and suppliers of energy, and find a way to tie in to existing grid or fossil fuel resources and the utility grid, you have great potential for micro-gridding. It can mean reduced fuel use and increased efficiency, and can serve as emergency backup power during disasters."

NREL engineers Greg Martin and Mariko Shirazi work on data capture for microgrid synchronization waveforms. American utilities are looking at smaller, flexible systems such as microgrids that can deliver electricity anywhere. *Photo by Dennis Schroeder, NREL 21936*

Microgrids can be integral to a system that doesn't want to rely on more coal or natural gas—or new plants operating on fossil fuels—to only meet the peak loads that may come just an hour each day, or just a few times each summer or winter. A new smarter system would have a specified interface to a battery and, say, a wind turbine that can smooth out the transition from one source of energy to another. Instead of relying on fossil fuels, the system can rely on wind, solar, and other alternative energies to get neighborhoods through those crucial hours of peak demand. Smart integration of a variety of components—both renewable and fossil fuel—can minimize expensive fuel use, while making the delivery of electricity cleaner and more efficient.

> "The plug-in vehicle in the garage, the appliance in the kitchen, the rooftop solar and battery storage—when they're all hooked together, how is it going to work? And can we get it to work in a way that is secure, reliable, and saves money?"
>
> — **BRYAN HANNEGAN,** *NREL Associate Laboratory Director for Energy Systems Integration*

Useful for Weather Outages, Which Are on the Rise

The White House Council of Economic Advisers and the Energy Department recently released the report *Economic Benefits of Increasing Electric Grid Resilience to Weather Outages*, which calls for more investment in the electric grid and identifies strategies for modernizing the grid to better prevent power outages. Those strategies include energy storage to improve system stability, along with microgrids and advanced communication and controls.

The April report from the Intergovernmental Panel on Climate Change warns that global surface temperatures will rise 9 degrees Fahrenheit without further mitigation of greenhouse gases. There have been 144 weather-related climate disasters since 1980 in which overall damages reached or exceeded $1 billion, events that have shattered and shocked nearly every region of the country, according to the Energy Department report *U.S. Energy Sector Vulnerabilities to Climate Change and Extreme Weather.*

Average annual temperatures across the 48 contiguous United States have risen approximately 1.5 degrees Fahrenheit since the dawn of the 20th century—and with this rise have come increasingly costly and increasingly frequent severe weather events that have taken a toll on people, property, and pocketbooks.

Hurricane Sandy pounded the East Coast in the fall of 2012, leaving devastation that affected 24 states. Utilities reported damage to more than 7,000 transformers and 15,200 power poles; two oil refineries with capacity of 300,000 barrels per day were shut down. The hurricane left 8.2 million people without power for weeks, and caused $71 billion in total loss. New York Governor Andrew Cuomo convened the New York State Commission 2100 in response to not only Hurricane Sandy, but other recent and unprecedented severe weather events such as Hurricane Irene and Tropical Storm Lee. The Commission recommended measures including protecting key transmission and distribution lines, strengthening marine terminals, and building a modern, more resilient grid that can take advantage of renewable energy and that can be a model for improving energy infrastructure nationwide.

NREL Director Dan Arvizu, who was a member of the New York 2100 Commission that issued the recommendations, said: "Given the magnitude of recent climate-related calamities, and the inevitability of more in the coming years, it is imperative that we grasp the opportunity to build a more resilient energy sector."

Priority must be placed on improving grid equipment and operations to better manage the complex, ever-changing load conditions—and to increase reliability and resilience. A more distributed and resilient energy infrastructure can overcome the long delays before power is restored, Arvizu said.

"Renewable energy can do much more than save on greenhouse gas emissions," he said. In the face of more and more extreme weather events, "*islanded* microgrids that combine renewable energy with backup storage can keep local power going when the grid goes down. And that can save both money and lives."

A key asset of some microgrids is that during a utility grid disturbance they can separate and isolate themselves from the utility seamlessly with little or no disruption to the loads within the microgrid. When the utility grid returns to normal, the microgrid automatically resynchronizes and reconnects itself to the grid in an equally seamless fashion.

Microgrids Scale up from Household Size to Large Networks

One house can have its own microgrid, a combination of, say, rooftop solar and a battery in the basement that stores the excess power generated by the sun and provides backup power to keep the furnace running in the case of a power outage.

Utilities working with homeowners or businesses can create a network of microgrids that help entire neighborhoods or cities to power through outages. In Portland, Oregon, customers with their own diesel generators have agreed to give the utility control of them when needed. The utility, Portland General Electric (PGE), uses a combination of solar power, battery storage, and backup diesel to ride through outages when the main system goes down. Tests at NREL addressed integration and communications issues, and helped PGE install a more robust system with minimal impact to electricity users.

NREL also helped test a microgrid system designed by the Consortium for Electric Reliability Technology Solutions (CERTS) that ties together natural gas co-generation and a microgrid gateway to provide both heat and electricity to customers, uploading and downloading power on and off the grid. This microgrid is currently owned and operated by the Sacramento Municipal Utility District.

This summer, NREL is collaborating at the ESIF with an Australian utility that is using inverters to integrate solar, diesel generators, and batteries. The effort will include development and testing of a microgrid control network that has the job of determining whether and when backup battery power is needed, and ensure consistent electricity is provided to users.

NREL's ESIF is the Place to Validate Integration of Power Sources

"It's a matter of getting stuff to work together," Martin said. And that requires partnerships. GE wants to sell appliances; Toyota wants to sell cars that plug into garage outlets. Sacramento Municipal Utility District needs to be sure that the rooftop solar and a box of backup batteries are working together seamlessly.

As the new generation of microgrids and inverters proves its mettle, there also needs to be an evolution in the standards that define the interface between the utility and the microgrid. "We're trying to make sure that these great new ideas work," Martin said. Solar arrays are becoming very robust, but there is still plenty of work to do to ensure that batteries and other equipment integral to energy integration communicate with each other flawlessly in real situations.

The ESIF has the capacity to test large components and systems, say, 500-kilowatt or 1-megawatt photovoltaic inverters. One of the ESIF's main missions is to be the last stop before the field. "Until we run it at rated power, kick it and bump it with grid fluctuations, and see what it actually does, we can't be sure it's going to function well in the field," Martin said. "That's why we're here. No one has ever been able to lab-test their equipment at a scale that is possible here at the ESIF."

— Bill Scanlon (May 28, 2014)

NREL Supercomputer Tackles Grid Challenges

"Big data" is playing an increasingly big role in the renewable energy industry and the transformation of the nation's electrical grid, and no single entity provides a better tool for such data than the Energy Department's Energy Systems Integration Facility (ESIF) located on the campus of the National Renewable Energy Laboratory (NREL). Imagined by NREL leaders who foresaw the possibilities for high performance computing (HPC), the ESIF's HPC data center is fulfilling the goal of handling large and complex datasets that exceed traditional database processes.

"As industry moves forward to integrate all these renewables, big data is a key piece of the puzzle," ESIF Business Development Manager Martha Symko-Davies said. "The links between modeling and simulation, hardware, and good, bad, and aggregated data—all parts of the whole puzzle—are captured at the ESIF through big data." That's why the ESIF's Peregrine supercomputer, dedicated by Energy Secretary Ernest Moniz in September 2013, is so important; it can do more than a quadrillion calculations per second as part of the world's most energy-efficient HPC data center.

Asking the Big Questions

"Peregrine provides much-needed computational capability to model complex systems such as the grid, to allow us to ask 'what if' questions, and to optimize how these systems are designed and deployed with much higher confidence in their efficiency and robustness," NREL Computational Science Center Director Steve Hammond said.

Increasingly, those "what ifs" involve the challenge of delivering distributed energy to the grid when the sun shines and the wind blows, while making it even more reliable than when the grid was a one-way delivery system of fossil-fuel-based energy. "By focusing on the integration and optimization of energy systems across the energy infrastructure, we can better understand and make use of potential co-benefits that increase reliability and performance, reduce cost, and minimize environmental impacts," NREL Director of Energy Systems Integration (ESI) Ben Kroposki said.

This focus will help map the pathway NREL will pioneer with the Energy Department to modernize the nation's electrical grid. The ESIF "will be a major focus of DOE to help us transform the energy system to the one we need in 2030," Moniz told the audience at the ESIF's dedication. The ESIF is "the step up we need to elevate energy systems integration," he said.

Thanks to the capacities of the ESIF and Peregrine, efforts are underway at NREL to move commercial-scale research and development and testing forward. In January 2014, NREL began to assemble a virtual link from the ESIF to NREL's National Wind Technology Center and other national labs and universities.

"Big data" is playing an increasing role in the renewable energy industry and the transformation of the nation's electrical grid. NREL's Peregrine supercomputer is already fulfilling the goal of handling large and complex datasets that exceed traditional database processes.
Photo by Dennis Schroeder, NREL 27775

"We're setting up this virtual network so that we can tap into other's resources and knowledge and not try to recreate it here at NREL," NREL Associate Laboratory Director for ESI Bryan Hannegan said.

NREL isn't working alone, Symko-Davies noted. "Researchers here, coupled with Energy Department efforts, and external partners—large and small companies, utilities, academia, policymakers, and others—are all helping to collectively solve problems."

> "Researchers here, coupled with Energy Department efforts, and external partners—large and small companies, utilities, academia, policymakers, and others—are all helping to collectively solve problems."
>
> — **MARTHA SYMKO-DAVIES,** *ESIF Business Development Manager*

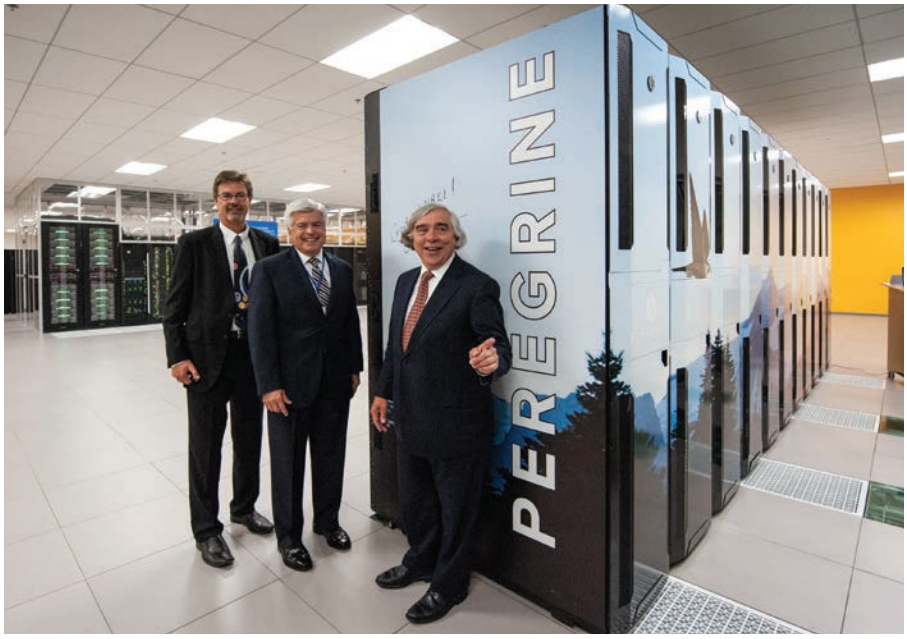
ESIF and NREL's Partners Work Together

Collaboration is key, and it is hard-wired into the ESIF's core. NREL teamed with Hewlett-Packard (HP) and Intel to develop the innovative warm-water, liquid-cooled Peregrine supercomputer.

The HP Apollo liquid-cooled supercomputing platform provides the foundation for numerical modeling and simulations, which allow scientists to gain new insights into a wide range of topics. However, as HPC systems scale up by orders of magnitude, energy consumption and heat dissipation stress the supporting systems and the facilities in which they are housed. With NREL's HPC data center, 90% or more of the computer's waste heat is captured and reused as the primary heat source for ESIF offices and laboratory space.

The ESIF truly was designed for partners—and NREL and its world-class facilities have made it known that they are open for business. "We've known that industry was eager for a place like the ESIF, which allows utility companies and investors to see technology working in real time and on a large scale," NREL Director Dan Arvizu said.

For example, Advanced Energy Industries is accessing the ESIF's Power Systems Integration Laboratory to test its new solar photovoltaic (PV) inverter technology with the facility's hardware-in-the-loop system and megawatt-scale



Energy Secretary Ernest Moniz, right, joins NREL Director Dan Arvizu, center, and NREL Computational Science Center Director Steve Hammond, left, at the unveiling of Peregrine. NREL collaborated with HP and Intel to develop an innovative warm-water, liquid-cooled supercomputer. Peregrine resides in the new ESIF data center and will help tackle the challenges of energy systems integration. *Photo by Dennis Schroeder, NREL 27496*

grid simulators. The company's inverter will help support a smarter grid that can handle two-way flows of power and communication while reducing hardware costs.

Given the nature of global climate change, it's vital that the ESIF has a long reach. In a recent joint initiative between the U.S. Navy and the lab, NREL successfully demonstrated a new custom-engineered energy management system to maximize solar PV on a naval base in Hawaii while smoothing the effects of variable solar PV generation by charging and discharging batteries.

As demand for the ESIF expands, it helps another key area of growth: commercialization. "When industry and NREL work closely together, great things happen. The abilities of the ESIF allow manufacturers, industry, and the clean energy sector to bring new ideas to market," NREL Associate Laboratory Director for Innovation, Partnering, and Outreach Bill Farris said.

And it appears likely that the ESIF and its HPC capabilities will be in increasing demand in coming years. The word is already out on the one-year-old lab facility, which is home to 200 scientists and engineers—and the editors of R&D Magazine have named it the 2014 Laboratory of the Year.

Not surprisingly, the ultra-efficient HPC data center gets the spotlight. It helped NREL earn a 2013 U.S. Department of Energy Sustainability Award for its leadership in green information technology, including the lab's electronic stewardship practices and world-class HPC data centers.

The ESIF and Peregrine model what the future holds for the grid and energy systems, while helping industry and partners find a path to commercializing the technology needed to make that transformation.

That's enough to make an energy secretary smile.

— Ernie Tucker (June 26, 2014)

"When industry and NREL work closely together, great things happen. The abilities of the ESIF allow manufacturers, industry, and the clean energy sector to bring new ideas to market."

— **BILL FARRIS,** *NREL Associate Laboratory Director for Innovation, Partnering, and Outreach*

SOLAR

NREL's solar research covers the full spectrum from fundamental studies in materials to commercialization.

Photo by Dennis Schroeder, NREL 29510

Crystal Solar and NREL Team Up to Cut Costs

A faster, cheaper way to manufacture silicon solar cells, partially funded by the Energy Department and fine-tuned at its National Renewable Energy Laboratory (NREL), has won a coveted R&D 100 award as one of the top technology innovations of 2013.

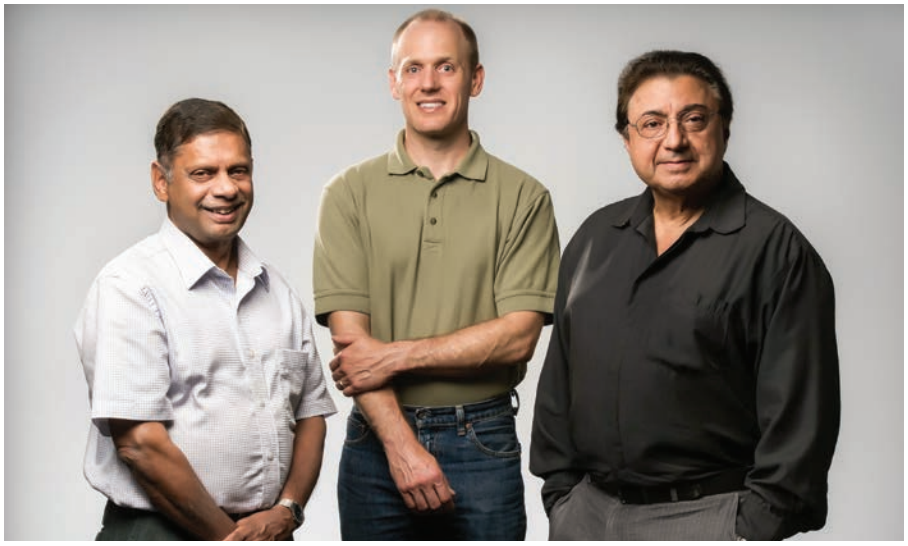
Crystal Solar's approach to growing high-quality, high-efficiency silicon wafers at 100 times the usual throughput and half the cost could be a game-changer, creating American jobs and stemming the flow of solar cell manufacturing overseas, says T.S. Ravi, chief executive officer of the Santa Clara, California-based company.

Even before he founded Crystal Solar, Ravi set a goal to speed up the manufacturing process. In 2011, his nascent company applied for the Energy Department's SunShot Initiative's Photovoltaic (PV) Incubator Program, which at that time was run out of NREL. The PV Incubator Program has a very competitive selection process, searching for ideas that are truly disruptive in terms of lowering costs.

"We applied for the program and were selected in late 2011," Ravi said, recalling a conversation he had several years ago with NREL's Harin Ullal. "I knew that if I could bunch a lot of wafers together, and find a way to remove the epitaxial wafer with a simple mechanical process, it could actually change the game in the solar industry."

Crystal Solar's direct gas-to-wafer method is epitaxial, which means it grows a layer of material on top of another material that has the same crystal structure. In the direct gas-to-wafer method—the official name is Direct Monocrystalline Silicon Wafer Growth by High-Throughput Epitaxy—gaseous layers of semiconducting silicon material are grown directly on reusable silicon substrates. The method has several advantages, including eliminating the waste incurred in the traditional approach, which involves sawing thin slices from a large ingot or block of silicon. In the new approach, wafers can be made thinner without compromising their quality or efficiency.

However, semiconductor material using the epitaxial approach typically grows very slowly—about two wafers an hour for the thickness needed for solar wafers. That's much too slow—and therefore costly—for solar cells. The Energy Department's SunShot Initiative has set a goal for solar energy of less than $1 per watt system price by 2020, as a way of making it cost competitive with fossil-fuel-based electricity.



NREL researchers Harin Ullal, left, Steve Johnston, and Bhushan Sopori were part of the team that won the R&D 100 award with Crystal Solar.
Photo by Dennis Schroeder, NREL 30490

Incubator Program at NREL Helped Drive the Technology

Crystal Solar worked closely with NREL into 2013. "NREL pointed us in the right direction," Ravi said. "All these things we wanted to prove—that we could grow these wafers at a high growth rate, that we could do it without compromising the quality of the wafers—required the silicon defect expertise at NREL."

"We helped them understand the nature of the defects and thus improve performance at the wafer and cell level," said NREL Principal Scientist Bhushan Sopori, who, along with Ullal and NREL's Steve Johnston, worked with Crystal Solar on the process.

Ullal noted that the efficiency of the rapidly made cells is greater than 20% in the lab, so once in panels on rooftops, they should compare favorably to the best solar modules being installed today. "The SunShot PV Incubator Program is very competitive," Ullal added. "Clearly, Crystal Solar had a unique process that really stood out. Compared to the traditional silicon technology that involves slicing, this eliminates several steps that have an impact on the cost of the final PV product."

Solar Wafers at 13 Cents per Watt

The new epitaxial system can produce up to 500 wafers per hour and sells for less than $5 million, while replacing traditional reactors and pullers. That translates to a wafer cost of about 13 cents per watt, less than half the typical cost of 30 cents per watt for high-end wafers, Ravi said. The entire module cost is projected to be less than 50 cents per watt—a reduction that could help nudge the installed cost of the solar system to less than $1 per watt.

Crystalline silicon commands 90% of the solar market, and despite the rapid success of thin films and other materials such as perovskite, will likely remain the leading technology in the near future.

Interest in the solar cells is huge, Ravi said. Crystal Solar is in the pilot manufacturing stage, and "we're struggling to keep up with the people who want our wafers. We want to set up a factory in the United States somewhere."

Ravi said the process lends itself to automation, which means labor costs—much cheaper in Asia—won't be such a big factor. "We don't have to go to a low-labor country—I'm very proud of that," he said. Even though the approach requires less manpower, it will mean numerous good-paying American jobs.

"We believe this technology will probably thrive in the United States, that it will be cheaper to do it here than anywhere else in the world," Ravi said. If the process continues to make high-quality efficient solar cells when ramped up to full manufacturing scale, it's a testimonial to the partnership between Crystal Solar, the Energy Department, and NREL, Ravi said.

> "NREL pointed us in the right direction. All these things we wanted to prove—that we could grow these wafers at a high growth rate, that we could do it without compromising the quality of the wafers—required the silicon defect expertise at NREL."
>
> — **T.S. RAVI**, *CEO of Crystal Solar*

Approach Eliminates Several Steps, Is Less Expensive

The approach is cheaper and faster because it eliminates several steps, Ullal said. The device is actually built as gaseous silicon is deposited on a solid silicon substrate. A dopant or impurity can create the junctions that force current flow much more easily than in traditional solar cell manufacturing, Ravi said.

Another advantage: The material doesn't have to be rotated as it does in the ingot-growth process, which means the wafer remains a true square—and that makes for better and more efficient packaging of the PV module.

The approach also incorporates less oxygen in the silicon layer, which has been shown to eliminate oxygen-related defects. That's important because it gives the photons that hit the cells a tiny bit longer to form into the electron-hole pairs that are essential to establishing a carrying current for electricity, and makes it less likely that the electron and hole will recombine. The difference is tiny—1.3 milliseconds versus a bit less than 1 millisecond—but crucial in the world of photons and electrons.

"Most silicon wafers are made in Asia," Ullal said. "But this epitaxy process gets you there. And 30% of the overall cost of a solar module is the cost of the silicon wafer."

Typically, for epitaxial growth, wafers are arranged horizontally as layers are added. Crystal Solar arranges them vertically, for a smaller footprint, and passes the gas through a narrower space for a much higher growth rate.

"The key challenge was how to hold that wafer vertically and still get uniformity," Ravi said. "That took us 2 and a half years of researching for just the right material, the right shape, and so forth. There are so many advantages of the epitaxial method that it seems like a no-brainer. But the reason no one has really done it before is that it is a very hard thing to do in practice."

His company is looking for a site with low-cost access to electricity and a well-trained technical workforce. "There's great demand for solar energy. We're taking about hundreds of gigawatts in the next couple of decades."

NREL's collaboration with Crystal Solar is just one of dozens of working agreements with industry. "Partnerships with innovative private companies are part of the lifeblood of NREL," said Kristin Gray, director of NREL's Technology Transfer Office. Gray and colleague Anne Miller noted that NREL, year after year, has more cooperative research and development agreements (CRADAs) with private companies than any other federal laboratory. For every dollar that the Energy Department invests in a CRADA, it attracts another $6 in total value from all industry contracts. During the past year, NREL signed 20 new license agreements and filed more than 60 new patent applications.

"NREL scientists and engineers, working with companies with innovative ideas for sustainable energy, are accelerating the move toward a clean energy economy," Miller said.

— Bill Scanlon (August 27, 2014)

NREL Unlocking Secrets of New Solar Material

A new solar material that has the same crystal structure as a mineral first found in the Ural Mountains in 1839 is shooting up the efficiency charts faster than almost anything researchers have seen before—and it is generating optimism that a less expensive way of using sunlight to generate electricity may be in our planet's future.

Researchers at the Energy Department's National Renewable Energy Laboratory (NREL) are analyzing the new material, perovskite, using the lab's unique testing capabilities and broad spectrum of expertise to uncover the secrets and potential of the semiconducting cube-like mineral.

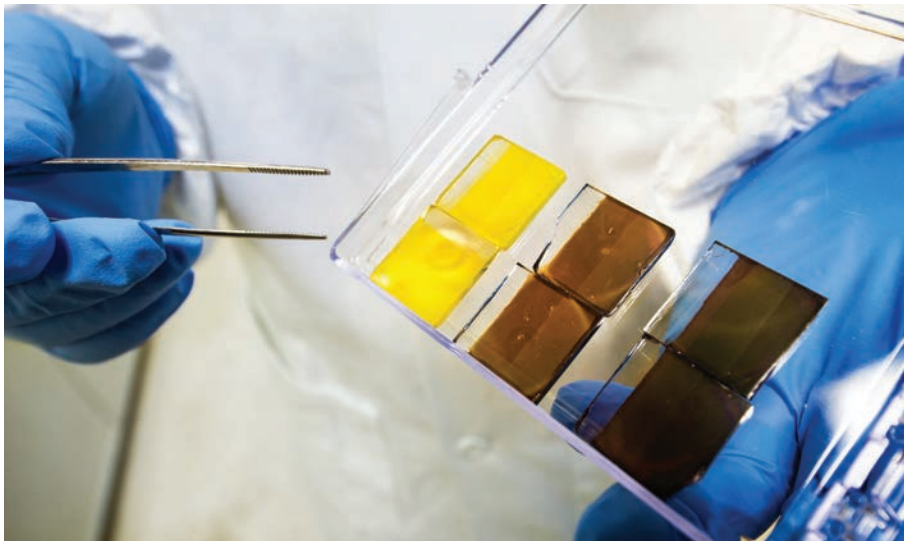
NREL has already produced three scientific papers on perovskite, reporting on the science behind the very large length of the electron pairs (or charge diffusion length) in mesostructured perovskite solar cells. The two most-studied perovskite device structures are mesostructured (of medium complexity) and planar (two-dimensional). NREL Research Fellow David Ginley, who is a world-renowned materials scientist and winner of several R&D 100 Awards, said what makes perovskite device structures so remarkable is that when processed in a liquid solution, they have unusual abilities to diffuse photons a long distance through the cell. That makes it far less likely that the electrons will recombine with their hole pairs and be lost to useful electricity. And that indicates a potential for low-cost, high-efficiency devices.

NREL Senior Scientist Daniel Friedman notes that the light-absorbing perovskite cells have "a diffusion length 10 times longer than their absorption length," not only an unusual phenomenon, but a very useful one, too.

Perovskite Is Flexible, Easier to Manipulate

The new cells are made from a relative of the perovskite mineral found in the Ural Mountains. Small but vital changes to the material allow it to absorb sunlight very efficiently. The material is also easy to fabricate using liquids that could be printed on substrates like ink in a printing press, or made from simple evaporation. These properties suggest an easy, affordable route to solar cells.

By playing with the elemental composition, it is also possible to tune the perovskite material to access different parts of the sun's spectrum. That flexibility can be crucial, because it means that the material can be changed by deliberately introducing impurities, and in such a way that it can be used



The band gap of perovskites can be adjusted by changing their compositions to access different parts of the sun's spectrum.
Photo by Dennis Schroeder, NREL 29513

in multijunction solar cells that have ultra-high efficiencies. Multijunction solar cells are an NREL invention from 1991, but because of high material costs, standard multijunctions are used mostly in outer space applications such as satellites and the Mars rovers. Cheaper multijunction cells based on perovskites could radically change this.

In 4 years, perovskite's conversion efficiency—the yield at which the photons that hit the material are turned into electrons that can be used to generate electricity—has grown from 3.8% in 2009 to just north of 16%, with unconfirmed reports of even higher efficiencies arriving regularly. That's better than a four-fold increase. By contrast, efficiencies of single-crystal solar cells grew by less than 50% during their first 5 years of development, and most other types of solar cells showed similar modest improvements during their first few years.

NREL materials scientists are encouraged by the possibility of further optimizing the materials. For example, replacing lead with tin in the cells could improve the efficiency of multijunction cells made from perovskite. Besides switching to a more environmentally friendly material, the change from lead to tin would also allow the finished solar cell to better withstand high humidity.

NREL Ideally Positioned to Help the Field

"We can help the field, especially in areas where they need help in reliability and larger development," including understanding transport, or moving electrons from the solar cell to a circuit, Ginley said. "Those are all the things we do well."

"Perovskite shows promise to be a whole lot easier to make" compared to most other solar cells, said NREL Senior Scientist Joey Luther, who works with nanomaterials. "It doesn't require high-temperature processing. You can just dip glass into two chemicals and get the material to form on it."

The field is growing fast, but that's because there is so much to do, Luther said. "Every technique that everyone has used for every solar cell in the past, they want to try it on perovskite solar cells to see what they can learn. Anytime you jump into a new material, you need to get a feel for how it works—you just have to play around for a while," Luther said. "Look at the layers, see what modifications you can make with new materials, see what you can do to tune it."

> "At NREL, we have this depth and breadth of understanding of materials, devices, transport, and, really, all aspects of solar cells that should help us make an important contribution to this new material."
>
> — **KAI ZHU,** *NREL Senior Scientist*

Maximizing Efficiency, Minimizing Costs

Luther predicts that researchers will approach perovskite from two different directions. One will be to make the best semiconductor possible without regard to cost, and the other will be to try to make it as cheap as possible, trying spray-on techniques, for example. "Those fields are going to merge eventually," he said, as researchers discover the optimal trade-offs.

"What is interesting about perovskite is that all the research groups—in Korea, England, Switzerland, the United States—they're all getting very high efficiencies," Luther said. "It's not as if just one person knows the secret."

The theoretical maximum efficiency of a perovskite-based solar cell is about 31%, meaning that of all the solar energy contained in the sunlight that hits the cell, 31% is converted to useful electrical energy. Multijunction cells based on perovskites could attain higher efficiencies still.

"The goal shouldn't be to stop at 20% efficiency," Luther said. "The goal should be to try to get to 28% or higher. In the lab, the best cells need to be almost perfect at small scale. Then the commercial people can stop at whatever efficiency is economical for them to deploy."

NREL has world-class experts in several fields needed for the exploration and improvement of this new promising material: experts in so-called III-V cells from the third and fifth columns of the periodic table; in quantum dots, materials, and transport; in computational materials design; and in doping materials with new materials to change their band gaps, and thus their usefulness in harvesting electrons.

In fact, NREL's latest world record has echoes of properties inherent in perovskite. NREL recently set a world record of 34% conversion efficiency for a gallium indium phosphide cell atop a gallium arsenide cell under lenses that multiply the sun's power. Last June, NREL set the world record of 31.1% for the same cell under one sun. In both cases, NREL reached unprecedented efficiencies by reducing undesired non-radiative recombination of minority carriers. It's that long-diffusion, short-absorption phenomenon that has scientists so excited about perovskite.

Remarkable Progress in Just Five Years

NREL Senior Scientist Kai Zhu is co-organizer of a scientific conference on dye-sensitized solar cells, which are low-cost thin-film cells. So far, he says, the majority of talks, posters, and papers proposed for the conference are on the subject of perovskite—so exciting is the field even though perovskite isn't technically a dye cell.

In 2009, Japanese scientist Tsutomu Miyasaka reported perovskite's potential as a light absorber and possible material for a solar cell, noting a 3.8% conversion efficiency, but that was such a low rate that it didn't spark much interest, said Zhu.

But in 2011, a Korean scientist, Nam-Gyu Park, who served as a postdoctoral researcher at NREL in the late 1990s, reported achieving 6.5% efficiency with perovskite. "Fifteen years ago, he was working in the same lab I am working in now," Zhu said. "So I started paying attention to his work on perovskites."

A year later, Michael Grätzel, a top solar scientist from Switzerland, teamed with Park on a paper, sparking more widespread interest. Their paper in the journal *Nature Scientific Reports* reported a conversion efficiency of about 10% with perovskite. "By then, I knew this was something I wanted to pursue," Zhu said. At the beginning of 2013, the efficiency level for perovskite had climbed to 12.3%.

"And then about a year ago, when they added chlorine to the materials, the electron and hole diffusion lengths just went through the roof," Ginley said. "The most remarkable thing is that you add a little bit of chlorine and you see how the diffusion lengths change—by a factor of 10. That really brought attention to them." Ideally, a solar cell has a diffusion length long enough for the electron to reach the contacts both above and below it, and thus escape the possibility that it will be trapped in its layer and recombine into an electron-hole pair.

When Zhu's proposal to examine perovskite was approved, the efficiency level had climbed to 14.1%. Now, the highest certified rate is 16.2% by Sang Il Seok of Korea. "Seeing how rapidly this field is progressing, I feel very lucky that I started on this more than a year ago," Zhu said.

Meanwhile, Zhu is in the midst of an experiment in which he prepares a precursor solution that converts from a liquid base to an absorber in a device. "This material is so easy to work with," Zhu said. "Working on solution processing, we can make a device in one or two days, from beginning to finish."

To boost efficiency levels even further will take more effort, Zhu concedes. "But this new material can probably be processed at a much lower cost" than rival materials, he said. It doesn't have to deal with the problem of the substrate not matching with the material above it, or with the delicate deposition process necessary with many alternative solar materials.

Several companies are already interested in forming cooperative research and development agreements so they can work with NREL on perovskite. "At NREL, we have this depth and breadth of understanding of materials, devices, transport, and, really, all aspects of solar cells that should help us make an important contribution to this new material," Zhu said.

— Bill Scanlon (April 15, 2014)

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GROWTH
FOR

TECHNOLOGY TRANSFER

Through a variety of commercialization programs, NREL works to stimulate the market for clean energy technologies and foster the growth of clean energy startups. *Photo by Dennis Schroeder, NREL 31971*

New Initiatives Debut at Industry Growth Forum

The clean energy revolution is now, and the Energy Department is stepping up its commitment to help innovators commercialize their best ideas. At the recent Industry Growth Forum (IGF) in Denver, Colorado, Assistant Secretary for Energy Efficiency and Renewable Energy David Danielson announced the new Lab-Corps program to accelerate the transfer of clean energy technologies from the national laboratories to the marketplace, so that game-changing innovations don't languish for lack of money and equipment.

The Energy Department's National Renewable Energy Laboratory (NREL) will be the hub of the new Lab-Corps, partnering with five other national labs—Argonne National Laboratory, Idaho National Laboratory, Lawrence Berkeley National Laboratory, Lawrence Livermore National Laboratory, and Pacific Northwest National Laboratory.

Building Clean Energy Ecosystems

Hosted by NREL, the 27th Industry Growth Forum was the ideal setting to announce Lab-Corps, as the Forum attracts 30 companies a year competing for the top prizes, and dozens of others pitching their ideas to venture capital firms, large corporations, philanthropies, and national labs.

The global clean energy market is valued at $250 billion this year, but will expand to a multi-trillion-dollar market in the next decade, Danielson said. If the United States is to play the leading role, it will need to rely on its strengths—innovation and entrepreneurship—and avoid "short-term-ism" thinking by venture capitalists and others in the financial community.

This will require effort from all sides, Danielson said.

- Venture capital firms should try to look more long term—saying yes to great ideas that may take a few years to bear fruit, rather than focusing on safer, but less innovative, bets.
- All players need to think about energy integration: how to layer devices, communications, and energy sources in such a way that larger loads of renewables can be seamlessly added to the emerging smart grid. He noted that NREL's new Energy Systems Integration Facility (ESIF) is the place where utilities and their vendors can test-drive the future electric grid.

Ashley Grosh of Wells Fargo and Richard Adams, director of NREL's Innovation & Entrepreneurship Center, smile after the announcement of the $10 million Wells Fargo Innovation Incubator program that will be run by NREL. *Photo by Dennis Schroeder, NREL 31964*

- Philanthropic organizations should try to step up with some cash to help great ideas get over the commercialization hump, he said. Partnerships and cooperative research and development agreements should expand.
- Startups and entrepreneurs need to form more partnerships with national laboratories to tap into the labs' equipment, expertise, and mentoring opportunities, so they can prove a concept or demonstrate a pilot project for $1 million instead of $20 million. Slowing the burn rate until the company has a product for the marketplace is essential in an era when easy money for clean energy has dried up.

The Energy Department can—and will—help out in all these areas and will be the "glue" that helps hold together the new clean energy ecosystems, he said. "I'm confident that together we can build this new model, engaging corporations and philanthropy like never before, stepping up investments from government, helping venture capital find that sweet spot where they can make money while still supporting these technologies at the crucial stage," Danielson said. And national labs need to both generate and support innovations, speeding them to the marketplace.

While news of the Lab-Corps announcement rippled through the Forum, it was business as usual for the inventors, entrepreneurs, investors, and venture capitalists looking to join forces to create the next big thing in clean energy. This year, the Forum's Best Venture award went to HiQ Solar for a solar inverter that weighs about one-third of typical inverters of the same power rating, costs less, and packs inside all the safeguards, reliability, and convenience that the solar industry is looking for.

HiQ CEO Lutz Henckels said he was born in Germany and doesn't like that Germany is ahead of the United States in percentage of renewables installed to date. "I don't buy the excuse that Germany has a newer infrastructure," he said. "America can absolutely regain the lead. The financing might be against us right now, but we have the innovators and entrepreneurs. We value startups."

Henckels said he has been to many similar industry growth forums, and the NREL-hosted one stands out because of the talent it attracts from both the public and private sectors. "Not many events compare to this…it's the best I've seen."

One Outstanding Venture award went to ClearCove Systems of Rochester, New York, which takes energy out of waste water in such a way that harvests more organics with four times more gas potential than other methods. "We use half as much power to treat waste," said CEO Gary Miller, who described his firm as "a blue-collar high-tech company."

"We're looking to monetize wastewater as a renewable energy source, and also as an economic value to the community," said Miller, who is seeking $4.5 million to scale up to the full production stage.

The second Outstanding Venture award went to Wetzel Blade of Pflugerville, Texas, which has a new way of building and manufacturing blades for the largest wind turbines. By breaking the blades into 60-foot sections, they can transport them at lower cost, and by assembling them in the field with a skeleton and skin, they can inspect the bonds beforehand and ensure there are no defects just before they are attached to the turbine.

"I can't even count the ways the Energy Department and NREL helped us get started," CEO Karl Wentzel said. "We got a half-million dollars to help get the technology out of the lab, and we worked with NREL on incubating a number of ideas. NREL will do our blade testing next year" at its National Wind Technology Center.

NREL Associate Lab Director Paints Picture of Electricity's Future

Forum keynote speaker and NREL's Associate Laboratory Director for Energy Systems Integration Bryan Hannegan predicted that entrepreneurs, utilities, and national labs will soon find opportunity to reengineer the standard energy business models. In the not-distant future, electricity delivery will look more like the current cell phone model, he said. Verizon, AT&T, and the others no longer charge by the minute for phone calls, yet they remain profitable by offering a set of services and a flat fee rate that people value.

Similarly, utilities and their partners may soon be primarily selling electricity as a service—based on comfort, convenience, transparency, and choice. Households may pay a flat rate for the convenience of doing nothing, letting smart meters decide how to save a little money by starting the dishwasher when the peak electricity demand has passed, for example.

Other households might opt for more individual control—cell phone alerts, for example, asking them whether they want to donate the solar energy from their rooftops to the grid for the next couple of hours in advance of a thunderstorm heading their way. Or, asking whether they want to download electricity into their electric vehicles, or perhaps upload it when the demand—and the price—is at its peak.

Choices will be paramount, and the companies that succeed in the new era will be those that are nimble, creative, and have fingers on the pulse of the customers.

Lab-Corps to Be Housed at NREL, Help Transfer Innovations to Market

Hannegan invited Forum attendees to partner with NREL and the ESIF to learn how their devices will meld with the energy system of the future. And, new Energy Department programs like Lab-Corps will help accelerate the transfer of high-impact clean energy technologies from the national laboratories into the commercial marketplace. Lab-based teams will gain direct market feedback on their technologies and help develop startups, as well as industry partnerships, licensing agreements, and other opportunities. Part of the programs' funds will pay for a competitive process for choosing the best ideas and for work at the labs at crucial times in the products' development.

"The national laboratories are science and engineering powerhouses," Danielson said. In support of President Obama's Lab-to-Market Initiative, the Lab-Corps program encourages the entrepreneurial spirit of the national labs to bring new technologies to the market to advance America's leadership in clean energy. "These are exactly the kind of new, innovative ideas we need to build and expand if we are going to get to where we need to go."

NREL will leverage its deep expertise in technology commercialization and the cleantech sector to develop, deliver, and manage the Lab-Corps training program across the laboratory sites. Over the next year, NREL and the five satellite labs will assemble, train, and support entrepreneurial teams to identify private-sector opportunities for commercializing promising sustainable transportation, renewable power, and energy-efficiency technologies at the labs. Each Lab Corps team will receive comprehensive training and access to a suite of commercialization resources, including technology validation and testing, facility access, techno-economic analysis, and other incubation services.

$10 Million Wells Fargo Initiative Will Boost Clean Energy Ideas

Also at the Forum, Wells Fargo presented a $10 million check to NREL for the launch of its Innovation Incubator (IN2) program, which aims to foster the development of early-stage clean technologies for commercial buildings.

"Due to pervasive market barriers, private-sector financing is typically limited or unavailable to bring new energy innovations from early-stage laboratory research to proof-of concept prototype and on to full commercial scale," said Richard Adams, director of NREL's Innovation & Entrepreneurship Center. "This leads to market 'gaps' that prove too difficult for many early-stage companies to overcome, which often ultimately results in promising technologies falling to the wayside. We are hoping to address these barriers to benefit small companies, our communities, and the economy."

The first list of IN2 participants will be announced early next year; they will receive research and technology support, as well as help with their business plans, from the experts at NREL.

Companies Attending Forum Have Raised More Than $5 Billion

The Wells Fargo/NREL partnership is just another example of how NREL is supporting the burgeoning cleantech industry. Since 2003, the early-stage, pre-commercial, and expanding cleantech companies that have presented or networked at the annual Forum have collectively raised more than $5 billion in growth financing.

NREL's Deputy Laboratory Director for Strategic Programs and Partnerships Bobi Garrett said: "What is so gratifying about putting on this Industry Growth Forum each year is the consistent feedback we get from the investors that the entrepreneurs and presenters are doing a really great job. The quality of companies that come to this event is really outstanding."

— Bill Scanlon (November 14, 2014)

NREL Uses Industry Best Practices to Add Partners

The Energy Department's National Renewable Energy Laboratory (NREL) is accelerating the availability of next-generation energy efficiency and renewable energy technologies in the marketplace by making it easier for industry partners to work with the laboratory.

Thanks to a commercialization strategy that focuses on innovation and partnering, NREL is one of the leaders in the Energy Department's national laboratory complex when it comes to transferring technologies to the market. In fact, NREL has more cooperative research and development agreements (CRADAs) than any other national laboratory (in Fiscal Year 2013, NREL boasted 166 active CRADAs and 28 new CRADAs).

"NREL is uniquely situated to partner to get technologies to market because of the agility, impact, and creativity found in our science and technology organizations and our partnering approaches," Associate Laboratory Director Bill Farris said.

For a laboratory that works on anywhere between 600 and 700 active agreements each year—many of those with repeat customers who have more than one active agreement with the lab—it's important to continuously improve and update the process and mechanisms for working with partners and making market impacts with innovative technologies.

Partnering Leads to Great Things

One example of an NREL technology making impact is the laboratory's transpired solar collector (TSC) technology, which was licensed to GeoSolarHeat in 2013. The company is using the technology to help cure and dry out ground litter for commercial poultry farms as well as heat the coops in colder months. TSCs provide heat from the sun, reducing propane and natural gas use to maintain minimum temperatures required for proper growth. Up to 95°F heat is needed during the poultry growth cycle. Heating fuel is the grower's biggest expense, but more importantly TSCs' free heat can allow the grower to bring in more fresh air, which reduces humidity and ammonia levels. High ammonia levels stunt bird growth, causing higher feed costs and less production per year. GeoSolarHeat believes TSC heat (up to 150°F) can mean downtime reduction up to 50%, giving growers more production days per year, lower costs, healthier birds, and increased profits.

"The big benefit to all this is more production with lower feed and fuel costs," GeoSolarHeat CEO John Wolf said. "There are tremendous energy savings here, reduced ammonia, and

Thanks to a commercialization strategy that focuses on innovation and partnering, NREL is one of the leaders in the Energy Department's national laboratory complex when it comes to transferring technologies to the market. Here, David Seivers, NREL biochemical engineer, left, and Erin Fetsch, senior scientist for Cobalt, oversee Cobalt's demonstration of its advanced biocatalyst production of butanol at NREL's Integrated Biorefinery Research Facility. *Photo by Dennis Schroeder, NREL 20211*

happier and better quality birds. We pair our patent-pending monitoring and control system with NREL's TSC technology to constantly read data from multiple sensors (sunlight, temperature, humidity, carbon dioxide, ammonia, motion, and sound and video) and control fans, dampers, and vents to optimize heat and provide readings and alerts to growers."

In a partnership recently honored with and R&D 100 award, NREL has teamed with Hewlett-Packard (HP) and Intel to develop the innovative warm-water, liquid-cooled Peregrine supercomputer at the laboratory's Energy Systems Integration Facility (ESIF). The HP Apollo liquid-cooled supercomputing platform provides the foundation for numerical modeling and simulations, which allow scientists to gain new insights into a wide range of topics. With NREL's high performance computing (HPC) data center, 90% or more of the computer's waste heat is captured and reused as the primary heat source for ESIF offices and laboratory space.

"When industry and NREL work closely together, great things happen," Farris said. "By partnering with NREL, commercial entities, along with other manufacturers, industry partners, and clean energy sector representatives, are able to reduce the risk of bringing innovative technologies to market faster and with more success."

Pilot Agreement Leading to More Partnerships with Industry Partners

NREL is making the partnership agreement process easier by serving as a pilot for using DOE's newest agreement type: the Agreement to Commercialize Technology (ACT). NREL is one of six national laboratories currently piloting the use of ACT, which was created to address requests by industry for flexibility in partnership agreement terms beyond what is available under a CRADA or work-for-others (WFO) agreement.

Anne Miller of NREL's Technology Transfer Office noted two of the most recent agreements with NREL developed out of opportunities that would most likely not have been available if ACTs were not an option.

Because ACTs are aligned with industry practices in areas such as intellectual property rights, indemnification, and payment issues, these agreements allow national laboratories such as NREL to more easily negotiate contract terms with potential partners to accommodate unique organizational requirements or project needs.

"For example, a company may need special provisions to address participation by multiple organizations or expectations regarding project performance," Miller said. "ACTs allow us to negotiate terms with much more flexibility than the standard agreement types and also allow us to pursue some opportunities we might not otherwise have been able to pursue."

Under NREL's first ACT, the lab will supply technical services to the International Renewable Energy Agency (IRENA), an intergovernmental organization that supports countries in their transition to a sustainable energy future. Signed on March 7, 2014, IRENA's ACT with NREL outlines how the laboratory will develop computer code for IRENA's geospatial data interface of the Global Atlas for Renewable Energy, which will support renewable energy technology project development, planning, siting, and feasibility analysis.

NREL's second ACT was signed with the Children's Investment Fund Foundation (CIFF), which aims to improve the lives of children in developing countries through impactful and sustainable projects. Under this agreement, NREL will provide technical support and regulatory assistance to the Mexican federal government to help it implement power system reform. NREL will conduct analytical research on specific topics related to climate and air quality and assist Mexico in developing best practices for utilities, grid operators, and regulatory and policymaking communities to support the implementation of clean energy technologies in Mexico.

Future opportunities for ACTs at NREL could include partnerships with other international organizations with complementary missions, non-government organizations, utilities, regulatory agencies, state and local governments, and even multi-party partnerships (for example, if a consortium of companies wants to work with NREL on the same project). Currently NREL has a range of agreements, including ACTs, in 43 states, as well as 31 foreign countries.

Because of the IRENA and CIFF ACTs, NREL is not only furthering the Energy Department's mission but learning to become more nimble in how it does business.

"Like all partnerships, we learn from this," Miller said. "It keeps us relevant to our industry partners and helps us better understand their needs."

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>
> — **BILL FARRIS,** *NREL Associate Laboratory Director for Innovation, Partnering, and Outreach*

Streamlined Licensing Means More NREL Technologies Hitting the Market

In addition to serving as a pilot institute for new agreement types like ACTs, NREL has been increasing the speed and scale of its commercialization efforts over the past several years. The lab has pioneered several industry-leading improvements to processes, licensing agreements, and tools that make it easier to identify and license innovative technologies.

In an effort to meet a 2009 goal of tripling the number of innovations over 5 years, NREL has streamlined its licensing agreement process and refined the lab’s licensing agreement template to make it easier for industry partners to access Energy Department-funded innovations developed at NREL.

“This has really been an ongoing, concerted effort,” NREL Senior Licensing Executive Eric Payne said. “When we began this effort, we engaged with the Energy Department’s Technology Transfer Working Group to conduct a comparative analysis on the types of licensing agreements and best practices used across the national laboratory space and academia, and identified four key areas that NREL could improve on. These changes have better positioned NREL to be in line with industry best practices.”

The process of identifying licensing best practices and attempting to standardize those best practices across all of the Energy Department’s national laboratories resulted in the publication of the Department’s Licensing Guide , which describes a “typical” Energy Department laboratory intellectual property (IP) license agreement in an effort to provide prospective licensees with an understanding of the terms and conditions found in most national laboratory IP license agreements.

“NREL was a big part of this effort,” NREL Technology Transfer Office Director Kristin Gray said. “The Licensing Guide does a wonderful job explaining each term of a license and its function. We hand it out to potential licensees for guidance on a regular basis.”

In addition to the improvements to the lab’s licensing agreements, NREL also developed the “Invention Evaluator” to assess new NREL innovations across eight parameters, which ultimately provides a dynamic “score” by factoring in elements of the innovation’s patentability, commercial impact, and licensing potential.

“We’ve thought a lot about the standard evaluation used for nascent energy technologies,” Payne said. “The problem we see in the marketplace in general is that if you don’t know how to pick the winners, you file for patent protection on everything, and we don’t want to do that.”

This standardized evaluation allows NREL to “prioritize the innovations coming out of $350 million of research to pick the ones with the highest impact on the Energy Department’s Office of Energy Efficiency and Renewable Energy’s mission space as well as the clean energy landscape,” Payne said.

“The process of choosing a technology to patent and ultimately license can never be foolproof,” Gray added. “It’s a notoriously complex process that you have to go through by gut instinct. We’ve helped give more rigor to it by providing some explicit parameters.”

NREL has developed a searchable database of more than 10,000 Energy Department patent records to identify bundles of complementary IP across the national laboratory system. This represents the first-ever functioning tool to bundle IP within the national laboratories—and NREL continues to interface with other laboratories to post bundled marketing summaries on the Energy Innovation Portal.

— Devin Egan (July 28, 2014)

WIND

NREL's experienced staff, unique research capabilities, and specialized state-of-the-art equipment provide industry partners and stakeholders with technical support from the design table to the marketplace for wind technologies. *Photo by Dennis Schroeder, NREL 31413*

NREL Software Tool a Boon for Wind Industry

Wind energy is blowing away skeptics—it's so close to achieving cost parity with fossil fuels that just a little extra efficiency is all that is likely needed to push it into the mainstream and past the Energy Department's goal of 20% wind energy by 2030.

That extra efficiency may be realized with the help of a software tool built by the Energy Department's National Renewable Energy Laboratory (NREL). It's called Simulator for Wind Farm Applications (SOWFA), and it can calculate how undulating ground, whipping blades, surface temperatures, and other variables alter the air flow and energy production at wind farms.

SOWFA's key innovation is that it simulates an extensive range of scales—from regional weather patterns down to the space between turbines and all the way to the movement of electrons. It gives a complete picture of an active plant, showing how controlling each turbine can influence the direction of the wakes, and detecting the effect on downwind turbines. And it helps researchers understand how local atmospheric conditions affect local wind around the wind farm.

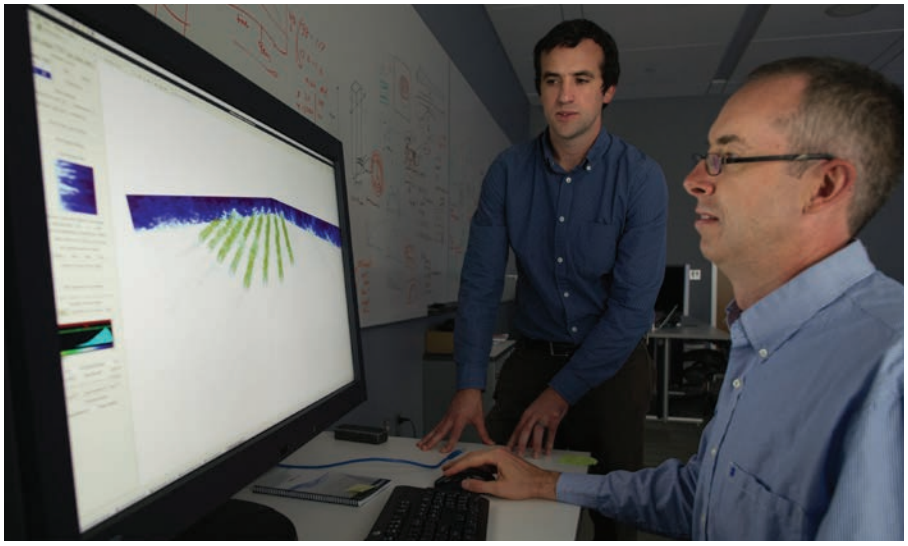
SOWFA is the first tool that enables developers to improve the performance of not only one wind turbine, but the entire wind farm. And because it is an open-source "community" software platform available for free to academics, investors, wind developers, and manufacturers, users have the support of an online forum where they can discuss problems and solutions with other SOWFA users.

One application of SOWFA is the simulation and design of coordinated control of individual turbines in order to maximize plant-wide output. Using these controllers, upstream turbines can yaw their rotors to redirect their wakes away from downstream turbines, substantially improving power capture. Wake losses at wind farms can reduce total power production by 10%. If SOWFA can be used to design controllers that cut those losses in half, that's a huge benefit. If employed at wind farms across the country and the world, the additional revenue could add up to billions of dollars.

SOWFA Simulates Wake Effect for Turbines Downwind

Across the Great Plains and at many spots offshore, if you see one wind turbine, you're likely to see a dozen or a hundred. A wind farm provides economies of scale—contract with a farmer or win a permit for offshore wind, and it makes sense to erect multiple turbines all tied to a single system.

However, those rows of giant turbines can be problematic. As the turbine's blades are turned by the wind, they also disrupt the wind, causing a wake similar to a calm spot behind a tree



NREL Senior Engineer Paul Fleming, left, and NREL Senior Engineer Pat Moriarty review wind farm data in SOWFA. SOWFA can simulate and design coordinated control of individual turbines in order to maximize plant-wide output. *Photo by Dennis Schroeder, NREL 31411*

> “In the past, wind farms have relied on dissipation to control that energy loss—they just move the turbines farther away from each other. Now, we can control it in a different way. And there are other ways to achieve more control.”
>
> —**PAT MORIARTY,** *NREL Senior Engineer*

or building. If that wake heads straight for the next turbine downstream—maybe 800 meters away—its churn will mean weaker wind and less power produced by that second turbine.

But SOWFA shows turbine manufacturers, wind farm developers, or investors how a yaw can impart a thrust that curves that wake around the downwind turbine. “Wake, from a power perspective, is lower-energy wind,” said NREL Senior Engineer Paul Fleming, one of the engineers using SOWFA in his research. “If you can move away that deficit of energy, you will have faster winds and more overall production at the wind farm.”

“In the past, wind farms have relied on dissipation to control that energy loss—they just move the turbines farther away from each other,” said NREL Senior Engineer Pat Moriarty, a leader of the SOWFA team. “Now, we can control it in a different way. And there are other ways to achieve more control.”

SOWFA was created to model all the different variables at a wind farm—the topography, the air, surface and air temperatures, even the effects of the turbines themselves. Other models have looked at pieces of the whole, but now that the wind industry is maturing and the cost margins are decreasing, it’s increasingly important to model the whole system and maximize energy production.

Turbines and Central Controller Talk to Each Other

With SOWFA, the central super-controller can receive information from individual turbines and send command messages to them. In other words, the central controller and the turbines can talk to each other. SOWFA’s central controller can send a message asking a turbine to adjust its yaw—but the turbine can override that command if conditions at the turbine are such that adjusting the yaw would be unsafe. This architecture is designed to mimic as closely as possible how wind plant controls might be implemented at a real wind farm.

Another reason SOWFA is unique among wind modeling tools is that it has the capacity to incorporate the heat on the earth’s surface into its calculations. The sun is the main reason that air moves. It causes different air temperatures and pressures, coaxing the wind in a particular direction at a particular speed and at different heights above the ground. The varying temperature of the ground and the hills and vales of the farm also influence how the wind moves through the atmosphere. In the daytime, when the ground is hot, the wind tends to be more turbulent, rising from the surface. At night, when the ground is cooler than the air, the wind becomes more horizontal and speeds up. The same rules apply offshore, except instead of the ground there is the water surface, and instead of hills and vales, there are the size and motion of the waves.

The software tool also can deliver the numbers to show a possible overall net benefit if that first row of turbines reduces the capture of wind so the second row can capture more.

Reducing Uncertainty Can Lower Financial Risk, Interest Rates

SOWFA has drawn acute interest from manufacturers, developers, and utilities. “One of the most important outputs of SOWFA is the reduced uncertainty,” Moriarty said. “The finance community cares not just about energy production, but about the uncertainty of energy production over the next 20 years that wind farm would be operating. They particularly want to know what the worst-case energy production can be.”

SOWFA’s improved look at physics will help the community better understand the uncertainty gap between the average energy production and the worst-case energy production. That, in turn, should lower the interest rates for financing a wind farm, which can be a huge part of the total cost.

Supercomputers Make the Modeling Possible

Supercomputers made SOWFA possible, said Moriarty, noting that he and his NREL colleagues started work on the project in 2005, but that its success accelerated as computers reached the ability to do trillions of calculations per second. To accurately predict the motions of wind at a wind farm, computers need to simulate the dynamics in the space occupied by up to a hundred turbines—and model the flows, counterflows, cross flow, and temperatures in every square meter.

Of course, the goal is to arrive at the most accurate forecasts of wind energy production before the turbines are erected. Moriarty, Fleming, and the rest of the team use NREL's Peregrine high performance computer to simulate the movement of air through rows of turbines.

Understanding the dynamics of a wind farm means analyzing the effects of everything from clouds to rises and dips in the terrain, and even the height of surrounding crops.

Researchers can use SOWFA to study how new control schemes can increase power production and reduce fatigue from wake effects, and developers can use SOWFA to move turbines like chessmen on a chess board to maximize output—all before construction begins.

The Energy Department, which provided funding for the SOWFA project, is in the process of developing experiments to test that the modeling predicted by SOWFA matches real-life conditions and energy output at the wind farms.

— Bill Scanlon (September 29, 2014)

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> **— PAT MORIARTY,** *NREL Senior Engineer*

NREL Senior Engineer Pat Moriarty, left, explains a wind turbine model at the ESIF Insight Center to Secretary of Energy Ernest Moniz, right, during a tour for the dedication of the ESIF. *Photo by Dennis Schroeder, NREL 27476*

°C – Celsius

°F – Fahrenheit

ACT – Agreement to Commercialize Technology

AFDC – Alternative Fuels Data Center

ARPA-E – Advanced Research Projects Agency – Energy

CEO – Chief executive officer

CIFF – Children's Investment Fund Foundation

CRADA – Cooperative Research and Development Agreement

CSP – Concentrating solar power

CU – University of Colorado

EERE – Office of Energy Efficiency and Renewable Energy

ESI – Energy systems integration

ESIF – Energy Systems Integration Facility

FCEV – Fuel cell electric vehicle

HP – Hewlett-Packard

HPC – High performance computing

IGF – Industry Growth Forum

IN2 – Innovation Incubator

IP – Intellectual property

IRENA – International Renewable Energy Agency

JEDI – Jobs and Economic Development Impact

LDRD – Laboratory Directed Research & Development

LEED – Leadership in Energy and Environmental Design

NREL – National Renewable Energy Laboratory

NSF – National Science Foundation

PEM – Polymer electrolyte membrane

PGE – Portland General Electric

PV – Photovoltaic(s)

R&D – Research and development

RPP – Research Participant Program

RSF – Research Support Facility

SOWFA – Simulator for Wind Farm Applications

SWCNT – Single-wall carbon nanotube

SULI – Science Undergraduate Laboratory Internship

STEM – Science, technology, engineering, and mathematics

TSC – Transpired solar collector

UC – University of California

USGBC – U.S. Green Building Council

UW – University of Washington

WAPA – Western Area Power Administration

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NREL is a national laboratory of the U.S. Department of Energy
Office of Energy Efficiency and Renewable Energy
Operated by the Alliance for Sustainable Energy, LLC

NREL/MK-6A42-63823 • March 2015

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