NREL: A YEAR IN CLEAN ENERGY INNOVATIONS

A Review of NREL's 2013 Feature Stories

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

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.

Cover photo by Dennis Schroeder, NREL 26174

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INTRODUCTION

The Energy Department's 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 the Energy Department'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 2013. The feature stories can be found online at 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 27743


EAGLE
GOODYEAR

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 19931

Biomass Analysis Tool Is Faster, More Precise

A screening tool from the Energy Department's National Renewable Energy Laboratory (NREL) eases and greatly quickens one of the thorniest tasks in the biofuels industry: determining cell wall chemistry to find plants with ideal genes.

NREL's new High-Throughput Analytical Pyrolysis tool (HTAP) can thoroughly analyze hundreds of biomass samples a day and give an early look at the genotypes that are most worth pursuing. Analysis of a sample that previously took two weeks can now be done in two minutes. That is potentially game changing for tree nurseries and the biomass industry.

When it comes to making fuels out of trees, crops, grasses, or algae, it's all about the cell walls of the plants. Will they make it hard or easy for enzymes to turn the biomass into sugars? Differences in cell walls are enormous, and choosing the right ones can make the difference between a profit and a loss for tree growers, or between a fruitful or fruitless feedstock line for biomass companies.

Finding that particular species, or that individual tree, that has the genetic markers for the optimal biofuel candidate has heretofore been laborious and painstaking.

The Energy Independence and Security Act requires that the United States produce 21 billion gallons of non-corn-based biofuel by 2022. The market for biofuels is expected to grow steadily between now and then. Market analysts say the successful companies will be those that can steer their enzymes through the cell-wall structures in the easiest and most cost-effective ways, including by making changes in the structures themselves.

Tool Can Pinpoint Phenotypes

To find out the chemical composition of the cell walls, companies have to sample large quantities of biomass, whether it's switchgrass, remnants of corn stalks, fast-growing trees, or algae.

The traditional strategy had been a multistep approach involving sample dissolution and chromatographic analysis, which can determine what the tree is composed of—but at the cost of disintegrating the sample.

NREL developed an approach using pyrolysis, analyzing the vapor from the samples produced by heat in the absence of oxygen, which is called high-throughput analysis pyrolysis, or HTAP. Pyrolysis destroys the sample, but the sample is

This tray of 80-milliliter samples was taken from a standard poplar tree, such as the one pictured here. It is ready to be loaded into NREL's molecular beam mass spectrometer for rapid analysis of the cell wall chemistry of each sample. *Photo by Dennis Schroeder, NREL 20223*

tiny—four milligrams for the pyrolysis approach versus 10 grams for the traditional approach.

Difference in Signal Intensity Identifies Gene Manipulations

The lignin in a plant is crucial for its development and insect resistance, but it can stand in the way of enzymes that want to get at the sugars locked up in the carbohydrates. It's the deconstruction of the raw sugars that produces the sugars the biofuels industry finds valuable.

Lignin is a big molecule. Heating it up in the absence of oxygen—pyrolysis—breaks it down into smaller fragments that can be read by a molecular beam mass spectrometer.

The ratios of lignin to carbohydrate components, together with the intensity of the lignin peaks, can tell a scientist how easily a plant will give up its sugars.

HTAP integrates a molecular beam mass spectrometer with the pyrolysis unit to quickly determine chemical signatures (phenotypes) on small amounts of biomass samples that can be used for, among other things, identifying the genes controlling the chemical makeup.

Samples drop into the oven, where the pyrolysis creates a vapor that is read by the mass spectrometer—a chemical fingerprint. The auto-sampler quickly moves the samples into place and back out again, so the measurements can be taken every couple of minutes or so. Combining the HTAP chemical phenotypes with information such as genetic markers can signal there is a gene nearby that controls those chemical phenotypes—for better or worse.

HTAP can potentially reduce the amount of energy needed for ethanol production, said NREL's Mark Davis, principal investigator on the HTAP project. And that would make a huge difference in the marketplace.

NREL's Tool Combines Precision and Speed

The path toward an ultra-fast, ultra-sophisticated screening tool went through ArborGen, one of the nation's largest tree seedling suppliers. "They sent us some samples and asked, 'What can you tell us about them?'" Davis said.

Turns out, it was a lot more than ArborGen expected.

"We put the samples in our mass spectrometer, which looked at their genetic transformations and the associated cell-wall chemistry changes," Davis said. They discerned dozens of changes in transgenic biomass samples, each slight genetic tweak corresponding with a slight difference in the amount of lignin in the sample.

NREL was able to tell ArborGen that one sample had, say, half the lignin of another sample. "We were giving them information in a week that it took a month or two for them to get somewhere else," Davis said. "Not only that, but we were getting better information and greater chemical specificity and resolution than they had seen before."

An Explosion in Demand for Quick Sampling

NREL had previously partnered with scientists from Oak Ridge National Laboratory, the University of Florida, and the University of California, Davis, to demonstrate that the HTAP method could combine with genetic information to identify genetic markers associated with cell wall chemistry traits. NREL's pyrolysis combined with a mass spectrometer was a big improvement over the old method of using wet chemistry to analyze, but the approach wasn't nearly fast enough to meet demand.

It still took a week to analyze samples from just 250 trees. "We were doing everything manually in a heated furnace," Davis said. "A single person would stand there all day feeding in samples." Even with this approach, the method that would soon evolve into HTAP identified numerous genetic markers associated with cell wall chemistry and provided greater chemical specificity and resolution than had been available before.

So, NREL used money from its internal general purpose equipment account to buy an auto-sampler, the final piece in the goal of combining automation, pyrolysis, spectrometry, and speed. NREL's partners in the project include Extrel CMS, which worked with NREL to design and fabricate the molecular beam mass spectrometer, and Frontier Laboratories, which provided the pyrolysis instrument.

NREL scientists integrated the autosampler, pyrolyzer, and molecular beam mass spectrometer to make HTAP. Other partners using NREL's rapid analytical tool for fuel research, besides ArborGen, are the University of Florida, the University

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> — **MARK DAVIS**, *NREL Principal Investigator for HTAP*

of Georgia, Greenwood Resources, the BioEnergy Science Center, and Oak Ridge National Laboratory.

Spectrometer Reads the Chemical Fingerprints of the Samples

The spectrometer's readings are translated into graphs that show single peaks that are easily identifiable phenotypes from which the scientists can infer information about the cell walls. Know the genes associated with the traits, and you gain the ability to manipulate the cell wall to your advantage.

"HTAP provides the information that, combined with other genetic information, tells us there's a gene controlling the plant's cell wall chemistry located somewhere on this chromosome—at the same location every time," Davis said. "Our partners have genetic markers for 1,000 trees and can pinpoint the gene that has an effect on lignin content, cellulose content, or some other factor affecting recalcitrance (the plant's resistance to give up its structural sugars). With that information, the partners can go back and find a tree in the natural population with similar genetic traits or use genetic transformation to introduce the desirable traits."

The data from the chemical makeup is averaged and generated in real time. "If we know what each of these peaks are related to, we can tell what has changed with each sample," Davis said. For example, the ratio of two types of lignin—guaiacol and syringol, or G and S—speaks volumes about how much trouble enzymes will have getting to the cellulose in a particular plant.

"In four minutes, you can look at the spectrum and see that this sample reduces lignin by half—because the S to G ratio has changed by a factor of two," Davis said. Meanwhile, the auto-sampler has already put another sample in place and is ready for a third. "That's information that prior to this would take two people two weeks to acquire."

The speed at which HTAP can analyze samples has launched a new niche market for the tiny cups arrayed on trays that accept the samples. "People send us thousands of samples at a time," Davis said. Now, NREL simply sends universities and companies the large trays of cups. The cups are filled with the samples. Glass fiber disks are used to hold the biomass samples in the cups, which are then sent back to NREL. Quickly sending cups and samples back and forth has slashed the cost of one of the most expensive steps in the process: sample preparation.

Tool Can Detect Minute Differences

HTAP has demonstrated extreme powers of discernment. Growers can determine that some of those identical-looking trees are actually a bit different. Using the information that is provided by HTAP, researchers and breeders can determine what genes in the cloned trees are responsible for the advantageous biofuel potential. And biologists then can graft a desirable cell-wall trait onto a new line of trees.

"We've phenotyped tens of thousands of samples so far," Davis said. "The tool provides a detailed comparison of hundreds of samples a day. Any biomass feedstock type being used for serious biofuels production—chances are, we've tested it."

— Bill Scanlon (February 26, 2013)

NREL Drives Toward the Future with Fuel Cell EVs

Efforts currently underway at the Energy Department's National Renewable Energy Laboratory (NREL) are contributing to rapid progress in the research, development, and testing of hydrogen and fuel cell technologies.

Building from more than 10 years of support from the Department's Fuel Cell Technologies Office on these topics, NREL has received four Fuel Cell Hybrid Vehicles—Advanced (FCHV-adv) on loan from Toyota. These vehicles will help NREL enhance its research capabilities related to hydrogen fueling infrastructure, renewable hydrogen production, and vehicle performance.

Zero-Emission Fuel Cell Vehicles are Rapidly Evolving

The Toyota vehicle represents another step toward the commercialization of fuel cell electric vehicles (FCEVs). Hydrogen fuel is most often produced using domestic resources and can also be produced using clean renewable energy technologies. When hydrogen is used to power an FCEV, the vehicle has zero tailpipe emissions.

The fuel cells in the Highlander FCHV-adv are representative of the FCEV designs being demonstrated today by automobile companies around the world, making this design an excellent platform for NREL's research activities. Toyota also plans to introduce an FCEV sedan to the U.S. commercial market in 2015.

The zero-emission FCHV-adv, based on a mid-size sport utility vehicle (SUV) platform, has an expected driving range of 325 miles and a fuel economy estimated at 60 miles per gallon of gasoline equivalent (GGE). GGE is a method for measuring the fuel economy of alternative fuels compared to gasoline and represents the amount of an alternative fuel equal to the energy in one liquid gallon of gasoline.

The vehicle is powered by a fuel cell system with light weight, high-pressure hydrogen tanks, an electric motor, a nickel hydride battery, and a power-control unit that determines the split of power from the battery or fuel cell stack to power the vehicle.

NREL to Explore Wide Research Platform

The four FCEVs, on a two-year loan from Toyota as part of a Cooperative Research and Development Agreement (CRADA)

An NREL employee test drives one of the Toyota Highlander fuel cell hybrid vehicles at the lab's Fuel Cell Hybrid Vehicle Ride and Drive Event. The event was part of Earth Week festivities at NREL. *Photo by Dennis Schroeder, NREL 25255*

> "These vehicles are emission free, but in most scenarios you still have emissions during the hydrogen production. If you can make the hydrogen using renewable resources you have the potential for this to be a truly zero-emission fuel source. We're pleased to have the opportunity to further investigate this potential."
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with NREL, will be put through a wide platform of testing and analysis at the lab. The vehicles were originally deployed in California in 2009 and have been redeployed to NREL as part of this CRADA.

"We're looking at the whole system—from renewable hydrogen production and vehicle fueling equipment to the impact of driving patterns and behavior on vehicle performance," said Keith Wipke, NREL Laboratory Program Manager for Fuel Cell and Hydrogen Technologies. "Because the vehicles will be four or five years old by the time our loan period ends, we will be able to observe extended durability and reliability, which are critical to the commercial success of these types of vehicles."

Testing will include observing how the vehicles interact with fueling infrastructure and fueling stations that operate at different pressures. While most hydrogen is currently produced from natural gas, at NREL, the vehicles will be fueled with renewable hydrogen made from wind and solar energy as part of the Wind-to-Hydrogen project at the lab's National Wind Technology Center. This project uses wind turbines and solar arrays to power electrolyzers that split water into hydrogen and oxygen.

"These vehicles are emission free, but in most scenarios you still have emissions during the hydrogen production," Wipke said. "If you can make the hydrogen using renewable resources you have the potential for this to be a truly zero-emission fuel source. We're pleased to have the opportunity to further investigate this potential."

Other tests will investigate how drivers interact with the vehicles and influence performance over the test period. Researchers will look at the effects of environment and driving patterns on the vehicles' energy storage and propulsion systems, and demonstrate the vehicles operational capability in real-world activities.

On behalf of the Energy Department, NREL is also planning public outreach and education efforts to better prepare the market for the deployment of these types of vehicles. NREL will offer first-hand exposure to hydrogen and fuel cell vehicle technologies to a variety of audiences, including the general public, academia, and the automotive industry.

Getting Ready for Our Transportation Future

FCEVs use hydrogen, stored in high-pressure tanks made of carbon fiber resin, which is fed to the fuel cell stack where it combines with oxygen from the air. The electricity produced by this chemical reaction is used to power the electric motor and charge the battery.

"For someone like myself who is not an electrochemist, it's truly a fascinating technology," Wipke said. "Hydrogen atoms interact with a membrane coated with small amounts of platinum, which splits the hydrogen into protons and electrons. The protons pass through the membrane, and the electrons go around a different path and do the useful electrical work. Eventually, they meet on the other side with oxygen from the air, and form water, which along with a little heat is the only byproduct of the process."

Fuel cell technologies and the use of hydrogen as a transportation fuel are becoming more visible as automotive manufacturers move these concepts closer to market.

But while these fuel cell technologies are proven and effective, there are still challenges in deploying them, particularly in

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terms of reducing cost and increasing durability. NREL’s long-term durability testing for FCEVs will provide important data toward solutions to these two interrelated challenges.

Another significant issue with deploying these technologies is the need to develop infrastructure around hydrogen production, delivery, and fueling stations.

“We need a lot of infrastructure in place for FCEVs to have widespread consumer acceptance,” Wipke said. “Most hydrogen fueling stations use delivered hydrogen instead of on-site production. That is the most economical pathway right now, but with our capabilities here at NREL we are able to fully explore the opportunities for on-site production.”

Despite the challenges, Wipke sees a strong future for the FCEV technology.

“Most automakers are committing to get to market with these vehicles before this decade is out. That is encouraging,” Wipke said. “The biggest reasons that they are so excited about this option for the future is that range and refueling time are not a concern compared to other new transportation technologies. This makes it a potentially very consumer-friendly transportation technology, one that will function much like what drivers use today.”

“It’s an exciting opportunity to help move these technologies forward, and we’re pleased to have an important role here at NREL.”

— David Glickson (June 21, 2013)

Wood-Boring Gribbles Intrigue Researchers

Tiny wood borers known colloquially as gribbles make their own enzymes and use them to eat through docks in harbor towns, earning enmity from fishermen all around the world.

Now, researchers from the Energy Department's National Renewable Energy Laboratory (NREL) and elsewhere are exploring whether that curse can be turned into a blessing for the biofuels industry.

The trouble with gribbles—that they can break down biomass into sugars even in harsh environments—might become the great thing about gribbles, as the industry searches for enzymes that can thrive in salt-rich, high-solids settings.

Gribbles (scientific name: *Limnoria quadripunctata*) are 1 to 3 millimeters long and have an organ called the hepatopancreas that extends almost the entire length of their bodies. This organ is where gribbles make their own enzymes. In other words, they don't rely, as termites, cows, and humans do, on the organisms that find their way into their stomachs to aid in digesting the food they eat.

The gribble enzymes also hold promise of tolerating salts better than other enzymes, likely due to the fact they evolved in a marine environment. These unique properties could teach biomass researchers how to make better enzymes that operate in a high-solids industrial environment, breaking biomass down more effectively into sugars, which can then be converted into ethanol or a renewable fuel to replace gasoline, diesel, or jet fuel.

And that could make the conversion of biomass to fuel both quicker and cheaper, say biofuels researchers from NREL, the University of Kentucky, and the Universities of York and Portsmouth in the United Kingdom. These scientists collaborated on a recent paper describing the crystal structure of a key enzyme produced by the gribble. The report was recently published in the Proceedings of the National Academy of Sciences of the United States of America. Britain's Biotechnology and Biological Science Research Council (the BBSRC) is funding the work by U.K. researchers. The Energy Department is funding the work by U.S. researchers.

A gribble is a tiny wood borer that produces its own enzyme that can devastate wood efficiently. Researchers hope that by studying gribbles they can learn ways to improve the process of turning biomass into liquid fuels. *Photo from Laura Michie, University of Portsmouth, United Kingdom*

Biofuels Industry Needs Super-Tough Enzymes

The biofuels industry needs tough, efficient enzymes that are tolerant of harsh industrial conditions. NREL Senior Scientist Gregg Beckham, one of the authors of the paper, said gribbles are marine creatures, so the enzymes in the gribbles' guts would seem to naturally thrive in high-salt environments.

Enzymes are typically harvested from fungi because fungi are responsible for most of the biomass degradation in nature. Gribbles live in inner-tidal zones, mango groves, rainforests, harbors, and coves, devouring wood where they find it.

The little wood borers drew extra attention from biomass researchers after scientists from the Universities of York and Portsmouth in 2010 published the exciting news that the gribble produces an enzyme from an important family of cellulases (specifically Family 7 cellulases), that are usually found in fungi.

The gribble, in fact, has three Family 7 enzymes, the workhorses of industrial enzyme cocktails. One of them, dubbed Cel7B, is the subject of the latest paper describing its crystal structure.

"There are striking differences between the gribble enzyme and those derived from the fungi," Beckham said. "We have some suggestions that those differences may teach us a few new tricks in engineering enzymes for enhanced performance in an industrial setting."

Enzyme Thrives in Super Salty Water

The researchers' tests of Cel7B found that it remained active at more than six times the salt concentration of the sea. It even became slightly more effective in its ability to degrade biomass as salt concentration increased, Beckham noted.

"For biomass conversion, industry wants to push up to very high solids, with very little water around. The gribble enzyme has evolved in a harsh, high-solids environment in the gribble gut, so it could very well thrive."

That's important to the bottom line because "the less water you have in the process, the smaller your reactor can be," Beckham said. The smaller the reactor, the more concentrated the sugar product is, and the more money can be saved in a biofuels production plant.

The authors of the scientific paper proposed that the enzyme can teach important things about engineering industrial enzymes for biomass conversion. The Cel7B enzyme may provide clues as to how to design particular features of enzymes for greater stability in industrial settings.

Learning How It Adapts

The work leading to the paper gave the scientists a better understanding of how the organism adapts and survives—and that will be very useful as research on the gribble continues.

The U.K. researchers used X-ray diffraction to solve the structure of the gribble enzyme and biochemical techniques to understand its activity. NREL researchers applied high performance computing to simulate the structure solved by X-ray diffraction to get a dynamic picture of the enzyme.

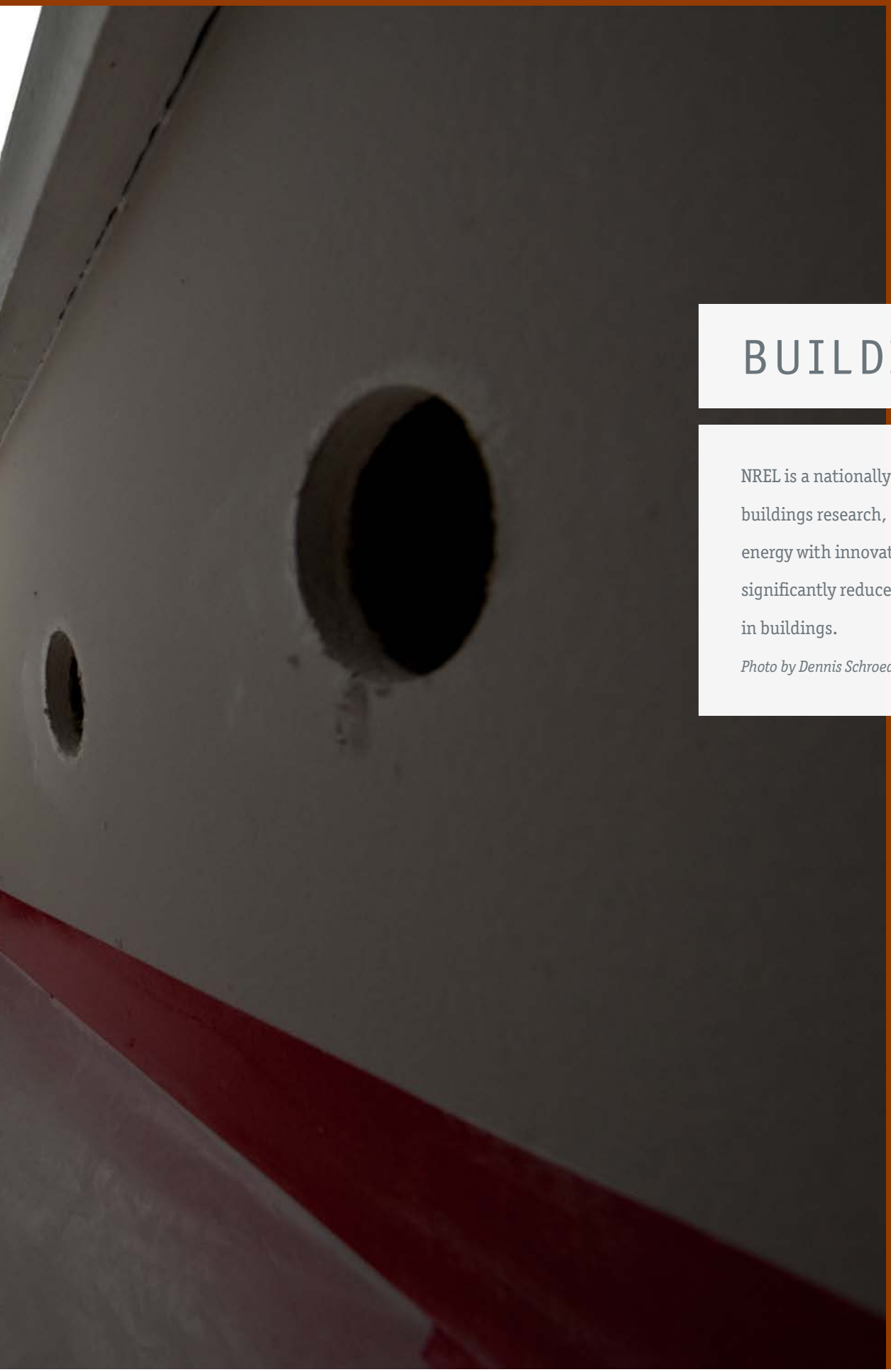
The National Bioenergy Center and NREL's Biosciences Center were a natural fit for the project because among their most important missions is to design new and better enzymes.

Characterizing the gribble enzyme is crucial to understanding it. The knowledge acquired could help in the design of a better enzyme for degrading biomass, leading to a product that could better compete with petroleum.

Combining structural biology with molecular dynamics made it possible to characterize the enzyme at the molecular level, the researchers said. "They work really beautifully together because structural biology gives you a static picture, and molecular dynamics simulations can give you a dynamic picture," Beckham said.

Going forward, the researchers will use high performance computing to compare the gribble enzymes to similar enzymes from fungi. "We will be able to use what we learn to make better predictions about enzyme activity, whether the enzyme can be used directly in biomass conversion or can be modified to be more like fungal enzymes while retaining useful characteristics, such as the ability for some high-solids tolerance," Beckham said.

— Bill Scanlon (July 24, 2013)



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 17969

Architects and Building Engineers Flock to NREL

Eight busloads of architects and mechanical engineers toured one of the world's largest net-zero-energy office building this summer at the Energy Department's National Renewable Energy Laboratory (NREL) and came away inspired with new ideas for how to design and build beautiful, eco-friendly structures on a budget.

Tickets for the tours sold out almost as fast as a Paul McCartney concert, the busloads another reminder of how professionals are embracing high-performance, energy-efficient buildings.

The premier professional organizations for architects and building engineers—the American Institute of Architects (AIA) and the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE)—both held their national conferences in Denver this summer, within a few days of each other.

Denver is just 14 miles from Golden, the site of NREL's main campus and its Research Support Facility (RSF), a 360,000-square-foot office building that Construction Digital Magazine last year named the top net-zero-energy building in the world. A group of NREL engineers including Sheila Hayter, Rachel Romero, and Shanti Pless organized the trips to NREL's campus—and led tours with help from the architects at RNL and SmithGroup JJR and the contractors from JE Dunn and Haselden, who worked with NREL to design and build the RSF and the new Energy Systems Integration Facility (ESIF).

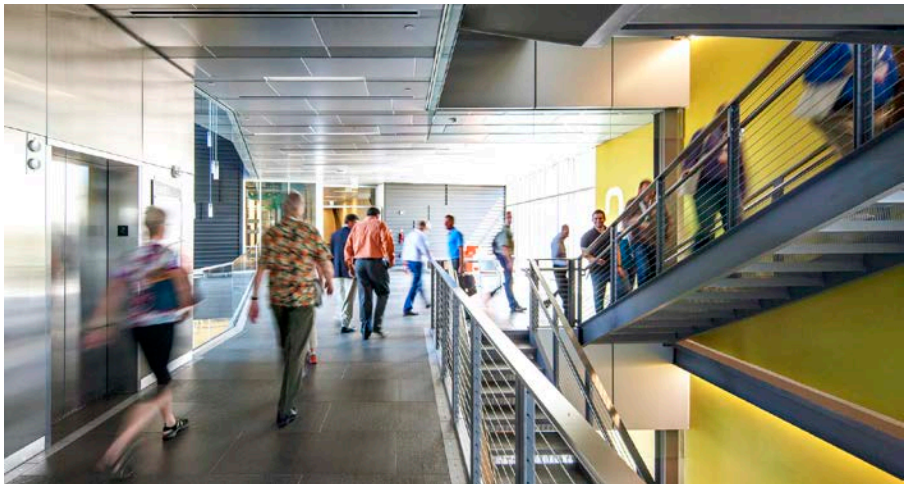
"People were lining up at will call to get tickets to the tour," said Angela Innes, marketing manager for JE Dunn Construction, the main contractor on the ESIF project. "We saw huge interest and got a lot of feedback from architects from all over the world."

The AIA architects and ASHRAE engineers marveled at the energy efficiency and the aesthetics of the RSF, and some dropped their jaws when they learned it was built in 2010 and 2011 for no more than the average square-foot cost—$259—of other office buildings in the Denver area. In addition, the engineers saw that using biomass to heat buildings is a viable option for saving greenhouse gases and viewed one of the most energy-efficient data centers in the world.

NREL Shows High Performance Is Economical

"Designers of commercial buildings are serious about creating energy-efficient buildings," said NREL's Hayter, who chairs ASHRAE's Planning Committee, is a past ASHRAE vice president, and previously served on the steering committee that developed the original charter for ASHRAE's Advanced Energy Design Guideline (AEDG) series that shows the way toward achieving 30% or 50% greater efficiency or net-zero energy.

"The architects visiting NREL were pretty amazed at the design of the RSF. They are anxious to learn how to make



The tour of NREL's Energy Systems Integration Facility (seen here) and Research Support Facility attracted eight busloads of architects and engineers this summer. *Photo from SmithGroup JJR/Bill Timmerman*

energy-efficient decisions with a very limited budget—without sacrificing aesthetics," Pless said. A full-day pre-convention workshop at the AIA conference gave architects the chance to do exactly that: make design decisions with an eye for energy efficiency. The workshop taught them how to use OpenStudio, an Energy Department tool developed at NREL, to evaluate the energy impact of early design decisions such as orientation, massing, fenestration, construction assemblies, and internal building activity. They created baseline energy models and then made what-if alternatives using energy conservation measures pulled from the online Building Component Library, another Energy Department tool developed at NREL.

"We sent 200 of our people to NREL. It was all sold out," said Nicolle Thompson, director of programs and sponsorship for AIA Colorado. "It was extremely popular. There are so many great projects at NREL, and many of our members participated in building that campus. The RSF and ESIF are getting such national recognition. It's not easy to build a net-zero building of that size economically. We wanted to show it off."

Tom Watson, past president of the 55,000-member organization, said ASHRAE depends heavily on NREL and other federal labs for support and collaboration. Watson said NREL employees played a key part in developing the energy-efficiency standards that have been distributed around the world. "It's had a global impact."

"We've built K-12 schools, retail establishments, grocery stores at 30% or 50% better energy efficiency than national standards," Watson added, referring to the AEDGs, of which 500,000 copies have been distributed. "We couldn't have done it without NREL's support. NREL people have been heavily involved in the standards and technical committees leading to future advanced energy designs."

In fact, NREL's Pless has chaired four of the eight ASHRAE committees working to develop the AEDGs. In addition to NREL's leadership with the AEDGs, NREL's Otto Van Geet is a member of the committee to create an energy standard for computer data centers, which by themselves use up 2% of the energy the American economy consumes each year. ESIF has an extremely efficient data center to support its petascale-level supercomputer. At this year's ASHRAE conference in Denver, Van Geet led a session on evaporative cooling, talking about how a building can provide comfort for a fraction of the energy cost of traditional air conditioning. Pless and Van Geet were keynote speakers at the conference, while NREL's Jesse Dean, Ian Metzger, Paul Torcellini, and Michael Deru played leadership roles.

Pressing the Case on a 100-Degree Day

Pless then led many of the NREL visits, walking the engineers and architects out of a 100-degree day into a building that was cool and comfortable without typical air conditioning—employing smart windows, radiant cooling, and a concrete labyrinth in the basement. Radiant cooling in the RSF can keep a space cool even on hot days. On those hot days, the solar panels on the roof generate twice as much energy as the building uses, Pless said. It's only on the coldest days of the winter that more energy is used than is produced.

"Showing off the RSF when it's 100 degrees out, and seeing people functioning and comfortable—and feeling the comfort yourself—that's a big deal," Pless said. "To feel what it's like to be in naturally ventilated buildings with the windows open is something they'll bring back with them. And we also offer a good example of how to be green and how to do it at a low square-foot cost."

When a new large building is being planned, it's usually the architects who decide what the building is going to look like—the orientation, the glass-to-wall ratio, and other first steps, Hayter said. Then, the engineers and contractors have to figure out how to fit the ventilation systems, cooling systems, and windows into that design.

A better approach that is starting to be embraced is to have the owner, architects, and engineers work together from the outset—ideally with an expert on green buildings as a consultant. That way, engineers can suggest better orientations, profiles, and window sizes, while architects can suggest how to achieve all that without sacrifices to the building's aesthetics.

Making the Case for Comfort, Beauty, and Economy

"Architects are artists," Hayter said. "For them to take the tour and see that zero energy can be done in a way that excites them artistically, and to see that it doesn't have to be a boring box, was important to them. They can still build with a sense of motion and beauty and a sense of place. We were able to talk to

different audiences—to the architects on beauty and the shell, and to the engineers on pragmatism."

The third crucial stakeholder is the owner—whether it be a private landowner contemplating construction, or municipal or state officials deciding on a new government building. By a happy coincidence, municipal and state officials in charge of building design are visiting NREL's RSF this month. "Owners are a big part of it," Pless said. "It's important to get them in on the planning so they can decide if this is something that they would let their architects and engineers do."

NREL gave a special presentation to those visitors interested in energy-efficient data centers. The audience included officials from major banks in several states. They learned that evaporative cooling can be used in data centers in climates that usually would preclude such technology. One visitor from South Carolina realized that for the eight driest months of the year, evaporative cooling, with its much lower energy load, could condition his company's data center. "They learned about conservation strategies that they would have normally just written off," Hayter said.

The battle has already been won to get architects, engineers, and building owners to strongly consider designing and operating buildings that perform 30% or 50% better than minimum energy-efficiency standards. Now, there is growing interest in finding ways to build net-zero-energy buildings at a competitive cost.

In several states, professional societies are putting pressure on lawmakers to mandate higher efficiency standards. As architects and engineers look for ways to meet these standards, they need look no further than NREL for a living example of how it can be done, Hayter noted.

Watson said a new push among building engineers is to promote energy efficiency, indoor air quality, and safety, with a focus on educating state and local lawmakers. "We're showing how energy-efficient buildings like the ones at NREL can mean a utility doesn't have to build more power plants financed by ratepayers. The total cost to the populace would actually be higher if they roll back the standards."

Pless echoed that thought: "The investments in energy efficiency can mean lower energy costs for all of a utility's customers."

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>
> — SHANTI PLESS, *NREL Senior Research Engineer*

A Lasting Impact

Mark Kurtz, design director for science and technology projects for Phoenix-based SmithGroupJJR, the architects for the ESIF, said: "The folks at NREL are really pushing things. At conventions we go to nationally and internationally, I can't think of another project or topic that folks are more interested in. How to build like NREL has done—with design excellence and efficiency excellence—at a price around $270 a square foot."

Brad Gildea of SmithGroupJJR, architecture project manager for the ESIF, led 12 tours of NREL attended by architects from around the country and the world. He said the difference in cost between just meeting the standards and building a truly energy-efficient or net-zero building has narrowed considerably the past 15 years. "There's always the argument between upfront costs and payback," he said. "But people are getting savvier. They're saying, if we rent a space, we don't want to pay a huge electric bill. The next frontier is the super-efficient net-zero building. We show them the bang for the buck they can get by investing in energy efficiency on the front end."

Gildea noted that buildings use 30% of the fossil fuels in this country each year. "NREL is leading the push in the building industry to significantly reduce energy usage by 2030."

— Bill Scanlon (September 3, 2013)

NREL Adds Eyes, Brains to Occupancy Detection

It's a gnawing frustration of modern office life. You're sitting quietly—too quietly—in an office or carrel, and suddenly the lights go off.

Grrr! Installed to save energy, the room's occupancy detector has determined that no one is around, so it signals the lights to turn off. You try flapping your arms to get an instant reset, and if that doesn't work, you get up, walk to the light switch, and turn the lights back on manually.

The next morning, you put duct tape over the sensor to keep it from working, or you ask maintenance to turn down its sensitivity—so it won't turn off the lights until it detects no motion for a half-hour or hour. And of course, that quashes the primary purpose of motion detectors, which is to save the company a lot of dollars on its electricity bill.

For 30 years, occupancy sensors have relied primarily on motion detection. But now there's something new.

The Energy Department's National Renewable Energy Laboratory (NREL) has developed and made available for license the Image Processing Occupancy Sensor (IPOS), which combines an inexpensive camera and computer vision algorithms that can recognize the presence of human occupants.

Greater Accuracy Leads to Flexibility, More Energy Savings

IPOS can detect with almost 100% accuracy the number of people in an area, spots where there are no people, the level of illuminance, and other variables.

"People have been playing with using image processing for occupancy detection for quite a while," said NREL Senior Engineer Larry Brackney, who developed IPOS with NREL colleague Luigi Gentile Polese. "What's novel about IPOS is that it's not just an occupancy sensor. It combines a lot of capabilities—occupancy detection and classification; how many people are in the space; are they sitting still or moving around? Where are they in the room? It offers the potential of putting light or ventilation only where it's needed. All functions are combined in a single sensor, and it's done in a way that is more robust than current sensor technology."

Its combined powers can, for example, detect that there are five people walking down Aisle 5 at a retail store, but none in Aisles 4 or 6. It can signal the lights to stay on in Aisle 5, but dim somewhat in the other two aisles. Big-box retail stores, reluctant to even dim the lights if customers are anywhere in the store, currently miss out on big energy savings because their existing motion sensors aren't accurate enough to detect vacancies by aisle or section.

What's more, an IPOS system set up in a big-box store could not only help save energy, but could also be used to play videos or commercials when occupants approach a screen or an exhibit, or to control animations for promoting products or services.

And in an office environment, IPOS can detect if there are people staying late, no matter how still they're sitting, and deliver that information so the building uses just the lights that are needed—no more, no less. The information can also be used to make instantaneous decisions on the amount of ventilation, air

Inside view of the computer in the Image Processing Occupancy Sensor (IPOS). The IPOS uses a synergistic approach with human face and motion detection through computer vision algorithms. *Photo by Dennis Schroeder, NREL 24419*

conditioning, or daylighting the occupants of the office need at that particular moment. And it can signal when security officers should be alerted.

In all, IPOS raises the accuracy of occupancy detection from about 75% to the upper 90% range.

Technology Honed in the Cell Phone World

Brackney and Gentile Polese said they started working on the idea for IPOS because office managers were expressing frustration with sensors that had too many false positives and false negatives.

But the timing was important too. IPOS can be made economically because it borrows from the technology of smartphones—commodity devices that combine a camera and a microprocessor and now sell for a modest price because so many of them are produced.

"It's a security system that can save energy as well," Brackney said. "It's really exciting that it no longer has just a single function."

IPOS's field of view is a 45-degree angle, much like most cameras, Gentile Polese said. "But its range is much longer than traditional occupancy detectors." Instead of a 20-foot-long detection field, a single IPOS device can detect faces and human activity up to 100 feet away.

While traditional technologies require a motion sensor in each monitored space, IPOS can capture images of larger areas—and it can replace several traditional occupancy sensors by segmenting the images into up to 16 virtual zones. The zones can be analyzed individually and simultaneously, enabling very large spaces to be monitored and controlled through a single IPOS sensor.

The sensors will likely sell for between $100 and $200 once a licensee starts producing them in volume.

IPOS Can Detect Human Faces and Traits—Anonymously

IPOS is comprised of a small camera sensor integrated with a high-speed embedded microprocessor and novel software modules. The device is small; in fact, the embedded computer is the size of a stick of gum. It can be installed in an unlimited number of spaces and positions, and the individual components can be coupled in many configurations and quantities to cover spaces ranging from small rooms to large commercial buildings.

In office buildings, the camera-based technology could draw objections from employees.

However, IPOS has the ability to keep the images out of the wrong hands, Brackney said. "The microprocessor on the sensor captures the image, analyzes it, and then destroys it" soon after processing, and it never leaves the device.

"We also have the capacity to blur the images" if there is worry about privacy invasion, Gentile Polese said. "It's trained to detect faces of people and human traits, but not to detect what kind of faces and what kind of people."

Great Return on Investment in Pilot Tests

A recent assessment of IPOS's potential by the Bonneville Power Administration found projected savings of up to $144 million with an investment of $250,000 in IPOS technology. That's a return of $576 for every $1 invested.

IPOS is currently being tested in a few environments, including a large retailer in Centennial, Colorado, that serves as a test bed for innovations that could later be launched nationwide.

At the store, IPOS devices are trained on the large walk-in freezers and refrigerators in the back. They are helping determine the energy loss when, say, doors are left open after stocking the shelves with food.

Today, lighting represents the largest electric load in U.S. commercial buildings—38% of total electricity, equating to $38 billion spent annually (on 349 billion kilowatt hours at $0.11 per kilowatt hour). Low-cost IPOS detectors ($100 to $200 per unit) that replace traditional motion-sensing technology can improve occupancy-detection accuracy by more than 20%, leading to enormous energy savings. Ninety-three percent of commercial space in the United States has no motion detection system at all, even though such systems now are mandated for new construction.

The moment the NREL team knew it had something special was when Gentile Polese finished quantifying IPOS's performance and realized there was agreement in the high 90% range between what the device detected and what was actually going on in the test rooms.

"One of the really exciting things is that this combines sensing technology with the retail market's need for a security system that can save energy as well," Brackney said.

— Bill Scanlon (June 4, 2013)

NREL Brings Precision, Savings to Energy Audits

An energy audit tool that more accurately pinpoints potential energy savings while potentially costing 35% to 75% less than traditional audits is set to hit the multi-billion-dollar energy retrofit industry next year.

The simuwatt Energy Auditor software package was developed by the Energy Department's National Renewable Energy Laboratory (NREL) in partnership with Denver-based software developer concept3D. simuwatt Energy Auditor replaces the clipboard-and-pencil approach of most building audits with a package that uses sophisticated, comprehensive computer modeling to find more potential energy savings.

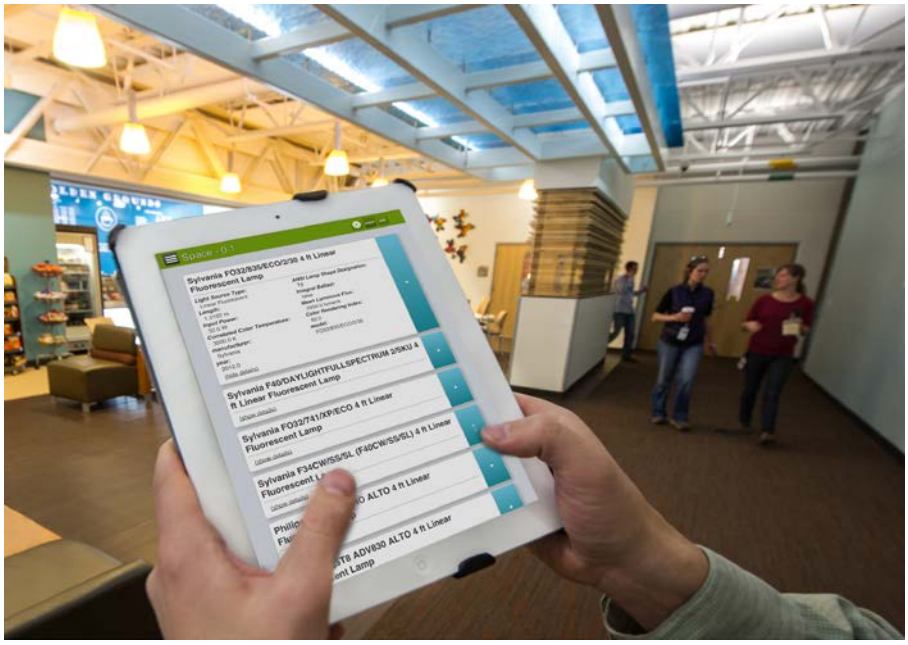
The commercial buildings sector in America alone represents 7% of total energy consumption worldwide. Commercial buildings in the United States consume about $134 billion in electricity each year for lights, computers, office machines, appliances, and the like, according to the Energy Department's Buildings Energy Data Book. Even a modest reduction in electricity costs would mean huge savings.

At the individual building scale, a 200,000-square-foot office building that pays $2 per square foot in energy costs annually can save tens of thousands of dollars of net operating income by reducing consumption modestly. And that doesn't include the benefits of reducing greenhouse gases and increasing the comfort level of building inhabitants.

Tool Makes Work Easier for Energy Service Companies

For many building owners, conducting energy audits is about as fun as a trip to the dentist. That's why they usually leave it to the professionals—the energy service companies, or ESCOs, that absorb the costs of the audit in order to spotlight possible energy and cost savings. Then, the ESCOs make improvements at low cost, in exchange for a share of the money saved on monthly utility bills.

It's a model that works primarily for large buildings today. Traditional audits can be cost prohibitive for small buildings, and with margins thin, ESCOs have little incentive today to absorb those costs due to lower total savings potential. simuwatt Energy Auditor offers to change this equation. It will allow ESCO employees to perform audits simply using



NREL Engineer Nicholas Long uses simuwatt Energy Auditor on his iPad to audit the lighting in a café on NREL's campus. The tool performs a building audit much more quickly and inexpensively than traditional methods, and allows for mobile, onsite data collection and storage, as well as 3-D visualization capability.
Photo by Dennis Schroeder, NREL 24506

mobile tablets and advanced energy modeling, skipping the laborious steps of manual input and transfer. "The hope is that by lowering costs, you can not only get deeper savings but also get into more buildings," said NREL Engineer Andrew Parker.

Oliver Davis, CEO of concept3D, said simuwatt Energy Auditor allows the user to gather key building information rapidly: "Its software-guided workflow allows customers to double their audit capacity. More audits mean more retrofit work, more revenue, and more efficient buildings."

When the audit is finished, it is stored electronically and serves as the baseline for the next audit, which is typically done a few years later. "The subsequent audit becomes verification, not a new discovery," said NREL Senior Engineer Larry Brackney. "So, the cost of subsequent audits comes down sharply."

A Melding of Several Ideas

Lars Lisell, an NREL engineer who works to deploy research ideas into the marketplace, said simuwatt Energy Auditor is "a combination of a bunch of different ideas that fit together very nicely. We came up with the idea of marrying the energy audit with energy modeling through OpenStudio and other tools. We'd already been working with concept3D on buildings software."

"NREL's deployment program had been doing energy audits for the Department of Defense, the Department of State, the National Park Service, and other federal agencies for quite some time," Lisell said. "When you spend a lot of time doing something, you start to notice that there are inefficiencies along the way—and realize there's a better way to do them."

concept3D, which pulled together the idea of capturing the geometry of a building by taking photos of the exterior, then layering those on top of a three-dimensional rendering of the building, has an exclusive license from NREL to develop the software tool for the marketplace.

NREL Taps into Existing Software Tools

simuwatt Energy Auditor benefits from existing tools, including the Energy Department's EnergyPlus, which runs simulations to determine energy flow; and NREL's OpenStudio, which allows users to quickly create a detailed EnergyPlus model of the building. EnergyPlus, which models heating, cooling, lighting,

> "When you spend a lot of time doing something, you start to notice that there are inefficiencies along the way—and realize there's a better way to do them."
>
> — LARS LISELL, *NREL Engineer*

ventilation, and other energy flows, was developed by NREL along with other national labs and research institutions.

NREL also tapped into concept3D's work to help develop and grow its Building Component Library (BCL). The BCL is an online archive of building energy modeling input data and conservation measures that can be used to create building energy models. The wealth of information helps narrow down how much savings can be expected in a particular type of building from, say, installing more efficient lighting systems, or replacing windows.

simuwatt Energy Auditor incorporates a model that lets users drag BCL components into an OpenStudio project. "They then can see the energy and cost impacts," Brackney said. Users can simulate the effects of adding overhangs to windows, changing rooftop units, changing lights, changing hours of operation—almost any building component that could improve efficiency.

simuwatt Energy Auditor can also measure the benefits of installing solar photovoltaic panels. "This would not be possible without OpenStudio and the BCL—that's why no one has done this before," Brackney said. "These are enabling technologies that we've developed here at NREL."

The melding of different capabilities was further enhanced by the growing popularity of electronic tablets. OpenStudio and the BCL have datasets that are ideally suited for electronic data collecting, and that allow the user to manipulate the numbers to see how big the savings can be.

For example, a user could pose the question: "Does it make economic sense to retrofit windows in this building?" The response from simuwatt Energy Auditor might be something

like this: "Yes, if it is more than three stories high and at least 40 years old and if you use these kinds of windows." And if that's not in the budget, then the user can change one parameter and see what difference it makes for the bottom line.

No other commercially available product has the ability to collect building data onsite, automatically move the data into an analysis tool, and perform a detailed energy simulation with the speed and consistency of simuwatt Energy Auditor. "With most audits, you're not quite sure what you're getting—you can get a big range," Brackney said. "With simuwatt Energy Auditor, you get the same numbers every time." And ESCO engineers can quickly train their junior engineers to use the tool.

Instead of hiring one person to do the audit and another one to, say, assess the strength of the roof for the loading of solar panels, with simuwatt Energy Auditor, the same person doing the audit can assess the value of the photovoltaic modules. And huge computers aren't needed to analyze the data, because while it can be analyzed locally, it also can be sent out to the cloud. "Cloud computing changes the game for running energy models and accessing data from any device, at a lower cost," Davis said.

Beyond the "Low-Hanging Fruit"

simuwatt Energy Auditor's built-in reporting mechanisms and assumptions provide much more useful information to decision makers, said Parker. Often, an audit will report that, say, lowering lighting density will save so many dollars. But a building owner needs to know what assumptions were made, how the costs break down, and how this will impact the operations of the building. Without that information, an energy audit can seem useless to building managers. "At every step, we can assemble the information that the accountants want to know—replacement costs, how long the bulbs will last, every detail," Brackney said.

Brackney noted that when it comes to energy retrofits, "all the low-hanging fruit has largely been plucked. Everyone has changed the light bulbs, the air filters. What's left to do is pretty capital intensive."

That means due diligence is essential—both to satisfy the building owners and to convince lenders, who must know the precise payback in energy savings on the loan. "Existing auditing processes aren't reliable enough or cheap enough for people to use them to get those answers," Brackney said. "So, they're not making investments to get to that next level of energy efficiency."

NREL, concept3D, and industry partners will test the potential savings from the tool by auditing 18 buildings at six Department of Defense bases.

Simplicity and Consistency Spur Ardent Interest from ESCOs

Interest is strong from ESCOs and other private-sector auditors eager to test simuwatt Energy Auditor. "Over the next six to eight months, we'll get a pretty good collection of actual data to compare with pre-existing audits, or conventional audits we do in parallel," Brackney said.

"The consistency of the measures is so important," Parker said. "Whoever creates a measure has to understand engineering, but once that's done, anyone can come in with any model, drag it in, and get reasonable results."

"It becomes very consistent and very simple," Brackney said.

— Bill Scanlon (October 22, 2013)

NREL Engineer Passionate about Energy-Efficient Buildings

In between dealing with a baby chick, a broken cello string, and a colleague needing a ski lesson, Sheila Hayter still makes time to tackle projects for the Energy Department's National Renewable Energy Laboratory (NREL) and ASHRAE (American Society of Heating, Refrigerating, and Air Conditioning Engineers), the worldwide organization for building engineers.

Hayter, 46, is a senior engineer and group manager for opportunities, evaluation, and implementation in the Deployment and Market Transformation Office at NREL in Golden, Colorado.

She's the kind of person who, when asked if she has a philosophy of life, responds with a laugh, "Oh, I don't have time for that."

Be it undeclared, she lives a philosophy of getting things done, of finding a balance between professional and personal, and of espousing her passion for energy efficiency in the buildings in which we live and work.

Ross D. Montgomery, a 2010–2012 ASHRAE vice president, says of Hayter: "She has incredible vision for the future of our industry. She makes our work fun, exciting, and interesting. She stays on the issues and is involved in the solutions. She is the agent of change and inspires young engineers to want to be a part of our industry."

Few people have been more instrumental in helping establish stringent standards for energy-efficient buildings or for pushing architects, engineers, and developers to strive for 50% or more savings beyond the standards. For the past 21 years, Hayter has worked at NREL. For even longer, she has served her favorite professional organization, ASHRAE, which sets the standards for building safety, efficiency and quality. She currently chairs the Planning Committee of the 55,000-member organization.

Juggling Family and Professional Life

On a recent Tuesday, though, Hayter's mind was on her three kids and domestic misadventures.

"One of our baby chicks died last night," she said. "We have five—three adult hens and two babies. But I'll need to buy another baby chick on my way home tonight, because the other baby needs a friend."

For the past 21 years, Sheila Hayter has worked at NREL; few people have been more instrumental in helping establish stringent standards for energy-efficient buildings in that time. For even longer, Hayter has served her favorite professional organization, ASHRAE, which sets the standards for building safety, efficiency, and quality. *Photo by Warren Gretz, NREL 07154*

All three of Hayter's kids ski, ride mountain bikes, and play the piano, but each also has a specialty musical instrument. Megan, 13, plays the flute; Kian, 9, plays the violin. And Brennan, 12, plays the cello—but not when the A string snaps, as it did this morning. That's one more errand for the way home.

"I'm overcommitted," Hayter said cheerfully. "That's because I have a hard time saying no when something sounds fun—both in my work and my personal life. But I do try hard to stay somewhat balanced between what I do here at NREL, and doing other things that keep my life interesting."

Hayter grew up in Manhattan, Kansas, where her father was a mechanical engineer—both in the private sector and as a professor at Kansas State University.

She surprised the family at 13 by earning enough babysitting and lawn-work money to take a school trip to Steamboat Springs—the first member of her family to go skiing. Thirty-three years later, her entire extended family skis, and in most recent years she has been a weekend ski instructor at Copper Mountain in the Colorado high country.

Advice—or Misinformation—from Dad

Asked what got her interested in math, science, and engineering, Hayter said: "I remember my dad helping me with math, and I was in tears because it didn't make any sense to me, and I asked him why I even have to take math. He said, 'You have to learn it because when you take thermodynamics you'll have to know it.'

"So, I thought everyone had to take math for when they take thermodynamics," she said. "It wasn't until college that I realized that you only have to take thermodynamics if you're in engineering—and then only if you are in mechanical or a couple other specialties in engineering."

By that time, she was hooked.

She joined one of the first student branches of ASHRAE and was in charge of bringing professional engineers to the university for talks. "That really helped me see the difference between engineering in an academic setting and the challenges facing engineers in real life," she said.

As a female mechanical engineering major, Hayter found herself outnumbered about 20:1. "Most of my professors were very supportive, but there was this one guy. I went to his office and asked him a question about a problem I couldn't figure out. He said, 'Well, girls can't do math. My daughters can't do math either.' He was just so dismissive. It was like he was saying, 'Just go away. I can't answer your question.'"

Hayter ended up getting an A in the class, partly, she says, to spite him.

Helping Set Standards for Cleaner Buildings

Hayter established and coordinates efforts within the federal government to build energy-efficient buildings. As an NREL engineer she has pushed the envelope on incorporating renewable energy into these buildings.

She has published 50 documents and papers in her time at NREL, including "Handbook for Planning and Conducting Charrettes for High-Performance Projects ," considered the "go-to" document for conducting design charrettes for energy-efficient buildings that are seeking LEED certification.

In addition, she chaired the committee that developed the original charter for ASHRAE's Advanced Energy Design Guidelines—both guides that specify achieving 30% or 50% greater efficiency than baseline standards, as well as guides that can get a building to net-zero energy.

Hayter was also on the original planning committee that conceptualized the international Solar Decathlon competition. And she was the technical lead for Boston and New York in the Energy Department's Solar America Cities program, helping push NYC's ConEdison to fully embrace leadership in solar energy.

Traveling the World on Behalf of Energy Efficiency

Hayter is a distinguished lecturer for ASHRAE. Typical of her schedule in a 12-month period: Four cities in India, five cities in Canada, two in Georgia; presentations in Salt Lake City, Anchorage, Billings, Wichita, and Manhattan, Kansas. Previous speaking engagements have taken her to Greece, Italy, Hong Kong, and the Philippines, in addition to other cities in the United States and Canada.

Hayter's envelope pushing has produced real, replicable results. For example, the U.S. Energy Policy Act mandates that federal buildings improve their efficiency based on percentage

> “There is this triangle where everybody is influencing everybody else—the Energy Department, NREL, and the professional organization, ASHRAE. Our success in increasing energy standards for buildings couldn’t have happened without the organizations working with each other.”
>
> — SHELIA HAYTER, *NREL Senior Engineer and Group Manager*

improvements to ASHRAE standards. That includes the whole building, from saving energy to improving air quality and making the climate more comfortable—all stemming from the push by ASHRAE and the Energy Department for more stringent standards and a holistic approach to buildings.

“There is this triangle where everybody is influencing everybody else—the Energy Department, NREL, and the professional organization, ASHRAE,” Hayter said. “Our success in increasing energy standards for buildings couldn’t have happened without the organizations working with each other.”

Changes—Mostly Positive—in Professional Career

Hayter is sanguine about the future, because she remembers 25 years ago when she would try to espouse the virtues of green buildings only to be greeted by yawns—save the cheers of a few ardent environmentalists.

Everyone else would harrumph that insulation costs more than cheap (at the time) energy and that natural ventilation was just too far out—something that hippies did.

But Hayter plugged away, with the help of some committed ASHRAE colleagues and her growing group of NREL building engineers. She helped building engineers around the country and across the globe to think about the building as a whole, including how energy efficiency can fit in with design and aesthetics.

“I’m a believer,” she said. “I think the ASHRAE standards are making a big difference. The standards are being incorporated in buildings all around the world.”

Her first manager at NREL gave her an important life lesson. “He told me, ‘Sheila, if it needs to get done, it will get done. Things that don’t get done—maybe they didn’t have to be done.’ He was telling me to prioritize and that you can’t beat yourself up over not getting to everything, including things that maybe weren’t so important in the first place.”

She’s still optimistic—but she’s still a bit worried.

“Now, when I speak to a group of engineers, they generally want to do the right thing; they think sustainability is great,” she said. “But in a lot of states, they still run into so many barriers. There are a lot of states with no renewable energy portfolio standards, no state or local incentives at all that can help pay for efficiency in buildings.

“These engineers want to design and build efficient buildings, but they don’t have a chance to do it. I talk to them about net-zero buildings, but the environment is just not conducive to applying those concepts.”

Today, most young engineers are entering the profession with an environmental ethic, she said. So in 10 or 15 years, sustainability may be an absolutely mainstream concept. “In 10 years, at the rate we’re going, maybe we’ll be 60% there. In another 10 years, maybe 75%.

“That would be all right.”

Until then, there are more committees to chair and more energy-efficient standards to toughen—not to mention the family trip to Fruita, Colorado, for mountain biking, the raft trip down the Colorado River, and the new A string for the cello. And for goodness’ sake, don’t forget the baby chick.

— Bill Scanlon (April 29, 2013)

Weatherization Work Guidelines Launched

Getting up and going to work is hard enough every day. But add to your burden the need to remember every step of your job down to the smallest detail—and the fact that if you want to change careers, your lack of credentials might mean starting from scratch. These are the challenges faced by many of the weatherization professionals working to make U.S. homes more energy efficient.

A recent collaboration between the Energy Department, its National Renewable Energy Laboratory (NREL), and the home energy performance industry is seeking to change this by supporting the weatherization workforce—for which demand has exploded in recent years—with consistent on-the-job tools, accredited training programs, and credentials that lead to better-defined career paths.

The Energy Department's weatherization program has been in existence for more than 30 years and has provided weatherization services to more than 6.4 million low-income households, reducing building energy use by 36%. To shepherd the weatherization industry into a new technological era, the Department's Weatherization Assistance Program (WAP), with support from the WAP National Training and Technical Assistance Plan, introduced the Guidelines for Home Energy Professionals project—and with it, three goals:

- Define quality work through standard work specifications
- Define quality training through a vetted accreditation process
- Define quality workers through advanced professional certifications.

Three years ago, NREL was tapped by the Energy Department to lead the project, and the end result was a new tool for weatherization professionals—Standard Work Specifications (SWS). SWS define the minimum requirements needed to ensure that the work performed during energy upgrades in

William Stewart with Veterans Green Jobs blows cellulose insulation in the attic of a home. A recent collaboration between the Energy Department, NREL, and the home energy performance industry is supporting the weatherization workforce with consistent on-the-job tools and accreditations that lead to better-defined career paths.
Photo by Dennis Schroeder, NREL 17957

single-family, multifamily, and manufactured homes is effective, durable, and safe.

"NREL was chosen because of our ability to bring industry together for market transformation activities," NREL Principal Laboratory Program Manager Dan Beckley said. "The industry wasn't going to invest in creating a document like this because it's not organized in that way. It was a great role for NREL to bring in existing partners and then parlay that into an industry effort."

The SWS can be used as an industry guide for workers, training instructors, homeowners, and program administrators involved in the home performance industry. In addition, the Energy Department is working to mandate that all WAP-funded weatherization efforts be inspected by a certified quality control inspector. The new Home Energy Professional Certifications require home energy professionals to demonstrate comprehensive and technical proficiency in the four most common job classifications in the home energy upgrade industry: energy auditor, retrofit installer technician, crew leader, and quality control inspector.

Collaboration from the Get-Go

According to the project team, before launching the SWS there was no go-to source on how to go into a house, retrofit it, and walk away recognizing that the job was done right.

"When we started the project three years ago, it was somewhat unprecedented. We initially brought together well over 100 experts to draft up the first of what these standards would look like," Beckley said. "This wasn't a lab exercise where we said, 'We think we know what's best;' rather, this was driven by industry. It was for industry, by industry—we simply were the facilitators and provided some technical expertise.

"We broke out the work activities into the sections of the house. For instance, if you are going to seal an attic, we want to make sure that as you come down the ladder, you know what the outcome should be. These standards don't tell you how to do the work; industry has its own standards and best practices."

NREL Project Manager Chuck Kurnik also noted: "We solicited all of industry for comments on the SWS, including industry associations and trade groups. We feel that all the industry feedback helped to make it a stronger document. Every time we would do a public comment period, the document would become stronger."

Over a three-year period, NREL had more than 300 industry professionals involved in the development of the SWS.

Shortly after the creation of the SWS, a new online SWS tool was in the works and launched in the last few months.

"One of the functionalities of the tool is that as a crew leader approaches a house, they will have a scope of work so they can hand out checklists to their crews," Beckley said. "The tool has a 'Favorites' functionality that allows you to identify and store details associated with any part of the house you are going to touch on that given day. Then you can go ahead and send those details via email to a mobile device, so workers have in their hands clear expectations for the expected outcome. And with the checklist, they can make sure before they walk away that they accomplished the task at hand."

NREL also developed an application programming interface (API) that is publicly available. Companies can take the API and integrate it into the tools that they develop for their employees—which could be handy for the industry partners integrating SWS guides into their training.

Industry Immediately Puts the SWS to Use

Amanda Evans, director of the New Mexico Energy$mart Academy, is using the SWS as part of an accredited training program for weatherization work.

"We like to put students in pairs and give them something they think they know how to do and ask them to write all the steps down in as much detail as they can," Evans said. "Once they've done that, we'll pull up the SWS, and they go through and see what they got and how many they missed. It's a tool to show them how their memory isn't as effective as using something that is clearly written out. We talk about how even pilots and doctors have checklists for their work."

Austin Energy is looking to revamp its multifamily rebate program, and for this municipal utility, the timing of the development of the SWS couldn't have been better.

According to Jaime Gomez, coordinator for Austin Energy's multifamily rebate program, his team was recently reviewing old notebooks from when the program was first developed.

> “More than half of U.S. states require certification for retrofit work, so there is a precedent for the weatherization market and retrofit market to maintain and hold certifications. These certifications are also transferrable nationally, so we’re now creating a more mobile workforce. Now, if there is a natural disaster somewhere, workers looking for employment have the skills and ability to help rebuild in another state.”
>
> — DAN BECKLEY, *NREL Principal Laboratory Program Manager*

They discovered that all of the forms and information had not changed since the early 1980s.

“We realized that everyone has caught up to what we are doing; we decided the time had come to change up our program,” Gomez said. “We’ve come up with a new way of thinking about how we are doing things. We decided to include a stringent handbook with the use of registered contractors. Along with that handbook, we need technical specifications, and it was going to be really difficult for us to come up with all of that on our own. This cut our workload considerably—maybe by more than half.”

Austin Energy is looking to launch its new multifamily rebate program this fall. “The fact that there is an online resource that includes very detailed work specifications, and to be able to just click and choose whichever ones we want to use and then include them in our handbook, is just phenomenal for us,” Gomez said.

Advancing Careers with Certifications

The SWS are intended to serve as a universal resource for the home energy upgrade industry and to ensure that everyone can speak the same language and have the same expectations around work. In addition, these specifications serve as the basis for the new Home Energy Professional Certifications.

“More than half of U.S. states require certification for retrofit work, so there is a precedent for the weatherization market and retrofit market to maintain and hold certifications,” Beckley added. “These certifications are also transferrable nationally, so we’re now creating a more mobile workforce. Now, if there is a natural disaster somewhere, workers looking for employment have the skills and ability to help rebuild in another state.”

The goal of the new Home Energy Professional Certifications is to provide weatherization workers with a logical progression for advancing their careers and businesses.

“The consumer is going to see an impact in consistently higher-quality work,” Kurnik said. “And the worker is going to appreciate it because they can now distinguish themselves from rogue contractors who are not investing in their workers.”

Other anticipated benefits of the professional certification program are improved service delivery, fewer callbacks, and reduced installation errors, which in turn should drive new business by delivering consistent performance that builds consumer value and trust.

“The program lends credibility to the growing weatherization industry, and as a result, it becomes recognized as its own industry,” Kurnik added. “This program should help the owners of these companies retain their workforce and gain market credibility.”

— Heather Lammers (September 30, 2013)


2013
MIDDLE SCHOOL
Electric
CAR
COMPETITIONS
May
18

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 25694

Fresh Faces Abundant at Colorado Science Bowl

It was a nail-biter of a finish at the 2013 Colorado High School Regional Science Bowl, hosted by the Energy Department's National Renewable Energy Laboratory (NREL), as a record 42 teams—including 10 schools participating for the first time—competed for a chance to challenge for the national title. The winner of the Colorado Science Bowl travels to Washington, D.C., for the National Science Bowl in April.

After a full day answering rapid-fire questions in physics, mathematics, biology, chemistry, earth and space sciences, and energy and general sciences, Lakewood High School (Lakewood, Colo.) scored a dramatic victory in the final elimination round to claim the Colorado championship and advance to the national competition. They defeated an experienced Cheyenne Mountain High School (Colorado Springs) team, which had made it to the final round of the competition for the third year in a row.

Lakewood Takes First Colorado Title

"This is pretty exciting," Lakewood team captain Tommy Fan said. "I felt that we were well prepared, but the competition here is so tough. I was just hoping we'd make it out of the morning elimination round. I'm thrilled that we won and will have the opportunity to represent Colorado at nationals."

Lakewood won the competition for the first time after participating for 11 years. They came from behind to defeat the Cheyenne Mountain team in the final round with a score of 38 to 16.

Members of the winning Lakewood team will begin their journey for the national title in Washington, D.C., on April 25. The Energy Department and NREL sponsor the Science Bowl program to provide an opportunity for students to embrace science, technology, engineering, and math studies as a primer for collegiate success and future careers.

"NREL is pleased to support the Colorado Science Bowl," said NREL Deputy Director for Science and Technology Dana Christensen. "It is important that we are actively encouraging the next generation of scientists and engineers, and programs like this act as a catalyst to help students make their decisions on what they want to study in the future. Our hope is that based on the positive experience of participating in Science Bowl, a lot of these students will make the decision to pursue a course of study in science or engineering."

More than 15,000 students across the United States compete for a trip to participate in the National Science Bowl. Only about 600 make it. The Lakewood team knows they will need to be at the top of their game as they prepare to go up against the best in the nation.

"We're going to need to study a lot more between now and April and go really in depth," team member Jacob Stufflebeam said. "For this competition we were mostly relying on the

Lakewood High School competes in the finals of the 2013 Colorado High School Regional Science Bowl. The team took first place at the event. From left: Peter Kim, Eli Veal, Tommy Fan, and Tyler Middleton.
Photo by Dennis Schroeder, NREL 24039

science we already knew and focusing on how to apply it to this type of competitive format. But now we are really going to need to step up our knowledge base to be ready for nationals. It's an exciting opportunity to learn more and test our knowledge against the best."

Competition Sees New Teams, Fresh Faces

In addition to an exciting finish and first-time champion, the Colorado competition this year was also notable for an explosion in new participation from schools around the state. Ten schools participated in the completion for the very first time.

First-time participants from Ellicott High School (Ellicott, Colo.) were very much in the spirit of the competition with their highly recognizable tie-dyed lab coats. Though they were eliminated in the morning round, the team thoroughly enjoyed the opportunity to be a part of Science Bowl.

"There are a lot of awesome people here, and we're so glad to have a chance to participate," Ellicott team captain Adam Moser said. "It's great to see so many kids out there that are interested in the same topics we are and to have a chance to test our skills against them. We've learned a lot from the experience and look forward to coming back next year."

One first-time school acquitted themselves particularly well in the completion. Tiny South Park High School (Fairplay, Colo.) has just over 130 students in the high school portion of their combined middle and high school. They struggled to find enough students to round out their team. Yet, they performed well enough to come out of the morning competition and win a couple of double-elimination rounds before ultimately being eliminated—all while competing against much larger urban and suburban schools with years of experience in the competition.

"We were really terrified in the first round, and our performance was not very good as a result," South Park High School team captain Shannon Hessler said. "Then we settled down and won the next round, which boosted our confidence. There are some really smart people here, and it felt good to know that we could hold our own with them. And we had a lot of fun, too."

The influx of new participants into the Science Bowl gave more experienced hands an opportunity to mentor the new students. Cheyenne Mountain High School senior Sara Volz has participated in Science Bowl all four years of high school, and her team made it to the final round three of those years. Volz will graduate this year and head off to MIT to study biochemistry, but first offers some advice to new students coming into the Science Bowl program.

"A lot of success in Science Bowl is about what you know," Volz said. "But even more of it is about working with your teammates and helping each other improve. The most important thing is not to get discouraged if you have a bad round or miss a few questions, and to just stay focused on the next one."

NREL Staff Pleased to Nurture Next Generation Scientists

Seeing students like Volz engaged in the sciences inspires NREL volunteer Carolyn Elam, manager of NREL's Energy Systems Integration Facility. "Competitions like this really help to motivate kids around these topic areas, and it's really important for us to support this because they are the next generation of scientists and engineers."

The Colorado Science Bowl is a large undertaking for NREL staff. It takes nearly 70 volunteers to run the competition on the day of the event, and many staffers return year after year. "This is my fourth year volunteering at Science Bowl," said Ian Metzger, an engineer in NREL's Integrated Applications Center. "It's a great experience, and I wish that there was a similar program where I went to high school."

NREL staff continue to participate in the event year after year as an opportunity to support and mentor students to excel in math and sciences.

"This is such a valuable program because it encourages the brightest young men and women in the country to pursue academic paths related to science," Metzger said. "It is really important that NREL and the Energy Department get behind this type of program and encourage these students. We will be counting on them to someday continue the work we have begun in advancing energy efficiency and renewable energy technologies as we strive to overcome present and future energy challenges."

—David Glickson (February 11, 2013)

Interns Make Robust Contribution to NREL

They travel far and wide, from all corners of the country. They come from a diverse set of backgrounds, and they have very different plans for their futures. But the 54 student interns at the Energy Department's National Renewable Energy Laboratory (NREL) this summer all have something in common—a thirst for knowledge and a desire to apply what they have learned in school to real-world science in a state-of-the-art laboratory environment.

Each summer, students make their way to NREL's facilities in Golden, Colorado, seeking an opportunity to work side by side with top researchers investigating the solutions to our energy challenges.

"Students get to take their knowledge from school and apply it in a national laboratory environment," said NREL Education Program Coordinator Linda Lung. "The students are contributing members of these research teams. It's an invaluable experience for both the interns and their mentors."

Interns Follow a Variety of Paths to NREL

For summer intern Adam Atia, life in Colorado is a very different experience. Atia, born and raised in Brooklyn, New York, took the train to City College of New York each day while he sought his undergraduate degree in environmental engineering and earth systems science.

As an intern in NREL's Transportation and Hydrogen Systems Center, Atia is testing vehicle efficiencies and emissions. His primary objective for the summer was to get an infrared spectrometer up and running, which would supplement the lab's current emissions analysis data and allow researchers to analyze a wider spectrum of emissions for a variety of fuel sources.

"This internship has been a great way to cap off my undergraduate degree with a different perspective on my work," Atia said. "My focus in school has been on air quality. The time I have spent in the lab at NREL has given me a chance to look air quality issues specifically from a transportation perspective. I am hoping to focus my future studies on renewable energy and sustainability while still applying my knowledge in air quality. This has been a great step toward that goal."

On the flip side, intern Jonah Richard grew up in Corinth, Vermont, a town with no stoplights and only one paved road. That road led Richard to Bard College, a small liberal arts

NREL intern Jonah Richard adds solvent to polymers that will be added to nanotubes in order to single out species of them. *Photo by Dennis Schroeder, NREL 26721*

college in upstate New York, where he recently completed his undergraduate studies in physics.

Richard chose to spend the summer at NREL's Chemical and Materials Sciences Center, investigating third-generation solar cells, which are still in early stages of development. He is also looking into potential applications of carbon nanotubes in photovoltaics and has found the work rewarding.

"I'd worked with fuel cells and carbon nanotubes in the past, but had never worked with photovoltaics, and it was a great opportunity to come here to use what I've learned on a different application," Richard said. "The facilities are amazing at NREL. Coming from a small liberal arts college that doesn't have a lot of hands-on research labs, it has been a fantastic experience to be able to work in an environment like this."

Coincidentally, despite their different backgrounds, both Atia and Richard are headed to Columbia University in New York City in the fall. Atia will be working toward a graduate degree in earth and environmental engineering while Richard continues his studies toward advanced degrees in chemical engineering and physics.

For summer intern Rachel Welch, the knowledge and experience gained through her internship is beneficial as she investigates options for her future. Welch, a native of Galesburg, Illinois, will be returning this fall to Lawrence University in Appleton, Wisconsin, to finish her undergraduate degree in chemistry.

While at NREL, Rachel is involved in research on thin-film solar cells at NREL's Chemical and Materials Science Center. Her efforts are focused on investigating new materials for solar cells and the best options for applying these materials to thin-film photovoltaics.

"It's been a really great opportunity for me," Welch said. "The materials we are looking at are comparable to existing materials but are new to this application, so there is very little study of them. The work we are doing is important and challenging. Doing this work has been a great way to dip my toes into materials science along with my chemistry background to see if I might want to pursue that further in the future."

NREL Researchers Provide Important Mentorship

Nurturing the next generation of scientists and engineers is a priority for the Energy Department's Office of Science and NREL.

"This internship program is a critical pathway for encouraging these students to pursue the next level of excellence," Lung said. "These students will someday be the scientists and engineers that advance the work we've begun here today, and we will be depending on them to continue our efforts toward a sustainable energy future."

To that end, each student intern is assigned a mentor from NREL's research community who guides and advises the students through their research and their collaboration within their teams. The students say their mentors are critical to their success.

"My mentor has really been great and has always been available to help when I need it," Richard said. "The mentors here really value us as scientists and as a part of their teams, even though we are undergrads. To get to collaborate with them and the research teams on such a high level is a tremendous learning opportunity."

The mentors enjoy the chance to work with such a talented group of young scientists and engineers and often find that they get as much out of the program as they give.

"I am invigorated by the passion that the interns have for learning and the enthusiasm they apply to their research," said NREL Scientist Todd Deutsch, a former intern in the program and now mentor to summer intern Erin Brahm. "These interns are fully on board with NREL's mission, and they can't wait to get started on their projects and make meaningful contributions."

While these mentors enjoy working with the interns and the personal satisfaction it brings, they also clearly understand how the intern program helps ensure that their research continues as we pursue solutions to our energy challenges.

"The internship program at NREL advances our mission by exposing motivated students to scientific challenges related to sustainable energy technologies at an early stage in their career," said NREL Senior Scientist Jeff Blackburn, mentor to Richard. "These students then serve as ambassadors to our

> “This internship program is really special because we each get a project that we see through from start to finish.”
>
> — **ERIN BRAHM,** *NREL Intern*

mission by starting discussions, research projects, and other programs at their universities. One energetic intern will inspire many others, helping to grow the pool of scientists needed to address our demanding global energy needs.”

Returning Interns Dig in Deep on Projects

For some interns, one summer at NREL is not enough, and they return for a second time, allowing them to dig in deeper on research topics they started the year before.

Erin Brahm has been an intern in NREL’s Hydrogen Program for the past two summers. Brahm, a native of Huntsville, Alabama, recently graduated with a degree in chemistry and mathematics from Sewanee: The University of the South and is heading to the University of California, Berkeley, this fall to pursue a Ph.D. in chemistry.

Brahm has been investigating research topics around hydrogen production from water using renewable electrolysis. Her work is focused on developing treatment processes to stabilize the semiconductors used in electrolysis, and she has enjoyed the chance to be able to explore this technology extensively.

“I’ve been an intern at NREL for the last two summers, and my research on this technology made me realize that this was the field I wanted to pursue as a career,” Brahm said. “So I am back again this year, and I chose my graduate school program based on being able to continue research in this area.”

Brahm has parlayed her experience as an intern at NREL into a clear direction for what she wants to do with her future.

“This internship program is really special because we each get a project that we see through from start to finish,” Brahm said. “We are doing real science and get to experience the entire process. Everyone here is so focused and dedicated to their research, and it’s fascinating to see all of the different disciplines and paths that are being studied to solve our energy challenges. It is an inspiring and amazing place to be.”

Adam Nelessen spends his time at NREL’s National Wind Technology Center just outside of Boulder working with the Offshore Wind and Ocean Power Group. Like Brahm, he jumped at the opportunity to be able to return to NREL for a second summer to continue his research. The Flagstaff, Arizona, native and recent mechanical engineering graduate of Northern Arizona University is on his way to Georgia Tech in Atlanta this fall to pursue a master’s degree in aerospace engineering.

Nelessen has been developing a computer modeling tool for wave energy research that will allow for the replication of the performance of wave energy devices operating in realistic conditions. This modeling tool will be important as wave energy begins to be looked at more closely as a viable alternative energy resource.

“It’s been an exciting opportunity because this is such a young industry and it has little in the way of standards for what the devices are going to look like,” Nelessen said. “As these devices come closer to commercial development, the need for good modeling tools is going to be increasingly important. I’ve really enjoyed the unique challenge of getting to do work as an intern in a new area where I feel that I can have a real impact.”

As a returning intern, Nelessen feels strongly that the lessons learned and hands-on experience gained at NREL will serve him well in the future.

“The continuity of being able to investigate this technology for such an extended period of time has been a great opportunity, because this summer I was able to jump right in and hit the ground running,” Nelessen said. “The work I will be doing in graduate school will look similar to what I’ve done here at NREL, so the experience I have had is going to apply quite well.”

— David Glickson (August 6, 2013)

Middle Schoolers Shine in Electric Car Races

Put a solar or lithium-ion car in the hands of a middle-school student, and watch adolescent angst and eye-rolling disappear—at least for a few hours.

"This is the best," said a boy from Greeley last week at the annual Colorado Junior Solar Sprint and Lithium-Ion Battery car competitions in southern Jefferson County on May 18.

"We rock; we are such risk-takers," said a girl from Douglas County.

It was the 23rd annual electric car competition sponsored by the Energy Department's National Renewable Energy Laboratory (NREL), the Energy Department's Office of Science, the Alliance for Sustainable Energy, Jefferson County Schools, Planet Honda, Dakota Ridge High School, and the Energy Department's Golden Field Office.

NREL and other sponsors hold the races each year to show middle-school students that science, engineering, and design can be rewarding, in an effort to encourage them toward careers in STEM—science, technology, engineering, and math. The batteries and solar panels are supplied by sponsors, but students design and build the rest of their cars themselves.

NREL Laboratory Fellow David Ginley, who served as official starter for the solar races, said: "For many middle schoolers, this activity represents their first hands-on connection to renewable energy and sustainable technologies."

Ninety-seven teams from 28 middle schools throughout Colorado were at Dakota Ridge High School on Saturday by the time the first-period bell rings on a weekday.

The sun was a near no-show, barely peeking through the thick clouds.

Undaunted, teams tweaked their model cars, added a rubber band here, dusted a solar panel there, and raced their vehicles 20 meters down neoprene tracks.

Xavier Urquijo from Summit Ridge Middle School in Littleton waits for the start signal to lift the folder covering the solar panel on his team's car, "Knight Hawk." His team was one of 97 from 28 Colorado middle schools racing solar and lithium-ion powered vehicles they designed and built themselves at NREL's 2013 Junior Solar Sprint and Lithium-Ion Battery car competitions on May 18. *Photo by Dennis Schroeder, NREL 25692*

The atmosphere was electric, akin to the pits at Talladega, with checkered flags, sponsor decals, and heart-racing, deadline-pushing repairs. Parents cheered, buffered disappointment, and cheered some more. Coaches corralled team members, who scattered to make last-minute adjustments to the hooks and paper clips that connected their cars to the guide wires down each lane.

> "We played around with the geometry until it was perfect."
>
> — **MICHAEL WHITAKER,** *Junior Solar Sprint Participant*

Girl Power, with a Hint of Nail Polish

Femininity was not going to take a back seat to engineering for the girls from Woodland Academy in Castle Rock. Sure, they had designed a solar-powered car that could roar down the 20-meter neoprene track in a tick above 6 seconds. But showing that brains and fashion can combine, they cut the chassis of their car in the shape of a bottle of nail polish.

"The black part is where you take the brush out, and the purple is the color of the nail polish," said Emma Ciafone, who was sporting purple toenail polish herself.

The four-girl team, dubbed "Sweet and Sassy," looked like they were ready for senior prom at Sparkle High School, with eye glitter, makeup, stylized coifs, and purple ribbons in their hair.

"We woke up at five to do makeup; we went a little overboard," said Sofie Weidenhues.

The Joy of Victory, the Agony of Wipe-Outs

"Let there be photons!" race starter Ginley yelled. And a few photons peeked through the clouds, enough to separate the wheat from the chaff among the solar engineering designs.

Some cars performed like champions on the practice track, but wavered in the actual races.

"I think my car has stage fright," said Taylor McCown of Merrill Middle School in Denver. "It goes forward and backward great on the test track, but I couldn't get it going when it counted."

"But we finished—that's something," said teammate Devin Shepard.

A team of girls from Southern Hills Middle School in Boulder had a solar car fast enough to make it to the semifinals, thanks in part to wrapping a wide rubber band around each wheel to reduce friction.

But they put more effort into whimsy with their car, "Blue Water Blast." "We used cellophane to make it appear that there was blue water inside," said Rya Muller.

They crafted two fish, a jellyfish, a crab, and an eel to place inside the cellophane-sealed box.

"They shake when the car moves, so it looks like they're swimming," said Mia Kirlan-Stout.

Awards for Speed, Design, and Sportsmanship

In the semis, "Blue Water Blast" and "Sweet and Sassy" were in the same heat, but neither advanced to the finals. "My car runs completely on solar, and there just wasn't enough sun," said Summer Hockey, chief designer for "Sweet and Sassy." "We gave it our best shot, but you can't always win. It was really fun."

It was congeniality like that—not to mention the eye sparkle and hair ribbons—that won "Sweet and Sassy" the Spirit Award for good sportsmanship, respectful behavior, enthusiasm, and courtesy. "Sweet and Sassy" also won the first-place design award in the solar car division.

The solar car speed winners, from the STEM School and Academy of Highlands Ranch, put long hours into engineering. "We played around with the geometry until it was perfect," Michael Whitaker said of his team's sleek car, which was comprised of a thin slab of glass and a protective cover over the solar panel to block the sun until it is needed. The team used a laser engraver to ensure the cover had the same dimensions as the car itself, and put holes in the glass to increase air flow.

"We spent a lot of time on the gear ratios so it wouldn't require much power to get to full speed," said Koby Dudley.

Rashid Zakiror noted that they could adjust the slab of glass up and down to match the angle of the sun. "I think the clouds

actually helped us, because our car might have needed less sunlight than the other cars."

During a break, several of the competitors drew inspiration from watching a neighboring exhibition race—high-school students from all over Colorado racing their larger model cars around an oval track at high speeds. It was an hour-long endurance contest, and the laps numbered in the hundreds.

Hauling a Bunch of Salt in Lithium-Ion Vehicles

In the lithium-ion battery car division, wheels were flying off cars like leaves in a storm. The "Dynamic Divas," racing against five all-boy teams, were in third place with a ticket to the semifinals when their car lost its grip on the guide wire and spun off the track.

The lithium-ion team from University School in Greeley was thinking speed and not much else. The cars need to be light, streamlined, and rugged enough to speed down the track while nestling a 26-ounce cylinder of salt above the chassis.

The team's balsa-wood car, "Lucky Charms," won a preliminary heat in 5.6 seconds, but the cardboard backseat gave way to the weight of the salt.

The team had a quick confab with their coach, eighth-grade STEM teacher Eric Buxman, and headed to the repair station.

Rubber bands are the duct tape of the car repair shop, but ultimately, the University School team decided on glue to strengthen the backseat.

A Competition to Inspire All Types of Students

"They're really doing excellent, but they're nervous," seventh-grade STEM teacher Keith Decker said. "Some of these kids struggle in class, but a competition like this brings out the best in them."

For the lithium-ion finals, the University School team of Trenton Elliott, Moises Martinez, Trevor Killen, and Devin Archuleta made a last-second decision to place the salt canister sideways across their car's backseat.

At the starter's command, they switched on the battery and the car blazed down the track in 5.52 seconds, winning by a couple of car lengths.

"STEM is our favorite class—at least when we were building our car, it was our best class," Archuleta said.

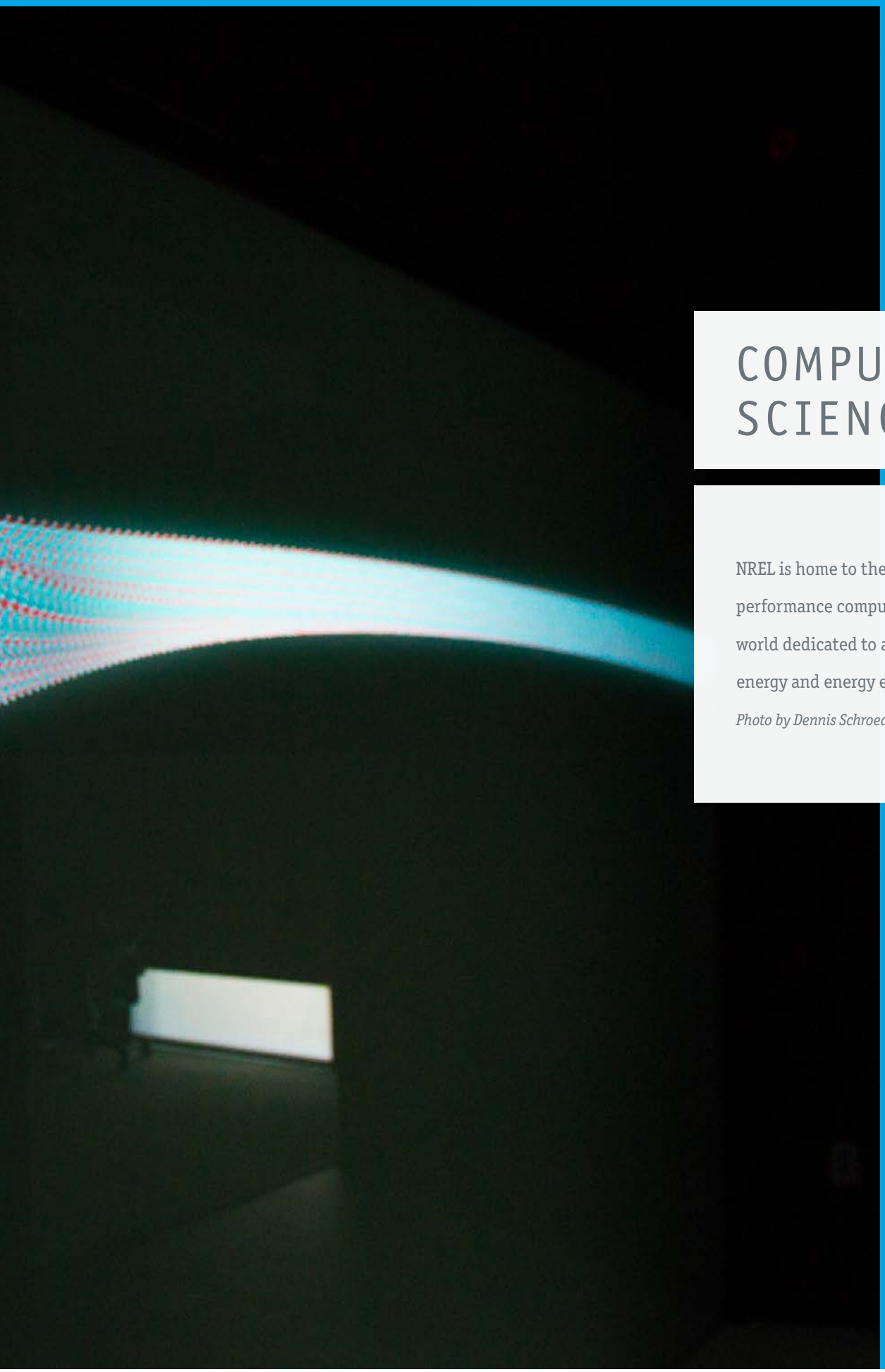
Tomorrow's Scientists and Engineers

Ginley, the NREL research fellow who served as starter for the solar races, said he's always gratified by the annual contest. "This year, the competition was so close," he said, indicating that a large number of teams had first-rate designs. "And they did it on a very cloudy day. Events such as these kindle the passion for renewable energy in the next generation."

Bill Farris, associate NREL laboratory director, said: "Some of our best young researchers first heard of NREL when they were in middle school, designing cars for this race. I'm betting that some of the kids here today will be working for us or designing cars someday."

If so, we can all look forward to a future of whimsical, fashionable, and speedy cars—all driven by renewable energy.

—Bill Scanlon (May 24, 2013)



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 26186

Makeover Puts CHARMM Back in Business

Biofuels scientists are asking more complex questions about how molecules spin, bond, and break when enzymes attack plants—all in the name of quickening the process of turning biomass into fuels for the sake of cleaner air and better energy security.

They're the kinds of questions that require trillions of mathematical operations each second on supercomputers. But, software engineers hadn't been able to keep up with the ever-increasing demands of the scientists and the growing capabilities of modern supercomputers. That is, until unique work at the Energy Department's National Renewable Energy Laboratory (NREL) supercharged an essential decades-old software program to run on a single high performance computer such as the new petascale computer at NREL's Energy Systems Integration Facility.

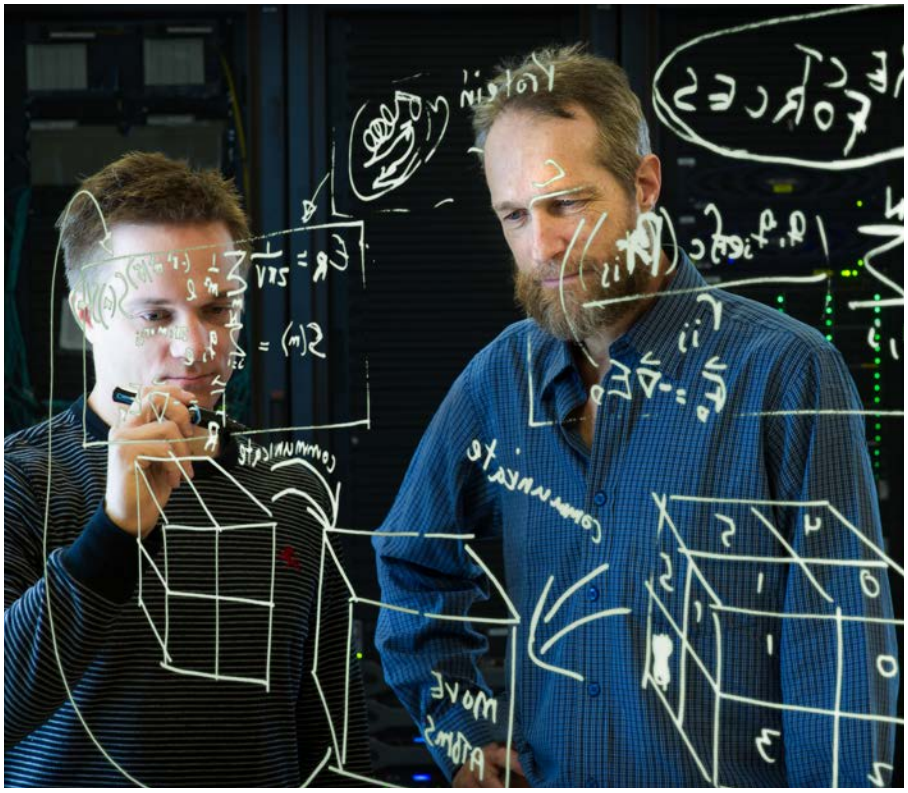
Software engineers at NREL have reworked codes and algorithms on the CHARMM (Chemistry at Harvard Molecular Mechanics) program to allow it to simulate molecular motion with millions to billions of steps of computation. It does so by simulating nanoseconds to microseconds of molecular motion, which takes days of computing time.

How long is a nanosecond? Well, a nanosecond (a billionth of a second) is to a second as a second is to 31.7 years.

And a nanosecond is a very long time when measuring all the movements of thousands of atoms in a molecule.

It takes a million molecular dynamics (MD) steps to simulate a nanosecond of molecular motion.

"For an average system of 100,000 atoms on a single modern processor core, it would take us half a day of computing to simulate less than half a nanosecond," NREL Senior Scientist Michael Crowley said.



NREL scientists Michael Crowley and Antti-Pekka Hynninen have developed algorithms that speed calculations done by the software tool CHARMM (Chemistry at Harvard Molecular Mechanics) by several orders of magnitude, using code such as the one pictured. Using the new petascale high performance computer housed in NREL's Energy Systems Integration Facility, scientists will be able to simulate the motions of thousands of atoms, leading to greater understanding of how molecular models work.

Photo by Dennis Schroeder, NREL 24348

But they need to simulate molecular motion for much longer than that—as long as 100 nanoseconds.

"Using the original version of parallel CHARMM, it would take half a year, no matter how many processors we used, to simulate molecular motion for that long," Crowley said.

Thanks to the improvements the NREL engineers made to the CHARMM algorithms and code, they can now do that simulation in a day with hundreds of processors running in parallel.

"To get a microsecond [1,000 nanoseconds] on a thousand processors will now take a few days," Crowley said.

The only limit on the questions scientists can ask—and expect answers to—is the speed of computing power. For more than a decade, each time scientists asked new questions that required faster computer power to answer, engineers could count on a computer's speed doubling every year or so to keep up.

"But this is not enough to keep up anymore. Computer chips are not getting any faster—they are getting more parallel," said NREL's Antti-Pekka Hynninen, a physicist and software engineer. "We now have to parallelize the code to multiply the speed at which the simulations can be run."

CHARMM Models Biological Reactions

CHARMM was developed at Harvard University in the 1980s to allow scientists to generate and analyze a wide range of molecular simulations, including production runs of a molecular dynamics trajectory for proteins, nucleic acids, lipids, and carbohydrates.

It is a favorite program of molecular researchers around the world for simulating biological reactions such as the action of cellulase on cellulose for converting biomass into ethanol. CHARMM is also a crucial code for the pharmaceutical industry.

CHARMM is unique in its ability to build, simulate, and analyze results of molecular motion in a single program. "It provides more methods of simulation than any other program, and the newest and most cutting-edge methods for thermodynamics, reaction sampling, quantum mechanics, molecular mechanics, and advanced imaging," Crowley said.

For all its advantages, though, CHARMM's crunching velocity hadn't kept up with the new demands and the new questions.

> "Computer chips are not getting any faster—they are getting more parallel. We now have to parallelize the code to multiply the speed at which the simulations can be run."
>
> —**ANTTI-PEKKA HYNNINEN,** *NREL Physicist and Software Engineer*

The size of the new biomolecular simulations is so large (more than 1 million atoms) and the simulation time so long (5 million time steps for the 10-nanosecond simulation) that they exceeded the capabilities of CHARMM.

So, three years ago, Crowley hired Hynninen to update the code and increase its performance.

If Hynninen had tried writing the entire 600,000 lines of code, he estimates it would have taken him about 10 years.

Instead, he focused on rewriting the heart of CHARMM, the molecular dynamics engine, and he was able to parse the chore down to two years. The molecular dynamics engine is where all the heavy computation is done. It may only represent 5% to 10% of the total lines of code, but it accounts for approximately 99% of the central processing unit (CPU) time in a typical simulation.

He's the first to admit it wasn't exactly a day (or two years) at the beach.

Hard, Laborious Work—with Shortcuts

"It's one of those very hard problems, mechanics of atoms and enzymes," Hynninen said. "There is really no limit to how a molecule can behave." Its motions are determined by the interplay of a multitude of interactions between each atom and every other atom nearby—through both chemical bonds and non-bonded interactions, he noted. That results in thousands of different kinds of interactions per atom. And there can be hundreds of thousands of atoms in a simulation. "And this makes writing the algorithms and code quite challenging."

> “I just started digging in. It’s a lot of sort of lonely work. Just to figure out the algorithms, I went through 20 legal tablets, drawing diagrams—and then writing the algorithm into code.”
>
> **—ANTTI-PEKKA HYNNINEN,** *NREL Physicist and Software Engineer*

The day-long task using hundreds or thousands of processors simulates a very brief moment cataloguing every move by thousands of atoms. “It’s not just that they all move but that each atom is feeling forces from thousands of other atoms,” Crowley said. “And each one of those forces has to be calculated for every atom at every step.”

On the time scale most of us are used to, observing action in microseconds of nanoseconds seems ridiculously short. “But they are long enough to answer lots of questions, because they show us what the molecule is probably doing most of the time,” Crowley said.

And simulating the motion of atoms answers important questions about how any enzyme can access the sugars in a plant.

The sugars the biofuels industry wants are locked up in a polymer called cellulose, which forms bundles or fibers of a few dozen polymer chains. CHARMM’s molecular dynamics can simulate those bundles and find how strongly they are held together, as well as what interactions are holding them together. Using CHARMM, scientists can also model the interaction of an enzyme with those bundles and determine how the enzyme peels the polymers out of the bundle. “We learn what forces it uses or how it reduces forces holding the bundle together,” Crowley said.

Entropy is a large factor in the process, so it’s not enough to merely calculate the energy. Scientists have to find out all the possible configurations of the molecular system. “It’s essential to find out how much each configuration is contributing to the average behavior—and that takes a lot of simulation time,” Crowley said.

They carefully examine the data to see which amino acids are interacting with the sugars. They observe how the overall structure of the carefully chosen enzyme changes and how it binds, twists, and bends the sugars to allow the chemical reaction that releases them.

Molecular dynamics code is quite easy to write if you do not care about performance, Hynninen said. But to code the algorithm to run very fast … that’s difficult.

“I just started digging in,” Hynninen said. “It’s a lot of sort of lonely work. Just to figure out the algorithms, I went through 20 legal tablets, drawing diagrams—and then writing the algorithm into code.”

The traditional approach is to divide the atoms evenly among the CPUs: the first CPU gets, say, the first 1,000 atoms, the second another 1,000, and so on.

The trouble with this approach is that each CPU has to talk to every other CPU at each molecular dynamics step to inform them what the others are up to. And that communication slows everything down.

To speed things up requires very clever shortcuts—communicating the smallest amount of information between the fewest computers. This means reorganizing the work to be done and which computer does it with those criteria in mind, and then making sure the work is equally distributed so there are no idle workers.

“We set up the problem so talking is minimized—the number of words and messages is stripped to the bone,” Crowley said.

Hynninen retained the strengths of the CHARMM code and combined them with ideas from other programs to enhance CHARMM’s speed.

“Now we’re back in the ballgame again,” Crowley said. “This is a huge, huge improvement. People are using CHARMM again.”

Funding for NREL's work on CHARMM came from two areas in the Energy Department's Office of Science—Advanced Scientific Computing Research (ASCR) and Biological and Environmental Research (BER)—as well as funds from the National Institutes of Health (NIH) for code modernization at the University of Michigan. Partners include the University of Michigan, Oak Ridge National Laboratory, and the University of California at San Diego.

Crowley and Hynninen vow to do all they can to prevent CHARMM from again slipping behind other codes in processing speed.

While national labs hire some of the world's best scientists, they typically don't hire software engineers and especially not scientists like Hynninen to do software engineering. It may not be a bad idea for them to start doing so, what with science frontiers becoming increasingly reliant on powerful computers and complex algorithms, Crowley said.

Computer Simulations Answer Questions About Enzyme Processing Bottlenecks

By fully understanding how enzymes find, reach, and act on the cellulose in plants, scientists may be able to engineer super-efficient enzymes that create abundant energy from algae or agricultural waste products.

The work is crucial because one of the most promising paths toward energy independence and clean energy requires biofuels to achieve price parity with gasoline.

Scientists know that cellulose-active enzymes act like protein machines, breaking bonds in procession and pulling out strands à la an assembly line.

But there is still plenty to learn, because bottlenecks in the process slow things down. NREL Senior Scientist Mark Nimlos uses CHARMM's molecular dynamics software to simulate some 50,000 atoms to try to uncover the bottleneck. The aim is to selectively replace a few amino acids to speed up the bond breaking.

Now that the new version of CHARMM is orders of magnitude faster—supersonic transport versus the Kitty Hawk plane, Crowley attests—the chances of solving problems such as those bottlenecks have increased exponentially. And the new and improved CHARMM should prove a boon to molecular scientists working with pharmaceuticals, as well.

Like a three-legged-race team moving in tandem, scientists and computer engineers have to count on each other to keep up.

Crowley compared Hynninen's borrowing of algorithms from other molecular dynamics software packages to "looking at how a VW is built to help you make your Chevy better."

"It's pretty darn hard to do if you don't understand the science," Crowley added. "That's why [Hynninen] is a real gem. He understands the science as well as the algorithms."

—Bill Scanlon (March 22, 2013)

New Ultra-Efficient HPC Data Center Debuts

Scientists and researchers at the Energy Department's National Renewable Energy Laboratory (NREL) are constantly innovating, integrating novel technologies, and "walking the talk." Since 1982, NREL has won 52 R&D 100 Awards—known in the research and development community as "the Oscars of Innovation"—for its groundbreaking work.

When it came time for the lab to build its own high performance computing (HPC) data center, the NREL team knew it would have to be made up of firsts: The first HPC data center dedicated solely to advancing energy systems integration, renewable energy research, and energy efficiency technologies. The HPC data center ranked first in the world when it comes to energy efficiency. The first petascale HPC to use warm-water liquid cooling and reach an annualized average power usage effectiveness (PUE) rating of 1.06 or better.

To accomplish this, NREL worked closely with industry leaders to track rapid technology advances and to develop a holistic approach to data center sustainability in the lab's new Energy Systems Integration Facility (ESIF).

"We took an integrated approach to the HPC system, the data center, and the building as part of the ESIF project," NREL's Computational Science Center Director Steve Hammond said. "First, we wanted an energy-efficient HPC system appropriate for our workload. This is being supplied by HP and Intel. A new component-level liquid cooling system, developed by HP, will be used to keep computer components within safe operating range, reducing the number of fans in the backs of the racks."

Next, the NREL team, which included the design firms SmithGroupJJR and the Integral Group, created the most energy-efficient data center it could to house and provide power and cooling to the HPC system. High-voltage (480 V_{AC}) electricity is supplied directly to the racks rather than the typical 208 V, which saves on power electronics equipment, power conversions, and losses. Energy-efficient pumps largely replace noisy, less-efficient fans.

"Last but not least, we wanted to capture and use the heat generated by the HPC system," Hammond said. "Most data centers simply throw away the heat generated by the computers. An important part of the ESIF is that we will capture as much of the heat as possible that is generated by the HPC system in the data center and reuse that as the primary heat source for the ESIF office space and laboratories. These three things manifest themselves in an integrated 'chips-to-bricks' approach."

Like NREL's Research Support Facility, the ESIF HPC data center did not cost more to build than the average facility of its kind. It actually cost less to construct than comparable data centers and will be much cheaper to operate. NREL's approach was to

Steve Hammond, director of NREL's Computational Science Center, stands in front of air-cooled racks in the high performance computing data center in the Energy Systems Integration Facility. The rest of the system will be built out this summer using warm-water liquid cooling to reach an annualized average power usage effectiveness rating of 1.06 or better. *Photo by Dennis Schroeder, NREL 24357*

minimize the energy needed, supply it as efficiently as possible, and then capture and reuse the heat generated.

"Compared to a typical data center, we may save $800,000 of operating expenses per year," Hammond said. "Because we are capturing and using waste heat, we may save another $200,000 that would otherwise be used to heat the building. So, we are looking at saving almost $1 million per year in operation costs for a data center that cost less to build than a typical data center."

Warm-Water Cooling Boosts Data Center Efficiency

The ultra-efficient HPC system in NREL's new data center has been designed in collaboration with HP and Intel. The HPC system will be deployed in two phases that will include scalable HP ProLiant SL230s and SL250s Generation 8 (Gen8) servers based on eight-core Intel Xeon E5-2670 processors as well as the next generation of servers using future 22 nm Ivy Bridge architecture-based Intel Xeon processors and Intel Many Integrated Core architecture-based Intel Xeon Phi coprocessors. The first phase of the HPC installation began in November 2012, and the system will reach petascale capacity in the summer of 2013.

In the spirit of overall energy efficiency, the Intel Xeon Phi coprocessor delivers on several fronts. According to Intel, it can easily port complete applications in a short time, so software engineers won't need specialized tools or new languages to support significant software packages. "Intel coprocessors also increase the efficiency of computer resource usage," said Stephen Wheat, general manager of high performance computing at Intel. "The methods of code optimization for Xeon Phi are identical to what one does to make the most of Xeon processors. Finely tuned optimizations for Xeon Phi almost always result in a better-performing source code for Xeon processors. As the optimized and tuned application is run in production, the achieved performance per watt on both Xeon Phi and Xeon processors allows achieving the results with the lowest energy use."

While some of the NREL HPC components may be off the shelf, the team is taking a different approach in cooling this supercomputer.

"In traditional computer systems, you have a mechanical chiller outside that delivers cold water into the data center, where air-conditioning units blow cold air under a raised floor to try to keep computer components from overheating," Hammond said. "From a data center perspective, that's not very efficient; it's like putting your beverage on your kitchen table and then going outside to turn up the air conditioner to get your drink cold."

"NREL's ultimate HPC system is currently under development and will be a new, warm-water cooled high-performance system," said Ed Turkel, group manager of HPC marketing at HP. "It will be a next-generation HPC solution that's specifically designed for high power efficiency and extreme density, as well as high performance—things that NREL requires."

Starting this summer, NREL's HPC data center will require just over 1 megawatt of power to operate. "That's a lot of power; the heat dissipated from that is very substantial," Hammond said. "Getting the heat directly to liquid rather than through air first and then to liquid is the most efficient way to utilize it."

Water being supplied to the servers will be approximately 75 degrees Fahrenheit (°F); the water returning from the HPC will be in excess of 100°F and is designed to be the primary source of heat for ESIF's office and lab spaces. Data-center waste heat is even used under the front plaza and walkway outside the building to help melt snow and ice. Thus, the heat byproduct from the data center will also improve safety around the ESIF.

Compared to a typical data center, NREL's HPC data center will be much warmer. The 75°F design point is a higher starting temperature for computer cooling. Starting at this temperature allows NREL to eliminate compressor-based cooling systems and instead use cooling towers. In a data center, this is comparable to a homeowner using an energy-efficient swamp cooler rather than an air conditioner. In addition, the pump energy needed to move liquid in the cooling system is much less than the fan energy needed to move the air in a traditional data center. Water is about 1,000 times more effective than air in terms of the thermodynamics, or the heat exchange.

"We're quite enamored with NREL being able to reuse the heat for the building and parts of the campus," Wheat said. "While others have done this before, here we are looking at a combined total efficiency goal and not just harvesting heat. We're looking to see how this can be the best solution for the entire campus."

Using the HPC's waste heat to boost the ESIF's sustainability and finding unique solutions to cut the data center's PUE are just what NREL does. "This is in our DNA; it is part of our mission at the lab, and we want others to follow suit," Hammond said. "NREL isn't one-of-a kind in what we are doing—but we've set out to be the first of a kind. For us, it just makes sense. Others can follow suit if it makes dollars and sense."

The lab's industry partners also see a long-term relationship for energy efficiency and HPC, especially when it comes to exascale computing.

"We see the area of HPC as being insatiable; people will have a need for ever-greater performance," Wheat said. "One of the things we are mindful of is that while our systems are becoming denser in terms of footprint, they are becoming more power efficient. NREL is the premiere place to demonstrate a means to continue the growth of HPC capability in an environmentally friendly way."

HP's Turkel echoes that sentiment: "As power-efficient and dense as our HPC systems are, to meet our customer's rapidly expanding requirements for performance, we would need to grow even our most powerful and efficient system to be impractically large and complex, while consuming enormous amounts of energy.

"To get to the levels of scale that our customers are demanding of us, we have to fundamentally change the dynamic around power, density, and performance," Turkel added. "We have to be able to do it in a much smaller package using less energy. This project is a step in that direction—and it's apropos that NREL is a partner in the effort."

"eBay, Facebook, and others have data centers that are water capable, but there aren't any products on the market now that are providing liquid cooling," Hammond said. "NREL is getting the first product that is direct-component liquid cooled. We're going to show it's possible, efficient, safe, and reliable."

Expanding NREL's View into the Unseen

The $10 million HPC system will support the breadth of research at NREL, leading to increased efficiency and lower costs for research on clean energy technologies including solar photovoltaics, wind energy, electric vehicles, buildings technologies, and renewable fuels.

The new system is crucial to advancing NREL's mission and will enable scientists to address challenges that have been intractable to date. The new system will greatly expand NREL's modeling and simulation capabilities, including advancing materials research and developing a deeper understanding of biological and chemical processes. "Modeling and simulation capability is a key part of advancing our technologies," Hammond said. "It allows us to do research we can't do experimentally because it would be too expensive, or would take too long if actual systems were built. We can mathematically model and run numerical simulations that allow us to understand things through direct observation."

Before building an HPC data center in the ESIF, NREL had a small system on its campus, while collaborating with Sandia National Laboratories on the RedMesa supercomputer to bridge the gap until NREL had a facility to house its own HPC system. For the past two years, the NREL/Sandia solution has been oversubscribed. "We averaged 92% utilization day in and day out; we needed much more capable systems to meet growing demand for modeling and simulation," Hammond said.

According to Hammond, NREL will also reach out to the local utility to study demand-response scenarios. "There are times in summer when electricity demand is high that we could shed load with the data center to help Xcel Energy." NREL could alter workloads and schedule particular jobs to run in mornings when there's a high demand for heat and cooling is less expensive. In another scenario, NREL could schedule workloads to take advantage of lower electricity costs or be mindful of when rates are higher to help reduce operating expenses. "There is a lot of interest in looking at how to integrate the HPC system in the building automation system as part of the energy systems integration work that we're doing," Hammond said.

"The computational activities at NREL had to be part of the efficiency equation," said Wheat. "A motivation for Intel to work with NREL was the ability to work together to validate how to do an efficient data center. We needed to be able to assure that we had the right balance of processor performance for the workload—with a performance-per-watt focus. Being a partner with NREL in this process is of value to us for demonstrating leadership in our community. Others are taking notice of what NREL has done; I believe we all benefit from that."

— Heather Lammers (March 11, 2013)

Scientists Go Eye to Eye with Research at ESIF

Joysticks, 3-D glasses, and room-sized stereoscopic views of some of the tiniest things in the universe—scientists at the Energy Department's National Renewable Energy Laboratory (NREL) now have a new way to view and interact with their data.

Researchers from national labs, universities, and utilities get a human-sized embodied view of molecules, enzymes, solar junctions, and polymers in the Insight Center at NREL's Energy Systems Integration Facility (ESIF).

The primary display in the Insight Center Collaboration Room is a glass wall 16 feet wide and eight feet high with a projection floor that extends about five feet outward, allowing the user to be physically immersed in the data. Six projectors blend together into a seamless image to illuminate the display: four projectors back-project onto the glass wall, while two projectors overhead front-project onto the floor.

Turning the body, even nodding the head, changes the researcher's view, affording him or her the best possible angle of a junction, molecule, or anything on the screen. Users can manipulate the scene from the comfort of a desk using keyboard and mouse, but they can also directly interact with models in three dimensions using a joystick (and eventually gloves).

It's much more than fun. Real scientific problems are being solved with these larger-than-life visualizations.

Despite the appearance, the image isn't actually three-dimensional. But with the aid of the room architecture, projectors, glasses, and tracking technology, it sure seems to be.

"The idea behind the Insight Center is to provide researchers new ways to view and interact with their data. For example, the immersive display is designed to help the brain process very complicated data by letting the user physically explore the imagery with the aid of these visualization and interaction technologies," said NREL's Kenny Gruchalla, senior scientist, who designed the Insight Center visualization rooms.

"Our brains are very sophisticated pattern-matching machines with a majority of our neurons dedicated to processing visual information. However, the brain has largely evolved to process visual information from an embodied perspective," he said.

Discovering Junctions Not Seen on the Desktop

Ross Larsen, a senior scientist and polymer expert at NREL, is a big fan.

He has used the Collaboration Room for two projects—organic radical batteries and organic photovoltaic (PV) cells—to understand how very large polymer molecules pack and

NREL Senior Scientists Ross Larsen, left, and Travis Kemper get a human-scale view of a molecular model of polymeric organic nitroxide radical film at the Insight Center Collaboration Room in the Energy Systems Integration Facility at NREL.
Photo by Dennis Schroeder, NREL 26174

intertwine, and how one chain is oriented relative to another chain in complicated arrangements.

He remembers the first day he serendipitously encountered one of his images on the big screen and made an almost instant discovery.

"I had this image of a coarse-grained model—blue and red pipes to represent a bulk heterojunction structure used in organic PV," Larsen recalled. "One day, the day before a VIP tour of the lab, that image was up on the big screen looking like huge eye candy."

He slipped on some 3-D glasses and walked toward the image. "All of a sudden, I noticed, 'Hey, wait a minute. There are five tubes converging at a node here—over there, there are three, and there are seven up there.'

"It occurred to me that it might make a big difference how easily a charge can move through a material if it has more options." An electron might be able to exit a device faster—and provide electricity more efficiently—if it had more of those seven-pipe junctions to work with than, say, three-pipe junctions.

He is still wrapping his head around the possible implications, but: "What was new to me was the idea that within a single morphology, there may be multiple different branching levels. The motions the electrons are undergoing—and the environment they are moving through—isn't nearly as simple as I thought."

Larsen said he "spent a lot of time staring at those things on my computer screen, rotating them around, and I never noticed anything like that. It took me just five minutes walking into that structure for the first time to see it. That got me very excited—that I discovered something new, even though I don't know yet what to make of it."

He is convinced that the human-sized scale of the model helped with the discovery. "I was encountering something about the size of another human. It lets you zoom in at the right scale—if it's too small, you might as well be at your computer. If it's too big, it can just be overwhelming."

High-Tech Glasses Give 3-D Illusion

In the Collaboration Room, optical trackers and infrared strobes work with 3-D shutter glasses to orient the images to the will of the user. The shutter glasses provide separate images for each eye. The glasses have LCD shutters that are synchronized with the projectors using a radio-frequency signal. When the right image is displayed, the left eye is shutter closed—and vice versa. The computer displays the images at 120 hertz, so the user gets 60 hertz per eye.

At the same time, reflective markers on the glasses allow the user's viewpoint to be tracked, providing a motion parallax, or an egocentric point of view. As the scientists view the space, they move the data because the glasses track the position and orientation of the operator's head. As the head moves, the computer modifies the position of the scene.

"It gives the illusion that these data models are in three dimensions and in the presence of the user," Gruchalla said. "As you move through the space, the tracker communicates your viewpoint to the computer. The computer then optimizes the scenery to that position, allowing you to physically move through your data."

Visualization work currently underway in the Collaboration Room is looking at data from the very small at atomistic scales to the very large at the scale of North America.

On the huge end of the scale, researchers studying the complex, turbulent flow fields around wind turbines can treat the space as a massive turbine-array-scale virtual wind tunnel, standing amongst the turbines and seeding virtual particles to see the complex flow patterns and better understand how turbine wakes and turbulence can cause early gearbox failure.

In a real-world wind tunnel, researchers use smoke to try to understand the dynamics of the flow. There are analogues to the smoke in the computational spaces of computer engineers. Using a numerical vector field, they can integrate a path through that field. They can see where a particle dropped in the flow would travel. The computational space affords many ways to investigate the flow that are not possible in a physical wind tunnel—not to mention operating on sizes that would be wholly impractical in the physical world.

On the tiny end, a researcher can, for example, use the immersive space to zero in on the junctions of a solar cell, sorting through the electrons and corresponding holes to see that multi-pronged junctions can cause entirely different dynamics than single- or double-pronged junctions.

Experiments Prove Worth of Human-Sized 3-D Visualization

Gruchalla has a Ph.D. in computer science. His master's research investigated scientific workflows in virtual environments at the University of Colorado (CU). His Ph.D. research focused on visualizations of large-scale turbulence simulations at the National Center for Atmospheric Research.

While at CU, Gruchalla conducted multiple controlled studies to investigate the added value of immersive visualization. In one experiment, 16 subjects planned the paths of oil wells in immersive and non-immersive environments. Fifteen of them finished the task faster in an immersive visualization environment such as the one at ESIF than they did on a desktop computer. And they also had a higher percentage of correct solutions than they did with the desktop.

In a separate study, three independent groups of biochemists visualized and interacted with individual biological modules in a virtual immersive environment. In each case, the groups yielded new insights after 90 minutes in the human-scale environment that they hadn't discovered during months or years examining the same data on a desktop computer.

In one case, a group found a molecular pocket that it hadn't seen before. The researchers credited not only the human-sized scale but the greater opportunity to collaborate during their interactive viewing of the giant models. Two of the groups produced new scientific papers in part as a result of these new insights.

"Once they're literally standing inside their molecule, and are able to interact three-dimensionally, they're able to make judgments and take measurements that wouldn't be possible otherwise," Gruchalla said.

Complementing the immersive virtual environment of the Collaboration Room is the Insight Center Visualization Room, which is used for presentations and the exploration of large-scale data. Its high-resolution screen is composed of more than 14 million pixels.

The presentation room uses LED projectors that generate minimal heat. They're rated for 60,000 hours of use, so they shouldn't need to be replaced for about 20 or 30 years—or, more likely, until new technology supersedes them.

The screen will be used for, among other things, displaying images and simulation results from studies of electric vehicles, wind farm performance, biomass-degrading enzymes, and PV materials. "Using the high-resolution, large-scale display [on the Visualization side] of the Insight Center, we now have the visual real estate to lay out a significant amount of data simultaneously that will enable the analysis of ensembles of these types of simulations," Gruchalla said.

The screen's size allows researchers to, say, look at 500 meteorological variables at one time, instead of the dozen or so they could examine on a desktop. That illuminates trends and correlations that would otherwise be lost on the margins.

Insight Center Boon to Energy Systems Integration Facility

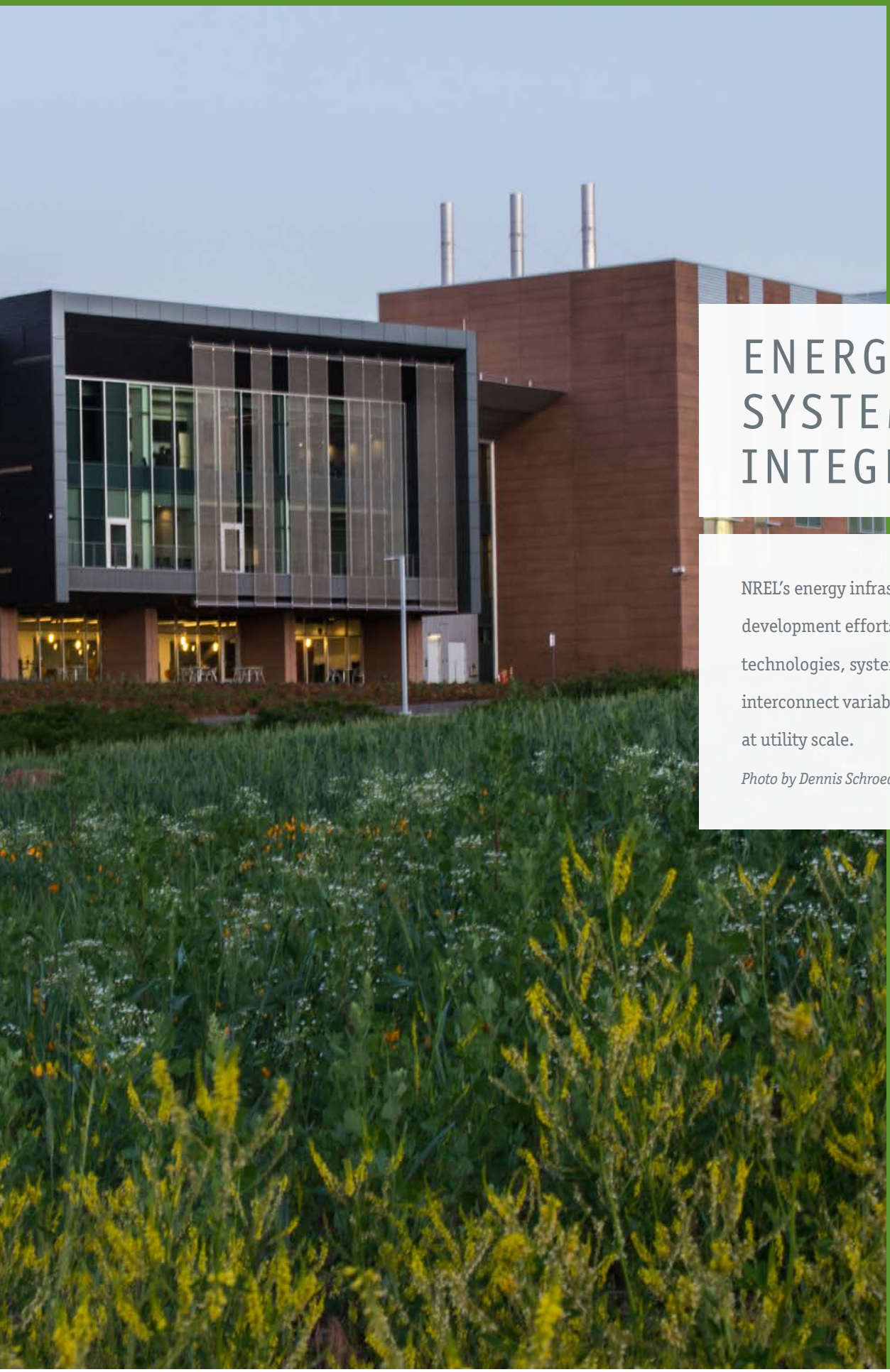
ESIF offers utility executives and other decision makers a place to research new technologies in a virtual environment before they're loaded onto the actual grid. The United States is moving into an era with a higher penetration of renewable energy and distributed energy resources linked to the electric grid. NREL's $135-million ESIF was built to help utilities prepare for the day in the not-too-distant future when the electric grid speeds power from all our energy resources to American homes, offices, and stores. ESIF's Insight Center used less than 1% of that budget—about $1 million—but is expected to make a significant difference for researchers trying to understand the newest complexities in an integrated grid.

The two visualization rooms work hand in hand with NREL's petaflop-scale high performance computer—which, not coincidentally, sits just a few feet from the big screens, connected by high-speed fiber. "What we're doing is using new tools to better delve into terabytes to petabytes of complex data," Gruchalla said.

The two new screens in the ESIF Insight Center open a different world to researchers used to peering into an electron microscope or a laptop screen to make discoveries.

"The researchers have been very excited to come in here and look at the data in large scale," Gruchalla said. "To explore and see things in these data is quite a thrill."

— Bill Scanlon (July 10, 2013)



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 26198

Energy Secretary Dedicates ESIF at NREL

On Wednesday, September 11, Energy Secretary Ernest Moniz dedicated a new federal lab building he said will be crucial to bringing more renewable energy onto the nation's energy system and building the reliable, clean energy infrastructure America vitally needs.

Moniz officially dedicated the Energy Systems Integration Facility (ESIF) at the Energy Department's National Renewable Energy Laboratory (NREL), where industry and utilities will go to demonstrate their new equipment and strategies at megawatt scale.

The ESIF "will be a major focus of the Energy Department to help us transform the energy system to the one we need in 2030," Moniz said before a packed crowd of scientists, policymakers, and industry leaders at NREL's Golden, Colorado, campus.

Moniz, who was confirmed as Energy Secretary in May, said tremendous advances in wind, solar, and fuel cell energy have pushed those technologies to the threshold of being major presences on the nation's electricity grid.

However, that presents a challenge because solar and wind are intermittent resources. And that challenge is complicated by increased severe weather events such as Hurricane Sandy that knocked out power in 21 states last year, Moniz said, emphasizing the need for a more resilient infrastructure in the near future.

Climate Action Plan to Guide Policy

The Secretary's first weeks on the job coincided with President Obama unveiling his Climate Action Plan, which focuses on doing more to address the risks of climate change. "I said that first day, 'I'm not here to debate the undebatable,'" Moniz said, referring to the strong belief among almost all climate scientists that the Earth is getting warmer due in part to fossil-fuel emissions in the atmosphere.

"We need to frankly acknowledge that we are facing the effects of climate change even as we try to kind of beat the clock with

Energy Secretary Ernest Moniz (center) joins NREL Director Dan Arvizu (left) and Steve Hammond, director of NREL's Computational Science Center, at the unveiling of Peregrine, the newest Energy Department supercomputer. The high performance computer inside NREL's new Energy Systems Integration Facility is capable of 1.2 quadrillion calculations per second. NREL collaborated with HP and Intel to develop the innovative, warm-water-cooled supercomputer. *Photo by Dennis Schroeder, NREL 27485*

mitigation and adaptation," Moniz said. "Our script comes from the President's Climate Action Plan. Both mitigation and adaptation to climate change are very much part of that agenda."

So now the nation's focus must be on energy integration—on delivering distributed energy to the grid when the sun shines and the wind blows, while keeping it as reliable as when the grid was a one-way delivery system of fossil-fuel-based energy, Moniz said. The new ESIF is "the step up we need to elevate the focus on energy systems integration."

The ESIF will also play a key role in helping regional utilities design resilient microgrids that will bring back power almost immediately to communities that now are bathed in darkness when storms such as Hurricane Sandy hit, Moniz said. "We need to reap the benefits of our tremendous technological advances to start developing solutions for our energy system."

Supercomputer's Green Data Center Teamed NREL with HP

Just before his talk, Moniz pushed a button that inaugurated the ESIF's high performance computer Peregrine, which can do more than a quadrillion calculations per second and is integral to the ESIF's capabilities. Peregrine supports NREL's research into energy systems integration, renewable energy research, and energy efficiency technologies, and will lead to increased efficiency and lower costs for clean energy technologies. NREL teamed with HP to develop the supercomputer.

Paul Santeler, vice president of the Hyperscale Business Group at HP, said the collaboration with NREL on the high performance computer and data center was the best partnership he's been a part of because both the company and laboratory learned so much—knowledge that will help other data centers go deep green. The data center for the Peregrine supercomputer in the ESIF is unique, because it uses the excess heat generated by the computer to warm water, and then uses that water to heat the entire building.

"When Steve Hammond [director of NREL's Computational Science Center] told me wanted to put in a petaflop-scale high performance computer, and that he wanted to cool it with warm water and use that water that comes off to heat the building, and then use the excess heat to warm the cement outside, I said, '*Riiight*,'" Santeler said. "We were doing something very unique and different—breaking boundaries. But the bottom line is, we nailed it. And we're making it commercially available so others can take advantage."

Moniz got a firsthand look at the ESIF's computing capabilities when he went into the ESIF's visualization room, donned special glasses, and saw on a 16-foot, 3-D-like screen how wind turbine blades can alter the wind flow as it approaches other turbines downstream. The same visualization room can give scientists a shifting, human-sized view of the inside of the molecules of a solar cell or biofuel.

"This will take us to a whole new ballgame," Moniz said. "It's an enormous advantage."

Utility CEO Stresses the Importance of Energy Integration

Xcel Energy CEO and Chairman Ben Fowke said the ESIF will grow even more important now that solar and wind are in many cases cost competitive with fossil fuels. He noted that Xcel leads the nation in wind power. His company now can purchase 20 years of wind power for less money than the comparable megawatts from natural gas, saving customers $800 million over the next two decades.

Wind forecasting software developed at NREL and elsewhere saved Xcel $20 million last year alone, and NREL research on the effect of cloud cover on solar energy will save even more, he said. Better forecasting means utilities can be more confident about the reliability of renewables, and that means less need for reserve power.

"We can really unlock the power of the future beginning today," Fowke said. "We're really excited about this next chapter in NREL's progress, and the integration of distributed resources into our grid. I'm confident our mission to deliver safe, clean, reliable power at a competitive price is in good hands because of partners like NREL."

Later, Fowke noted that Xcel during certain hours uses 80% wind energy, and so far it's gone off without a hitch. "Our number-one job is to make sure our customers can rely on the lights staying on," he said. "As the energy portfolio diversifies, we'll be depending on wind and solar forecasts and the capabilities of the ESIF more than ever."

Partnerships Announced with Toyota, U.S. Army

The Energy Department also made two other important announcements while the Secretary was at NREL.

NREL will work with the Energy Department and Toyota North America to research ways to integrate plug-in electric vehicles into the power grid. Scientists and engineers at the ESIF and NREL's Vehicle Testing and Integration Facility will use 20 Prius plug-in hybrid electric vehicles to develop and explore ways to help grid operators accommodate the fast-growing U.S. electric vehicle fleet.

Tom Stricker, vice president of energy and environmental research for Toyota North America, said "this new, amazing facility" will be crucial to analyzing the grid effects of Toyota's new plug-in Priuses. Hybrid, plug-in electric, and alternative fuel vehicles now comprise 16% of all Toyotas sold, he noted.

Stricker also said that Toyota will reveal its first production hydrogen fuel cell vehicle—a mid-sized sedan—at the Tokyo Motor Show in November. Its North American debut will be at the Consumer Electronics Show in Los Angeles in December.

He said Toyota will continue to work closely with NREL researchers at the ESIF. "We need continued collaboration between industry and government to solve the problems we face."

NREL is also working with the U.S. Army to develop a power system comprised of solar energy, battery power, and generators that can provide electricity to forward operating bases. Using the integrated test capabilities of the ESIF, NREL will complete a prototype of the Consolidated Utility Base Energy (CUBE) system and validate its performance, reliability, and projected energy savings.

ESIF's Role Will Be Transformative

NREL Director Dan Arvizu said that without partners such as Toyota, Xcel, HP, and the Energy Department, the ESIF wouldn't be what it is.

The ESIF will allow industry decision makers to model what an increasing penetration of solar or wind energy onto the grid would look like in real time, at a level of accuracy and detail never seen before, Arvizu said.

Manufacturers can test new energy equipment at megawatt power, Arvizu added. Vendors can analyze the optimal equipment balance as the energy system adds storage and two-way data sharing. ESIF brings together pertinent tools to integrate technologies in ways that weren't possible before.

David Danielson, the Energy Department's assistant secretary of energy for renewable energy and energy efficiency, lauded NREL for having the vision seven years ago to know that such a facility as ESIF was needed—and for pushing for it with the Department. "At every step, NREL provides critical leadership that guides policy."

Technological Success Speeds the Move to Energy Integration

Moniz noted that for solar, wind, light-emitting diodes (LEDs), and fuel cell batteries, the past few decades have seen plummeting prices and a huge rise in deployment.

The cost of solar power has plummeted 99%; wind led all technologies in new deployments last year; the price of LED bulbs has fallen from $50 to $15, and each one can save a homeowner $100 over a lifetime; and fuel cell prices have dropped sharply, while safety and longevity have improved greatly.

"A lot of us still have this lingering idea that these technologies are five or 10 years away, but really, we are on the threshold," Moniz said. "Each of these will be a material part of our energy system very soon."

That makes the ESIF and the successful integration of myriad forms of energy all the more crucial, Moniz added. Referring to the battering the nation's infrastructure took from recent extreme weather events such as Hurricane Sandy, and the need for a more flexible, integrated system that accommodates clean energy, Moniz said: "Mother Nature is pointing out that if we don't take care of our energy system, she will."

— Bill Scanlon (September 18, 2013)

NREL Connects EVs and Grid Integration

Engineers working at the Vehicle Testing and Integration Facility (VTIF) enjoy a stunning view of the Denver skyline. However, some days the view includes Denver's 'brown cloud'—air pollution caused in part by vehicle emissions. While disheartening, the brown cloud helps the engineers focus on future technologies that will drastically reduce—and ultimately eliminate—those emissions.

Researchers at the Energy Department's National Renewable Energy Laboratory (NREL) are advancing a more sustainable transportation future by incorporating advanced electric vehicle technology, expanded use of renewable energy resources for vehicle charging, and grid integration.

"Our goal is to target the key innovations necessary to accelerate the rate of adoption for electric drive vehicles," said Bob Rehn, group manager for testing and analysis at NREL's Center for Transportation Technologies and Systems. "In addition, our efforts are focused on scenarios that will incorporate expanded use of renewable energy resources to charge those vehicles."

The Right Tool for the Job

The VTIF, which has been in operation for just over a year, was built with a specific focus on testing electric vehicles, charging options, and grid integration, all of which are critical for expanded transportation infrastructure around plug-in electric vehicles (PEVs).

"There are a lot of entities investigating components of electric vehicles, grid integration, or infrastructure," said NREL Vehicle Systems Engineer Mike Simpson. "There are very few places looking at how they all come together as a much larger, connected system. This facility was designed from the ground up to specifically address that intersection point."

Capabilities at the VTIF include vehicle energy management within smart grids, vehicle charge integration with renewable energy resources, bi-directional vehicle charge testing and demonstration, and vehicle thermal management. Four test bays at the facility allow for multiple tests to be conducted at once in controlled environments and can accommodate a wide variety of vehicles, including one test bay built specifically to conduct testing on heavy-duty vehicles. An upcoming addition to the facility is an 18-kilowatt solar array, which will be tied directly to vehicle charging and will allow researchers to do expanded work around the use of solar energy to charge electric vehicles within microgrids.

Better Charges and Better Grids

Further advances in how electric vehicles charge—and how they interact with power grids while charging—is critical to the future deployment of PEV technology. Much of the work being done at the VTIF is centered on this effort and is being done in collaboration with efforts at NREL's new Energy Systems Integration Facility (ESIF).

"We're bringing together systems that have never had a reason to talk to one another before," Simpson said. "There are enormous opportunities to bring value to this intersection of vehicle and grid, which will increase adoption of these technologies."

Key VTIF research is focused around smart charging. Smart charging involves direct communication between a vehicle and a charging station, bringing information that allows grid operators, charging stations, and potentially the vehicles themselves to decide when and how to charge the vehicle. The average electric

NREL scientist Michael Kuss of the NREL Electric Vehicle Grid Integration Team reads data from test electric vehicles at the Vehicle Testing and Integration Facility.
Photo by Dennis Schroeder, NREL 20079

vehicle sits, undriven, for 20 to 22 hours out of a day, but only takes 2 to 4 hours to charge using current technology. This makes an electric vehicle a very flexible load on the power grid.

This flexibility creates opportunities for NREL researchers focused on smart charging applications that will leverage the most economical and environmentally sustainable charging options—all while still allowing for on-demand use of the vehicle by the driver.

A four-hour fill up doesn't quite compete with gasoline engines for on-the-road demand, so engineers are exploring scenarios for fast charging. A fast charge can potentially recharge an electric vehicle in 15 to 25 minutes if the battery is close to empty. This technology employs the conversion of alternating current (AC) grid power to direct current (DC) power, which can be delivered directly to the battery pack. This method allows for faster charges using smaller charging equipment.

Additionally, VTIF researchers are exploring opportunities for bi-directional charging. Bi-directional, or vehicle-to-grid, charging employs smart charging capabilities but also allows for the vehicle to discharge back to the grid, which turns the vehicle battery into a grid storage device. This capability is of particular interest when combined with microgrids. A microgrid is a potentially self-sufficient segment of the grid that is connected to the power grid at large but has the ability to provide and manage its own energy. In a future scenario where there may be variable production from intermittent renewable sources, readily available storage could buffer that variability. With bi-directional charging, electric vehicles have the potential to play that role, and the vehicle becomes an asset in a smart grid or microgrid. Particular areas of interest for this technology emerge around emergency backup power or the use of vehicle fleets for this purpose.

"We need to be exploring all of the different value streams to enable wider electric vehicle adoption and improved interaction with the grid," Simpson said. "We can implement all of these different tactics in harmony with one another here at the VTIF. It's a very exciting opportunity."

Expanding the Use of Renewables with the Green Signal

The next big step for PEVs is expanding the use of renewable energy as a resource for charging. This involves utilizing enhanced smart charging technology to charge vehicles when the most renewable resources are available on the grid—often at the lowest possible cost to consumers. NREL has developed a specific technique for integrating detailed real-time data into a charge management algorithm, referred to as the 'Green Signal.'

The Green Signal would monitor the availability of renewable resources, as well as utility market prices. It would charge the vehicle when the renewable resources are most available and at the lowest possible cost per kilowatt hour. This gives consumers the opportunity to 'buy low' when their electricity cost is low while at the same time maximizing the use of renewables. The technology also monitors vehicle use times to ensure that the vehicle is fully charged when needed.

NREL will be exploring the Green Signal in the coming years using a fleet of electric vehicles plugged into onsite vehicle charging stations, which have been equipped with modified software to add this functionality.

"It's an exciting opportunity to bring more renewables into the equation in a cost-competitive way," Rehn said. "This software will allow us to enhance charging with solar or wind when it is at a cost that is equivalent to, or less than, that of conventional sources. By having a fleet of vehicles, we will be able to investigate doing this at a reasonable scale, being able to control individual chargers and vehicles at different times as the available resource is available, and we'll be able to develop the algorithms needed to evaluate when and how it makes the most sense to utilize this charging method."

Expanding Vehicle Range with Enhanced Thermal Management

Once an electric vehicle is charged and disconnected from the grid, the next important step involves maximizing the vehicle's range between charges. PEV range can be reduced 30% to 45% due to heating and cooling, so NREL engineers are investigating opportunities to change this dynamic and increase range via vehicle thermal testing and analysis.

"Our focus is on improving the thermal efficiency of efficient electric vehicles, with specific emphasis on climate control," said NREL Senior Engineer John Rugh, who serves as task leader for the vehicle thermal management work taking place at the VTIF. "The impact of climate control on an electric vehicle can be huge, and we are working with industry partners to conduct these tests and assess technologies that will reduce climate control loads for both heating and cooling of the vehicles."

These tests, which take place outside on the VTIF's test pad, involve two heavily instrumented electric vehicles. The instruments measure temperatures on the interior and exterior of the vehicles during a 'thermal soak' when the vehicle is sitting in a parking lot or during a cool-down cycle after the vehicle has been powered. The temperatures are fed into a data acquisition system and recorded for future analysis. In addition, an onsite weather station immediately adjacent to the vehicles provides accurate weather data.

"One of the biggest concerns with electric vehicles is range," said Rugh. "The battery of an electric vehicle is a finite energy source at the beginning of a drive, so reducing loads related to climate control allows more of the battery capacity to go toward vehicle range. If we can accomplish that while at the same time maintaining or improving occupant comfort, it can go a long way toward increasing the range of the vehicles and hopefully lead to expanded adoption of these vehicles by consumers."

Plugging into Our Transportation Future

NREL researchers are keeping their eyes on the future and how the VTIF's increased capabilities could impact how we power transportation.

"We're very proud of this new facility and the potential impact that it can have," Rehn said. "It gives us an opportunity, working in collaboration with our industry partners and the Energy Department, to better understand how all of these issues work together. This will lead to putting more electric vehicles on the street with a reduced cost of ownership and will allow them to be charged using the maximum possible amount of sustainable energy resources."

Another Angle on Transportation Fuels Reduction—Heavy-Duty Vehicles

Research at NREL's Vehicle Testing and Integration Facility (VTIF) will have a significant impact on the reduction of fuel use and vehicle emissions in another arena—heavy-duty vehicles.

The focus is on idle reduction for long-haul trucks, which use approximately 685 million gallons of diesel fuel in the United States each year for rest-period idling. This is about 6% to 7% of their total fuel use. One of the primary reasons for this idling is operating climate control and cabin comfort systems when the truck is not being driven.

"We're helping the heavy-duty vehicle industry reduce their fuel use," said NREL Senior Research Engineer Jason Lustbader, task leader for the heavy-duty vehicle climate control work taking place at the VTIF. "Our goal is to achieve at least a 30% reduction in climate control loads for these trucks with a three-year or better payback period for the industry by 2015."

Using test truck cabs located on the VTIF outdoor test pad, researchers are investigating a wide variety of cab thermal management technologies in collaboration with their industry partners. Electronically powered idle-reduction climate control systems in the cabs allow the engineers to look at the impacts of different technologies on the climate control loads.

A specific area of interest is paint. Research has shown a significant reduction in power needed for rest-period climate control just by switching the cab color from black to white. Engineers are investigating advanced paints that may look one color but behave and perform thermally like a different color. This could potentially allow trucking companies more flexibility when selecting paint colors—without sacrificing efficiency. This advanced paint work is currently being quantified through modeling and additional testing.

Another focus of this work is advanced insulation for truck cabs. Working with industry partners, researchers have shown a 34% reduction in the electrical power required for air conditioning by using advanced insulation materials.

"The VTIF is a perfect location to do this work," Lustbader said. "The south-facing test pad has no obstruction or shading and was designed specifically to facilitate this type of cab thermal management research."

The opportunities for consumer benefit by reducing costs of long-haul trucking are significant. Almost everything we purchase, from groceries to office supplies to fuel for our own vehicles, arrives via truck. So reducing the transport costs in any significant way will have an impact on the cost of those goods.

"We have an opportunity to make a real impact with these projects, an opportunity to reduce our national level fuel use and impact how we're using that fuel, in a way that can have a direct positive impact for industry and consumers," Lustbader said. "And we get to do some really fun engineering, too, solving complicated problems and helping move solutions forward to the point where it makes good sense for them to be used in the real world. That's what this type of research is all about."

— David Glickson (January 31, 2013)

LABORATORY OF THE FUTURE

By developing the laboratory of the future, NREL helps facilitate innovation, serves as a leader for sustainable development, and supports a transformation of national energy systems.

Photo by Dennis Schroeder, NREL 22363

At NREL, Sustainability Goes Beyond Campus

The Energy Department's National Renewable Energy Laboratory (NREL) relies on a team of sustainability experts to make sure the lab "walks the talk."

From its ultra energy-efficient buildings to its campus-wide infrastructure, NREL has built a state-of-the-art "laboratory of the future" to facilitate innovative research, development, and commercialization of renewable energy and energy efficiency technologies.

NREL's sustainability program, Sustainable NREL, underscores the lab's success in leading the nation toward a clean energy future by engaging employees in a "living laboratory" that minimizes NREL's use of resources, including energy, materials, and water, while receiving the maximum value from resources used.

"We apply what we learn to our facilities, and then we monitor, validate, and process the information not only from a building level, but a campus level as well," said Sustainable NREL Director Frank Rukavina.

Sustainable NREL drives many of the day-to-day operations on the NREL site. The team helps integrate energy, water, and material resource conservation and efficiency applications at the lab. They also generate short-term and long-term planning measures for NREL's "Campus of the Future" while overseeing data collection and analysis of performance metrics for federal reporting. Now the team is looking for ways to share that knowledge beyond the NREL campus.

"We are always looking for ways to educate people on what Sustainable NREL is and what we do," Rukavina said.

In addition, Rukavina said Sustainable NREL has a longstanding goal to foster social and environmental responsibility and implement initiatives that will showcase the laboratory as a global model for sustainability.

"We help with efforts to use NREL as a leading example for sustainable buildings and campus design," Rukavina said. "We don't just support and report; our focus is to export what we learn to other groups."

Over the last few years, Sustainable NREL has been ramping up its efforts to be visible in the community and help showcase the renewable energy and energy efficiency technologies developed

(Left to right) NREL's Jesse Dean, Wally Piccone from the City of Lakewood, and NREL's Frank Rukavina assess the utility room at the City of Lakewood's Graham House. NREL is coordinating a joint effort with the City of Lakewood and Red Rocks Community College to audit the Graham House and make suggestions for sustainable and energy-efficient modifications. The property was donated to the City and is used for public meetings and events. *Photo by Dennis Schroeder, NREL 25562*

at NREL. Those efforts have been rewarded with a number of key awards from the White House and the Energy Department.

"While many of the lab's researchers are hard at work developing the next breakthrough technology that will have a lasting impact on the energy landscape, we are following that model as well," Rukavina said. "NREL is taking lessons learned and sharing them through reports like the NREL Biennial Sustainability Report and community projects like the Graham House and the NREL Parking Garage Workshop."

Making the Graham House a Model of Energy Efficiency

Built in the 1948, the Graham House is a Frank-Lloyd-Wright-style home perched on a bluff in the Denver suburb of Lakewood. The 7-acre property has sweeping views of the Rocky Mountains, and it's an ideal gathering place for small community meetings. That was the intent of owner Jean Graham when she donated the property to the city in 1997.

Now a park property that's part of Lakewood's Community Resources Department, the mid-century-era home is in need of an energy-efficiency makeover. In fact, the city hopes the makeover will benefit the community in two ways: with energy savings and as an educational showcase.

"We hope the Graham House will be a model project with energy-efficient systems that will help educate visitors on ways to save energy," said Lakewood Director of Community Resources Kit Botkins.

With assistance from Sustainable NREL and Lakewood's Red Rocks Community College, energy audits were completed for the Graham House earlier this spring.

"It is an older home so there are lots of ways we can improve its efficiency, including simple things like lighting and heating," Botkins said. "These are improvements that other homeowners would be interested in making—and we also believe the enhancements will increase the facility's use by the city, as well as residents."

Although the city is still looking for funding for recommended improvements, the students at Red Rocks Community College have already benefited from the joint project.

"Working with the students at Red Rocks on the initial energy audit was intentional on the part of the city," Botkins said. "We thought it would be cool to have students who are learning to do this, actually learn the process on an example in the field that they could be involved in from beginning to end."

It's More Than a Parking Garage

NREL's parking structure may look like your average parking garage. But "everything that we do at NREL has multiple purposes," Rukavina said. "For instance, the parking garage—its purpose is for staff to park cars, but at NREL, it's another laboratory for grid integration, electric vehicles, and sustainable building design."

While it may not be glamorous, a parking garage typically uses 15% of the energy used by the building that it is designed to support. Making NREL's garage an attractive structure that's both affordable and high performing presented a unique combination of challenges. In the end, the design team came up with a structure that is expected to perform 90% better than a standard garage built just to code.

In March, NREL and the Energy Department hosted the NREL Parking Garage Workshop to share the message of parking sustainability with planning managers, construction managers, and other stakeholders. Attendees included representatives from the Regional Transportation District and Colorado Department of Transportation, local businesses, government agencies, and universities—many of which are planning to build parking structures in the near future. The goal was to communicate NREL's building process and help others understand opportunities for replication while raising the energy performance of parking structures.

Linda Kogan, sustainability director for the University of Colorado's Colorado Springs campus, was one of the workshop attendees. "The workshop was incredibly valuable with very specific strategies that we are already pursuing to reduce energy consumption, including planning for electric vehicle charging stations. We will follow up on recommendations specific to energy-efficient parking garages such as occupancy and daylighting sensors, daylighting design, LED lights, and photovoltaic panels."

"We feel that working with the community through these different agencies is a natural extension of our mission," Rukavina said. "We're planning to have an impact in the years and decades to come."

—Heather Lammers (June 14, 2013)

NREL Takes Efficiency to the Great Outdoors

Americans have become increasingly familiar with the Leadership in Energy and Environmental Design (LEED®) designation for buildings from the U.S. Green Building Council (USGBC). LEED gives building owners and operators a framework for implementing green building design, including energy efficient solutions. But what about the land outside of the building?

The Energy Department's National Renewable Energy Laboratory (NREL) was selected to join the pilot program for the Sustainable Sites Initiative (SITES)—a new certification system for sustainable landscaping. Not only did NREL participate in the pilot, but the lab recently joined 15 other projects that have received SITES certification for sustainable site design, construction, and maintenance. NREL's rating came in at three out of a possible four stars.

"For buildings, we tend to concentrate on LEED certification, which is great from a structure standpoint," NREL Senior Sustainability Project Manager Michelle Slovensky said. "The SITES certification was developed because the industry felt there weren't standards that cover the horizontal aspects of a project. Not only should your building have a sustainable and efficient design, but so should your infrastructure and your landscaping."

SITES is a partnership between the American Society of Landscape Architects (ASLA), the Lady Bird Johnson Wildflower Center at the University of Texas at Austin, and the United States Botanic Garden. The USGBC is also a stakeholder in the program, and anticipates incorporating the SITES guidelines and performance benchmarks into future LEED green building rating systems. The pilot that NREL participated in included 150 projects from 34 states.

The new SITES program fits well with NREL's mission to "walk the talk," and the lab had the opportunity to participate in the pilot thanks to the recent construction of its Research Support

NREL's new detention pond handles storm water runoff by discharging water into three forebays, which reduce water flows and trap sediment and debris. It is also an important local habitat that provides wildlife with food, water, shelter, and safe areas to raise their young. It's this approach to integrated landscaping design that has earned NREL a three-star SITES designation—the LEED-equivalent designation for sustainable landscaping. *Photo by Dennis Schroeder, NREL 23189*

Facility (RSF) and the accompanying garage and storm water management systems.

"We felt that if we have the highest-performing buildings, we should look at our campus to find ways it can be used as an example of a sustainable campus and living laboratory," Slovensky said.

> "We felt that if we have the highest-performing buildings, we should look at our campus to find ways it can be used as an example of a sustainable campus and living laboratory."
>
> — MICHELLE SLOVENSKY, *NREL Senior Sustainability Project Manager*

SITES Brings Landscaping Planning to the Forefront

While LEED seeks to minimize the carbon footprint of buildings, SITES demonstrates how a landscape can actually sequester carbon and regenerate living systems. But building those systems requires careful site management planning—from day one of the project.

"It's not a whole lot different than LEED in that when we were looking at the design of the RSF, our mindset was that we were going to build the most energy efficient and sustainable building possible; the SITES program extends that mindset to include the building and the site," Sustainable NREL Director Frank Rukavina said.

"For someone new to the design process, it's a good thing to think about all of the planning that needs to go into sustainable site development at the beginning of the process, and not at the end," Slovensky added.

Roughly 30 acres on NREL's South Table Mountain campus were included in the SITES certification. NREL's sustainable campus vision was achieved through key planning principles such as low-impact development and smart growth.

A Pond That Is Not Just a Pond

As part of the SITES project, NREL incorporated low-impact development techniques that establish natural drainage for storm water and minimize impacts on local habitats.

"This was a big step for us because our project site previously had no managed landscaping," Slovensky said. "With all of the recent construction, there was a large amount of disturbed land that we are bringing back in the most sustainable way possible.

"Often, when people look at native landscapes, they think they understand the ecosystem, but instead they produce a garden. Where I think NREL has been successful is that we have built something that has become its own self-sustaining ecosystem. It can thrive on its own."

Landscape aside, a large part of the NREL SITES project was a new system for managing storm water from new buildings, parking lots, roads, and other impervious surfaces. But this doesn't look like just any detention pond.

NREL's pond covers more than five acres and can detain more than 3 million gallons of storm water. It's also a habitat for migratory birds, including western bluebirds, robins, Bullock's orioles, and spotted sandpipers. NREL staff enjoy seeing regular visits from deer as well as the occasional coyote and red fox.

But the real purpose of the detention pond is to handle storm runoff by discharging water into three forebays, which reduce water flows and trap sediment and debris. The water then slowly progresses through a series of shallow basins, where native plants biodigest excess nutrients such as nitrogen and phosphorous. The shallow marsh at the south end of the pond is a wetland that receives moisture in the spring, but may be dry during much of the year. Spring moisture promotes the growth of water-loving plants and, in turn, aquatic insects, which feed the swallows, nighthawks, and bats.

Not only is the area designed as a wildlife habitat, it is a unique amenity for NREL staff, as it includes a looped trail that is one-third of a mile long.

"One of the things the SITES program looks at is innovation, and the storm water pond was a significant example of this

> “We had a great opportunity with all of the recent construction on NREL’s campus to do everything as ‘right’ as we could—and this included integrating our new building and landscaping into the existing ecosystem.”
>
> — FRANK RUKAVINA, *Sustainable NREL Director*

on NREL’s campus,” Slovensky said. “Most people would have just put a hole in the ground and called it good. We set it up so it looked like a park first, even though its primary function is storm water retention. It not only protects from flooding, but it cleans the water as well.”

Building with the Land in Mind

Low-impact campus build-out strategies that promote walkability and interaction on campus are another part of NREL’s SITES planning. Construction was completed in October 2011 for the 361,000-square-foot LEED Platinum RSF, which is “home” to 1,325 employees. The RSF’s rooftop solar photovoltaic array helps offset the building’s annual energy use, and it is a net-zero energy facility. The SITES project scope also included integrated campus transit, pedestrian LED site lighting, prairie restoration, and expanded campus utilities.

“NREL’s philosophy on sustainability is to operate the lab with the least impact on future generations,” Rukavina said. “We had a great opportunity with all of the recent construction on NREL’s campus to do everything as ‘right’ as we could—and this included integrating our new building and landscaping into the existing ecosystem.”

Other RSF-related features that were considered as part of the SITES designation include:

- Installing educational signs to explain the site’s sustainable features
- Harvesting materials on site
- Installing special products for prairie grassland and wet meadow establishment
- Incorporating a historic landmark “firing range wall” that was moved during construction and recognizes the NREL campus’ previous life as part of the U.S. Army’s Camp George West.

NREL Leading by Example

In 2007, NREL’s Science and Technology Facility was the first federal building to be certified LEED Platinum—so it’s fitting that NREL’s RSF project has followed suit as the first federal project to be accredited by SITES.

“The SITES program helped us take a new look at our plans for a sustainable campus so we could refine what we were doing,” Rukavina said. “As a result, we have three projects that are moving forward as part of a living laboratory concept, including the stewardship of the wildlife corridor that goes through the campus, tracking a successful reestablishment of the plant community, and water quality monitoring. We are required to not only monitor these items but also publish results in a journal, which matches up nicely with the science side of the lab’s mission.”

— Heather Lammers (December 10, 2013)

RSF Influences New High Performance Buildings

The Research Support Facility (RSF) at the Energy Department's National Renewable Energy Laboratory (NREL) has hosted thousands of visitors since it opened as one of the world's largest high performance office buildings. Generating buzz about the energy savings possible in commercial buildings is exactly what the Energy Department and NREL have been aiming for.

"There are days when I think I should quit my job and just be a tour guide," jokes NREL Senior Research Engineer Shanti Pless. "But I'm willing to do it because I see the impact taking people through this building has on our future energy savings."

Energy savings is precisely what the RSF demonstrates every day as 1,800 NREL staff start their workdays in a 360,000 square-foot Class A office building that generates as much electricity as it uses, thanks to rooftop photovoltaics. Even after potential visitors hear that the RSF was built at the same price as a non-efficient building, they can be skeptical—until they see it with their own eyes.

"Seeing is believing," Pless said. "Everyone who comes through the RSF realizes this can be done and this is what it looks like. And they learn that they don't have to do something new—they can replicate a lot of what NREL's already done."

Commercial buildings represent roughly one-fifth of U.S. energy consumption. Still, the perception remains that it's easier and less expensive to build a building the way it's always been done rather than putting in the work to make the leap to high performance office buildings.

"This high performance, net-zero facility is one of those things that wouldn't have come to fruition if a national lab hadn't demonstrated that it is possible," said Ron Judkoff, NREL's principal program manager for buildings research and development. "And, as a result of the Energy Department's and NREL's leadership, and the building energy design tools that NREL is producing, industry is starting to recognize it can be done as well."

Energy-efficient features found in NREL's Research Support Facility, including daylighting, are being replicated in other buildings across the country. *Photo by Dennis Schroeder, NREL 19911*

Just over two years since the opening of the first phase of the RSF, Pless notes that the ripple effect is reaching deep into industry. "The effect is across the whole spectrum, including architects, engineers, and subcontractors," he said.

Changing the Rules to Build in Seattle

Even when you are enthusiastic about constructing the most energy-efficient building possible, roadblocks can appear where least expected.

The 50,000 square-foot Bullitt Center in Seattle, Washington, is being built with one goal in mind—to be the greenest, most energy-efficient commercial building in the world. Like NREL, the Bullitt Foundation is looking to change the way buildings are designed, built, and operated. The building design team is working to meet the ambitious goals of the Living Building Challenge.

The Bullitt Center will generate as much energy from rooftop photovoltaics each year as the six-story structure uses; the catch is that Seattle is notorious for its lack of sunshine. The building also will collect all of its water, including drinking water, from the rain that falls on its roof—which will then be stored in a 56,000-gallon cistern. Once the water is used inside the building, it will be treated and then returned to the soil. More than 1,000 building components were researched to make sure nothing in the building released any toxic material at any time during its life cycle. It is the world's first six-story structure with composting toilets. Built to survive major earthquakes, the Center has a design life of 250 years.

According to Bullitt Foundation President Denis Hayes, the building faced more legal and financial challenges than technical obstacles.

"We were shocked to learn that it is flat-out illegal to build this sort of ultra-green building in any city in America," Hayes said. "But Seattle changed its building code to allow super-green buildings to meet performance standards as an alternative to prescriptive standards. A building built to code is generally the lousiest building that is not illegal to build. We wanted the design flexibility to construct a building that used less than one-fourth the energy of a code building."

The city's political leaders and planning officials weren't the only ones Hayes had to convince.

"We were also constrained by the fact that most banks wouldn't lend us any money. When the appraiser asked, 'What are your comps?' We didn't have any," Hayes said. "No bank saw any value in producing all our own electricity, our own water, treating our own waste on site. Certainly no bank was prepared to finance the extra cost of a 250-year building. The discounted present value of a dollar received 250 years from now, or even 100 years from now, is zero. Modern finance is deeply biased against durability.

"We are going to be working with banks, appraisers, and real estate professionals to bring them through the building and use it as a magnet to help think through how we can overcome these obstacles and create a situation where this sort of building becomes easier to finance and build than an inefficient building," Hayes added.

Private sector obstacles aside, it was helpful to see that NREL had successfully completed a high performance office building, Hayes said. "Visiting NREL was reassuring. Somebody had already shown how to meet some of the goals that we were aspiring toward. When something already exists, you know that what you are trying to do is possible."

Similarities between the Bullitt Center and the RSF include an emphasis on daylighting. The Center features large, 10-foot-high windows weighing 700 pounds each. They open to provide not only lighting but natural ventilation. The windows will be hooked up to a series of sensors that feed into the building's control system to tell what the indoor and outdoor temperatures are, how fast the wind is blowing, whether it's raining, and how much carbon dioxide is in the air, all of which let the building's "brain" determine whether the windows should be open or closed.

Staffers working next to the window can override the system, but only for 30 minutes at a time to optimize the building's performance. Every person working in the building will be within 30 feet of an operable window.

Plug load management is something that the Bullitt Center design team took into greater consideration after visiting NREL.

"It was very impressive, the degree to which NREL is monitoring the things that people are doing on their side of the plugs," Hayes said. "We'd known that we could do dramatic things with efficient refrigerators, dishwashers, and lighting, but the

> “It may sound corny, but after seeing the RSF, it really was the first day of the second half of my career. I saw the integration at RSF, the total comprehensive thinking, and thought, ‘I’ve got to get involved in a project that’s going in this direction.’”
>
> — KENNER KINGSTON, *Director of Sustainability for Architectural Nexus, Inc.*

fact that NREL was paying so much attention to the real work side of the house—the computers, monitors, printers, and task lights—caused us to go back and look at our IT really carefully.”

“I’m thrilled that NREL is jumping out in front on issues like this,” said Hayes, who was lab director of the Solar Energy Research Institute in the late 1970s and early 1980s, prior to the name change to NREL in 1991. “NREL’s research and development has always been its strength, but there’s something about actually living what you preach. And, just as important, NREL paid special attention to the economics of it.”

The first tenants of the Bullitt Center will begin moving in next month; the grand opening is scheduled for April 22, which is Earth Day.

Planning a High Performance Building for Salt Lake City

Seattle isn’t the only city that will see NREL’s vision on its skyline.

“It may sound corny, but after seeing the RSF, it really was the first day of the second half of my career,” said Kenner Kingston, director of sustainability for Architectural Nexus, Inc. “I saw the integration at RSF, the total comprehensive thinking, and thought, ‘I’ve got to get involved in a project that’s going in this direction.’”

When a municipal client in the Salt Lake City, Utah, area asked him to design an administrative office space, Kingston knew the RSF would help sell his client on the idea of going for high performance design. “Usually, when I see another net-zero building talked about, it’s always on the coast or in Hawaii—somewhere with a temperate climate. The RSF is particularly relevant because it is in a high mountain desert.”

Kingston also brought his client out to the RSF so they could see firsthand what was possible. “They came back with validation, feeling like it was what they wanted to do. The RSF became the measuring stick that was referred to over and over again while planning the project.”

As was the case for the RSF, daylighting is an absolute for the building design that Kingston is working on. “On this project, the ratio of closed to open offices is 50-50,” Kingston said. “This created a unique challenge since we were trying to put the closed offices on the north side of the building; in this case, we needed two north sides.”

To solve the dilemma, the design now includes a capped light well in the center of the building so the planners could have two north elevations. The light well is unconditioned space that draws the sun five stories into the building. “It makes the daylighting possible from the inside of the building, and we don’t get the temperature swings of an exterior space,” he added. “Even after I’m done with this project, I’ll be on the hunt for the next net-zero opportunity in our neck of the woods, and I’ll again use the RSF as an example of what can be done.”

Cornell University Looks to Build a Living Lab in NYC

An opportunity to build a campus in the heart of New York City doesn’t come along often. But on the southern end of Roosevelt Island, administrators with Cornell University are carefully planning out a 12-acre campus focused on educating the next generation of students to conduct cutting-edge research on a living model of sustainable development.

> "I'm excited to see the industry start to pick this up and run with it, without us being actively involved in each project."
>
> — SHANTI PLESS, *NREL Senior Research Engineer*

The Cornell NYC Tech campus will be built out in several phases, with groundbreaking for the first phase slated for 2014. Part of the first phase will be a four-story, 150,000-square-foot academic facility that will be the flagship building for the campus. The first academic building is being designed to be high performing and very energy efficient. On-site renewable energy is being studied to determine the feasibility of making it net-zero energy.

"We had an opportunity with a whole new campus to figure out a plan to make our first net-zero academic building," said Robert R. Bland, senior director for energy and sustainability with Cornell University. "We've had quite a bit of input from NREL, and my visit to the RSF showed me the opportunities to be deeply energy efficient. The New York State Energy Research and Development Authority is partnering with us and contributing funding to the design effort."

The first academic building will use multiple approaches for achieving energy efficiency, including photovoltaics and geothermal. When complete, Cornell NYC Tech will include approximately 2 million square feet of academic, residential, and corporate research and development space and will house more than 2,000 graduate students along with faculty and staff.

But even more exciting than the opportunity to create a sustainable campus is the opportunity to educate and guide students at the university. "We would like to make this a living laboratory for graduate students to research and advance our academic mission in the built environment," Bland said. "We want to make it inspirational and educational."

Already, seven teams of students are involved in the campus planning and design. In the future, the buildings will be studied with intensive energy modeling and monitoring. "We'll do real-time monitoring, and we intend to create a smart microgrid on campus," Bland added. "It's really exciting to be able to work on a new academic model."

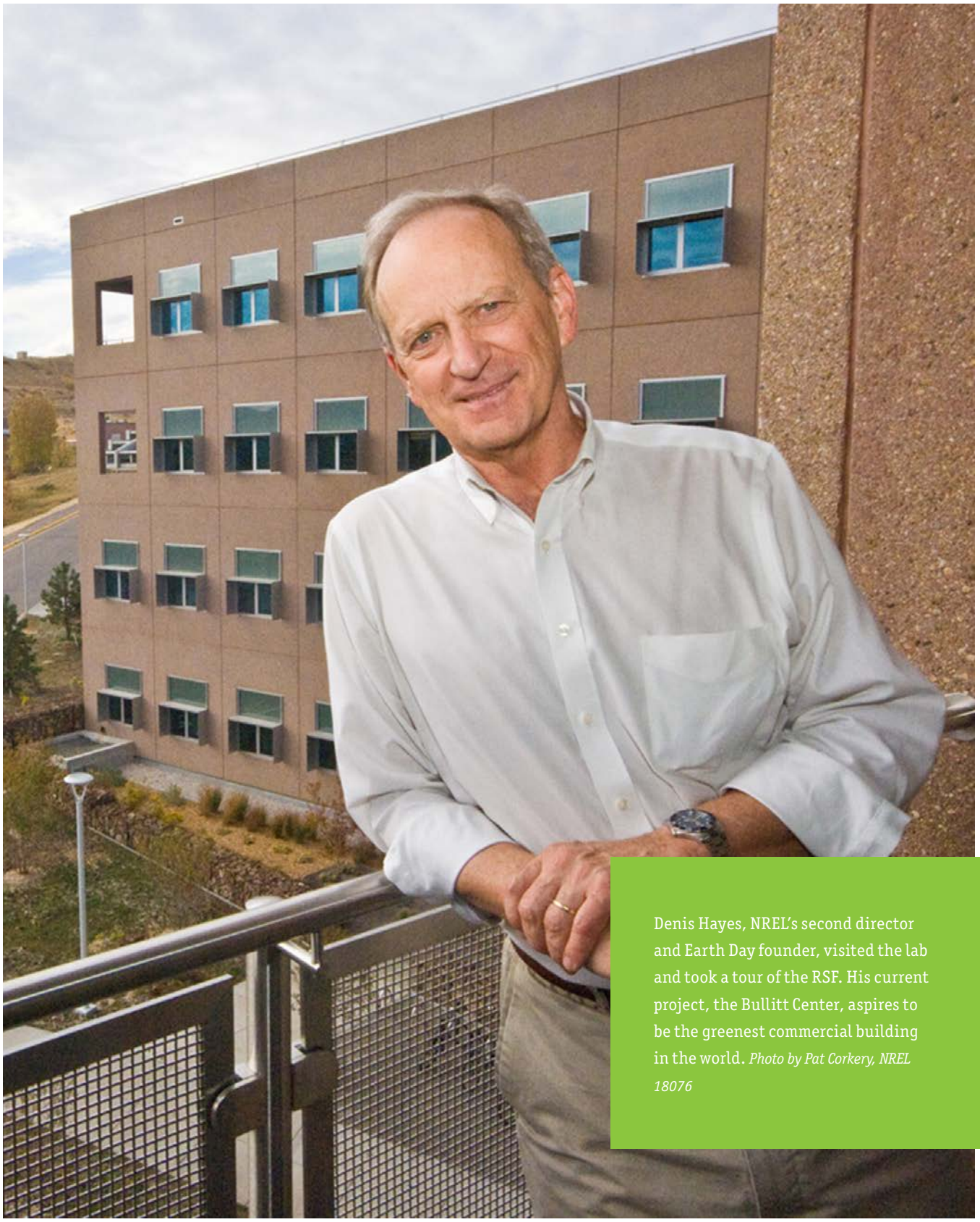
Industry Is Taking Notice

The RSF's accomplishment and significance are being recognized by industry. The RSF has garnered more than 30 awards for features ranging from construction to sustainability. The most recent, a first-place 2013 American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) Technology Award recognizes achievements by ASHRAE members who have successfully applied innovative building design. NREL researchers who influenced the energy-efficient design of the RSF included Shanti Pless, Paul Torcellini, Otto Van Geet, and Ron Judkoff. The RSF project followed the integrated design process and used design tools and concepts developed by the NREL Building Technologies Program over the past 30 years. In addition, Stantec Consulting, Inc, a member of the RSF design team, received AHRAE's Award of Engineering Excellence. This award is given to an outstanding project receiving a first-place ASHRAE Technology Award and has only been awarded two other times in ASHRAE history.

All these examples mean Pless sees a road to success for high performance buildings—and fewer days as a tour guide for the RSF.

"I'm excited to see the industry start to pick this up and run with it, without us being actively involved in each project," Pless said. "When I no longer have to answer calls about projects or give tours, I'll know that we've succeeded."

— Heather Lammers (January 24, 2013)



Denis Hayes, NREL's second director and Earth Day founder, visited the lab and took a tour of the RSF. His current project, the Bullitt Center, aspires to be the greenest commercial building in the world. *Photo by Pat Corkery, NREL 18076*

NATIONAL AND INTERNATIONAL IMPACTS

NREL facilitates comprehensive energy solutions by helping put renewable energy and energy efficiency technologies to work across the nation—and around the world.

Photo by Dennis Schroeder, NREL 24991

Nation Could Double Energy Productivity

Researchers at the Energy Department's National Renewable Energy Laboratory (NREL) have long understood that *using* energy more efficiently can be just as beneficial as finding new ways to *produce* energy more efficiently.

On Feb. 7, NREL Director Dan Arvizu and a blue-ribbon panel of 20 energy experts drove that message home, declaring that the United States can double its energy productivity by 2030—and do so in ways that bolster the nation's economy.

Unveiling their recommendations at the National Press Club in Washington, D.C., Arvizu and other members of the Alliance to Save Energy (ASE) Commission on National Energy Efficiency Policy said that doubling energy productivity could create a million new jobs, while saving the average household $1,000 a year and reducing carbon-dioxide emissions by one-third.

"Serving on the Commission on National Energy Efficiency Policy over the past year has been a unique and rewarding experience," Arvizu said. "The commission's recommendations provide a bold yet attainable roadmap for revolutionizing our nation's use of energy, and boosting our economy and improving our environment along the way." The commission was organized and sponsored by the ASE, and the full report is available on the ASE website.

The commission said its ambitious goals can be accomplished by unleashing investments in energy efficiency concepts and technologies throughout the economy, modernizing our energy infrastructure, reforming regulatory measures to promote efficiency, and educating consumers and business leaders on ways to reduce energy waste.

In December, Arvizu testified on the importance of greater energy efficiency before the U.S. Senate Finance Subcommittee on Energy, Natural Resources, and Infrastructure.

"Perhaps the most compelling evidence that energy efficiency measures can have dramatic effects in the future is the often-overlooked fact that they already have produced so many benefits for our nation," Arvizu noted in his testimony. To the same point, a report by the commission showed that the nation would be using fully 50% more energy than we currently use today had we not taken advantage of all the energy efficiency opportunities we have developed and deployed over the past three decades.

The NREL director's work on the commission and his testimony before Congress are but two illustrations of how NREL has been a leader in cutting-edge energy efficiency solutions.

A wealth of NREL experience and research knowledge was included in Arvizu's contribution to the commission's report. Dick DeBlasio, NREL's chief engineer for renewable electricity and use applications, Austin Brown, a Washington, D.C., analyst

NREL Director Dan Arvizu and a blue-ribbon panel of 20 energy experts said that the United States can double its energy productivity by 2030—and do so in ways that bolster the nation's economy. In this photo, Arvizu speaks to commercial building stakeholders at NREL. *Photo by Dennis Schroeder, NREL 20897*

in NREL's Strategic Energy Analysis Center, and Gary Schmitz, NREL senior manager for government relations, worked closely with Arvizu and ASE staff to ensure the recommendations reflected the latest in energy efficiency analysis and R&D concepts from NREL programs.

In addition to NREL's R&D on renewable energy generation technologies such as solar and wind, the laboratory has major programs to improve energy efficiency in the nation's two largest sectors of energy use: buildings and transportation.

More Efficient Buildings

Forty percent of the nation's energy is used in buildings—from hospitals to factories, restaurants to office complexes.

NREL is helping the nation's architects and engineers find ways to reduce by 50% the energy intensity of large hospitals, schools, and retail buildings. NREL created the modeling and optimized the software for the Advanced Energy Design Guidelines (AEDGs) that spearhead the effort.

U.S. hospitals spend more than $5 billion annually on energy, equaling about 2% of a typical hospital's operating budget. NREL Senior Research Engineer and AEDG Project Chairman Shanti Pless said: "Our job is to develop those best practices, along with the professionals in the industry, and put them together in an easy-to-implement guide."

Schools Finding Big Energy Savings

NREL researchers helped New Orleans build 40 new schools and renovate 38 others in the wake of Hurricane Katrina's devastation—demonstrating an average energy savings of 30%. Among cost-saving measures, the blueprints called for pretreatment of humid air rather than overcooling the entire airflow; aligning the new schools on an east-west axis, with large, efficient, south-facing windows; and smart monitors to assure that only the lights that are needed are turned on.

The potential savings are monumental, amounting to some $75,000 per year, per school. In the United States there are about 100,000 public schools. This year, $14 billion will be spent constructing about 750 new schools and renovating others, according to School Planning & Management magazine. If all the new and renovated schools followed green-school designs, the savings would be more than $50 million the first year, compounded each succeeding year. And the average school is built to endure 50 to 100 years.

Green Is the Color of Disaster Relief

In the aftermath of Katrina, NREL researchers helped city officials develop the Energy Smart New Orleans Plan, which includes residential energy audits, incentives for energy efficiency, low-income weatherization, commercial and industrial programs, pilot programs for photovoltaic arrays, solar domestic hot water systems, and education outreach. In a city in which 55,000 houses were abandoned, NREL worked with builders to achieve 15% to 30% energy savings on homes for middle-class and lower-income residents.

In 2007, a tornado leveled nearly the entire town of Greensburg, Kansas. Town leaders invited NREL scientists, and together they rebuilt a town that achieved 50% energy savings. The farm-supply town formerly tried to attract tourist dollars with the largest hand-dug well in the country. Now, it is a mecca for architects, planners, and vacationers who want to see how wind and solar energy can combine with energy efficiency to create a vibrant, attractive community.

NREL's Living Laboratory of Energy Efficiency

Last year, *Construction Digital*, a monthly online magazine, named NREL's Research Support Facility (RSF)—a 326,000-square-foot building housing 1,300 employees—the top net-zero energy building in the world. A net-zero building uses no more fossil-fuel-based energy than it produces via renewables. In all, the RSF has received more than 30 awards for sustainable design and construction.

The "SolarWall" transpired collector, light louvers, electrochromic and thermochromic windows, thermal storage walls, and NREL's Open Studio software tools that simplify optimal energy design, are getting friendly receptions in the marketplace.

NREL's Golden, Colorado, campus now has several buildings that have achieved lofty LEED (Leadership in Energy and Environmental Design) status, and it hosts visitors from around the country and the world who want to replicate the energy efficiencies on display at NREL.

Don't Forget the Parking Garage

Parking garages are opportunities to save a lot of energy because, while they are often an afterthought, they typically use 15% of the energy used by the buildings they are designed to support.

NREL's new parking garage attracts builders and architects because it is mostly daylit, performs 90% above code, and has enough solar panels on its roof to help the 1,300-employee RSF achieve net-zero energy. For every watt saved in the building or garage, that's $33 worth of photovoltaics a company doesn't have to buy to achieve net-zero energy.

Cooling Efficiently in All Climates

Nothing runs up the energy bill like air conditioning. Air conditioning currently accounts for 15% of all electricity use in the United States, and can be as much as 70% of use during hot summer days.

NREL researchers borrowed ancient cooling ideas and combined them with outside-the-box thinking to come up with a radically new kind of air conditioning. NREL's Desiccant-Enhanced Evaporative (DEVAP) system first dehumidifies the air, and then sends it through an evaporative cooler to produce cool, dry air in any climate. The keys are paper membranes that separate the air from the water and the liquid desiccant, and a re-routing mechanism that uses a thermal cycle to refresh the desiccant and vent moisture away. The technology has the chance to lower air-conditioning energy bills by 40% to 80%, because it uses water rather than electricity to perform most of the process.

"The idea is to revolutionize cooling, while removing millions of metric tons of carbon from the air," said NREL Mechanical Engineer Eric Kozubal, principal investigator of the DEVAP cooling system. DEVAP uses no environmentally damaging working fluids, such as the chlorofluorocarbons used in vapor compression systems.

Energy Efficiency Starts at Home

TV blasting, air conditioner humming—that's no time to start the dishwasher, do laundry, or bake a cake.

NREL's Automated Home Energy Management (AHEM) Laboratory uses real plugs, panels, and appliances to study how consumers can save energy by running their appliances at the optimal time of the day—or have smart monitors do it for them. The "smart" home of the near future will communicate with the electricity grid to know when power is cheap, tell appliances when to turn on or off, and even alert when renewable energy resources are available to offset peak demand.

"We are very cognizant of the fact that every home is part of a larger energy system," NREL Senior Engineer Dane Christensen said. "We've modeled the AHEM Lab around a real home. The idea is that eventually our appliances and homes are going to be able to 'talk' to the grid."

The goal of the Energy Department's Building America program is to reach 50% energy savings for new construction and 40% savings for building retrofits.

Energy Efficiency Spreads to the Grid

NREL's new Energy Systems Integration Laboratory (ESIF) helps optimize energy efficiency by hosting companies and utilities large and small that want to test how their products can integrate renewables onto the grid in a seamless way.

In its electrically interconnected laboratories, research partners can literally plug in and test new energy technologies on real and simulated power systems before hooking them up to the grid.

"We help utilities and companies that want to design new equipment that will increase the penetration of renewables into the energy grid," Acting Group Manager for Distributed Energy Systems Integration Bill Kramer said. "We can also test natural gas field generators. If you don't take into consideration the overall system and only work on a component at a time, you will never come up with the optimal solution."

Testing the Energy Efficiency of Battery-Powered Cars

NREL's Large-Volume Battery Calorimeter (LVBC) is helping put more energy-efficient automobiles on the road. It precisely measures the heat generated by batteries for electric drive vehicles, analyzes temperature's effects on systems, and helps pinpoint ways to manage battery temperatures for the best performance and maximum life.

> “Perhaps the most compelling evidence that energy efficiency measures can have dramatic effects in the future is the often-overlooked fact that they already have produced so many benefits for our nation.”
>
> —DAN ARVIZU, *NREL Director*

Affordable, long-lasting, high-performing batteries are keys to consumer acceptance of automobiles that can get the equivalent of 100-plus miles per gallon.

The Military Reaches for Energy Efficiency

NREL teamed with the U.S. Army on the Army Vision for Net Zero program, an ambitious effort to increase energy productivity and to get 25% of energy from renewables by 2025. Army bases responded enthusiastically, dozens accepting the challenge to reach net-zero energy, or to reduce water use and waste by 30% to 50%. Strategies include solar daylighting, photovoltaics, and turning waste into energy.

NREL is helping in war zones, too, where Army bases are replacing bottled water and barrels of diesel with solar systems that purify water and heat barracks. The changes don’t just boost energy productivity; they mean fewer dangerous truck rides to forward bases—and that saves lives.

Converting Waste Gas into Usable Energy

The amount of natural gas simply flared or vented from oil wells globally is enormous—equal to one-third of the amount of petroleum used in the United States each year. And every molecule of methane vented to the atmosphere in that process has the global-warming capacity of 12 molecules of carbon dioxide.

NREL biofuels scientists working with industrial and university partners are developing microbes that convert methane found in natural gas into liquid diesel fuel. The novel approach could reduce greenhouse gas emissions and lower dependence on foreign oil.

Their proposal—to develop a microbe that eats the methane in the gas—won a $4.8 million Advanced Research Projects Agency—Energy (ARPA-E) award from the Energy Department. If the wasted 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.

“The direct conversion of methane to diesel has the potential to dramatically increase energy supply while mitigating greenhouse gas impact,” said Dr. Jennifer Holmgren, CEO at LanzaTech, NREL’s manufacturing partner in the consortium.

And Much More

NREL researchers also have helped boost energy productivity—for the present or the future—by, among other things:

- Finding ways to get two electrons from a single photon of light;
- Discovering a cost-effective way to virtually eliminate wasteful reflection off a solar cell;
- Helping engineer an economic way to place transparent solar cells in window glass;
- Engineering ways to get biofuels and hydrogen from algae;
- Coming up with new standards for efficient, aerodynamic wind turbines; and
- Creating the world-record-efficient solar cell, the multi-junction SJ3, with a 44% conversion efficiency.

—Bill Scanlon (February 7, 2013)

NREL Teams with Navy to Cut Energy Use

Check off a list in your head of the government organizations that play a role in the security of the United States. The Department of Defense (DoD) and Homeland Security probably come to mind, as well as the CIA or FBI. While the Energy Department's National Renewable Energy Laboratory (NREL) may not even make the list, in fact, the national laboratory is doing its part to help provide energy security and reduce energy costs for the military as an energy advisor to DoD and, in this case, the U.S. Navy.

"NREL is uniquely positioned to support DoD's mission to reduce energy costs, decrease reliance on foreign oil, and ensure energy security," NREL's Director Dan Arvizu said. "Our experience in demonstrating and validating innovative energy technologies is critical to their mission success."

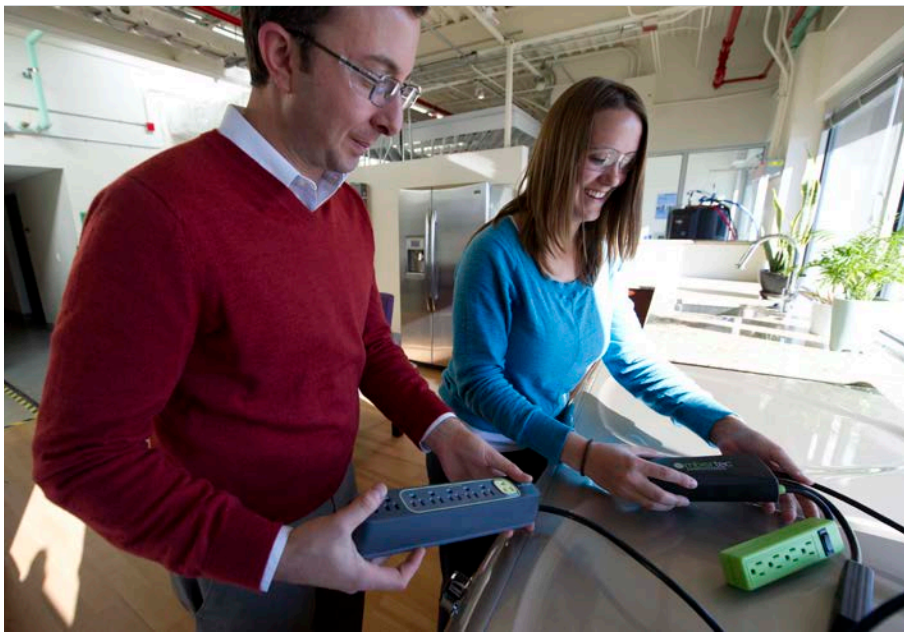
DoD accounts for 80% of federal energy use, and it spent $19.4 billion on energy in 2011. NREL is currently focused on helping slash the 21% of DoD energy costs that are spent to operate DoD installations around the world.

"DoD is the biggest energy user in the United States. NREL and DoD's missions are not the same, but they do complement one another," DoD Energy Program Director Steve Gorin said. "The military's mission is operational excellence, and the cost of energy has been a huge variable that they can't predict. Anytime the price of oil goes up or anytime there is a grid outage, it impacts how they accomplish their mission. In the case of NREL, our mission is to innovate and to work with others to get technologies out there and transform the energy economy. Put the two together, and you have an early adopter with a huge market working alongside an energy innovator."

To put into perspective how large a facilities energy consumer DoD is, consider that it has:

- 507 permanent installations
- More than 300,000 buildings and 200,000 other structures
- More than 2.2 billion square feet of facilities space.

DoD realizes that relying on a singular national energy grid puts its facilities and critical infrastructure at risk. So the Navy and NREL are looking for solutions to meet the Navy's ambitious energy goals, which include: evaluating energy efficiency and use when awarding Navy contracts for systems and buildings; increasing



NREL engineers Dane Christensen and Bethany Sparn test advanced power strips at NREL's Automated Home Energy Management Laboratory. The lab enables researchers to study the complex interactions of multiple appliances and plug-load devices with the broader distribution grid. NREL will be helping the U.S. Navy study these energy-saving devices in homes and offices at the Joint Base Pearl Harbor-Hickam in Hawaii and Naval Base Guam. *Photo by Dennis Schroeder, NREL 20165*

alternative energy use on shore by producing at least 50% of shore-based energy from alternative sources; ensuring that 50% of Navy and Marine Corps installations will be net-zero energy.

"Energy security is a key priority for the Department of Navy [DoN] and the way we conduct future operations for our warfighter and for our fleet," said Tom Hicks, deputy assistant secretary of the Navy for energy. "We look forward to our partnership with NREL as it helps us meet our energy goals."

"NREL is excited to help the Navy advance its energy goals by providing test beds to demonstrate energy technologies," Gorin said. "We believe a few things can happen. First, we can make an impact by helping the nation's single largest energy user be more efficient. This will reduce risk to the military when adopting new technology, and it will help it meet energy goals through demonstrations and then replication. Finally, helping organizations like the Naval Facilities Engineering Command (NAVFAC) to be early adopters of these technologies will help to catalyze civilian commercialization."

Work Begins on Hawaii and Guam

The NREL-Navy partnership began in August 2011 as part of a $20-million project focused on improving energy security. "These investments are for projects for near-commercial technologies that will be cost efficient for DoN," said Hicks.

The project is expected to last two and a half years and will be carried out in three phases.

From the beginning, NREL and the Navy formed an integrated team to seamlessly manage the demonstration projects. Formally known as an Integrated Product Team, an IPT is a multidisciplinary group of people who are collectively responsible for delivering project outcomes.

During the first phase of the partnership, NREL worked to identify what technologies would help meet Navy energy goals, along with the best locations to demonstrate them. The Navy specified that at least one demo must happen on Hawaii and another on Guam. In the end, eight technologies were chosen for demonstration with roughly half at each location. The technologies are now being installed and studied to see which are viable. The final phase will be to report on the technologies and help transition them to other sites and the commercial market.

"These technologies are near commercial, but not yet widely available," NREL Principal Investigator Jeff Dominick said. "We plan to demonstrate these technologies under rigorous test conditions and evaluate performance with an emphasis on cost savings and energy security."

Saving Energy, Money at the Home and Office

The technologies being installed fall into three general categories: advanced HVAC (heating, ventilation, and air conditioning), building efficiency, and advanced renewables and facility integration.

"The support of NAVFAC Pacific and the component commands of NAVFAC Hawaii and NAVFAC Marianas were instrumental on this project. Their planning, engineering and construction expertise to NREL helped ensure the demonstration projects were realized," said Scott Mauro, energy/sustainability lead for the office of NAVFAC's Chief Engineer. "The projects selected have broad application to DoD facilities, and through this partnership with NREL, we continue to improve our ability to assess and implement shore energy technologies. These infrastructure improvements will lower total ownership cost to our supported commanders, in support of the Navy's energy goal to increase the use of alternative energy ashore."

In helping the Navy improve its energy use, NREL is looking to cut the intensive HVAC use on bases. The teams will install a variety of advanced HVAC demonstrations, including energy-saving retrofit kits that can go on an existing rooftop air conditioner on a warehouse or office space. The team will also test a high-efficiency rooftop unit that, depending on the building type or climate, provides a possible second solution for energy savings.

"It's a partnership, so we want to give DoD options. Depending on site-specific conditions, we can decide if it makes more sense to swap out the unit or do a retrofit," Gorin said. "Because of the size, number, and geographic distribution of facilities DoD operates, it won't be a one-size-fits-all solution."

The final demo in the HVAC category uses liquid desiccant to dehumidify the air and reduce the amount of both conventional air conditioning and potential reheating that would be needed to make the space comfortable.

The next project will try to cut energy use at the home and office by installing advanced plug-load controls and looking at whole-building retrofits.

"Most people don't have a baseline understanding of what their plug-load energy use is," Dominick said. "We take for granted the energy used when plugging in office equipment and multimedia devices at home. Our team will be gathering those data and then putting in the controls to show how much energy is saved, not only in plug loads, but whole-building energy use for both residential and commercial buildings."

The work includes examining various advanced power strips to see which are best suited for particular uses and settings. For instance, is one set of controls better used at naval offices, while another smart power strip should be used in naval housing? In addition, eight houses will receive deep, whole-house energy-efficiency retrofits to determine the best paths for energy and cost savings.

"Not every housing unit is built the same, or is in the same climate," Gorin said. "But this is a validation of the baseline modeling process and the various tools that can then be used in other climates as well."

The last category of work is in advanced renewable generation and facility integration. One project will evaluate a system that enables higher penetrations of renewables on the local grid with a mix of control and energy storage technologies, which will improve overall power quality. A second project is a waste-to-energy gasification system developed by the Army. It had to be modified to be used at a Navy commissary and will be fueled by waste cardboard and food scraps (the wet waste will be dehydrated before use). Finally, a photovoltaic (PV) thermal solar collector will be studied with the potential to garner up to three times the energy from a single rooftop as PV alone. This is important for military bases that have constrained rooftop areas and could boost the renewable energy output to help meet the ambitious goals for onsite renewable generation.

Helping the Navy Move Technologies Beyond Demonstration

Just because all these technologies will be tested on sites in Hawaii and Guam doesn't mean they all will be deployed to Navy bases around the world.

"This initiative is providing a good environment for technology providers to demonstrate the performance of their technology to the Navy," Gorin said. "But we are also putting these technologies through the wringer. You can have a successful demonstration where the technology is not ultimately selected for commercialization. A successful demonstration project means we have conducted testing and comprehensive analysis to help the Navy make informed decisions."

The key for the NREL team is not only validating which technologies will work best for the Navy and DoD, but also laying a foundation so they can be adopted Navy wide.

"This hit home when we sat down with the Navy to define what deliverables they wanted," Gorin said.

"Traditional demonstration programs would concentrate almost exclusively on the technical performance and cost savings. For this project, NREL was also asked to look at how the demonstration process dovetails into how the Navy does business. NAVFAC has been a great partner to help execute, install, and test these technologies so that we can take that knowledge and achieve wide Navy adoption of technologies that save money and enhance mission performance."

As part of this technology transition, NREL is working with key stakeholders and nonprofits to support civilian commercialization. This will provide a diversity of suppliers, U.S. jobs, and ultimately a lower price point for the Navy.

"DoN realizes the importance of partnerships with organizations like NREL to develop and refine energy programs across the department," said Hicks. "This partnership is the way forward for the Navy to achieve its energy goals."

According to Gorin, NREL brings a great deal to the table as a partner for possible future DoD efforts through its technology expertise and the ability to measure and demonstrate performance and cost savings. "This is a joint initiative, and the real power and value is that it is a collaborative effort where NREL and the Navy both bring critical and complementary elements to the mission."

— Heather Lammers (April 19, 2013)

Saudi Arabia Looks to NREL for Solar Monitoring Expertise

Saudi Arabia is planning to move aggressively into renewable energy, with plans to install more solar and wind power in the next 20 years than the rest of the world has installed to date.

The Kingdom of Saudi Arabia is working with the Energy Department's National Renewable Energy Laboratory (NREL) for training and expertise in measuring its solar resource.

The importance of setting up networks to gauge and predict the strength of solar radiation in varying meteorological conditions convinced the Saudis to choose NREL as a partner.

Nine Saudi engineers spent nine days at NREL last month, studying and discussing topics as theoretical as Ångström's law and the scatter-absorption ratio for the atmospheric effects on solar radiation, and as practical as the effect of sandstorms on solar panels. NREL experts also engaged the Saudi staff with topics including waste-to-energy, geothermal technologies, calibrations, and solar resource forecasting.

NREL and its partner Battelle will support the installation of more than 50 monitoring stations in the Middle East kingdom this year to measure the solar resource and gauge the best spots for solar power plants and will also train local Saudis to operate and maintain the instruments and stations.

It's a crucial part of Saudi Arabia's plan to spend billions of dollars over the next two decades to install more than 50 gigawatts of renewable power in the country and meet at least 30% of its electricity needs with solar energy by 2032. That's more gigawatts of renewable energy than were installed in the entire world as of 2012.

The overarching goal is to double electricity capacity by 2030 and have half of that energy originate from renewable sources such as wind, solar, and geothermal. The kingdom is expected to write a number of large contracts in 2013 alone.

Determined to Diversify

Why Saudi Arabia? Why does a nation that has huge oil reserves want to become a leader in renewable energy?

"Saudi Arabia is determined to diversify its energy sources and reduce its dependence on hydrocarbons," said Wail Bamhair, the project manager for the Saudi team that visited NREL. "Renewable energy isn't just an option, but absolutely necessary. We have the means to build renewable energy, and we need to do it."

Because Saudi Arabia is lacking in coal and natural gas, it uses a tremendous amount of energy to desalinate water and heat turbines to bring electricity to homes and businesses. Electricity is particularly in high demand during the Saudi summer when temperatures routinely top 110 degrees Fahrenheit and air

Mike Dooraghi works with engineers from K.A.CARE to install a rotating shadowband radiometer at the Al-Uyaynah Research Station near Riyadh. *Photo by Steve Wilcox, NREL 24992*

conditioners are rumbling. Economists have suggested that a big move into renewable energy can strengthen Saudi Arabia's economy and free up millions of extra barrels of oil for export. Bamhair said that while Saudi Arabia has a lot of sun, it also has challenges such as a variable climate, sandstorms, and even the occasional snowstorm in the northern regions. He shared photos he took of a sandstorm that in a few short minutes plunged an afternoon into darkness along a busy thoroughfare near the capital, Riyadh.

"We are working hand-in-hand with experts from NREL and Battelle who have these amazing minds," Bamhair said. "We are looking for them to build our human capacity. We are here to see, to learn, and to transfer the knowledge."

Forty years ago, Saudi Arabia had a population of about 5 million mostly nomadic people. Now, it's home to 27.5 million people, and most live in cities, including Riyadh, Jeddah, and Dammam.

Building a New City to Support Renewables

Saudi Arabia has envisioned a new organization to bring together researchers and manufacturing facilities for the renewable energy push. It is called the King Abdullah City for Atomic and Renewable Energy, or K.A.CARE. Nancy Carlisle, director of NREL's Integrated Applications Center, and her team also are assisting the Saudis by providing expert insight into lab design and how it can integrate with the city.

"The king and the kingdom recognize that it's important to look at non-fossil energy sources," said Tom Stoffel, NREL's group leader for Solar Resources and Forecasting.

The Saudi government is paying for the projects. In NREL's case, the parties will sign "Work for Others" agreements in which the American taxpayer pays nothing, but the general knowledge learned can later be used again to help improve renewable energy technologies in the United States.

Saudi Arabia and NREL have worked together before. In the 1990s, NREL helped launch research centers for the King Abdulaziz City for Science and Technology that was established in 1977.

The new partnership grew out of a visit by Saudi officials in 2010, which included a typical guest tour of the Solar Radiation Research Laboratory at NREL's Mesa Top facilities. Stoffel noticed his visitors were paying very close attention. "At the end of the tour, one of them asked us if we could help put 100 to 200 monitoring stations in the kingdom," Stoffel said. "After I picked up my jaw, I said, 'Yes, that's what we do.'" NREL is the site of an annual internal gathering to recalibrate solar radiometers and maintains the calibration standard for the United States.

Solar Monitoring Key to Knowing Resource, Engaging Stakeholders

Saudi Arabia eventually decided to put the project out for bid. NREL, partnering with Battelle, won the contract.

"The kingdom is tapping into our expertise on climatology, geography, and population density to make the best decisions on where to put the monitoring stations and the solar power plants," NREL Senior Engineer Stephen Wilcox said.

"They wanted to do this quickly because they need to demonstrate to stakeholders and potential investors a kingdom-size capacity for renewable energy," Stoffel said. NREL's measurements "will help decide where to put a central photovoltaic power plant, or a concentrating solar power plant of a particular size," he added.

Wilcox and NREL colleague Michael Dooraghi have already set up three solar measurement stations in Saudi Arabia as part of an initial training and outreaching event, including one in Riyadh, one just outside Riyadh, and one near where the new city will be built, about a 45-minute drive from the current K.A.CARE headquarters in Riyadh. Tripods holding several solar monitoring instruments are anchored either in the ground or on heavy concrete ballasts.

"It's important that they know precisely what the solar resource is so the financial stakeholders can know exactly what kind of return to expect," Wilcox said. "The more uncertainty in the measurements, the more uncertainty there is in the analysis. They could either make $100 million or lose $100 million based on how well the measurements are taken."

Some of the stations will be research quality, using instruments similar to the best ones at NREL.

Others will be self-contained stations that are powered by photovoltaics (PV) and placed farther into the deserts or even

some of the lesser-known areas of the kingdom. Crews will stop by every week or two to do maintenance on those stations.

A third type of station will be simpler yet, measuring just a subset of the factors that the larger stations measure. Those stations, though, play a crucial role in getting the whole climactic picture, including determining the role of microclimates and the impacts of large clouds passing by central solar power stations.

"We're trying to put together the best measurement network in the world," Wilcox said.

Mapping and Monitoring All Over the Globe

NREL's solar and wind resource assessment teams have mapped these renewable energy resources in several countries around the world.

For Saudi Arabia, the resource mapping will help officials decide where to put the large stations and where to distribute the smaller ones.

The data the stations collect can also be compared to other data NREL has collected around the world in its solar and wind integration studies. These data will be incorporated into the K.A.CARE Renewable Resource Atlas, currently under development by Battelle as part of the same project, and will be available online for researchers and others to use. Among the information will be data on solar radiation, the solar spectrum, temperature, dust levels, humidity, and wind speeds.

"They need to know about variability to maintain a stable grid—and that means making good predictions about what the next three minutes, the next hour, the next three days are going to look like," Wilcox said.

The fact that the Saudi king can order a huge nationwide project has its advantages. The United States and other countries can learn rather quickly what a full-scale embrace of renewable energy will look like in terms of planning, cost, and avoiding surges on the electricity grid or other mistakes.

Dr. Maher Alodan, head of the Research, Development, and Innovation Team at K.A.CARE, said last year that the project is a crucial one. Identifying primary sources of energy is a critical first step. "Undertaking such a project will require a comprehensive study that can only be carried out successfully if we know the specific geographic locations, and most importantly, the quality of solar radiation, and the factors that may affect the available resource."

At NREL last month, Bahmair said: "Our dream is to move Saudi Arabia to the first rank of nations in terms of sustainable energy. We have the smart young people, but we are looking to NREL and Battelle to share their expertise.

"This is the time for it," Bamhair added. "And NREL is the right facility to help us move forward. They are opening the door—and we have to walk through it."

Concentrating Solar Power to Play Critical Role

The Saudis also plan to make a big leap into concentrating solar power (CSP), the cousin of solar PV technology. In fact, 25 of the 41 gigawatts of planned solar energy will come from CSP.

PV panels convert photons from the sun directly into electrons for electricity, but only work when the sun is shining. CSP technologies use mirrors to reflect and concentrate sunlight onto receivers that collect the sun's heat. This thermal energy can then be used to drive a steam turbine that produces electricity.

CSP can store that heat in molten salts for up to 15 hours and can thus team with PV to help bring electricity to homes and businesses when it's most needed—in the evening hours when the sun has set, but the appliances, TVs, and air conditioners are still in demand. NREL's recent paper on that capacity, *Enabling Greater Penetration of Solar Power via Use of CSP with Thermal Energy Storage*, has sparked renewed interest in the two solar technologies sharing the load.

"The first project—installing the monitoring stations—is important for the CSP piece, too, because CSP depends on knowing the measure of clean-sky radiation," NREL's Scott Huffman said.

NREL will be overseeing the installation of the solar monitoring stations. The K.A.CARE Renewable Energy Atlas will be ready for access by late summer, with the full monitoring network in place before the end of the year.

— Bill Scanlon (May 13, 2013)

SOLAR

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

Photo by Dennis Schroeder, NREL 26730

Device Tosses Out Unusable PV Wafers

Silicon wafers destined to become photovoltaic (PV) cells can take a bruising through assembly lines, as they are oxidized, annealed, purified, diffused, etched, and layered to reach their destinies as efficient converters of the sun's rays into useful electricity.

All those refinements are too much for 5% to 10% of the costly wafers. They have micro-cracks left over from incomplete wafer preparation, which causes them to break on the conveyers or during cell fabrication.

Scientists at the Energy Department's National Renewable Energy Laboratory (NREL) have developed an instrument that puts pressure on the wafers to find which ones are too fragile to make it through the manufacturing process—and then kicks out those weak wafers before they go through their costly enhancement. NREL's Silicon Photovoltaic Wafer Screening System (SPWSS) is a cube-shaped furnace about 15 inches each side, and can be retrofitted into an assembly line.

The PV industry generated $82 billion in global revenues in 2010, producing 20.5 gigawatts of electricity from sunlight.

Processing solar cells costs about 15 cents for each watt of potential energy, and the cells comprise about half the cost of an installed solar module. If a way can be found to eliminate the cost of the 5% to 10% of cells that are destined to fail before they're finished, potential annual savings run into the billions of dollars.

It's the kind of savings that can make the difference between a U.S. manufacturer winning or losing.

Wafer Screening System Simulates Manufacturing Stress

NREL's Silicon Photovoltaic Wafer Screening System, developed by NREL scientist Bhushan Sopori with colleagues Prakash Basnyat and Peter Rupnowski, exposes a silicon wafer to thermal stress in the form of carefully calibrated high temperatures.

The process looks a lot like the toasting belt that turns a cold sub sandwich into a warm one. As each wafer passes through a narrow—15-millimeter—high-intensity illumination zone, different strips of the wafer are exposed to the heat. That way, the stress travels through the wafer.

"We create a very high temperature peak," said Sopori, principal investigator for the SPWSS. "The idea is to create a thermal stress, like putting very hot water in a glass."

The temperature can be calibrated precisely—most usefully by correlating it to the thickness of the wafer, because the thinner the wafer, the less stress it can withstand. Every manufacturer has different levels at which their wafers can break from stress,

NREL postdoctoral scientist Rene Rivero readies a wafer for the Silicon Photovoltaic Wafer Screening System. *Photo by Dennis Schroeder, NREL 20252*

so the SPWSS can be calibrated precisely via computer to meet the needs of each solar cell maker.

The SPWSS is essentially a furnace shaped like a trapezoidal prism to narrow the focus of the light and increase its intensity. The ceramic sides of the furnace reflect the light to the intensity zone and ensure that almost no energy is wasted.

The lamps can be as hot as 1,800 degrees Celsius (°C), but the hottest part of the wafer will feel about 500°C on its surface.

It's the rapid increase in thermal energy—made possible by the geometry of the furnace and its highly reflective surfaces—that causes the stress. While one 15-millimeter strip of the wafer is feeling 500°C of stress, the strip adjacent to it feels much cooler. The hot strip wants to expand, but the cool strip doesn't want any part of that. It's these competing forces that cause the stress. "Every micron of the wafer sees this thermal stress," Sopori said.

The micro-cracks or breaks that occasionally develop from the thermal stress mirror the stress that will happen to weak wafers as they go through the assembly process. The difference is that the thermal testing happens first, before the expensive coatings and layers are added to the wafers.

Inside the SPWSS is a reflective cavity that uses nearly 100% of the energy from the power source, wasting almost none of it. That keeps the energy costs down, bringing the total cost of operating the system to "some fraction of a penny per wafer," Sopori said.

Low-Cost Instrument Can Enhance U.S. Competitiveness

In recent years, the United States has lost a large portion of its global market share of PV production, from 42% in 1997 to merely 4% in 2011. Because of this trend, analysts who study the solar industry say it will take dramatic changes in solar cell materials and production to ensure that the most innovative and lowest cost PV technologies are manufactured in the United States.

The loss in revenue due to broken wafers—which increases dramatically as the wafers move closer to completion—is an important barrier to solar energy becoming cost competitive with other energy technologies. Manufacturers need better, less expensive ways to make the cells.

In a typical manufacturing facility, about 5 to 10 of every 100 wafers of 180-micron thickness break or otherwise fail. With the increased use of even thinner cells, breakage frequency is likely to grow. The PV industry typically does not prepare wafers in a way that can maintain their high mechanical strength. Even a suction cup that moves the wafers from one process to another can cause the micro-cracks that doom wafers to failure.

System Can Test up to 1,200 Wafers an Hour

A system that can screen just a sampling of wafers doesn't tell manufacturers which wafers to use and which ones to toss.

The manual version of SPWSS screens 1,200 wafers an hour and costs $60,000. That's quick enough for most manufacturers to screen every wafer without slowing down their conveyers. The upgraded SPWSS-A automatically separates broken wafers and costs $100,000. The failed wafers are swept out and melted down to be processed again into boules of solar-grade silicon.

Building on Success of NREL's Optical Cavity Furnace

With the SPWSS, Sopori built on the success of his Optical Cavity Furnace, which uses optics to heat and purify solar cells at unmatched precision while sharply boosting the cells' efficiency. Sopori won an R&D 100 award in 2011 for the furnace, which encloses an array of lamps within a highly reflective chamber to achieve an unprecedented level of temperature uniformity.

Like the SPWSS, it mitigates energy loss by lining the cavity walls with super-insulating and highly reflective ceramics, and by using a complex optimal geometric design. The wafer itself absorbs what would otherwise be energy loss. Like a microwave oven, each furnace dissipates energy only on the target, not on the container. "The most efficient way to generate light for the Silicon Photovoltaic Wafer Screening System is to use it in conjunction with the Optical Cavity Furnace," Sopori said.

— Bill Scanlon (January 11, 2013)

New Solar Cell Is More Efficient, Less Costly

American innovators still have some cards to play when it comes to squeezing more efficiency and lower costs out of silicon, the workhorse of solar photovoltaic (PV) cells and modules worldwide.

A recent breakthrough—the product of a partnership between manufacturer TetraSun and the Energy Department's National Renewable Energy Laboratory (NREL)—could spark U.S. solar manufacturing when the approach hits the assembly line next year. The innovative design, simple architecture, and elegant process flow for fabricating the cells make the technology a prime candidate for large-scale production.

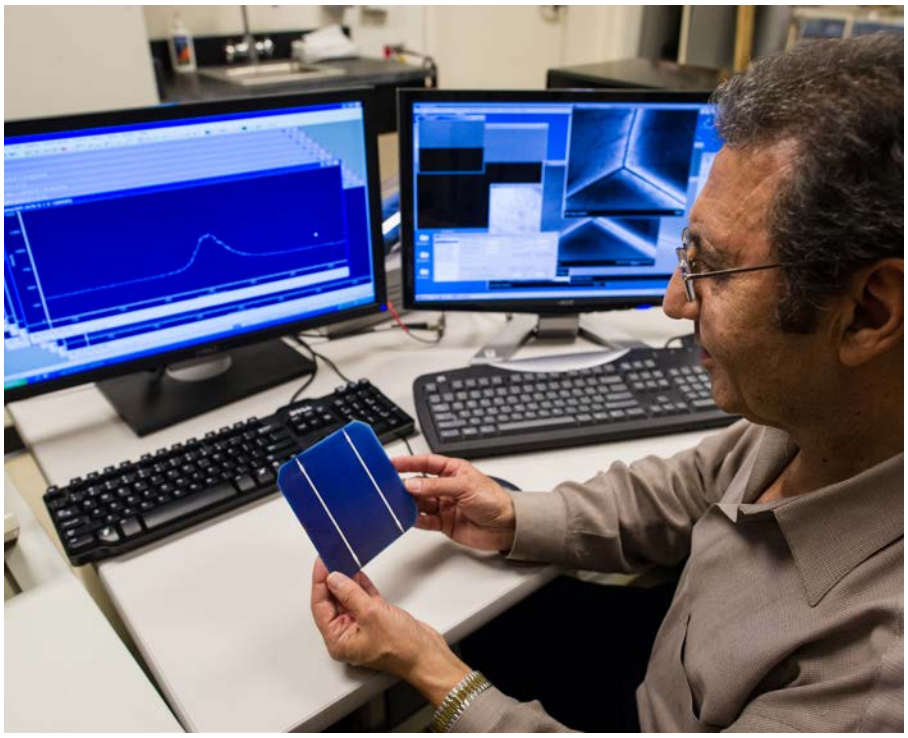
Solar industry leader First Solar acquired TetraSun in April 2013, about the time *R&D Magazine* honored TetraSun and NREL with one of its coveted R&D 100 Awards for the year's top innovations.

Potentially Disruptive Technology Attracted Attention of PV Incubator Program

Typically, silicon PV cell manufacturers add a grid of thin silver lines to the cell via a screen-printing process to form the front contacts.

The TetraSun cell instead loads 50-micron-wide copper electrodes on its front contacts in a way that prevents diffusion of the metal—which can degrade performance. The new process exceeds the performance of traditional heterojunction cells without the need of any special equipment, complicated module assembly, or costly transparent conductive oxides. That adds up to a significant cost advantage when it comes to high-volume manufacturing.

"It's a potentially disruptive technology, and that's why we decided to work with TetraSun," said NREL's Martha Symko-Davies, who headed the Energy Department's SunShot Initiative PV Incubator program when TetraSun received a grant from it back in 2010. "The Incubator program supports potentially disruptive innovations from small startups.



NREL Principal Scientist Mowafak Al-Jassim holds a TetraSun PV cell in the cathodoluminescence lab at NREL. The TetraSun cell combines increased efficiency and low cost, breaking the usual rules for solar cells. *Photo by Dennis Schroeder, NREL 27974*

> This shows we still have innovation in the United States. People thought there was nothing left to be done in silicon, but there is something left to be done.
>
> —MARTHA SYMKO-DAVIES, *Past PV Incubator Program Manager*

"This shows we still have innovation in the United States. People thought there was nothing left to be done in silicon, but there is something left to be done."

Symko-Davies was referring to the Shockley-Queisser limit, which postulates that the efficiency of silicon solar cells can't exceed 29%; that is, no more than 29% of the photons that hit the cell can be converted into electricity. Modern monocrystalline solar cells don't achieve much higher than 22% conversion efficiency due to practical considerations such as reflection off the cell and light blockage from the thin wires on its surface. That's why analysts are enthusiastic about the TetraSun cell, which comes in at 21% efficiency even as copper replaces silver to lower the cost.

TetraSun had a unique idea, but NREL's measurements and characterization capabilities made it practical. "As the margins go down with silicon, the cost of every component becomes significant, especially when you're talking about square miles of this material," said NREL Principal Scientist Mowafak Al-Jassim. "We're trying to make enough of these solar panels to generate gigawatts of power. That's a lot of silver. We needed to replace silver with an equally good conductor, but one that was much cheaper."

Detective Work: Finding Defects, Switching Recipes

Copper is a good conductor and connector, but unlike silver, copper doesn't like to stay where it's put. Researchers had to find a way to control the diffusion of the copper so it wouldn't shunt off and short out the cells and modules. Al-Jassim's role was to develop the means to characterize the new contacting scheme that uses copper. He turned to scanning capacitance microscopy to investigate and optimize the electrical properties of the contacts.

As NREL and TetraSun perfected the technique, the partnership between the national lab and the private company was akin to long-distance chess, with e-mails and packages traveling back and forth. TetraSun would send a sample, and NREL would examine the uniformity and continuity of the copper on the device.

The first several times, NREL researchers peering through microscopes at the copper saw not ribbons, but beads, representing discontinuity of the metal, a serious imperfection that causes poor performance of the cell. It was back-and-forth forensics work, examinations of tiny sections of large silicon wafers—156 millimeters on a side, larger than a CD case.

"We'd e-mail TetraSun the results; they'd see all those imperfections and try a different recipe or approach. We'd test it again, and e-mail the results again," Al-Jassim said. "Eventually, we got what we wanted to see.

"It was a very laborious process because we had to sample many parts from various areas of the cell," Al-Jassim added, noting that the copper grids are about one-twenty-fifth the width of a human hair. "But that's where NREL shines—when we are measuring at the nanoscale."

NREL also helped TetraSun increase cell yields while keeping a high efficiency. "We told them why the good cells were good, and why the bad ones were bad," Al-Jassim said. "It really is scientific detective work. It's not easy, but NREL is very well equipped to do this."

In addition, NREL performed tests to validate the TetraSun cell's reliability:

- A damp heat test in which the cells were exposed to temperatures of 85 degrees Celsius (°C) at 85% relative humidity for 1,000 hours

- A thermal-cycling test in which the cells were subjected to 200 cycles during which the temperature changed from -40°C to 85°C
- An ultraviolet (UV) test in which the cells were exposed to dosages of UV rays.

Maximizing Savings More Essential Than Ever

The importance of squeezing every last penny of savings from a solar cell has grown rapidly the past five years, as manufacturers try to ramp up to gigawatt scale and as the Chinese industry has lowered costs and margins.

Lately, companies almost always have had to increase costs to improve the efficiency of their solar cells. "TetraSun was able to keep the costs down while improving efficiency by two absolute percentage points, which is very significant," Al-Jassim said.

NREL's Harin Ullal, who managed the research with TetraSun, said achieving 21% efficiency in just 18 months is unusual—and indicative of the cell's disruptive technology. "That compares to 17% to 19% efficiency for screen-printed silicon cells," he said.

Ullal noted that the new technology, besides replacing expensive silver with abundant copper on the front contact grid, uses n-type silicon wafers, which have been doped with impurities that give them an excess of conductive electrons. (By contrast, p-type cells are doped to have more electron holes than electrons.) The n-type wafers can improve cell efficiency compared to the more common p-type wafers, which can suffer light-induced degradation. The innovations in the TetraSun cell structure design, corrosion resistance, and choice of n-type silicon material doping all added up to the efficiency gain of more than two absolute percent.

"By 2020, this technology could potentially reach the Energy Department's SunShot target of one dollar per watt for PV systems and about 6 cents per kilowatt hour for electricity generation," Ullal said.

Leading the team for TetraSun were Oliver Schultz-Wittmann, Denis DeCeuster, Adrian Turner, and Doug Crafts. In addition to Al-Jassim, Symko-Davies, and Ullal, NREL's team included Peter Hacke, Chunsheng Jiang, and Richard Mitchell.

First Solar built its worldwide reputation on cadmium telluride solar cells, which come from the second and sixth columns of the periodic tables. Those elements are costly by the pound, but require such thin layers that they can challenge silicon on price. But today, silicon continues to grab the lion's share of the solar market. With the acquisition of TetraSun, First Solar now is poised to have a presence in both thin films and silicon.

First Solar CEO Jim Hughes said in April that his company acquired TetraSun because its crystalline silicon cells achieve high efficiency using a simpler design, require fewer process steps, and have wider tolerances than conventional multicrystalline silicon solar cells. Hughes noted that the TetraSun technology also saves costs with its large-format wafers and by eliminating the need for expensive silver and transparent conductive oxides.

"This breakthrough technology will unlock the half of the PV market that favors high-efficiency solutions, which has been unserved by First Solar to date," Hughes said at the time of the R&D 100 Award announcement. He said that adding the TetraSun option to First Solar's market-leading cadmium telluride cells "gives us a unique end-to-end suite of solutions" to serve the spectrum of commercial applications.

"There has been tremendous focus in the solar industry on improving cell efficiency and cost," Ullal said, noting that often technical advancements that offer efficiency improvements are more complex and costly. "This technology is special because it offers improvements in both performance and production cost at the same time."

— Bill Scanlon (November 8, 2013)

NREL Test Helps Make Moisture Barriers Better

Moisture—in the form of humidity, water spills, or rainfall—spells early demise for cell phones, light-emitting diode (LED) displays, TVs, and solar photovoltaic (PV) panels worldwide.

Standing between that nefarious moisture and the device at hand is a transparent film barrier that must work flawlessly year after year, even decade after decade.

Now there is a test that can detect infinitesimally small amounts of moisture—and that can therefore give much greater assurance that the barrier films will last.

Developed by the Energy Department's National Renewable Energy Laboratory (NREL), the NREL Electric Calcium Test, or e-Ca, uses unique design elements to measure corrosion from water using calcium.

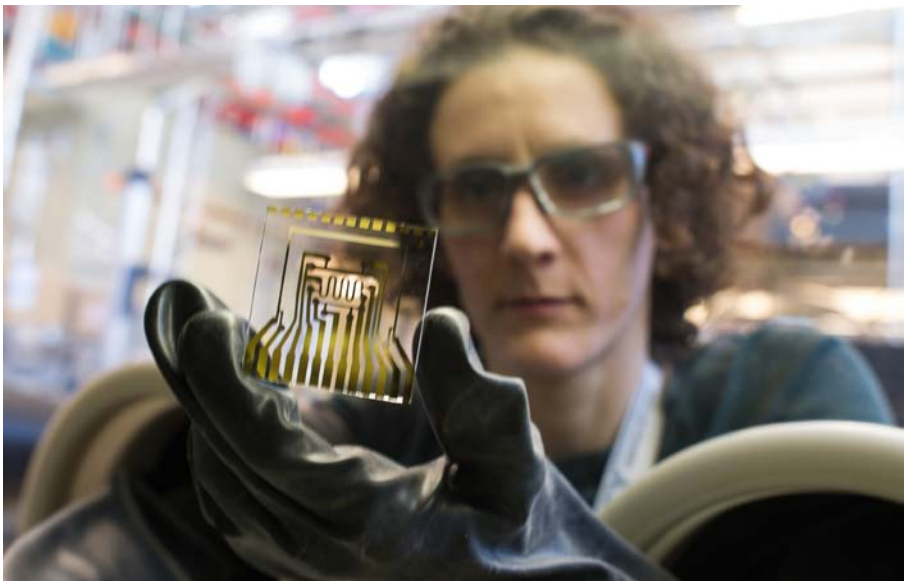
Industry durability standards for PV modules call for tests lasting 1,000 hours in damp heat conditions. Module manufacturers want to be assured that any barriers they use will be able to pass the moisture-blocking test, so they can focus on optimizing the rest of the module. And they want to make sure that anything they buy has passed rigorous quality control.

The e-Ca method is 100 to 1,000 times more sensitive than other commercial tests designed to detect small amounts of moisture. NREL's test can detect down to 10 to the minus seven, or one ten-millionth of a gram of water per square meter per day. And it has 15 times greater throughput than the best commercial methods on the market today.

NREL's e-Ca method arrives at a time when the organic light-emitting diode (OLED) market is poised to explode—from $4.9 billion in 2012 for OLED displays to an expected $26 billion by 2018.

The method uses low-cost test cards with calcium metal traces that serve as moisture detectors. Any water vapor that passes through the barrier film reacts with the conductive calcium and forms resistive calcium hydroxide. It's that change in resistivity that yields the rate at which the water vapor permeates the film—the water vapor transmission rate, or WVTR.

The test cards are made in large batches in a moisture-free environment. When a barrier is ready to measure, it is sealed on one side of a metal donut-shaped 'spacer' element with the test card sealed to the other side. The whole assembly forms a small diffusion cell that can be tested in almost any environment. The spacer also serves as a convenient and reproducible means of



NREL scientist Arrelaine Dameron works with an Electrical Calcium Test (e-Ca) glass card in a glovebox. The test measures water permeating through the thin-film barriers that guard cell phones, TVs, OLEDs, and PV cells. *Photo by Dennis Schroeder, NREL 24462*

adhering and controlling the flow of the edge seal that is used to seal the barrier to the test card, thus assuring that the barrier is the only thing being tested.

The assembly then attaches to custom NREL-assembled measurement electronics inside an environmental chamber that delivers a certain combination of heat and humidity. A good climate for testing is 45 degrees Celsius (°C)—113 degrees Fahrenheit (°F)—and 85% humidity, a condition hotter and wetter than even Bangkok, Thailand, on a miserable day. Testing in conditions beyond anything likely to be found in nature allows the test to be completed in less time. Another useful climate for testing is 85% humidity and 85°C, which is equivalent to 185°F and is a required reliability metric for PV manufacturing. Testing at 85°C ensures materials will be able to pass relevant qualification tests, and testing at 45°C gives permeation values relevant to the most severe climates in the world.

Invention Born Out of Necessity

Five years ago, NREL scientists Arrelaine Dameron and Matthew Reese were both working on projects that required them to either make or research barriers. "We realized we didn't have the means to test in the sensitivity range we needed," said Dameron, who works in NREL's Chemical and Materials Science center.

NREL Senior Scientist Michael Kempe, who is part of NREL's PV Reliability group, joined them, and the trio started to devise a user-friendly test that could detect moisture in minuscule quantities.

"We started with a test method that had been reported in the literature, but we found that there were a number of ways we wanted to make it better," said Reese, who works at the NREL-based National Center for Photovoltaics.

So, the NREL team improved on the method in several key ways. Instead of depositing calcium directly on the barrier, they opted to deposit it on separate test cards. Instead of using one large, unpatterned calcium square, the test cards contain several maze-like ribbons of calcium, allowing both higher initial resistances for each trace (making it easier to measure) and redundancy built into every test card. They also inserted a calcium 'witness' sensor that monitors the integrity of the edge seal.

The team tested a large number of materials to find an easily assembled and durable edge seal that could last for months to years at high temperatures. Then, perhaps most critically, they introduced a spacer element that allows them to vary the ratio of the exposed barrier to the calcium sensor area. In previous calcium tests, this was always fixed at a one-to-one ratio. NREL's test can amplify the sensitivity by funneling 100 to 1,000 times more moisture to the moisture-starved calcium sensors, compared to other tests. This is particularly important because even when the moisture is amplified 100 to 1,000 times, the amount of calcium consumption that is ultimately sensed when testing extremely good barriers can be as small as a fraction of an atomic layer per day.

Key to the test's sensitivity is a four-point connection—two wires to send current through the calcium resistor, and two more wires to measure the voltage. This technique removes the effects of leads and contacts so that tiny changes in resistance can be measured more confidently. The four-wire connection to the outside world is made by gold traces because they are insensitive to moisture. Even though the cards use tiny amounts of precious metals and require careful protection in a moisture-free environment, they can be produced for such low prices that they can be discarded at the end of each test.

Bringing all these innovations together allows NREL's test to beat today's commercial apparatuses that measure WVTR in both sensitivity and throughput. At best, a standard commercial system can get to a WVTR sensitivity of 50 parts per million. However, developers of flexible electronic devices such as OLEDs, organic PV, and other thin-film technologies need a sensitivity of less than one part per million to ensure investors that their money is going to products that will last.

The NREL test reaches that sensitivity and works for film barriers for all kinds of devices—copper indium gallium diselenide (CIGS) PV cells; flexible stainless steel foils that can be glued to a roof; outdoor LEDs; and, of course, nearly all new TVs and cell phones.

Testing Several Samples at Once—and at Greater Sensitivities

Barriers used today are made on rolls about a meter wide and potentially miles long. The goal might be to keep out moisture to the tune of one one-thousandth of a gram per day. To assure

> “When the tests are done, you can say that the material is good, that the variability is this much, and that there’s maybe one chance in a million that this barrier will fail.”
>
> —MICHAEL KEMPE, *NREL Senior Scientist*

against imperfections, a barrier manufacturer may want to design the film to be 100 times more water resistant than that.

Quality control can be performed by testing a few samples at, say, mile one, and another few at mile two, and so forth. Manufacturers can be assured that if those samples pass muster, then the entire batch is very unlikely to include any stretches that fail to seal at the 100-times-lower threshold.

“It’s designed to ensure that the process is robust,” Kempe said. “When the tests are done, you can say that the material is good, that the variability is this much, and that there’s maybe one chance in a million that this barrier will fail.”

If the barriers had to be tested one at a time, the tests would be prohibitively expensive, requiring the use of multiple testing stations to keep up with demand. Previous technology could test just a couple samples a week. The NREL scientists devised a way to test 128 barriers simultaneously, a significant increase in throughput.

A barrier of 10 to the minus four—four to five more orders of magnitude than the moisture protection required for food packaging—is the minimum threshold at which the material starts to provide protection for 20 years. Even at this level, after 20 years, a device accumulates a layer of water almost a micron thick. This can be catastrophic if the electronic materials that are being protected are themselves about the same thickness. Ten to the minus seven is 1,000 times better. “When you design something, you want everything to work perfectly—you don’t want it to just barely squeeze by,” Reese said. “You want to give yourself an extra factor of 10, and then you can be much more confident.”

This helps explain why the measurement is so complex. Even with the amplification NREL’s spacers provide, at 10 to the minus seven, just one one-hundredth of a nanometer of calcium would be consumed per day. “The overall aim is to be able to measure very low permeation rates over a long period of time with multiple samples, and to do it economically,” said Kempe.

Markets Need Assurance Film Barriers Will Endure

NREL is ready to license the e-Ca technology to deposition equipment manufacturers that make barriers by the mile, or perhaps to universities. Film-barrier testing “is an important part of a very large market,” Reese said. “It’s a very enabling technology. Without the ability to measure the barriers, it’s much more difficult to control them and to be able to say that your product is better than someone else’s product.”

OLEDs are being hailed as the future for displays in devices such as TVs, computer monitors, and cell phones. OLEDs produce a better quality of light than traditional LEDs and can be molded into any shape, while saving some 90% of the energy used to power incandescent lights. The Energy Department has shown its commitment to OLEDs with $40 million in funding for R&D.

NREL’s moisture-permeation test method can provide the assurance that barrier films passing the WVTR test can be counted on to keep out damaging water month after month, year after year.

“We have devised a way to constantly monitor an infinitesimally small change in water presence,” Dameron said. “We can do it reproducibly by integrating a user-friendly assembly process, and we can do it for many samples simultaneously. This is what makes our test unique.”

— Bill Scanlon (November 25, 2013)

Third Consecutive IEEE Cherry Award for NREL

Keith Emery always had amazing computer programming skills, but he lacked that special gift for creating solar cells. So, 30 years ago he switched to something more in his wheelhouse—characterizing and measuring the efficiency of solar cells and modules.

He succeeded so well, building a world-class testing facility at the Energy Department's National Renewable Energy Laboratory (NREL), that he was recently given the annual William R. Cherry Award by the Institute of Electrical and Electronic Engineers (IEEE)—one of the most coveted awards in the world of solar photovoltaic (PV) energy.

Emery is the third consecutive Cherry Award winner from NREL. In 2011, Jerry Olson, who developed the multi-junction solar cell, won the award. Last year, Sarah Kurtz, who helped Olson develop the multi-junction cell and is now a global leader in solar module reliability, won the award. And three other NREL scientists have won the Cherry Award in earlier years—Paul Rappaport (1980), Larry Kazmerski (1993), and Tim Coutts (2005). Emery says the cross-fertilization at NREL, with great scientists inspiring greatness in others, is the reason there have been so many Cherry Award winners at the lab—and is certainly the reason he won his.

Greg Wilson, director of NREL's National Center for Photovoltaics (NCPV), said: "Having three consecutive Cherry Award winners from the NCPV validates the strength of the PV program at NREL and the high degree of confidence that the international PV community has in our staff."

Emery, Kurtz, and Olson agree that NREL could not have won three Cherry Awards in a row without being given the time to research high-risk approaches to solar cells—a luxury rarely afforded private industry.

"NREL has had a sustained program in PV for 30 years," Kurtz said. "The industry is changing very rapidly, and companies come in and go out of business. What is unique about NREL is that people here have been able to stay and work in the same fields and become experts. If we didn't have that continuity

NREL researcher Keith Emery uses a high-intensity pulse solar simulator to test a concentrator solar cell in his laboratory at NREL. This summer, Emery was presented the Cherry Award by the IEEE. *Photo by Dennis Schroeder, NREL 18578*

it would be impossible to achieve that level of expertise and therefore that level of recognition."

Kurtz recalls that when she and Olson began working on a multi-junction approach to solar cells using indium and gallium, "everyone thought it was a stupid direction, because they knew it wouldn't work." That consensus opinion would have been enough to frighten away investors, but a national lab like NREL has the advantage of "exploring directions companies would think are too high-risk for them," she said.

"It was their [Kurtz's and Olson's] long-term attention to that material, plugging away at all kinds of problems, that made it work," Emery said. "They ultimately showed that it was superior to anything else. Satellite manufacturers picked up on it, and now all the satellites in space and all the concentrator PV systems use that technology."

Emery Set the Gold Standard for Measuring Solar Cell Efficiency

Emery has a Teddy Roosevelt moustache and routinely climbs high rugged mountains in the Colorado Rockies. But the Cherry Award startled this usually unflappable man.

"I was very surprised," Emery said.

Others aren't surprised, citing his work to bring iron-clad certainty to the claims made by solar companies about the efficiency of their cells and modules—not to mention the 320 scientific publications he's written.

"Accredited measurements from Emery's laboratories are considered the gold standard by the U.S. and international PV communities," said NREL colleague Pete Sheldon, deputy director of the NCPV. "Keith has been a leader in cell and module performance measurement techniques that have been the foundation for the credibility of PV efficiency standards for a quarter century."

The award is named in honor of William R. Cherry, a founder of the PV community. The award recognizes an individual engineer or scientist who has devoted a part of his or her professional life to the advancement of the science and technology of photovoltaic energy conversion.

In the world of solar cells, a seemingly small improvement in efficiency is almost always a very big deal. Higher efficiency links directly to cost and helps solar cells compete with other forms of energy.

Before Emery brought strict standards and independent analysis to testing and measurement, claims of high efficiency would be published in the literature without any independent verification.

"We decided that independent verification was important for credibility," Emery said. He and his NREL colleagues standardized measurement techniques, testing cells and modules under identical environmental conditions. But that meant that companies didn't always like the efficiency numbers they were getting back from Emery's lab.

"The happiness factor was never in our favor," Emery said. "We were coming in with lower efficiencies than the customer expected."

Emery and his colleagues stuck to their guns, and soon certification from NREL was de rigueur in the solar cell world. "Our goal is to eliminate surprises," Emery said. "If the measurements on their end disagree with our measurements, we show them why. It's in everyone's best interest to know what the environment is."

The service is readily available so researchers and companies have equal access to the resources needed for independent efficiency measurement, he says. "We provide the same playing field for everyone. We have to thank the Energy Department for this. They've funded it. We've been able to offer the service to everybody from national labs to a lot of low-budget startups. They all get the same verification."

Good Times with Electronics and Chemicals

Emery spent the first 25 years of his life in Lansing, Michigan, attending public schools before going on to Lansing Community College.

His interest in electronics goes back to seventh grade, when he made a five-tube amplifier out of a junk box hi-fi and a TV set. "I would have violated every safety rule we have at NREL, but that's a separate issue. I've always been interested in computers, going back to the days of paddle switches, punch cards, and paper tapes."

Emery started working with chemicals in community college, including some chemicals that are so potentially hazardous they're not even allowed in some research centers today. "Yes, I had fun with chemicals."

He earned his bachelor's and master's degrees at Michigan State University, where he fell under the tutelage of Stan Ovshinsky, whose pioneering work in amorphous silicon semiconductors set the course for many technologies and industries. More important to Emery, Ovshinsky introduced his young graduate students to energy-conservation devices, delivered a lecture on amorphous silicon, and "treated us like VIPs," springing for the occasional expensive meal.

Emery was getting close to earning a doctorate for his work on high-energy lasers when he had a change of heart, thanks in part to Ovshinsky opening his eyes to the potential of silicon, as well as his involvement in the growing environmental and renewable energy movement.

Making the Switch from Lasers to Renewables

"It was one of the first Earth Days, in the early 1970s," he said. "I was in graduate school having a great time working on high-energy lasers. But they were Star Wars lasers—the Strategic Defense Initiative.

"I wanted a career outside the military-industrial complex," he said. "With the excitement of those first Earth Days, and with the oil embargo, doing something in renewable energy was appealing."

He landed at Colorado State University to fabricate and test indium tin oxide on silicon solar cells. "Back then a thin film was depositing indium tin oxide on a silicon wafer," he said. "People would roll their eyes now if you called that a thin film."

NREL's predecessor, the Solar Energy Research Institute (SERI), offered him a job—impressed, by and large, by his computer skills. "I always had a knack for programming," he said. "Every lab that hired me wanted me for my programming. They didn't want me for anything else."

At SERI, Emery soon found that his expertise wasn't in making solar cells, but rather in testing them. "There's an art to making solar cells," he said. "I could deposit a good one in about 50 tries. The true artists can make them in about 10."

Building a World-Class Lab

So, Emery developed the test equipment and put together the data-acquisition system for characterizing and measuring the efficiency of solar cells. Turns out, his programming skills were essential to computer-control measurements and numerical control of instruments. "That's what we needed to build our lab."

He has spent his career building the capabilities of that testing and characterization lab, making it one of a handful of premier measurement labs in the world—and the only place in the United States that sets primary standards for solar-cell characterization.

A few years back, Emery published a paper on how to artificially increase solar-cell efficiency—not to encourage cheating, but to warn journal editors to be suspicious of claims.

"There have only been three or four papers in the past 35 years that have made claims that were outright bogus," Emery said, lauding the solar community for its integrity. Still, editors need to be on the lookout for exaggerated claims.

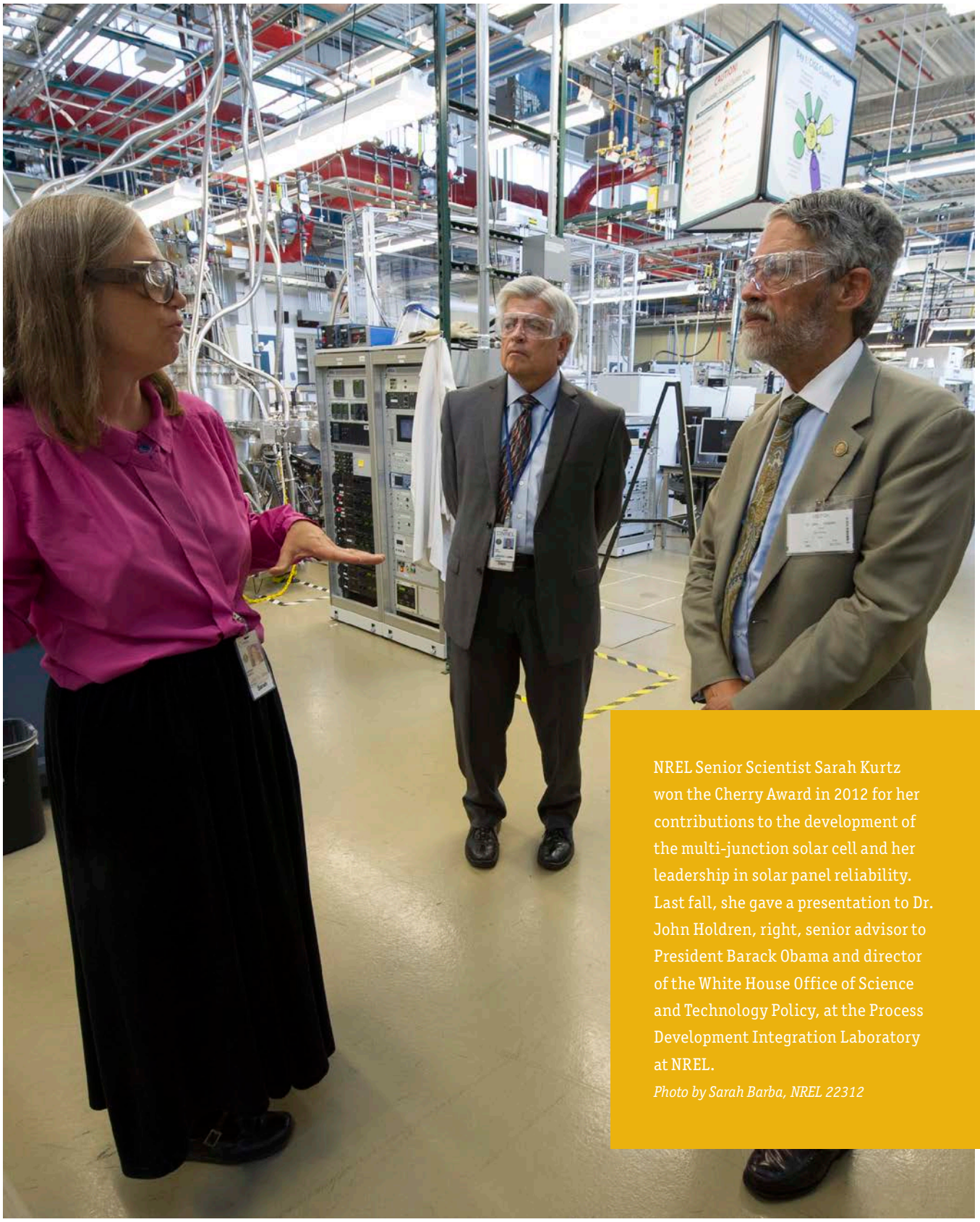
New materials will have to be more efficient and more economical than silicon to make a big dent in the market, Emery says. "They have a huge learning curve to keep costs down," he said, referring to thin films, organic PV, amorphous silicon, and other products just now moving from national labs to private companies. On the other hand, the newer materials have a great chance of invading niche markets such as solar cells on clothes, on signs, or on things that shine and glow or are hit by a laser. The multi-junction cell, for example, has already proven its superiority in outer space.

When he's not at work, Emery enjoys the Colorado outdoors. Emery and his wife, Pat, just published a paper on their own solar house, for which Emery dug the ditches, painted, and installed the insulation.

And at work, he'll keep testing and measuring the products of extraordinary research, as he continues to keep his lab among the best in the world at measuring solar module capacity.

As for the Cherry Award, Emery gives much of the credit to the colleagues who work in his lab and who have on average about 16 years of service at NREL. "Take my team away, and I wouldn't have gotten this award—it's that simple."

—Bill Scanlon (August 19, 2013)



NREL Senior Scientist Sarah Kurtz won the Cherry Award in 2012 for her contributions to the development of the multi-junction solar cell and her leadership in solar panel reliability. Last fall, she gave a presentation to Dr. John Holdren, right, senior advisor to President Barack Obama and director of the White House Office of Science and Technology Policy, at the Process Development Integration Laboratory at NREL.

Photo by Sarah Barba, NREL 22312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NATIONAL RENEWABLE ENER
D
NREL
2013
Outstanding Venture Award
NREL Industry Growth Forum

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 start-ups.

Photo by Dennis Schroeder, NREL 28272

Bright Ideas Chase Investor Dollars at Forum

A company that can generate electricity using low-temperature waste heat was the big winner at the recent 26th annual Industry Growth Forum in downtown Denver, a gathering of people who have no qualms about making money while helping to build a more sustainable world.

The annual gathering sponsored by the Energy Department's National Renewable Energy Laboratory (NREL) brings inventors and entrepreneurs together with investors and venture capitalists to spark courtships that can lead to the next big thing—a taller wind tower, a better battery, a way to use enzymes to detect chemicals in the fracking process, a more efficient solar cell. This year, nearly 400 attended the two-day event at Denver's Grand Hyatt Hotel on December 3 and 4.

Innovative ideas, sustainable solutions, and startlingly simple, outside-the-box, almost-ready-for-market products for reducing greenhouse gases and turning profits abounded. Attendees remarked on how the presentations continue to mature, as they wend their way from the research lab to pilot scale, then manufacturing scale, and on to the marketplace. Pie-in-the-sky didn't make the cut, but rational solutions won raves.

Expert panels of judges assessed the 30 best innovations; they heard 10-minute presentations and asked questions for another 10 minutes. Dozens of other companies presented their ideas to investors in short, one-on-one bursts, in the sustainable energy world's version of speed dating. Examples: a four-person start-up needs $250,000 to sustain it through building a prototype; a 16-person company needs $2.5 million to crank up to manufacturing scale.

Money Goes to Ideas That Show a Clear Path to Profits

Potential investors wanted to see not just crisp, clean presentations, but true opportunities to make money with new green technologies. And they saw them in spades.

There was Keystone Tower Systems of Massachusetts, which has devised a way to build tapering towers for wind turbines right at the wind farm. If that doesn't sound like much, consider that it is near impossible to transfer wind towers more than 80 meters long across the nation's highways, because the diameters of higher towers would rise too high on the truck bed and smash into overpasses.

Ilan Gur (right), program director and technology-to-market senior advisor for ARPA-E, networks with company representatives and investors at NREL's 2013 Industry Growth Forum in Denver. *Photo by Dennis Schroeder, NREL 28324*

Keystone's solution is to have trucks ship flat, trapezoidal steel plates to the wind farm, where the company runs them through a machine that will turn them into conical shapes with a continuous taper. That way, they can grow as high as 160 meters and still be made of just one-inch-thick steel—much more cost-effective than the three-inch steel and tons of extra concrete that would otherwise be needed to make such tall towers.

And why, the panelists wanted to know, is it so important to grow wind towers that high? Keystone CEO Eric Smith had the answer: In the eastern half of the nation, where hardwood trees grow tall, shorter towers aren't efficient because the trees block the wind. Sturdy, cost-effective 160-meter towers can bring reliable wind power to that half of the nation, boosting wind energy production by 38%while lowering costs by 20%, Smith said.

Keystone didn't win one of the three grand prizes at the Forum, but like a lot of other companies that made presentations, it garnered plenty of interest from the investment community.

Companies Presenting at Forum Raised More Than $5 Billion since 2003

Since 2003, companies presenting at the Forum have cumulatively raised more than $5 billion in growth financing, noted Bill Farris, associate laboratory director for NREL's Innovation, Partnering, and Outreach office.

The winner of the Best Venture award was Ener-G-Rotors, Inc., a New York company that sells devices that make it economically viable to generate electricity from low-temperature heat. Every year, billions of dollars of energy are thrown away in the form of waste heat, CEO Michael Newell told the judging panel made up of scientists, engineers, and investors. The Energy Department has identified waste heat as the number one opportunity for industrial energy efficiency—a potential $6 billion annual market. Ener-G-Rotors uses expanders to generate electricity from a lower temperature than was previously possible. The company got initial funding from the New York State Energy Research and Development Authority, but is now looking for private capital to expand its manufacturing.

Outstanding Venture awards were given to:

- Boulder Ionics Corporation, a Colorado-based producer of high-purity ionic-liquid electrolytes that are sufficiently stable and cost effective for use in grid-scale batteries. The electrolytes double the energy storage of ultracapacitors and enable batteries to have 10 times higher energy density, according to Boulder Ionics founder Jerry Martin. The breakthrough comes at a time when solar and wind farms are loading more distributed renewable energy on the grid, amplifying the need for storage solutions. The electrolytes also could factor in the electric vehicle market.
- HIECO, out of Alberta, Canada, which produces a non-thermal, non-chemical method for pasteurizing liquids called High Impedance Electroporation.

Seven Colorado Companies among 30 Asked to Present

Several other companies won investor interest.

OptiEnz Sensors, LLC, a startup using research from Colorado State University, puts enzymes on biosensors to detect chemicals in water. The method can be useful in the 600,000 fracking wells in the country, and can also be applied to the dairy, food, and beverage industries.

In the fracking process, eight to 10 barrels of water are used for every barrel of oil or gas equivalent harvested from the wells one to two miles below the surface, OptiEnz CEO Steve Witt said. That water can be contaminated with benzene, xylene, methane, or other organic chemicals. "Rather than waiting a week for results, we can offer continuous in-place monitoring, with immediate results and an 85% reduction in annual costs."

The device sends light down a fiber-optic cable to a sensor tip that is coated with a fluorescent dye embedded with different enzymes for each possible organic chemical. The change in the light that's reflected back indicates the presence and concentration of different chemicals.

OptiEnz was looking for $750,000 to complete its business development and expand its in-house manufacturing of the sensor tips. Witt, like other presenters, outlined the timeline to profitability, the possible return on investment, and an exit strategy—what kind of company might acquire the six-person startup, and when.

> "Right now, I just want to make the transition from entrepreneur to successful entrepreneur."
>
> —**DOUG HUTCHINGS,** *CEO of Picosolar*

Fabriq, another Colorado-based company, has found a way to make energy monitoring cost effective for smaller buildings by placing the software in the cloud. CEO Mark Verheyen said the cost falls from a prohibitive $2.75 per square foot to a manageable $1.10 per square foot for the 95% of buildings in the United States that are less than 50,000 square feet. He said the average smaller building can then save $14,000 per year in lighting costs by taking advantage of motion detection, dimming, and other features enjoyed now by larger buildings. Fabriq built its business model on an energy monitoring system first developed at NREL.

Annual Forum Is Place to Identify Trends in Green Technology Sector

Many attendees said the annual trek to Denver is a must-do.

"I like to come here to see where the investment money is going, and see what the trends are," said Chet Kolodziej, executive director of the nonprofit Freedom Field, which supports renewable energy projects in northern Illinois. "Five years ago, most of the presentations were on solar, and made by CTOs. Now, more people from the business side are making the presentations—that shows a maturation. In terms of the technology readiness levels, where 1 is a laboratory idea and 10 is a product you can buy at Walmart, the ideas here are about a seven or eight. They're what I'd call pre-commercialization."

A year ago, Doug Hutchings was a 29-year-old recently minted Ph.D. trying to raise money in the one-on-one "speed dating" process at the Forum. This year, he was back as a presenter, touting his company, Picosolar, which has a hydrogenated super-emitter that reduces the need for silver on solar cells, while increasing efficiency. He told the judging panel that the benefits are worth $140 million a year to a typical manufacturer. Hutchings' breakthrough with Picosolar won a SunShot Initiative award from the Energy Department.

Hutchings said he was encouraged by feedback at the Forum and hopes to leverage $1 million in federal funding to get $2 million from private investors. "It's a wonderful audience here," he said. "If nothing happens with the first interaction, you're at least setting up a process for engagement. You follow up; you don't want to play too easy to get."

Asked if he is likely to be a serial entrepreneur or stick with his current company, Hutchings laughed and said: "Right now, I just want to make the transition from entrepreneur to successful entrepreneur."

Turnout, Quality of Products Grow in Tandem

Farris said Forum turnout was greater than that of the previous year, and the quality of presentations was outstanding. He said the green energy industry is at a good spot on the "hype curve. When things get overhyped, there is irrational exuberance, then a fall to a trough. That's when the really strong companies, the ones that are more viable, come in. That's where we are now. Investors are commenting on how strong and prepared the presenting companies are, and on the soundness of their business models. We're seeing more variety now—battery storage, energy management, water management, building technologies, as well as photovoltaics. Year to year, the Forum helps you see what's happening in the clean tech sector."

NREL Director Dan Arvizu said the tough marketplace and the exit of many companies from the clean energy sector forced a maturing of the industry. Presenters this year are the cream, having proved their resilience. The Forum bringing together researchers and marketers helps speed innovations to the marketplace, Arvizu added. Without it, important networking wouldn't take place. "The relationships built and information shared at the Forum are vital to the advancement of clean energy technologies."

— Bill Scanlon (December 17, 2013)

Katie Hoffner, vice president of marketing and strategic alliances for Prieto Battery, gives her company's presentation to the judging panel at NREL's 2013 Industry Growth Forum in Denver. *Photo by Dennis Schroeder, NREL 28330*

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 28250

Change Is in the Air at NREL's Wind Center

The National Wind Technology Center (NWTC) is at the nexus of a changing landscape, where the mountains meet the plains. It's also where changes in the wind industry are being previewed. And, a visitor or passerby will notice significant yet subtle changes taking place on site, including a new turbine installation and new blades on another of the site's giant turbines.

Researchers at the Energy Department's National Renewable Energy Laboratory (NREL), along with their industry partners, are advancing a more sustainable energy future at the NWTC by leading the way in testing the most advanced wind turbine technologies and preparing them for future deployment.

"The addition of modern megawatt-scale wind turbines has been critical in the development of our center," NWTC Director Fort Felker said. "It has changed the way the wind industry thinks about NREL in the sense that the work we are doing is relevant, impactful, and immediately beneficial to them. The continued partnership efforts on these turbines demonstrate how our industry partners value the contribution we provide and the important role we can play in testing new technologies."

More Power at Lower Wind Speeds

NREL entered into a partnership with Alstom, a French power-generation company, in early 2011 when its ECO 100 wind turbine was installed at the NWTC for certification testing.

The next step in that partnership took place recently when the turbine was updated to test a new, state-of-the-art blade design. The change converted the ECO 100 turbine into an ECO 110 turbine with a behemoth 110-meter rotor diameter, making it the largest and most powerful wind turbine currently on the NWTC site.

"This is the largest machine we've ever had our hands on," NREL Test Engineer and Project Manager Jeroen van Dam said. "It's always an exciting opportunity to get to apply our testing methods to a larger or newer concept and continue to validate those methods."

The unique rotor design of the Alstom turbine required that the blades be switched out, one at a time, in the air. The logistics of such an operation were tricky and required two very large cranes with skilled operators and teams of staff on the ground

Crews lift a blade assembly onto the nacelle of Gamesa's G9X-2.0 MW turbine at the NWTC. *Photo by Dennis Schroeder, NREL 20244*

> “Wind energy is going to continue to play a key role in creating a stronger and more sustainable American economy. This partnership with NREL is an exciting venture that showcases Gamesa’s commitment to enhanced clean energy development, as well as our ability to deliver reliable, efficient, and cost-effective wind turbine technologies to the U.S. marketplace.”
>
> —DAN BRODERICK, *Engineering Manager for Gamesa North America*

and inside the turbine. The installation also required calm weather—hardly a given at the notoriously windy NWTC site.

The Alstom ECO 110 turbine with the larger blade configuration is specifically designed to operate efficiently at lower wind speeds. Longer blades mean more wind is captured, allowing greater power generation at lower speeds. The downside of this longer blade configuration is a greater risk of damaging structural loads on the turbine at higher wind speeds. The testing at NREL will focus on power performance and mechanical loads to validate computer modeling that predicts the design loads. This is part of the certification efforts for this turbine blade design before it can enter the U.S. market.

“There is great potential for developing medium wind speed resources throughout the United States and Canada,” said Albert Fisas, director of innovation for Alstom’s North American Wind business. “With this upgrade complete, Alstom and NREL will launch a commissioning and testing program to certify the performance of the new rotor configuration for use in North America and worldwide.”

A Stronger Wind Turbine for Stronger Winds

In another collaboration with the wind industry in late 2011, NREL began testing a G97 Class IIIA 2.0 megawatt (MW) turbine from Gamesa Technology Corporation, Inc. This public-private partnership was developed to study and test a variety of components and systems on the turbine and to guide development of the next generation of wind turbines being designed specifically for the U.S. market.

Testing on the original turbine was completed, and in order to continue the collaborative research, the turbine was recently upgraded with a new rotor and other components, including a new control system. This upgrade to a Class II version of the Gamesa G97 model will allow the turbine to operate efficiently at higher wind speeds.

The International Electrotechnical Commission (IEC) develops international standards for wind turbines. The IEC standards set wind classes for conditions a turbine might see at hub height in a given location from I to III, with Class I winds being the highest (speeds averaging 22 miles per hour) and Class III winds the lowest (speeds averaging 17 miles per hour).

“From the outside, you can’t really tell the difference between this one and the original—the differences are very subtle,” van Dam said. “The Class II design has different blades and more material in strategic places to make it a more robust design capable of standing up to stronger Class II wind speeds.”

NREL testing of the Gamesa turbine will focus on evaluating the new design features of the G97 model and will lead to certification for use in the U.S. market. NREL’s work will also include power performance testing and acoustic testing of the Gamesa design.

“Wind energy is going to continue to play a key role in creating a stronger and more sustainable American economy,” said Dan Broderick, engineering manager for Gamesa North America. “This partnership with NREL is an exciting venture that showcases Gamesa’s commitment to enhanced clean

> "These types of collaborations demonstrate a commitment to crucial technology development and the public-private partnerships necessary to ensure the continued momentum of the wind power industry."
>
> —FORT FELKER, *NWTC Director*

energy development, as well as our ability to deliver reliable, efficient, and cost-effective wind turbine technologies to the U.S. marketplace."

NREL Leading the Way to Expanded Deployment and Lower-Cost Wind Energy

It might appear odd that these two projects—one wind turbine being refitted to accommodate lower wind speeds while another is updated to handle higher wind speeds—are happening simultaneously and at the same location. However, the NWTC site is uniquely positioned to meet the demands of both.

"Our site regularly gets Class II and Class III wind speeds, with Class I extremes," van Dam said. "The variety of wind we get at this location allows for us to do a wide variety of testing effectively. And the fact that we often get very high winds here makes it a great location to test structural loads on all types of turbine designs, regardless of their intended wind speed for deployed use."

Additionally, the expertise and efficiency of NREL's testing capabilities make the NWTC an attractive location for this type of continued collaboration.

"We have unique capabilities to support the type of testing that they want to do," van Dam said. "Also, with the site and infrastructure we have here, and the benefit of being pre-permitted on public land, the deployment of prototype technologies can be expedited. This helps get newer designs certified and to market quicker."

NREL's ultimate goal in this testing is to foster the technological developments necessary for wider deployment of wind energy in the marketplace at the lowest cost possible. New wind turbine designs that are able to efficiently handle a wider regime of wind speeds and the ability to select technology that is optimized for a specific location and wind resource will allow greater deployment of wind energy in more areas where it may not have otherwise been practical.

"These newer designs will have a lower cost of energy, and this can directly lead to greater market penetration," van Dam said. "Our work in testing these new designs and having them be quickly deployed, effectively validated, and proven is a critical part of the process."

Industry Collaborations Building a Big Future for Wind Energy

NREL researchers are staying focused on the path forward for wind energy. Continuing to lead the way in testing new technologies and maintaining a cutting-edge approach to working with the wind industry makes the NWTC a valued partner. NREL places a high importance on its collaborations with industry and sees these partnerships as critical to meeting the nation's goals of moving toward a clean energy future.

"We are pleased to have a dynamic and diverse group of industry colleagues working with NREL as R&D partners," Felker said. "These types of collaborations demonstrate a commitment to crucial technology development and the public-private partnerships necessary to ensure the continued momentum of the wind power industry. Our role is to help reduce the technical risks and thereby help accelerate next-generation technology into the marketplace. NREL is proud to be at the forefront of this important work."

— David Glickson (April 4, 2013)

New Test Facility to Improve Wind Turbines

Premature failures of mechanical systems have a significant impact on the cost of wind turbine operations and thus the total cost of wind energy. Recently, the Energy Department's National Renewable Energy Laboratory (NREL) took a giant step forward in the quest for more reliable, lower-cost wind power with the addition of the new 5-megawatt (MW) Dynamometer Test Facility at its National Wind Technology Center (NWTC). The new facility dramatically expands the capability of NWTC engineers and their industry partners to verify the performance and reliability of wind turbine drivetrain prototypes and commercial machines.

The facility is capable of testing drivetrains up to 5 MW—large enough to test virtually any land-based turbine—and employs dynamically variable loading capabilities that will allow researchers to better simulate conditions a turbine might experience in the field.

"These new capabilities make this a very special facility, one of the largest and finest of its kind in the world," NWTC Director Fort Felker said. "It gives NREL an enhanced ability to do comprehensive testing of modern multi-megawatt wind turbine systems in a laboratory environment to verify their performance and reliability before they are widely deployed."

A Cutting-Edge Test Facility for the Future of Wind Energy

A dynamometer system replaces the rotor and blades of a wind turbine and allows researchers to control the turbine drivetrain's mechanical and electrical systems while simulating normal and extreme operating conditions. Historically, this testing has been done under torque (rotating) loads only. The new state-of-the-art facility at the NWTC, funded with the support of the Energy Department and the American Recovery and Reinvestment Act (ARRA), incorporates a non-torque loading system into the testing regimen, a hydraulic device that allows for simulation of both the rotational and bending loads that a wind turbine rotor places on a drivetrain.

"The non-torque loading system is what really sets this facility apart from other comparable test sites," NWTC Dynamometer Project Manager Mark McDade said. "This allows us to test the drivetrain system with the types of loads that it will see in a real-world application. It's a very important feature for a test

NREL engineer Scott Lambert (left) and Project Manager Mark McDade discuss calibrations being done on the new dynamometer at the 5-MW Dynamometer Test Facility at NREL's National Wind Technology Center. *Photo by Dennis Schroeder, NREL 28229*

> "As more and more renewable energy generation and storage technologies are added to our electricity mix, it is critically important that we understand how these systems will perform on the larger electric grid, how they will react to disturbances, and how they will be able to provide benefit to the grid from a systems integration standpoint."
>
> —MARK MCDADE, *NWTC Dynamometer Project Manager*

apparatus because the adverse impacts these types of loads can have on a system are significant."

The system features a 6-MW motor, which provides the power to a turbine during testing. The motor turns at very high speed and low torque. The motor drives a gearbox, which transforms the output to the high torque and low speed that is appropriate for a wind turbine drivetrain. This provides the rotating loads on the test article.

Add to this motorized torque testing the non-torque loading capability unique to the NWTC, and NREL is able to put a wind turbine drivetrain through the most realistic loading tests possible in a laboratory.

Reliable Wind Turbines for Industry Mean Lower Costs for Consumers

Dynamometer testing is used by industry to confirm proper operation and reduce the risk of deploying wind turbine prototypes before they are put into service. By reproducing operating conditions in a laboratory environment, engineers can verify the performance of a turbine's systems, including generators, gearboxes, power converters, bearings, brakes, and control systems. Conducting these tests before deployment is important because unanticipated failures can be detected and corrected early in the development process, leading to a lower cost of ownership for wind farm operators—and ultimately lower-cost wind energy for the consumer.

"These machines are expected to operate reliably in the field, often in harsh conditions, for 20 years or more," Felker said. "The ability to comprehensively test these systems in the lab, to verify their reliability and performance before they go into service, is a critically important capability for the wind industry."

The first tests being done at NREL's new dynamometer facility are on a 2.75-MW wind turbine the Energy Department acquired in partnership with General Electric (GE). The GE system is being used for the calibration and commissioning of the testing equipment in the facility, which will also provide the industry partner with useful data on this particular turbine model.

"The only way to deliver advanced technology at a lower cost of energy with high reliability is to be able to test and learn," GE Senior Manager for Wind Technologies Tom Fischetti said at the dedication event for the facility. "Being able to do that here at ground level instead of in the field, 300 feet in the air, is very important to GE and the rest of the wind industry. This is state-of-the-art technology, and we are excited to be able to partner with NREL and the Energy Department by being the first user of the facility."

Helping the Power Grid and Wind Turbines Work Better Together

Another important new capability that enhances the value of the work being done at NREL's 5-MW Dynamometer Test Facility is the Controllable Grid Interface (CGI), a powerful energy systems integration tool that allows engineers to precisely control the electrical grid conditions that a test article will see.

The CGI simulates various grid disturbances, such as over-voltage or under-voltage events, allowing engineers and industry partners to determine how grid-connected systems will react to these events in a controlled environment.

This type of testing—performed offline from the grid, but simulating a real-world grid environment—enables users to verify performance, assure compliance with standards, and understand failures in a fraction of the time and cost that it takes to perform similar tests in the field.

The CGI can also help engineers determine how these systems will be able to provide ancillary services to the grid, as well as test and optimize the grid-integration-related performance of a unit before it is deployed.

"This is a significant capability for NREL, and one that is very complementary to the work that will be done in the dynamometer," McDade said. "As more and more renewable energy generation and storage technologies are added to our electricity mix, it is critically important that we understand how these systems will perform on the larger electric grid, how they will react to disturbances, and how they will be able to provide benefit to the grid from a systems integration standpoint."

The CGI can test not only the integration performance of wind turbines, but also that of a wide variety of grid-integrated energy systems, such as utility-scale solar photovoltaic (PV) generation, PV inverters, and energy storage systems.

Working Today Toward the Technologies of Tomorrow

In addition to enabling deployment-readiness testing, the new NREL test facility will be able to examine future technology innovations, such as advanced drivetrain systems, that promise to usher in the next generation of higher-performance, lower-cost wind turbines.

Research at the facility will accelerate the development of new wind energy technologies, providing an opportunity to verify the concept and performance of prototype technology improvements at the pilot level before moving them into the marketplace.

This capability will allow research engineers to test a specific component, such as a generator or a gearbox, within the scope of a full system, to confirm that it meets its performance, efficiency, and reliability goals before introducing it into the operating fleet of wind turbines.

The NWTC has continued to grow its testing capabilities over time to meet the ever-expanding needs of the wind industry. This is the third dynamometer test facility at the laboratory, adding to the existing capabilities of previously installed 225-kilowatt and 2.5-MW test systems. The two smaller systems have directly contributed to the growth of the higher-performance, lower-cost, and more reliable wind turbines seen in use today. The new 5-MW facility is the next step forward toward even larger wind systems with increased performance expectations.

"Important basic R&D will be done in this facility to answer the key engineering questions that will allow us to develop the next generation of wind turbine technology," Felker said. "We need to continue to push the cost of energy down while at the same time improving the performance and reliability of these systems. A laboratory environment such as this, where we can seek the answers to these questions is an important step toward meeting those goals."

— David Glickson (December 26, 2013)

°C – Celsius

°F – Fahrenheit

AEDG – Advanced Energy Design Guidelines

AHEM – Automated Home Energy Management

AIA – American Institute of Architects

API – Application programming interface

ARPA-E – Advanced Research Projects Agency – Energy

ASE – Alliance to Save Energy

ASHRAE – American Society of Heating, Refrigerating, and Air-Conditioning Engineers

BCL – Building Component Library

CEO – Chief executive officer

CGI – Controllable Grid Interface

CHARMM – Chemistry at Harvard Molecular Mechanics

CPU – Central processing unit

CRADA – Cooperative Research and Development Agreement

CSP – Concentrating solar power

CU – University of Colorado

DEVAP – Desiccant-Enhanced Evaporative

DoD – U.S. Department of Defense

DoN – U.S. Department of Navy

e-Ca – Electrical Calcium Test

ESIF – Energy Systems Integration Facility

FCEV – Fuel cell electric vehicle

FCHV – Fuel cell hybrid vehicle

GE – General Electric

GGE – Gallon of gasoline equivalent

HPC – High performance computing

HTAP – High-Throughput Analytical Pyrolysis tool

HVAC – Heating, ventilation, and air conditioning

IEC – International Electrotechnical Commission

IEEE – Institute of Electrical and Electronic Engineers

IPOS – Image Processing Occupancy Sensor

LED – Light-emitting diode

LEED – Leadership in Energy and Environmental Design

MD – Molecular dynamics

MW – Megawatt

NCPV – National Center for Photovoltaics

NREL – National Renewable Energy Laboratory

NWTC – National Wind Technology Center

OLED – Organic light-emitting diode

PEV – Plug-in electric vehicle

PUE – Power usage effectiveness

PV – Photovoltaics

R&D – Research and development

RSF – Research Support Facility

SERI – Solar Energy Research Institute

SITES – Sustainable Sites Initiative

SPWSS – Silicon Photovoltaic Wafer Screening System

SWS – Standard Work Specifications

UV – Ultraviolet

V – Volt

VTIF – Vehicle Testing and Integration Facility

WAP – Weatherization Assistance Program

WVTR – Water vapor transmission rate

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