NREL
NATIONAL RENEWABLE ENERGY LABORATORY

NREL: A YEAR IN CLEAN ENERGY INNOVATIONS

A Review of NREL's 2011 Feature Stories

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

Cover photo by Dennis Schroeder, NREL/PIX 19795


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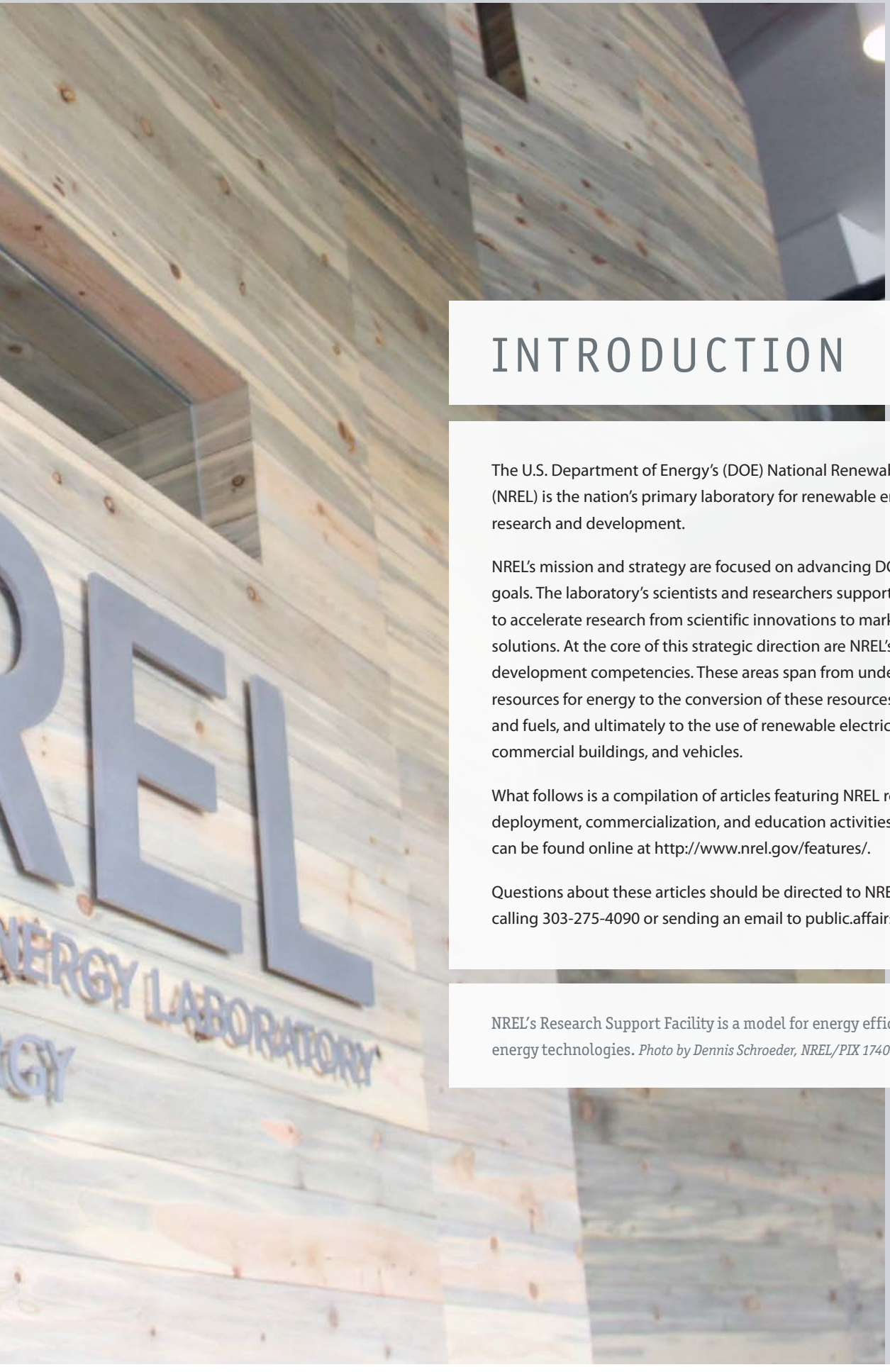

INTRODUCTION

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

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

What follows is a compilation of articles featuring NREL research and development, deployment, commercialization, and education activities in 2011. The feature stories can be found online at http://www.nrel.gov/features/.

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

NREL's Research Support Facility is a model for energy efficiency and renewable energy technologies. *Photo by Dennis Schroeder, NREL/PIX 17404*


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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/PIX 20037

Antarctica's Ice Puts Electric Vehicles to Test

The punishment your car endures on a cold winter commute pales in comparison to the veritable torture that researchers at the U.S. Department of Energy's (DOE) National Renewable Energy Laboratory (NREL) are inflicting on two electric utility research vehicles—all in the name of science.

For these e-ride Industries EXV2s, commutes are short in distance but long on darkness and temperatures that dip below -50°F at the McMurdo Station in Antarctica. However, if these electric vehicles (EVs) can prove they are tough enough to take on Antarctica, then they will help offset current fossil fuel use and pollution at the station. These more efficient and less resource intensive EVs could replace the base's extensive fleet of diesel trucks, snowmobiles, and buses.

"This project is specifically looking at reducing the amount of petroleum used down in Antarctica," NREL Senior Task Leader Ted Sears said. "Transporting vehicle fuel to Antarctica is costly and resource intensive, and requires great planning as well. Managing energy use very carefully is critical because of potentially harmful effects on the environment."

The Polar Regions are pristine research environments and the National Science Foundation's (NSF) Office of Polar Programs is working with NREL and DOE to incorporate more renewable energy and energy efficiency practices into its current facilities. In fact, NSF and Raytheon Polar Services own one of the vehicles and DOE/NREL own the other.

"Each gallon of fuel NREL can demonstrate can be displaced with renewable energy will make a real difference," Sears said. "At this point, it looks promising given that two renewable resources—solar and wind—are already on 'the ice' and can be used to power vehicles. So, we've put two test electric utility vehicles down there, to see how they function.

"Of course, we'll be examining the power needs of any proposed McMurdo Station electric vehicle fleet to ensure it would not negatively impact the other power needs and operations at McMurdo. It may be that a mix of vehicle types, electric and conventional, is appropriate, depending on the operational needs at the facility."

Getting There Is Half the Battle

"E-ride's EXV2 was chosen mainly because of its truck frame and its design as a utility vehicle," said NREL Senior Mechanical Engineer Ian Baring-Gould, who leads the laboratory's work in polar environments.

Researchers thought these were the units that would best fit the kind of vehicle uses found in Antarctica where pickup trucks are currently the vehicle of choice. The e-ride EXV2 is designed as a two-person vehicle with a truck-like bed and larger utility-style

NREL is leading a project that will test two EVs at McMurdo Station. The goal is to reduce dependence on imported fuels in Antarctica and validate the performance of the vehicles in extreme conditions. *Photo by Dennis Schroeder, NREL/PIX 18308*

tires for use on dirt roads. It has a maximum speed of 25 mph under "normal" driving conditions and uses an array of lead-acid batteries. For deployment to Antarctica, the EVs were outfitted with insulation for the batteries as well as battery heaters.

NREL worked closely with NSF and Raytheon Polar Services during the selection and manufacturing process. But, the work really started once the EVs made it to NREL's campus in Golden, Colo.

"We did some initial testing at NREL using a cold cell and dropped the temp to -9°F while the EVs were on a dynamometer," Sears said. "We saw that the vehicles function as we expected, and were able to capture data during cold temps."

Once the EVs were outfitted with initial data logging equipment, NREL took the vehicles to Raytheon to make sure the data loggers could communicate wirelessly with the NSF and Raytheon servers and get information back to NREL. From there, it was off to California via flatbed truck. These EVs cannot be driven on the highway because their top speed is only 25 mph. Once in sunny California, the EVs were put on a boat to Christchurch, New Zealand, and from there, a transport plane to McMurdo. The e-ride's plane landed on the ice in February 2011, on one of the last flights in before the harsh winter season hit.

"I love the photos from when the vehicles were unloaded in Antarctica," Sears said. "They just look to me like they are cringing as their tires hit the ice going, 'I don't know about this.'"

Working on 'The Ice'

After the long haul to Antarctica, the EVs are now getting used on a daily basis.

"They've been there for over a month now and are working, but we are heading into the bad weather now and we'll see how these vehicles do," Sears said. "Even if they are only good in the summer months, we would be happy with learning this and with the associated amount of petroleum savings."

In just over a month, the EVs have been driven more than 70 hours and logged nearly 140 miles. The data collection will continue for at least one year, capturing data during the most brutally cold months and the more "mild" summer months. The main concern as the Antarctic summer fades into winter is—how well will the batteries hold up?

> "It may be that a mix of vehicle types, electric and conventional, is appropriate, depending on the operational needs at the facility."
>
> **—TED SEARS,** *NREL Senior Task Leader*

"Empirical data on the capability of the vehicle batteries in such cold is critical," Sears said. "As a result, we are trying to learn everything we can about how the vehicle systems operate and respond in the extreme cold. Despite the vehicles being equipped with battery warming devices, there are still going to be limitations on their capabilities."

Not only in Antarctica but around the world, there are many remote locations looking at renewables to reduce fuel use. "That is one of the prime reasons we are testing this in McMurdo," Baring-Gould said. "In this case we are looking at EVs for McMurdo, but there is a huge market out there from rural communities in Alaska to islands in the Pacific that need to look at the transportation sector and how EVs can play a continuing role in their ability to reduce dependency on imported fuels."

In his recent State of the Union address, President Barack Obama called for putting one million EVs on the road by 2015. "These may not be the exact roads he was thinking of, but nonetheless, we are taking new technology and deploying it," Sears said. "This project really offers NREL a significant opportunity to increase the visibility of small electric vehicles, expand our experience with them, and validate the performance of the vehicles in extreme conditions."

—Heather Lammers (April 26, 2011)

Best for Batteries: Not Too Hot, Not Too Cold

With average U.S. gasoline prices approaching $4 a gallon, drivers and automakers are thinking electric. Previously steered in this direction by concerns about pollution and dependence on foreign oil, consumer interest in electric-drive cars continues to surge. But before Americans are able to flip the switch from gasoline to electricity, automakers need batteries for the next generation of electric vehicles that can deliver the range, performance, reliability, and safety drivers expect.

The Large-Volume Battery Calorimeter (LVBC) is a crucial tool to help put these new automobiles on the road. Unveiled last year by the U.S. Department of Energy's National Renewable Energy Laboratory (NREL), the LVBC is designed to precisely measure the heat generated by batteries for electric-drive vehicles, analyze temperature's effects on systems, and help pinpoint the ways to manage battery temperatures for the best performance and maximum life. The Vehicle Technologies Program at the U.S. Department of Energy supported the development and fabrication of the LVBC for advancing battery technologies for advanced vehicles.

To make electric-drive vehicles that are attractive to consumers, the batteries that power those cars need to be affordable, high-performing, long-lasting, and operate at maximum efficiency in a wide range of driving conditions and climates. The next generation of electric-drive cars and light trucks will be required to travel farther on electric power alone, placing greater energy demands on the vehicles' battery packs. As the packs get larger, regulating battery temperatures become even more important in helping improve performance, lifespan, safety, and affordability. The best tool automakers have for assessing thermal control and optimizing battery performance is NREL's LVBC.

> "NREL's large-volume battery calorimeter is the first system large enough and accurate enough to test the whole battery systems for electric vehicles."
>
> **—DR. SAID AL-HALLAJ,** *Chairman and CEO of AllCell*

NREL's Large-Volume Battery Calorimeter has the highest-capacity chamber in the world for testing of this kind. From the bottom clockwise are NREL researchers Matthew Keyser, Dirk Long, and John Ireland. *Photo by Dennis Schroeder, NREL/PIX 18912*

"NREL's Large-Volume Battery Calorimeter is the first system large enough and accurate enough to test the whole battery systems for electric vehicles," says Dr. Said Al-Hallaj, chairman and CEO of AllCell, a major battery integrator. "We strongly believe that this leading-edge instrument is critical in developing the battery management system of the next generation of electric vehicles."

"Larger and more advanced versions of the lithium ion battery technology that powers laptops are the next wave in energy storage for plug-in hybrid and all-electric vehicles. High temperatures shorten the life of lithium ion batteries, while cold temperatures diminish lithium ion batteries' power capabilities and hurt overall vehicle performance. NREL's LVBC is the only calorimeter capable of accurately quantifying the heat generation and efficiency of these lithium ion batteries," said NREL Principal Engineer Ahmad Pesaran, who leads the vehicle Energy Storage projects.

Greatest Volume and Accuracy

The largest and most-accurate device of its kind, the LVBC can determine the exact amount of heat generated by battery cells, modules, sub-packs, and even some full-size packs as they are charged and discharged. It combines a high volume test chamber and wide temperature range options with state-of-the-art thermal isolation and control, current load capabilities, and precision measurement.

In addition, the LVBC is the only calorimeter designed to test the liquid-cooled batteries found in the Ford Electric Focus, the Chevy Volt, and the Tesla Roadster. GM used an earlier NREL calorimeter to help create the Volt battery.

"We knew there was a need for this technology. Testing cells and smaller modules in lower-capacity calorimeters was only giving us—and car and battery manufacturers—part of the picture," said NREL Senior Engineer Matthew Keyser, who developed the LVBC.

Despite the LVBC's large size, its heat-flux measurements are extremely precise, recording heat rates as low as 15 milliwatts and heat inputs as low as 15 Joules—about the amount of energy released while rubbing your hands together. Achieving this degree of sensitivity in such a large volume required a number of design innovations, including superior thermal isolation and the ability to test batteries under realistic driving conditions. The instrument is able to determine heat levels and energy efficiency within plus or minus 2% of actual values.

> "NREL's LVBC is the only calorimeter capable of accurately quantifying the heat generation and efficiency of these lithium ion batteries."
>
> **—AHMAD PESARAN,** *NREL Principal Engineer*

Members of the U.S. Advanced Battery Consortium, which includes Chrysler, Ford, and GM, realize that in-depth analysis of battery heat management issues can help automakers troubleshoot thermal issues and engineer systems capable of maintaining batteries within the ideal temperature range. The comprehensive and accurate information that the LVBC provides will be critical to the automotive and battery industry as new advanced batteries and thermal management systems are optimized for the next generation of electric-drive vehicles. NREL is testing batteries from a number of battery developers including A123 Systems, LGChem-CPI, and Johnson Control Saft in the LVBC.

By addressing thermal management issues in the design stage, before these vehicles hit American roadways, carmakers are more likely to offer consumers affordable, high-performance options to gasoline-powered automobiles—and relief from high prices at the pump.

—Anya Breitenbach and Julia Thomas (May 13, 2011)

Low Emission Cars Under NREL's Microscope

Cars that plug into solar panels for electricity or run on hydrogen may sound like something found only on the pages of science fiction novels, but engineers at the U.S. Department of Energy's (DOE) National Renewable Energy Laboratory (NREL) are driving these futuristic vehicles today.

Recently, NREL engineers were able to spend six weeks kicking the tires on a Kia Borrego Hydrogen Fuel Cell Electric Vehicle (FCEV) and ongoing agreements with Toyota and Mitsubishi mean a plug-in Prius and Mitsubishi i MiEV electric vehicle will be demonstrated and tested at NREL for the foreseeable future.

"DOE wants people to see that these vehicles are not just drawings on some designer's table," NREL Vehicle Systems Engineer Mike Simpson said. "These technologies are practical, real, and getting out into the marketplace."

Simpson is leading a DOE/NREL program to acquire advanced technology vehicles to support research at NREL with a secondary goal of displaying and demonstrating the technologies to consumers. "We have displayed all of these vehicles at public events this summer to help consumers see how all of these technologies can meet the needs of today's drivers," Simpson said.

Vehicles in NREL's fleet feature promising technologies designed to increase efficiency, reduce emissions, and use renewable resources without sacrificing safety or comfort.

NREL engineers collect real-world data on these vehicles to evaluate their performance. The research findings are made available to vehicle manufacturers along with the DOE and other national laboratories. In addition to the Prius and i MiEV, NREL has evaluated a Mercedes-Benz A-Class F-Cell vehicle and is actively looking to expand.

"We are currently working with a number of manufacturers to bring more plug-in and fuel call vehicles to NREL," Simpson said. "We are bringing them in to support testing in areas unique to NREL like grid integration and thermal effects on comfort and batteries."

Kia's Quick Test Run

While the i MiEV and Prius are under a longer-term lease and loan to NREL, the lab had an opportunity to evaluate the Kia Borrego FCEV, a vehicle that features one of the most advanced hydrogen fuel cell systems being tested.

"The benefit of having the Kia at NREL was direct, hands-on exposure to the technology," said NREL Senior Engineer Keith Wipke. "NREL staff work on all aspects of the hydrogen cycle—from production to storage to delivery—and having the vehicle at the lab lets them see one of the key applications for the hydrogen technology."

According to Wipke, Kia is scaling up facilities to support FCEV production in 2014–2015, and the automaker is representative of several other car companies that are actively pursuing adding hydrogen fuel cell vehicles to their consumer offerings.

Generations of car enthusiasts experience cars of the not-so-distant-future as NREL displayed alternative energy vehicle technologies including a plug-in Toyota Prius (left) and an electric Mitsubishi i MiEV (right) at summer events in Colorado in 2011. *Photo by Dennis Schroeder, NREL/PIX 19470*

"Part of this step is to demonstrate the power train technology to make sure it works in all different climates and that they haven't overlooked anything," said Wipke.

"By partnering with NREL during this evaluation period, Kia's engineers were able to obtain valuable data about the FCEV's performance from multiple users who accumulated test mileage in various driving situations and conditions," said Orth Hedrick, director, Product Planning, Kia Motors America. "We also received valuable feedback from NREL engineers regarding the development and tuning of the fuel cell."

The Kia FCEV has a 115 kw-fuel cell stack, which is housed under the floor of the passenger compartment. Rather than using gasoline or electricity, the SUV-sized vehicle is fueled with compressed hydrogen at 700 bar and has a range of 466 miles per fill-up, which is the equivalent of 59 mpg. The demonstration vehicle had a 110 kw traction motor 100 kw ultracapacitor rather than a battery.

"This vehicle was unique because it had something I've never experienced, which is an ultracapacitor instead of a battery," Wipke said. "It seems to be very powerful, with great pick up."

Wipke sees the hydrogen fuel cell vehicles potentially appealing to consumers whose needs cannot fully be met by battery electric cars, but who want a low carbon footprint. "One of the key things about the impact of hydrogen technology is that these are full-function vehicles with no limitations on range or refueling rate so they are a direct replacement for any vehicle. For instance, if you drive a full sized SUV and pull a boat up into the mountains, you can do that with this technology and you can't with current battery-only vehicles, which are more geared toward city driving."

NREL Makes Emissions a Zero Sum Game

NREL engineers are able to boast a truly zero emissions fuel cycle for the Kia FCEV's hydrogen fuel. The Borrego was fueled with hydrogen made from wind and solar energy as part of the Wind2H2 project where wind turbines and solar panels are linked to electrolyzers, which pass the renewably-generated electricity through water to split it into hydrogen and oxygen. The hydrogen can then be stored and used later to generate electricity from a fuel cell.

> "There are going to be next generation improvements in the fuel cell and the production pathways and storage, which means there will continue to be research into hydrogen fuel cell technology after products start coming on the market."
>
> —**KEITH WIPKE,** *NREL Senior Engineer*

"Having a FCEV vehicle here helps people draw the connection and say, 'I get it.' We have a vehicle technology today where you can make the fuel onsite using renewables, where the process is zero emissions."

The manufacturer also has an eye toward the future of emissions friendly vehicles.

"Kia is one of the auto industry's current fuel economy leaders and we are actively researching and developing several advanced powertrain solutions designed to increase efficiency and reduce emissions," Hedrick said. "While there is still much that needs to be done in terms of fuel cell electric vehicle development, partnerships like the one with the NREL continue to help Kia make significant strides in the area of powertrain development and will help the brand achieve longer term objectives of reducing fleet emissions while meeting or exceeding more stringent government requirements."

As more and more advanced vehicles hit the market, there will still be a role for NREL and other DOE labs to help manufacturers refine and improve their products.

"There are going to be next generation improvements in the fuel cell and the production pathways and storage, which means there will continue to be research into hydrogen fuel cell technology after products start coming on the market," Wipke said. "Hybrid vehicles, such as the Prius, have been on the market for 10 years in this country and there is still a very active Vehicle Technologies program at DOE and NREL looking into improving hybrids and batteries."

—Heather Lammers (August 17, 2011)

Alternative Fuels Data Center Keeps Pace

How things can change. The year is 1991. While working at CERN Labs, Tim Berners-Lee releases information on the Internet describing his invention, the World Wide Web, and WWW debuts as a publicly available Internet service. To help further set the stage for this story, consider:

- In 1991, the 14.4 kbps modem was introduced.
- Word was not the leader for creating documents—it was WordPerfect.
- The Macintosh (Apple) PowerBook was announced. The screen was a 640 X 400 monochrome LCD panel. Hard drive options were 20MB, 40MB, or 80MB. Cost topped out at $4,599.
- At NREL, the Alternative Fuels and Advanced Vehicles Data Center began.

The U.S. Department of Energy's (DOE) Clean Cities program and the National Renewable Energy Laboratory (NREL) celebrated the 20th anniversary of the Alternative Fuels and Advanced Vehicles Data Center (AFDC) in 2011, which is today, an abundant online resource for alternative transportation information. The AFDC was created in 1991 as a repository for alternative fuel vehicle performance data in response to the Alternative Motor Fuels Act (AMFA) of 1988. AMFA required DOE to start testing vehicles that run on alternative fuels such as ethanol, natural gas, and propane, and to make the results available to the public.

Low Tech Beginnings

"Some of the initial tools for the AFDC, like the station locator, were literally piles of paper on my desk," NREL Senior Project Leader Wendy Dafoe recalls. "I had to put that information into a spreadsheet and call and confirm that it was correct. That, along with some big data dumps from industry, started out what is the station locator now. There was no Web tool and no intention for us to push it out. We just wanted to know what was out there."

Early on, the AFDC functioned as a dial-up computer network that allowed users to submit data and access results. Users could also order technical reports and other documents via a telephone hotline.

"We had no idea what it would become," Dafoe added. "But, NREL staff Kevin O'Connor and Bob Wooley had a vision that we needed to track and store data over time, and transform it into useful and useable information for fleets. Now, it's a one-of-a-kind, publicly accessible website that provides robust, intuitive tools, data, and information about alternative fuels and advanced vehicles."

The AFDC used an ORACLE Relational Data Base Management System along with a software package capable of providing statistical, graphic, and text information to users. Then, as technol-

A plug in hybrid electric vehicle leaves the NREL campus; drivers can find convenient charging stations using data from the AFDC's website or mobile station locator. *Photo by Dennis Schroeder, NREL/PIX 19699*

ogy advances continued to accelerate, NREL launched the first AFDC website in 1995.

"We had the right group of people to put the building blocks in place," Dafoe said. "We didn't get ahead of ourselves. We understood the next step was identifying available vehicles or talking about fuel myths. Today, the building blocks are Web tools that fleet managers can use to see the cost of vehicles and what the incentives are."

> "It's a one-of-a-kind, publicly accessible website that provides robust, intuitive tools, data, and information about alternative fuels and advanced vehicles."
>
> —**WENDY DAFOE,** *NREL Senior Project Leader*

Technology Changes

Now the mobile device that many of us carry in our pockets has computing power that greatly outpaces the desktop computers of the 1990s. What is now your phone can browse a multimedia driven World Wide Web, take photos, and give you turn-by-turn directions to a meeting across town using global positioning satellites.

The AFDC website, as well as the data behind it, has expanded over the years, establishing the AFDC as an indispensable source of information for fleets, fuel providers, policymakers, consumers, and others seeking to reduce petroleum use in transportation.

"Now the Clean Cities program and the AFDC are growing into deployment anytime, anywhere," NREL project manager Johanna Levene said. "If you've got your mobile device, you can find the alternative fuel station that's closest to you."

Although pushing out mobile applications is a current focus for NREL staff, they are also working to educate buyers on picking the right fit for their needs.

"Alternative fuels are just like any other advanced technology, they can be the right solutions in the right place," Levene said. "We want people to have access to information and data that allows them to make informed buying decisions that reduce petroleum dependence. The information on the AFDC can arm buyers with information about light and heavy duty vehicles for their application and the fuel choices for those vehicles. It can help them understand the cost of infrastructure and what the emissions impacts of their choices are.

Data Sharing—Some Things Never Change

From the beginning, the AFDC was all about collecting and sharing data. It still is, just the names of entities using AFDC data—TomTom and MapQuest—are impressive. "We know that the information in the AFDC gets used by vehicle manufacturers, states, and non-governmental organizations in their research and on their Websites," Dafoe said.

In fact, the data requests have snowballed in recent years and NREL staff realized they needed to do something to automate some of the process. Last year, the staff added a data download feature on the AFDC website, which lets users download a flat file of station information. Toward the end of 2011, the team launched a new NREL subsite that provides data feeds for computer programmers to use as part of their mobile and Web applications. The first data set to be offered through the service is a comprehensive, nationwide list of alternative vehicle fueling station locations from the AFDC. Developers are now able to retrieve the data through a Web services API (application programming interface).

"The cool thing about this type of Web service is the user doesn't have to store or maintain the data," Levene said. "The second we update it, it is updated on their website."

The obvious question is, "Where will the AFDC be in another 20 years?" Given how rapidly technology has changed in its first 20 years, staffers were hesitant to speculate, but AFDC Manager Trish Cozart did put the past 20 years into perspective. "The AFDC has stood the test of time. Celebrating the 20th anniversary is really a tribute to the ability of NREL and DOE to continually focus on delivering quality data and content and, at the same time, be forward thinking about the technologies available to deliver that content to the right people at the right time. We're poised and ready to meet the changing needs of the alternative fuel marketplace and take the AFDC out to the next generation," Cozart said.

—Heather Lammers (October 18, 2011)

BIOMASS

Through biomass research, NREL is developing technologies to convert biomass—plant matter such as trees, grasses, agricultural residue, algae, and other biological material—to fuels. These biofuels will reduce our nation's dependence on foreign oil, improve our air quality, and support rural economies. *Photo by Dennis Schroeder, NREL/PIX 19549*

Searching for a Diamond in the Muck

Most people scorn algae as pond scum, but Lee Elliott embraces the slime, captures it, filters it, and analyzes it for its potential to grow like weeds and fuel the airplanes and automobiles of tomorrow.

Elliott is a 21st century prospector. His Eldorado isn't gold, but that elusive briny pond or brackish puddle that houses an algal species that both is rife with oil and multiplies quickly.

Elliott, a graduate student at the Colorado School of Mines and a researcher at the U.S. Department of Energy's National Renewable Energy Laboratory (NREL), logged 3,500 miles last year driving his car across the West in search of promising algae.

Eight times, his tires went flat in the deserts of the Southwest while searching for saline lakes. But it wasn't until last month, as he was looking for a few last samples close by NREL's Golden, Colo., campus, that he had an encounter with a prairie rattlesnake—a four-foot diamondback.

"The rattlesnake was a surprise," Elliott said. "I'm always on the watch for them when I'm sampling, and this is the time of year for rattlesnakes in Colorado. They're out there for their last bit of sun. It just happened to be sitting right where I wanted to be."

With nonchalance, he grabbed a six-foot tree limb, picked up the rattler, and deposited the snake out of harm's way.

Following Back Roads to Brackish Waters, Promising Algae

When he's not transplanting rattlers, Elliott searches for algae everywhere: in rivers, ponds, lakes and puddles, in red, green, purple, brown or orange muck. Along with road maps, he carries a portable lab, a large Tupperware box with a water quality meter, several filters, and other sampling equipment.

He dips his sampler into dirty water, measures its salinity and pH, and filters it to remove debris and organisms that might graze on the algae. He pinpoints the location via geo-positioning satellite.

City and suburban dwellers need a lot of fresh water, and farms, trees, plants, and livestock need much of the rest. But microalgae can grow in brackish, saline, or brine water that can't be used by humans, farms, ranches, or nurseries. So, microalgae have a clear advantage over other biofuel crops in that they can use this marginal water source—including all the water in the oceans.

Not only do algae grow in unlikely settings, but their ability to convert the light they receive into biomass has the potential to outperform that of land plants. Trees, grasses and shrubs typically are not very efficient in capturing and converting the sun's energy into biomass, but some algae are believed to be capable of much higher efficiencies, with some scientists thinking ideal

Balancing on a board, NREL researcher Lee Elliott dips into a marshy creek in Golden, Colo., to grab samples of algae. *Photo by Dennis Schroeder, NREL/PIX 18511*

strains may be able to approach the maximum theoretical photosynthetic efficiency under the right conditions.

To help increase the nation's energy security and to ease pollution, President Obama has called for the production of 36 billion gallons of biofuels by 2022. This fall, the U.S. House of Representatives passed the Algae-based Renewable Fuel Promotion Act which would put algae on tax parity with cellulosic biofuels—both qualifying for a $1.01 per gallon production tax credit and a 50% bonus depreciation for biofuel plant property.

The search for fast-growing, oil-producing algae is made more difficult by the fact that algae tend to produce oily lipids when they're under stress—but that same stress tends to inhibit their growth.

So, Elliott searches widely, looking for sites with a variety of water chemistry, ranging from fresh water to saturated brine solutions.

The Great Salt Lake, for example, is several times as salty as sea water, depending on the water levels, yet many species of algae thrive there.

Elliott found algae growing in evaporation basins in Nevada where the salinity was so high it was on the verge of precipitation.

"I got a very good idea of how much salt there is in the southwest," Elliott said. "There is a lot of barren wasteland out there where you can dig a basin, fill it with salty water from a brackish, saline, or brine aquifer, put some algae in and they can grow just fine."

The Algae Advantage: Easy Conversion to Fuels

Microalgae produce chemicals that can be converted readily to fungible fuels that seamlessly integrate into today's fuel-making process. The algae use photosynthesis to turn carbon dioxide into organic matter, establishing a carbon-neutral fuel source.

Microalgae can be used as biological solar cells to capture the energy in sunlight and fix inorganic carbon into renewable, energy-rich lipids that can be converted readily to biodiesel. That's why the major oil companies are pumping money into projects like Elliott's. They understand the potential for microalgae to make a dent in the current demand for liquid transportation fuels, which is at 130 billion gallons a year in the United States alone.

> "There are 40,000 described species, with the potential for hundreds of thousands, if not millions, of different types of algae out there."
>
> —**LEE ELLIOTT,** *NREL Researcher*

But the best way to reduce production cost is to maximize lipid productivity. And some researchers are betting that the best way to do that is to identify native strains that already possess the ideal feedstock traits that make them commercially viable.

So, in 2008, the Colorado Center for Biorefining and Biofuels (C2B2) began funding a collaboration between NREL and the Colorado School of Mines to establish a culture collection of up to 500 unique strains of microalgae, each measured for lipid production and growth potential.

And that's when Elliott, a doctoral candidate at CSM, went to work.

In 2008, he traveled 2,800 miles through Colorado, New Mexico, Arizona, and Utah, collected 45 raw water samples and directly isolated the algae in the samples using a cell sorter.

During his 2009 trip, he went as far west as Nevada and California, and as far south as Nogales, Ariz., seeking more diversity, focusing on samples from more conductive or saline sites.

He determined the route after a literature search for saline bodies of water in the western United States. He visited most of the sites listed in research paper on diatom diversity from the early 1990s that described more 30 sites with this peculiar type of algae that have cell walls completely made of silica, which is essentially glass.

"I'm just looking for diversity," Elliott said. "There are 40,000 described species, with the potential for hundreds of thousands, if not millions, of different types of algae out there."

In the Light Room, a Colorful Collection of Promising Algae

Once back in the lab, Elliott began isolating and screening the algae. Initially, he adds chemically diverse growth media as a tool for selection of robust and diverse strains that can later be isolated.

Working with Elliott are the principal investigators Philip Pienkos of NREL and Matt Posewitz of Colorado School of Mines; research participant Corinne Feehan; NREL scientist Lieve Laurens; and NREL research technician Nick Sweeney.

The researchers stain the algae samples with a dye which, when a blue light is shined on them, turns the lipids a fluorescent green while chlorophyll naturally appears as a fluorescent red. "They light up like Christmas trees," Elliott said. The blue light is generated by lasers in a confocal microscope and in a Fluorescent-Activated Cell Sorter, or FACS. The FACS analyzes algae based on the levels of fluorescence, which are then used for sorting algal cells. Inside the FACS, the sample is injected into a fluid stream that separates the cells, allowing single-cell resolution. Interrogated with laser light, the algae fluoresce, and that level of fluorescence is measured and then use for sorting in real time.

Upstairs, in the newly constructed Algal Research Laboratory, some samples hang in photobioreactor bags, while other strains circulate through a shallow raceway pond in the adjoining greenhouse, its current propelled by a paddle wheel. Elliott will use these systems to test the most promising strains at larger scale over the next year. But the whole collection is a valuable source of biodiversity, so all samples are being frozen in liquid nitrogen so they can be preserved for long term storage and analyzed later.

The goal is to screen the collection, now numbering 360 isolates, and determine the five best performers. The strains best at combining fast growth and enhanced lipid production will likely be developed further as promising biofuel feedstock.

Some scientists are talking about harvesting microalgae for fuel from cities' waste-water treatment plants, where they proliferate to the frustration of waste water engineers because the organisms foul treatment tanks. In effect the algae could be used for additional nutrient recovery from secondary waste water that is currently discharged into the nation's river systems. This would be hugely beneficial to the aquatic ecosystems that are currently being deluged with excessive nutrients, such as the Mississippi delta where an extensive dead zone extends for thousands of miles into the Gulf of Mexico every summer initiated by massive algal blooms that thrive on all the nutrients released into the water upstream.

> "The commercially viable solution will likely involve not one, but several production scenarios."
>
> —**LEE ELLIOTT,** *NREL Researcher*

Scientists also think that the desert southwest has the best growing conditions to build huge algae farms, to take advantage of the abundance of sunlight. To produce something cost effective enough to be competitive with gasoline or petroleum diesel will require highly economical production facilities that use waste nutrients and are capable of nutrient recycling, use natural rather than artificial light, and use economical harvesting and fuel conversion processes. Marketing the co-products, such as selling the leftover biomass as animal feed, also is essential for a positive cash flow.

"The commercially viable solution will likely involve not one, but several production scenarios, probably most using very shallow open ponds, maybe 20 centimeters in depth (8 inches) to allow for maximum light penetration," Elliott said. "You'd have a big paddle wheel churning the pond—and dividers, so the algae go in a big loop." The tiny energy producers would churn, harvest the light-energy of the sun, proliferating and making oils and other valuable co-products right there under the desert sun.

—Bill Scanlon (January 14, 2011)

Researchers stain algae samples with a dye which, when a blue light shines on them, turns the lipids a fluorescent green while chlorophyll naturally appears as a fluorescent red. *Photo by Dennis Schroeder, NREL/PIX 18514*

NREL Expands Biofuels Partnerships

The scenario for your business dream plays out like this. You have an idea to make a fuel from biomass using a biochemical conversion processes. You and your investors have completed bench-scale tests of your process, but now it is time to take it to the next level and process up to one ton of dry biomass a day. However, in a tough economy you don't want to build your own demonstration facility, but still need somewhere to test it. It turns out that "somewhere" is located at the U.S. Department of Energy's (DOE) National Renewable Energy Laboratory (NREL).

This past year, NREL completed construction on phase one of its Integrated Biorefinery Research Facility (IBRF) and phase two is currently underway. The idea for the IBRF is deliberate—a place for NREL and industry to test demonstration-scale projects and speed the commercialization of biofuels.

"The IBRF is designed specifically to help industry scale up their technology," NREL Team Leader for Partnership Development John Ashworth said. "We have created an empty bay in the facility so someone can bring in their own pretreatment reactor or other equipment required for biochemical biomass conversion. Companies can use part of our system or they can use their own technology and we can run it in parallel with ours. That way, they can see if their system is better than ours."

NREL's creation is a $33.5 million pilot plant and facility upgrade capable of supporting a variety of advanced biofuels projects. The IBRF boasts a 27,000 square foot high bay with one area where industry partners can bring in and test equipment, as well as upgraded laboratories, additional office space, and access to NREL expertise. The IBRF also features enhancements to NREL's existing biochemical pilot plant which now includes:

- Three parallel front-end process trains for pretreatment through enzymatic hydrolysis
- The ability to do research on pretreatment using a range of pH conditions
- The capability to handle high solids concentrations through enzymatic hydrolysis.

"Industry partners can come in and try whatever they might have in mind from a very mild pretreatment to a very strong pretreatment and the system is set up for that," Ashworth said. "The high solid enzymatic hydrolysis reactors sit directly beneath the pretreatment reactors. All of this allows us to really push the limits of how you can use the system and still get to sugars."

NREL's pilot plant has been serving the lab for more than a decade and researchers have made significant discoveries along the way. But, putting that new-found knowledge to the test was becoming a challenge. "Our existing pilot plant was at capacity, we no longer had room to add equipment," NREL Manager for Bioprocess Integration R&D Dan Schell said. "We've learned a lot over the years

NREL's Daniel Schell stands in the open high bay near an acid impregnator in the IBRF. The new facility accommodates biofuels pretreatment with alkalis as well as various dilute acids. *Photo by Dennis Schroeder, NREL/PIX 18534*

but didn't have the capacity to expand the pilot plant and add more equipment or newer cost-effective technology."

Flexible Facility Welcomes Many Treatments

Taking that as a lesson learned, flexibility has become a key word when NREL staff discuss the capabilities of the IBRF.

"We looked at how we could upgrade the pretreatment systems to meet current and future needs and test a wider range of reaction conditions," Schell added. "The new system can operate at residence times as low as several minutes up to two hours. This gives us the ability to support a wide range of pretreatment catalyst options, including dilute acid and alkali-based treatments."

Researchers also can use the IBRF to conduct high solid enzymatic hydrolysis. The ability to test biochemical processes using high solids is a key metric for increasing biofuel concentrations and decreasing production costs.

"In the IBRF, we have two large batch mixers that perform high solid enzymatic hydrolysis," Schell said. "Once we liquefy the biomass in the high solids reactors, we can pump it into a conventional stirred tank reactor and finish converting biomass to sugars. This gives us the capability to perform enzymatic hydrolysis at commercially relevant solids levels."

Although research in cellulosic ethanol derived from corn stover—the stalks, leaves, and cobs—is a focus for research at NREL, the new capabilities of the IBRF open the doors to all types of fuels research. "The IBRF is not restricted to one end fuel," Ashworth said. "The technology here will work just fine if someone wants to make butanol or take lignocellulose and go to jet fuel or diesel. All of these technologies on the biochemical side use pretty much the same front-end pretreatment and enzymatic hydrolysis equipment."

NREL Does Some Extra Investigation

Working with DOE's Office of Biomass Program, the IBRF will help NREL researchers gather data that demonstrates the achievement of U.S. goals for cellulosic ethanol cost targets. It is now a race against the clock with the goal for cellulosic ethanol to be cost competitive with corn grain ethanol by 2012. Longer-term goals outlined in the Energy Independence and Security Act of 2007 (EISA) require that the United States use 36 billion gallons of renewable fuels by 2022, all in an effort to offset U.S. dependence on foreign oil.

> "The IBRF is set up to be the facility where you can prove your technology at an engineering or demonstration scale before getting the investment capital to build a large factory."
>
> —**JOHN ASHWORTH,** *NREL Team Leader for Partnership Development*

"The idea is for us to facilitate industry success by showing that it is possible to achieve these conversion goals, and that, with the right circumstances, industry can have more confidence in their ability to commercialize the technology," Schell said.

Right now many along the path to commercialization are focusing on the big three operation units—pretreatment, enzymatic hydrolysis, and fermentation. According to Schell, there are other issues that NREL is beginning to tackle, including looking at the liquid effluent that comes out of the various biochemical conversion processes. "We also are facilitating success of industry by being able to explore the less glamorous research issues that may have a huge impact on process economics," Schell said.

The advantage to NREL doing some of the nitty gritty work at the IBRF is that the lab can provide high-level information to all industry players letting them know what's in a possible waste stream, what can be done to treat it, and the costs.

"Industry can take that initial information and see how it will impact their economics," Schell said. "It's an issue that people ultimately are going to be highly concerned about but, right now, they are focused on understanding and improving performance of the major unit operations."

"I think the important thing about the IBRF is to understand that government is never going to commercialize this technology," Ashworth added. "It is a transition from a bench scale system which is cheap to run. Then the IBRF is set up to be the facility where you can prove your technology at an engineering or demonstration scale before getting the investment capital to build a large factory."

—Heather Lammers (February 28, 2011)

Farm Fields Could Yield Jet Fuel of the Future

Ever since the Wright brothers took their historic flight at Kitty Hawk, the aviation industry has been looking for ways to fly further faster. Now with the help of the U.S. Department of Energy (DOE), Virent, Inc., and DOE's National Renewable Energy Laboratory (NREL), planes may soon take to the skies using less petroleum.

In June, DOE announced an award of up to $13.4 million dollars to Virent and its partners to develop a process to cost effectively convert cellulosic biomass—in this case the non-edible parts of corn—into jet fuel.

"Projects such as these are helping us to diversify our energy portfolio and decrease our dependence on foreign oil," said Energy Secretary Steven Chu at the announcement. "Together with our partners, the Department is working hard to expand the clean energy economy, creating jobs in America, and providing sustainable replacements for the fuels and products now provided primarily by petroleum."

"This is all about making drop-in fuels or infrastructure-compatible fuels," NREL Manager for Bioprocess R&D Richard Elander said. "These are fuels that are close, if not identical, to the same molecules that are in gasoline, diesel fuel, and jet fuel. They are compatible with our existing vehicles and infrastructure in terms of engines, fueling, and pipelines."

It's Not the Same Lignocellulosic Conversion

It is important to note that the end result of the combined NREL-to-Virent lignocellulosic conversion process is not ethanol. While ethanol is a reasonable substitute for gasoline, is not a substitute for jet fuel due to ethanol's lower energy density and other properties required for jet fuel.

"Rather than fermenting corn stover into ethanol, in this scenario, the biomass is appropriately deconstructed and then catalytically converted into energy dense hydrocarbon molecules that are indistinguishable from petroleum based jet fuel," Virent Senior Director for Feedstock Development Andrew Held said.

Idaho National Laboratory will provide the corn stover for the experiments. NREL will then use acid or other chemicals to pretreat and deconstruct the biomass, creating a new compound, or hydrolysate, containing sugars and other forms of soluble carbon.

"One of the interesting features of the Virent technology is, not only can they uses simple sugars, they can also use slightly longer chain sugars, plus they can also use some of the 'undesirable' products from when we over-treat the biomass," Elandar said.

Over-treating happens in the lingocellulosic conversion process because the biomass has to be broken down enough to get to the hard-to-reach sugars. The process is not perfect, so some of those sugars can be over-treated and become sugar degrada-

DOE announced in 2011 an award of up to $13.4 million dollars to Virent, NREL, and partners to develop a process to cost effectively convert cellulosic biomass into jet fuel. *Photo by Dennis Schroeder, NREL/PIX 19805*

tion products. According to Elander, "This particular process has the opportunity to use a wider range of sugars and other soluble carbon compounds that are generated in the deconstruction process than we've traditionally been able to, which is a good thing because it means potentially higher yields."

Virent will take the hydrolysates produced in NREL's Integrated Biorefinery Research Facility (IBRF) and use a proprietary catalytic conversion technology to make the final jet fuel. "We remove the oxygen to make the deconstructed biomass more amenable to further processing, ultimately turning the hydrolysates into the same hydrocarbons that make up ordinary jet fuel," Held said.

While NREL has an important role in the agreement in deconstructing the quantities of biomass needed for the project, the lab has two other equally important tasks. First, NREL will perform techno-economic analysis of the project to make sure it is financially feasible in the long run, and second, NREL will study the fundamentals properties of catalysts used in the process.

"One of the challenges that has to be demonstrated by Virent is the lifetime of their catalyst," Elander said. "The only way to prove that a catalyst will last a long time is to run it for a long time. In order to run it for a long time, they are going to need a large quantity of deconstructed biomass to put through. NREL's IBRF will come into play to generate several tons for this process. We can then gauge how the catalyst behaves."

Looking for More Partners

NREL completed the second phase of a $33.5 million upgrade to the IBRF in late 2011. The facility is unique in its ability to handle a wide range of biomass feedstocks and pretreatment processes. Three parallel pretreatment processing trains allow for the testing of conversion processes using differing technologies under a wide range of conditions. The IBRF can handle high concentrations of solids in the pretreatment and enzymatic hydrolysis steps, a key factor in reducing costs. In addition, NREL has fuel testing capabilities and facilities and is a recognized leader in techno-economic and life cycle analyses.

"Virent has been very impressed with the technical capabilities of NREL as a result of our work with the National Advanced Biofuels Consortium," said Held. "When we were planning a project to put to together for this DOE award, we thought NREL's team would be a very good fit in terms of supplying us feedstock materials needed for Virent's catalytic conversion technology."

> "NREL and DOE are looking for more partners like Virent to help speed the integration of drop-in fuels into America's existing infrastructure."
>
> —**ANDREW HELD,** *Virent Senior Director for Feedstock Development*

NREL and DOE are looking for more partners like Virent to help speed the integration of drop-in fuels into America's existing infrastructure.

"I think the DOE is appropriately trying to encourage national labs and private parties to work together," Held said. "This project embodies top-notch experience and capability at a national lab with a promising company that is moving forward with innovative technology."

The IBRF's equipment and facilities, including 27,000 square feet of high bay space, can support unparallel research flexibility for industrial partners. Industry partners can bring in new technologies or processes into the IBRF to evaluate them in an integrated biorefinery setting. NREL has state-of-the-art laboratories that enhance its capabilities in fermentation, analytical chemistry, biomass conversion, molecular biology, and thermochemistry. For companies looking to collaborate with NREL, the pretreatment processing trains, fermentation capabilities, and new labs can be reconfigured to meet the project's needs.

"Ultimately, by leveraging the investments DOE has made in the IBRF and NREL, industry partners can develop biofuels and bioproduct conversion processes and technologies faster to enter markets sooner and more profitably," Elander said.

—Heather Lammers (November 8, 2011)

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/PIX 17290*

Retailers Checking 'Nice' on Energy Savings List

As the latest holiday shopping season ends, American retailers are gearing up for the next big event. Their brightly lit buildings will feature the latest sales and the energy needed to power eye-catching displays will be readily available.

Together, residential and commercial buildings account for a staggering 40% of energy use in the United States.

Although the power is always "on" for use in our country's buildings, the U.S. Department of Energy (DOE) and its National Renewable Energy Laboratory (NREL) are working with the nation's commercial building owners—from retailers to offices and warehouses—to discover new and innovative ways to reduce commercial building energy use.

DOE's Commercial Building Partnerships (CBP) program is a public/private, cost-shared program that pairs selected commercial building owners with DOE's national laboratories and private-sector technical experts. The goal is challenging, yet simple: new commercial construction is designed to consume at least 50% less energy than today's code allows (ANSI/ASHRAE/IES Standard 90.1-2004), and retrofits are designed to consume at least 30% less energy.

Teams representing NREL, three other DOE national laboratories, and private sector experts provide technical know-how throughout the project. Working with companies and their design teams, laboratory staff identify energy efficiency technologies across building systems—including building envelope, HVAC (heating ventilation and air conditioning), lighting, and miscellaneous electrical loads—all while using advanced energy modeling to achieve optimum whole-building performance.

The potential energy savings means a financial benefit for companies and consumers alike.

"An underlying idea with CBP is to demonstrate that energy efficiency makes good business sense," NREL Senior Engineer Greg Stark said. "We are helping the companies develop better stores that use significantly less energy than their current prototypes—and for roughly same cost as their current buildings."

Consumers also could see a benefit from the work NREL is doing under the CBP program. According to researchers, a typical retailer needs to make upwards of $50 in sales to cover every dollar it spends on energy costs. Saving energy means savings for customers.

NREL researchers are taking a whole-building approach when looking at energy saving solutions for CBP members. "We are not just looking at individual technologies," NREL Senior Mechanical Engineer Adam Hirsch said. "In order to hit these levels of energy savings, companies have to take a multi-pronged approach."

"We work very closely with their design and engineering teams to brainstorm new efficiency measures," added NREL Project Lead Michael Deru. "Due to our enhanced analysis capabilities, we are able to provide better energy analysis—especially when it comes to analyzing those measures all across the country."

NREL's Jennifer Scheib checks lighting levels as Rois Langner records them in the grocery section of the SuperTarget in Thornton, Colo. *Photo by Dennis Schroeder, NREL/PIX 19508*

Coming up with energy saving solutions that can be repeated throughout the United States is a key CBP goal.

"It's important for us to work with these large companies because they can replicate the lessons learned across their building portfolios," Deru said. "Walmart is the largest private consumer of electricity in the United States. And, because they are so big, they can make a large impact that ripples out into the industry by creating a marketplace for new energy efficient technologies."

Other opportunities abound to expand the program's reach. Current CBP projects represent more than 8 million square feet of commercial real estate. These same partners have committed to reproducing low-energy technologies and strategies throughout their building portfolios, which represent nearly 4 billion square feet of commercial real estate.

"These retailers are cooperating and sharing information across industry," Deru said. "This effort can motivate manufacturers to make higher efficiency equipment, especially if they know these big companies are waiting to buy it."

SuperTarget Retrofit Saves 2 Million kWh of Electricity

One retailer working with NREL is Target, the United States' second largest general merchandise retailer. "We worked with the engineering and design teams at Target to come up with a list of measures that would help them save energy at an existing Colorado store," Deru said. "In the end, we came up with solutions that exceeded the 30% energy savings goal for a retrofit project."

If the actual savings in the Thornton, Colo., SuperTarget match the modeling results, each year the store will save more than 2 million kilowatt hours (kWh) of electricity and 3,300 therms of natural gas. But, coming up with such significant energy savings was a challenge for the NREL team.

"Target is very advanced on their own, which made this a tough project," Deru said. "As an existing building approaches 30% savings, it gets harder to find options that make economic sense. Target already is aggressive with their lighting systems. However, we were able to include incremental lighting improvements such as LED lights in their walk-in coolers, daylighting in the front of the store, and removal of additional lights.

"On the HVAC and refrigeration systems, we studied several options, ultimately recommending exhaust energy recovery units, evaporative condensers, variable speed fan control, and high efficiency replacement units. We also took a close look at plug loads and helped to implement turning off the drink coolers at night and putting their cash registers in standby mode when not in use. Ultimately, we were able to add another 7–8% savings on their overall savings."

Walmart Balances Heat, Humidity, and Cooling

When the CBP program began a few years ago, it was mostly DOE and lab employees doing the work. Now, in an effort to share knowledge with industry, the teams are bringing in third-party design and engineering firms to help with projects. In this case, NREL, Stantec, and CTA Architects Engineers are working with Walmart to design a new store outside of Dallas.

"As part of CBP we are testing ideas that have been part of the NREL's Buildings work for a long time," Hirsch said. "We put out design guides with recommendations for hitting these advanced energy savings levels. Now, working with industry, we can test those out and see how they match up with the needs of companies' business models."

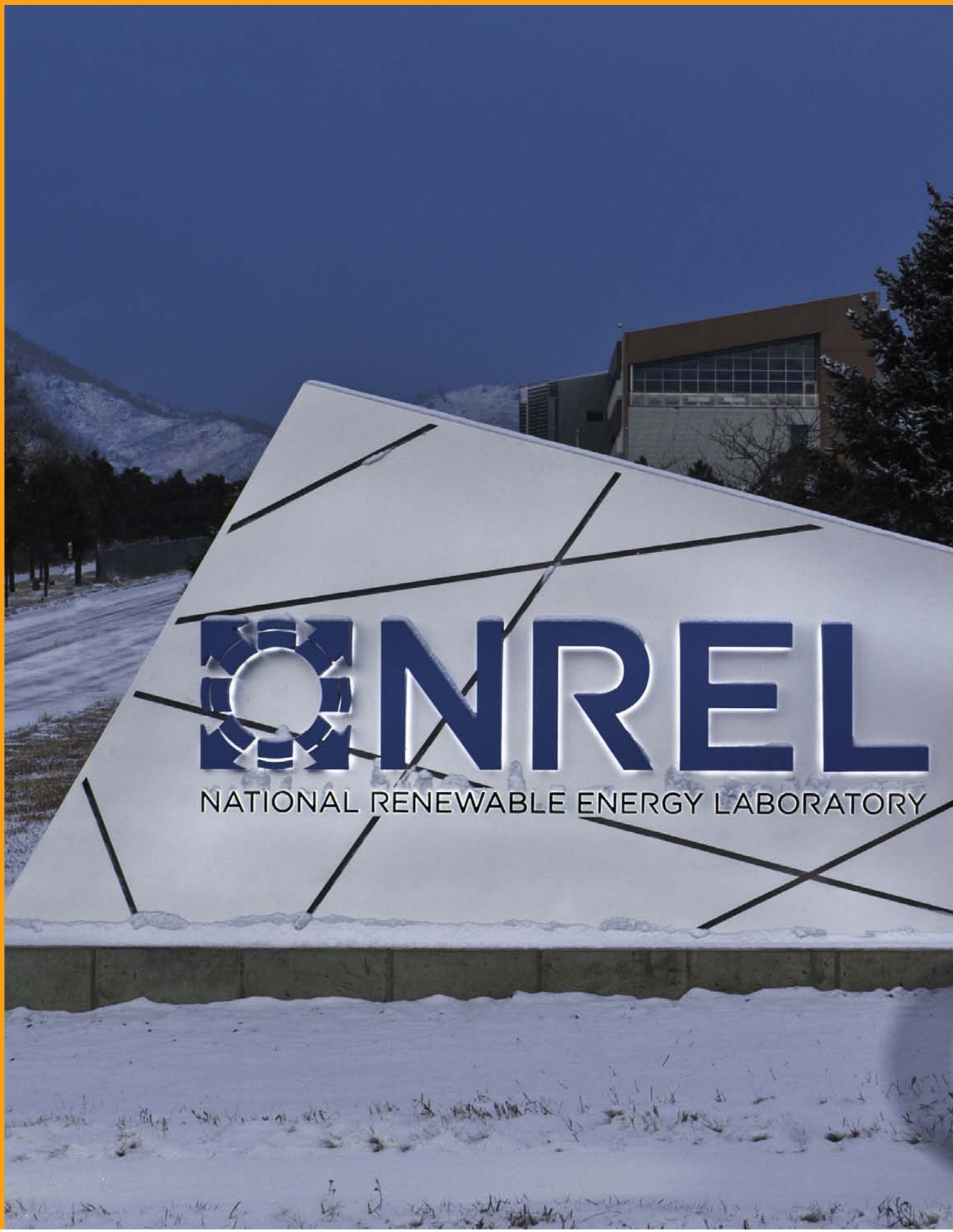
According to Stark, one difference with the Walmart project is the team is looking at balancing HVAC and refrigeration energy. This can be very important in a place like Dallas where the humidity is high. "Keeping humidity low helps reduce refrigeration energy—for example, it lessens the number of times you have to defrost the freezer case doors. However, reducing the humidity level takes HVAC energy. NREL, Stantec, and CTA worked closely with Walmart to find the humidity level that reduces the combined HVAC and refrigeration energy use and minimizes the overall energy use in the store."

"NREL clearly has done a lot of work on big retail projects, including looking at commercial refrigeration energy savings, which is a big part of one of the facilities we are currently looking at," added Stantec Associate David Okada.

According to Okada, other solutions on the table for the Walmart project include putting doors on as many of the refrigeration cases as possible and reducing lighting energy.

"It's been an enjoyable process to work with people who have pushed the envelope very far when it comes to energy savings," Okada said. "It's also great to be involved with pushing the savings to the next step."

—Heather Lammers (December 27, 2011)


NREL
NATIONAL RENEWABLE ENERGY LABORATORY

EDUCATION

NREL's involvement with the local community provides opportunities to learn about renewable energy, energy efficiency, and sustainability practices. *Photo by Dennis Schroeder, NREL/PIX 18298*

Colorado School Headed to Science Super Bowl

It's been said that it takes a village to raise a child. When it comes to fostering the hopes of America's budding scientists, the national laboratories can be a big part of that village. For more than two decades, the U.S. Department of Energy, its Golden Field Office, and the National Renewable Energy Laboratory (NREL) have been actively encouraging high school students to stretch their knowledge of math and science through the Colorado Science Bowl.

"It is amazing to see the high caliber of students that this event attracts every year," NREL Education Program Coordinator Linda Lung said. "What has been more exciting is seeing science bowl students participating in DOE's undergraduate research programs at NREL, and even coming to work at NREL after they receive degrees. Also, these past interns now participate as judges for the Science Bowl."

Fairview Grabs Its First Colorado Title

In early 2011, a team from Fairview High School (Boulder, Colo.) soundly overcame challenger Cheyenne Mountain High School (Colorado Springs , Colo.) by a score of 106 to 70 after correctly answering rapid-fire questions in physics, math, biology, astronomy, chemistry, anthropology, and earth sciences.

Victory was particularly sweet for team captain and high school senior Charles Xu. "I have a pretty extreme competitive streak. One thing that really got me wanting to win was that in the three previous years that I've done Science Bowl, we've never won a regional title outright. Three years ago, we went to the national competition when the first place team could not go—the satisfaction of winning one officially, with no cloud of doubt is a big impetus."

That competitive nature may have also played a hand in the team's preparation strategy.

"We did a ton of practicing—three hours a week—and then we ramped it up right before the competition," Xu said. "Math is a great strength of our team, but we also have a lot of people who are really fast on the buzzer."

Members of the winning Fairview High School team journeyed for the national title in Washington, D.C. on April 28, 2011.

> "It is amazing to see the high caliber of students that this event attracts every year."
>
> —**LINDA LUNG**, *NREL Education Program Coordinator*

The Fairview High School Science Bowl team holds up their trophy and celebrates after winning the 2011 Regional DOE Science Bowl held at Dakota Ridge High School. *Photo by Dennis Schroeder, NREL/PIX 18516*

Each year, more than 15,000 students across the United States vie for a trip to D.C. to compete at the National Science Bowl. Only 520 make it. Even the students who don't earn a trip to the finals agree that competing in the Science Bowl bolsters their understanding of the sciences.

"I can honestly say that I have learned so much in biology and chemistry because I have had to study for the Science Bowl," Sara Volz, a 10th grader with Cheyenne Mountain High School. "I feel good when I can buzz in and say, 'I totally know that.'"

That's high praise considering that in the 9th grade, Volz competed in the International Science and Engineering Fair with a project titled, "Enhancing Algae Biofuels: The Effects of Nitrogen Limitation and CO_2 Infusion on the Oil Yields of Nannochloropsis oculata."

Volz also noted that she's hoping to one day secure a college internship at NREL in bioenergy. It's this cycle of participation and future employment that NREL and DOE hope the Science Bowl competitions will foster.

"There's more to learning about science and engineering than you see on the 'Big Bang Theory,'" NREL Associate Laboratory Director Bob Hawsey added. "These students really rock, and NREL is focused on helping to nurture the best and the brightest of these, some of whom will be our future employees."

NREL Volunteers Don't Mind the 'Work'

It's seeing young women like Volz engaged in the sciences that inspires the NREL volunteer Katie Gaston, a chemical engineer in NREL's Thermochemical Pilot Plant. "I like to see the kids so excited about science. As a female engineer, I also like to set a good example for the students."

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 something I enjoyed so much that I couldn't imagine not being here this year," Cheryn Engebrecht, an engineer in the Residential Buildings Group said. "I wish I had this experience when I was in high school."

"These students really rock, and NREL is focused on helping to nurture the best and the brightest of these, some of whom will be our future employees."

—**BOB HAWSEY,** *NREL Associate Laboratory Director*

Even President Obama and the First Lady have caught the enthusiasm for the Science Bowl. Mikayla Nelson, a high school freshman from Billings, Mont., sat with First Lady Michelle Obama at the 2011 State of the Union Address. Nelson earned her place there by leading her team to a first place finish at the National Middle School Science Bowl for the design document of the team's solar car. The President also noted in his address to the country that, "We need to teach our kids that it's not just the winner of the Super Bowl who deserves to be celebrated, but the winner of the science fair…"

NREL leaders also hope that more adults will celebrate and mentor students to excel in math and sciences.

"I had great support from the adults in my life while in high school—from my parents and aunts and uncles, and from my teachers," Hawsey said. "NREL is forever linked to sustainable, clean energy systems, and we want to show our support for students who aspire to be our nation's next scientists and engineers."

—Heather Lammers with contributions from David Glickson. (February 8, 2011)

Solar and Hydrogen Car Races Spark Imaginations

The call to advance America's energy research and development continues to make headlines across the nation. From President Barack Obama's state of the union speech touting American innovation, to a recent visit to the U.S. Department of Energy's (DOE) National Renewable Energy Laboratory (NREL) by Vice President Joe Biden where he declared "Science is back," NREL and DOE are leading the charge to bring meaningful math and science activities to students through events such as the 2011 Junior Solar Sprint and Hydrogen Fuel Cell car competitions.

The Junior Solar Sprint and Hydrogen Fuel Cell car competitions are just a couple of the educational tools NREL and DOE provide to teachers to help them educate students in scientific principles with an atmosphere of fun and excitement.

According to NREL's Education Coordinator Linda Lung, one of NREL's major education goals is to get renewable energy technologies such as solar panels and hydrogen fuel cells into the hands of future engineers, scientists, and decision makers.

"This is a great engineering design challenge where students can see how changes in their car's transmission and gear ratios reflect in the car performance, exactly the same way engineers in the automobile industry would," Lung said. "I have witnessed the same schools come back year after year with better designs and faster cars. Teachers are so excited about this hands-on science competition, that they have incorporated the car competition as part of their science curriculum to meet the requirements of the state science standards."

The Colorado competition is organized by NREL's education program, which supports similar competitions in 26 states nationwide. It is designed to generate enthusiasm for science, technology, engineering, and math (STEM) skills.

"To get kids involved in math and sciences, I think we need to get away from memorizing terms and reading a textbook to getting the kids doing science and creating their own experiments," Eric Benson, team coach and teacher at The Logan School for Creative Learning, said. "NREL's solar and hydrogen car races are fun and kids can then see the relevance of math and science."

Today's renewable energy and energy efficiency research and development are only part of the new energy equation. Educating students, teachers, and consumers is the other key to finding new renewable ways to power our homes, businesses, and cars.

"Our core classroom teachers will nudge kids who haven't tried as many math and science courses into this program," Benson said. "For our winning hydrogen team, one team member was really into the science and the other got energized about it as she worked on the car. It was great to see."

Solar race judge and NREL employee David Ginley with winning hydrogen design team, "Larry the Leaf" members. The all-girls team also captured the Spirit Award for exhibiting good sportsmanship, including fairness and respectful behavior. *Photo by Dennis Schroeder, NREL/PIX 19195*

Girls Rule the Hydrogen Raceways

Girl power was a force to be reckoned with at the 2011 Hydrogen Fuel Cell car competitions at Dakota Ridge High School in Jefferson County, Colo. An all-girl team from The Logan School for Creative Learning took first place in the Hydrogen Fuel Cell Car Speed Race with a car covering 10 meters in 4.82 seconds.

If team spirit could be captured and converted to energy, then the all-girls team from Woodlands Academy could power a couple of city blocks with their enthusiasm. The team won best Hydrogen Fuel Cell Car Design and the coveted Spirit Award for good sportsmanship and respectful behavior.

"We modeled our car on the Nissan Leaf, the electric car that is widely available to consumers," Team Captain Naia Tenerowicz explained. "But, we put a twist on it because with electric cars you are still using coal, which has some emissions. But, with hydrogen fuel cells your only by-products are water and oxygen. We thought it was a great twist, plus it's an adorable car running down the track."

Choosing to focus on the design of a hydrogen fuel cell model car rather than a solar race car was a deliberate decision for team, "Larry the Leaf." "We liked doing the hydrogen because there is more flexibility with the design since you don't have a solar panel sitting on top—instead you have a little cell inside," Tenerowicz said.

However, simply putting together a fuel cell car in the right way is not enough to win the design competition. "Explaining everything to the judges is key to show that you know what you were doing and understand it, Tenerowicz said. "There was so much hard work that went into it, we measured everything and made sure it was perfect, and I think the judges understood that."

Competing on an all-girls team topped off the race for teammate Sam Henry, "We have an all girls team to break that stereotype that this is just for guys—and it's been awesome."

Solar + Students = a Photon Finish

But boys were not sitting idly on the sidelines; on the next set of raceways they took home the big awards. The Logan School for the Creative Learning's solar team named, "Thundercougarfalconbird" took top honor for design as well as having the fastest car at the event. The team's car covered a 20 meter track in 5.95 seconds.

> "NREL's solar and hydrogen car races are fun and kids can then see the relevance of math and science."
>
> —**ERIC BENSON,** *Team Coach and Teacher at The Logan School for Creative Learning*

"I got involved through an elective course at my school called Vehicles of the Future," said team member Aiden Carley-Clopton. His thoughts on winning the solar design contest echoed that of Team Larry the Leaf for hydrogen, "I think we won best solar design because I was able to explain how everything worked on the car and not just why I included it."

Coach Benson had another perspective. "To get ready we set up track in the hallway with fishing wire to test the cars. The kids were really enthused. They would work, and then test, then get frustrated. Once they got their cars going straight, one student was even doing a 'happy dance' in the hallway.

"Getting the cars to go straight is one of the more challenging aspects for the teams. They would have to take the axles off, re-glue, and try again. And, that's how it works. You just don't build it right the first time. You have to fiddle with them and learn what is going on in order to make it better."

NREL's Junior Solar Sprint and Hydrogen Fuel Cell car competitions are sponsored by DOE's Office of Science, DOE's Golden Field Office, Haselden Construction, Jefferson County Public Schools, Dakota Ridge High School, Warren Tech, Rocky Mountain Bottled Water, The Alliance for Sustainable Energy, LLC, and NREL.

—Heather Lammers (May 31, 2011)

New Magazine Highlights Clean Energy Innovations

Groundbreaking and potentially game-changing technologies at the U.S. Department of Energy's (DOE) National Renewable Energy Laboratory (NREL) are now featured in a new online quarterly publication, *Continuum Magazine*.

The first edition of the quarterly webzine features NREL's new one-of-a-kind research facility, the Energy Systems Integration Facility (ESIF), where utilities and vendors will turn to learn how to build a smarter, more efficient utility grid that can handle increasing amounts of solar, wind, and bioenergy.

NREL is the nation's primary federal laboratory for renewable energy and energy efficiency research and development (R&D). Its mission is to develop renewable energy and energy efficiency technologies and practices, advance related science and engineering, and transfer knowledge and innovations to address the nation's energy and environmental goals. Toward that end, the laboratory had earned 47 R&D 100 awards by 2011, the annual awards by *R&D Magazine,* which identify the top 100 technological innovations each year.

More Than an R&D Laboratory

But NREL is more than an R&D lab. Its world-class testing facilities help wind, solar, biofuel, battery, and smart-window manufacturers determine the reliability and durability of their products before reaching the market. More than any other national lab, NREL pushes research out the front door and into the bays of industry.

Its more than 100 cooperative research and development agreements with private industry help companies license technology, overcome scientific hurdles, and ramp up to manufacturing scale. NREL offers a continuum of services from fundamental science to deployment and commercialization.

> "This is a big jobs opportunity. It's a technology opportunity that is truly leveraging what is really good about our country—and that's innovating things into the marketplace quickly."
>
> —**DANA CHRISTENSEN,** *NREL's deputy director for science and technology*

The Energy Systems Integration Facility, featured in NREL's new Continuum Magazine, will simulate, in real-time, the ebb and flow of various electricity generating systems and the fluctuating demands of electricity customers. *Illustration from SmithGroupJJR, NREL/PIX 20362*

"We chose the name Continuum because it represents the iterative nature of the research our scientists perform, as well as the way in which NREL bridges science and market need," NREL Communications Director Tom Stites said.

Each subsequent issue will focus on particular aspects of NREL's research and leadership role in advancing renewable energy and energy efficiency technologies—from innovative science to widespread market adoption.

First Edition Highlights Big Opportunities

The feature article on the ESIF in the inaugural edition shows how utilities can simulate the real-time ebb and flow of various electricity generating systems and the fluctuating demands of electricity customers. It's a capability that has never been available before.

Another article in the first edition examines DOE's SunShot Initiative, and NREL's role in incubating the kind of disruptive technology that will lead to solar energy becoming cost-competitive with other ways of generating electricity.

Dana Christensen, NREL's deputy director for science and technology, calls it a "Herculean challenge" to bring solar energy to the marketplace at cost parity with other sources of energy. But it is a challenge that would pay enormous dividends. "The organization, the country that makes it happen first is going to control the market," Christensen said. "This is a big jobs opportunity. It's a technology opportunity that is truly leveraging what is really good about our country—and that's innovating things into the marketplace quickly."

Also featured in the inaugural edition are articles on wind energy, and on how the military is using clean energy to power vehicles and military bases.

> "Continuum Magazine is dedicated to stepping beyond the technical journals to reveal the laboratory's vital work in a real-world context for important stakeholders near and far."
>
> **—DAN ARVIZU,** *NREL Director*

Magazine Offers Insights, Understanding

NREL Director Dan Arvizu said *Continuum Magazine* is "dedicated to stepping beyond the technical journals to reveal the laboratory's vital work in a real-world context for important stakeholders near and far."

Each quarterly issue will provide "insights into the latest and most impactful clean energy innovations," while spotlighting the researchers and unique facilities that make it happen, Arvizu said.

For the past 33 years, NREL has been on the ground floor of most of the technologies used by the leading names in renewable energy today, Arvizu said. *Continuum* spotlights the technologies "that can be deployed and used at the scale required to really make a difference for the nation."

—Bill Scanlon (June 15, 2011)

Turning Warehouses into Solar Powerhouses

When the U.S. Department of Energy's (DOE) National Renewable Energy Laboratory (NREL) launched the Executive Energy Leadership Program (Energy Execs) in 2007, the goal was to inform private and public decision-makers about renewable energy and energy efficiency as well as inspire them to adopt clean energy technologies.

From President Obama touring the roof top solar installed at Denver Museum of Nature & Science (project of alum Dave Noel, DMNS vice president of Operations) to Business Modeling for Solar to Hydrogen Energy Storage (project of alumni Sanjeeva Senanayake, vice president, HSH Nordbank and Jason Coccia, associate, Booz Allen Hamilton, Inc.), the program has yielded many significant success stories. But 2007 Energy Execs graduate and Prologis Vice President for Renewable Energy Drew Torbin has raised the bar—significantly.

Project Amp Ramps Up

Recently, DOE announced a $1.4 billion partial loan guarantee to support the launch of Project Amp. Dubbed by DOE as the largest rooftop solar program in U.S. history, the loan guarantee submitted by Prologis' partner Bank of America Merrill Lynch, will enable Prologis to install photovoltaic (PV) panels on warehouse and distribution centers across the United States.

Torbin was a driving force behind Project Amp. "We call these facilities distribution centers because they serve to distribute goods and are therefore close to population areas and as a result close to the grid. Project Amp brings new meaning to the term distribution center because we are now distributing power from those rooftops. In our view, there is no better place from which to distribute power."

The offer of conditional commitment from DOE will be the cornerstone of a financing vehicle that can fund up to $2.6 billion in solar projects on Prologis roofs. The projected energy generated from Project Amp after four years is approximately 733 megawatts (MW) of solar power, which is similar to the total amount of PV power installed in the entire United States in 2010.

"This unprecedented solar project will not only produce clean, renewable energy to power the grid in states across the country, but it will help us meet the SunShot goal of achieving cost competitive solar power with other forms of energy by the end of the decade," U.S. Energy Secretary Steven Chu said in the announcement. "In addition, Project Amp will create at least a thousand jobs across the United States and increase our global competitiveness in the clean energy race."

Even though the buildings in the Prologis portfolio are quite large, the energy demand within them is not equally as large. The buildings are warehouses or distribution spaces and the

2007 Energy Execs graduate and Prologis Vice President for Renewable Energy Drew Torbin's Project Amp received a $1.2 billion loan guarantee from DOE in 2011 to install solar on warehouses. *Photo by Dennis Schroeder, NREL/PIX 19354*

largest energy load is from lighting, which is why Prologis chose to send the buildings' power directly to the grid potentially offsetting energy for more than 88,000 homes.

"At the end of the day, we are buying land, we are putting a distribution center on it—using it to create value for that piece of property," Torbin said. "Project Amp is a great way for us to create additional value for those existing assets. We are leasing roof space, we are building out solar facilities and we are creating value. The biggest piece missing to do this at scale was an efficient form of financing."

Although Prologis was just starting to embrace solar on roofs of its U.S. properties when Torbin completed Energy Execs, he credits the program with giving him the knowledge to take it to the next level. "Energy Execs is a phenomenal program. I can truly say that there is no other offering anywhere in the world like it. It provides a strong foundation for anyone who wants to get involved in renewable energy."

According to Torbin, the solar efforts at Prologis have grown exponentially since his being a part of NREL's Energy Execs. When Torbin graduated, the company had approximately 6 MW of solar installed. Currently, with projects under construction, Prologis has more than 60 MW on rooftops.

"Now with Project Amp, we are going to grow exponentially. We are only limited by the dollars available and that's $2.6 billion," Torbin said. "At today's pricing, that's about 733 MW of PV."

Energy Execs—A Peer-to-Peer Network

The 2011 Energy Execs class ran its five-session course May through September. NREL staff believes that year's execs formed important bonds early on thanks to a surprise visitor.

"Our classmates are from all over the country and that is a leveling influence, it forces them to reach out to each other from day one," former program instructor and NREL's Manager of Stakeholder Initiatives Carol Tombari said.

The 2011 class attended an announcement made by Vice President Joe Biden at NREL. And, while the class waited for the vice president to speak, participants had a chance to mingle and bond. While a visit by the vice president is rare, it's an experience NREL is uniquely positioned to offer executives hoping to delve into clean energy. The lab can capitalize on its many scientists and technology experts to help participants learn more about renewable energy and energy efficiency applications, analysis, and related regulatory issues.

> "Energy Execs is our chance to touch the influencers and decision makers throughout our country."
>
> —**CAROL TOMBARI,** *NREL's Manager of Stakeholder Initiatives*

"Energy Execs is our chance to touch the influencers and decision makers throughout our country," Tombari said. "We can't tell them everything about renewable energy in the limited classes we have, but we can arm them with information so they know what questions to ask. Our goal is to make them dangerous."

Arming the Energy Execs means they leave the program with a support system. "We give them contacts at NREL so when they've left, they know who to call to get the information they need," Tombari said. "Along with that expert network, they also form a peer group of current students and alumni that they can relate to and share questions with."

Torbin leaned on that network for Project Amp, "NREL staff were a huge help, and really gave me some good insights into how to navigate the process," Torbin said.

2011 marked 100 participants completing the NREL Executive Energy Leadership program. NREL has so much interest in the leadership program it implemented a new condensed course called the Energy Execs Institute. The inaugural three-day institute was held in July 2011. It is now a regular program in addition to the annual leadership program. Tombari noted that working with the execs is a highlight for her professionally, and she mentioned the students, staff and NREL all benefit from the program. "On one hand, the Energy Execs brand has helped enhance NREL's reputation in communities and companies we may have not touched," Tombari said. "But the graduates also proudly refer to themselves as Energy Execs and capitalize on this credential as they undertake clean energy projects."

—Heather Lammers (July 18, 2011)

NREL Mentors Keep It Real for Summer Interns

In the summer of 2011, workers at the U.S. Department of Energy's (DOE) National Renewable Energy Laboratory (NREL) are advancing our understanding of hydrogen fuels, carbon nano catalyst technology, the use of indium zinc oxide in thin film solar cells and many other research areas. The results were published in journals and presented at industry conferences. The teams doing this groundbreaking work aren't NREL senior scientists or engineers, but the lab's undergraduate interns.

For 10 weeks every summer, college students from across the county migrate to Golden, Colo., to work side-by-side with top researchers at the only national laboratory solely focused on renewable energy and energy efficiency research and development.

"This is not simulated research," said NREL Education Program Coordinator Linda Lung. "They are part of a research team."

Being part of a research team is an opportunity Natalie Bodington-Rosen is fully aware of as she works on depositing indium zinc oxide onto thin film solar cells. The goal is to make the cells with less indium to reduce costs. "Having all of these resources at your fingertips and not thinking 'can we do this' but, 'let's find a way to do it' is a wonderful experience," Bodington-Rosen said.

Coaching Tomorrow's Workers

Nurturing science interests in students from middle school all the way to graduate school is a priority for DOE.

"The summer internship program is our greatest program for workforce development," Lung said. "We are trying to figure out the workforce needs are for DOE and what NREL can to meet that need."

DOE-sponsored education programs begin with middle school students via the hydrogen fuel cell and solar car races. High school students are engaged through the National Science Bowl. "Then we say, 'hey, wouldn't you like to do an internship?'" Lung added. "It's a good fit because we already know they are interested in science and we have seen this education pipeline work with interns later becoming NREL employees."

The other priority DOE has is energy literacy and getting young people to understand the source of the energy that powers their homes so they can make informed decisions when it comes to using it. That is a message that resonates with summer intern Amy Tsang who is researching the manufacturing process for hydrogen fuel cell membranes. "I think it is very important to continue our research and further our technology," she said. "We are going to have to reduce our dependency on fossil fuels because of high prices and climate change. Our world has to change to a different energy strategy and renewables is it."

For many of the NREL interns, this is the first time working in their field, or even in a professional work environment. Intern training covers basics from research roles and responsibilities—with a high priority on safety—to dress codes. But, it's also important to show results at the end of the 10 weeks.

"They have specific deliverables," Lung said. "Our interns have to produce a research paper and a poster session." The students have the opportunity to see their research published in the Journal of Undergraduate Research. They also can be selected to present at the annual American Association for the Advancement of Science (AAAS) annual conference.

NREL intern Amy Tsang disconnects a hydrogen cell after a test. *Photo by Dennis Schroeder, NREL/PIX 19438*

Months before the summer starts, NREL mentors are given the opportunity to view the database of hundreds of applicants and select the intern who best matches their project.

This is NREL Scientist Matthew Lloyd's second year working with a summer intern. "It's beneficial for both the mentor and the student," Lloyd said "I've found that it's worth the time that you have to invest in the student and it pays back in spades to be involved in the program."

The student working with Lloyd, Skyler Jackson, is optimizing layers in organic photovoltaic devices, which means making the same devices repeatedly but with slight variations. The team is varying the processing conditions for a zinc oxide electron transport layer and looking at how it impacts overall performance of a PV cell.

"In optimizing the device layers, I'm having them do work that is particularly time consuming, and it is work that I would normally do, and it would take a large chunk out of my day," Lloyd said. "It really boosts our productivity to have an intern devote time to this project."

First-time NREL mentor and postdoctoral researcher Andriy Zakutayev got excited about the idea of mentoring a college intern after attending a conference session on mentoring and building relationships between students and the advisers.

"I envision, at some point, doing work in academia and I also had a lot of work and figured it would be great to have a student working with me over the summer who could benefit from the work we do at NREL," Zakutayev said.

Zakutayev's intern, Frank Luciano, is helping bring to life a thermoelectric power measurement tool that Zakutayev built. "I was really impressed with the number and the quality of the students who applied," Zakutayev said. "My intern just finished his freshman year. When I think about myself and my friends at that age, we didn't have half of what they already know. I just wish the program was larger and more students could participate."

In 2011, 35 students took advantage of NREL's summer program. While the summer season marks a peak in internship program participation, a variety of programs run year-round:

> "It's great to understand what research really is and when you get here it is mind-blowing."
>
> —**AMY TSANG,** *NREL Summer Intern*

- DOE's Science Undergraduate Laboratory Internship Program (SULI)
- DOE's Community College Institute (CCI) for Science and Technology
- DOE's Pre-Service Teacher (PST) Internship Program
- DOE's Office of Science Graduate Fellowship Program (SCGF)
- NREL's Research Participant Program is funded by program dollars and provides university students an opportunity to participate in the laboratory's research and development programs, initiate new areas of research, and establish a base for ongoing collaborations.

"Although we benefit from the students' work, it's also incredibly beneficial for them," Lloyd said. "It puts them at the top of the list for other research positions. Or, if they are going on to grad school, the summer programs through DOE really make the students stand out from their peers."

While the opportunities for interns to learn while working at NREL are immense, the opportunities for discoveries are even greater. "It's great to understand what research really is and when you get here it is mind-blowing," Tsang said. "You realize how much there is to discover and how little we do know about our world."

—Heather Lammers (August 8, 2011)

NREL Intern Wants to Make a Difference through Chemistry

Annie Greenaway is applying her chemistry skills to a thorny problem associated with hydrogen fuels this summer—and the National Renewable Energy Laboratory (NREL) intern thanks her parents for nudging her toward the right career path.

The Truman Scholar and Goldwater Scholarship winner recalls the day when she succumbed to the inevitable.

"I was a junior in high school, and I had to take either biology or chemistry, so I chose chemistry, but that's not what I really thought I wanted to do," said Greenaway, who fancied herself more of a literary or political type.

"But my parents said, 'You come home, and that's all you talk about, what happened in chemistry class today,'" Greenaway added. "So I thought, maybe that's what I should be doing."

How to reconcile her ambitions for politics with her unexpected love for chemistry?

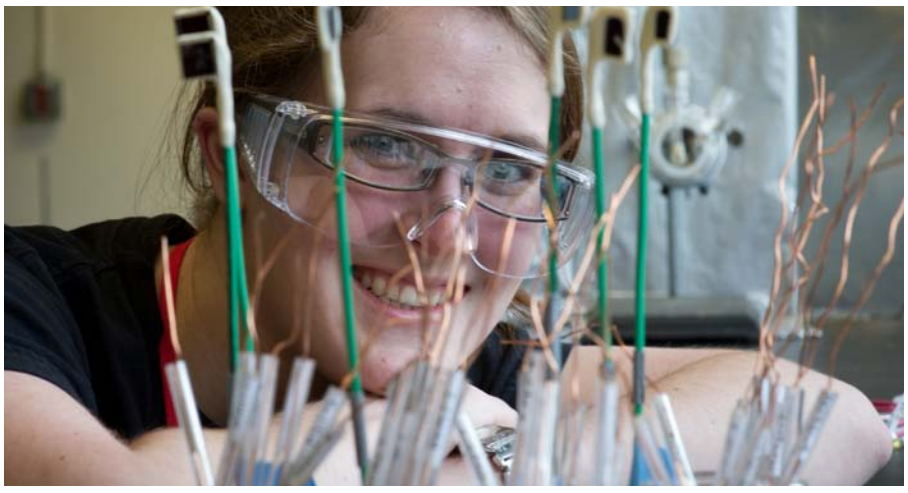
"I realized that a lot of politicians don't have any scientific background, and of course they are the people deciding on funding," she said. How about chemical research in renewable energy, so if she gets into the policy side, she can do so with the expertise of a scientist?

Greenaway, who attended Thornton High School in the Denver suburbs, shopped around for a small college that might have what she was seeking.

She found Hendrix College in Conway, Ark., which offered a chemistry major that emphasized green chemistry. At Hendrix, she thrived, heading up the Culinary Club, but also heading up a project to eliminate heavy metal use in the General Chemistry curriculum. Greenaway won a Goldwater Scholarship this spring to help her with her undergraduate expenses. During her junior year, she studied a semester in Brussels, Belgium, where she investigated how European Union countries were meeting their requirements for using renewable energy, and promoting the use of solar, wind and other alternatives to fossil fuel.

She liked the feed-in tariffs that many of the European nations adopted, and especially liked the 20-year guarantees that renewable energy would fetch a stable price.

> "The goal is to combine them to get something that splits water pretty efficiently."
>
> —**ANNIE GREENAWAY,** *Truman Scholar and Goldwater Scholarship winner*



NREL intern Anne Greenaway is working with electrodes and electro chemistry cells in the hydrogen lab. 2011 marked her second year as an intern at NREL. *Photo by Dennis Schroeder, NREL/PIX 20325*

She'd love to play a part in bringing those kinds of long-term price guarantees to the United States, but realizes that Americans and Europeans often have different values and priorities. "You can't just make these wild claims and decide to do things without the political will to back you up."

The European goals are ambitious: a 20% improvement in efficiency by 2020, at which time 20% of energy will be provided by renewables and 20% of the transportation fuels will be biofuels.

At NREL, Greenaway is working on hydrogen production with senior scientist Todd Deutsch, himself a graduate of NREL's internship program a decade ago.

"We're using semiconductor technology to split water and produce hydrogen," she said. "Right now we're making samples, testing them, and characterizing them."

Her samples include three photoanodes, which drive oxygen oxidation, and three photocathodes, which drive the reduction of hydrogen. She used various techniques to turn them into electrodes.

"The goal is to combine them to get something that splits water pretty efficiently," Greenaway said. As soon as her samples are made and tested, she'll start working at NREL's mesa-top labs.

The summer of 2010 was Greenaway's first with NREL's Science Undergraduate Laboratory Internship. She learned a timeless reality about science.

"We were working on something that had potential to be a huge breakthrough," Greenaway recalled. "None of it worked out … but it had to be done, someone had to do it." That work, done by interns, answered important questions and cleared the way for a new approach this summer to the hydrogen electrolysis question.

She thinks hydrogen "is going to be huge," an important part of the transportation fuel mix in the future, and hopes support for research will continue.

"Car companies think hydrogen is coming," Greenaway said. "Almost all of them have one fuel-cell vehicle in the pipeline for 2015. It all is going to depend on the wide-scale deployment of hydrogen-fuel centers. You don't want to drive 400 miles and then be stuck without a place to fill up."

> "I came to the conclusion that the best way for me to be involved and to affect policy is through renewable energy. That's why I wanted to work at NREL."
>
> —**ANNIE GREENAWAY,** *Truman Scholar and Goldwater Scholarship winner*

Greenaway will graduate from college in 2012. Her Truman Scholarship will pay for much of her graduate education, and she intends to get a doctorate in chemistry.

In the summer of 2012 she'll spend 10 weeks in Washington, D.C., working with a congressman or a think tank on science and policy—two things in her wheelhouse.

The Truman Scholarship Foundation searches for people who can be change agents, students who are looking to go into public service.

"I have strong political leanings and I wanted to do something socially relevant," Greenaway said. "I don't think I'd make a good politician because I'm too opinionated and not willing to make political compromises.

"I came to the conclusion that the best way for me to be involved and to affect policy is through renewable energy. That's why I wanted to work at NREL."

As a Truman Scholar she has pledged to work three years in a public service field—education, government, military or a non-profit. That's right up her alley. "I'd love to be in the national laboratory system and to be at NREL if I can be.

"NREL is a great place to work, and I love Colorado," Greenaway said. "The focus here is really great."

—Bill Scanlon (August 8, 2011)

ENERGY ANALYSIS

Analysis at NREL aims to increase the understanding of the current and future interactions and roles of energy policies, markets, resources, technologies, environmental impacts, and infrastructure. These analyses are used to inform decisions as energy-efficient and renewable energy technologies advance from concept to commercial application. *Photo by Dennis Schroeder, NREL/PIX 19931*

OpenStudio Visualizes Energy Use in Buildings

Look around you. Odds are, you are indoors reading this story using a computer or mobile device, perhaps sipping on a favorite cup of coffee. If you are indoors at this moment, you're draining energy from one of the largest consumers of energy in the United States—a building.

Together, residential and commercial buildings account for a staggering 40% of energy use in the United States. However, the U.S. Department of Energy's (DOE) National Renewable Energy Laboratory (NREL) is developing a suite of tools to tame this energy beast—and it is free to anyone who wants to use it.

Whether retrofitting existing buildings or designing new buildings, energy modeling is a core component to changing a building from an energy guzzler to an energy sipper. "It's much cheaper to run an energy model than it is to build the wrong building or do the wrong retrofit," said NREL Senior Engineer Nicholas Long.

DOE's EnergyPlus is a powerful simulation engine that provides comprehensive building energy modeling. NREL is working to add tools to EnergyPlus, via its OpenStudio Application Suite, to improve overall functionality and make EnergyPlus easier to use.

New Tools Help Carve out Energy Savings

"The easiest way to describe OpenStudio is a wrapper on top of EnergyPlus," Long said. "OpenStudio handles the building geometry, building envelope, plug loads, people, and daylighting, along with many other inputs. It adds all of that data into one big massive engine and spits out results. Industry professionals will find that OpenStudio will help them quickly and easily analyze the energy use in their buildings."

The first version of OpenStudio was released in 2008 and is a plug-in that leverages Google SketchUp, a user-friendly 3-D drawing program. "OpenStudio was originally developed so people could view and edit geometry for EnergyPlus models," NREL OpenStudio Developer David Goldwasser said. "We've now expanded it to be able to view and edit a lot of the other attributes of EnergyPlus building models, for example putting in loads like lights, equipment, and simple HVAC systems."

"OpenStudio goes a long way toward easing workflows for industry professionals," said Larry Brackney, NREL manager for analysis tools in commercial buildings. "We've enhanced it and there are a slew of new features—some of which NREL has developed and some of which we are just leveraging from Google and their massive investment in SketchUp."

The new suite of OpenStudio tools includes the SketchUp plug-in plus:

- **ModelEditor** provides users with a simpler way to edit the building model. It includes a way to access components that don't have a physical representation in a building, like a mechanical system.

OpenStudio software developers Larry Brackney, David Goldwasser, and Nicholas Long appear in one of the OpenStudio computer visualizations that helped to design the RSF building at NREL. *Photo by Dennis Schroeder and David Goldwasser, NREL/PIX 18545*

- **ResultsViewer** is a way to review EnergyPlus simulation data in a graphical format. It allows users to look at the data, draw conclusions and compare results.
- **RunManager** is an application to run simultaneous simulations. This powerful tool can be used to run simulations on a desktop, computer cluster or even a super computer. Designers can compare results between differing models to see where the best energy savings can be achieved.

The OpenStudio plug-in also heavily leverages a feature in SketchUp called Match Photo which uses photographs of a building to create a 3D model—almost effortlessly. Once the 3D model is finished, users can use the plug-in to trace over windows and doors for EnergyPlus' use in running an energy model. It's a tool that developers believe fills a need, especially for crews planning a building retrofit. "I see Match Photo as a killer app because this is an area that's not been well served in the market," Brackney said.

"We really appreciate Google's integration goals. We think that with a lot of the things they are connecting—like Google Earth and Building Maker and SketchUp—there is collaboration between all of these technologies. It is creating this rich set of building geometry models that we can use for energy modeling. There's a great synergy there between what they are doing and what we are trying to do."

Open Source Makes User Customization Easy

Although collaboration with Google is important to the NREL development team, more important is collaboration with OpenStudio users.

"OpenStudio uses open source code so if someone wants a feature that we don't have the time or the funds to write, there are two options," Goldwasser said. "First, they can write that code and submit it to us. We look at it and decide if it gets accepted and works with what we want. Another option is for them is to use an API [application programming interface] and 'plug-in' to our software and write applications without changing our code."

OpenStudio is made available to anyone under the GNU Lesser General Public License, which allows third-parties to easily integrate the functionality into their applications without requiring them to contribute their code back. "We're not selling this product, it's free. And, what's nice about it being open source is that someone can integrate it into their workflow," said Brackney.

For users, "our goal at NREL is to help people design buildings that are more efficient so that we use less energy," added Brackney.

To show how easy it is to develop an API to "plug-in" to OpenStudio, NREL developed a simple API for Heating, Ventilation, and Air Conditioning (HVAC) modeling. "SystemOutliner is a graphical user interface for constructing HVAC systems, which has been one of EnergyPlus' Achilles' heels," Brackney said. "It's an awesome example of how quickly users can build a very deep, meaningful user interface to OpenStudio that meets a real need."

"The key is all about accessibility, making the notion of doing energy modeling more and more accessible, and eliminating the excuse for not doing energy modeling."

Another potential barrier to using any new software is training, but NREL has seen to the user's needs here as well. "We have extensive online video tutorials on how to use the new OpenStudio tools to help get users up and running sooner," Long said.

In fact, the OpenStudio website and YouTube Channel have nearly two hours of videos that walk users through differing workflow applications for the program. The site also has full documentation for the API and source code to browse, and it is continually being updated by NREL staff.

"What's great is that if I get a lot of questions on a certain subject, I can add in documentation on the fly and I don't have to wait for the next release," Goldwasser said.

There is also a user's forum moderated by NREL for people to post questions and ideas for OpenStudio.

"The user support we provide is incredible," Goldwasser added. "We provide a quick response, and if it's a valid question, it might result in a new training video."

"I'm really pleased with the way NREL is approaching this software development," Brackney said." We've got a full-blown software development team using rigorous software development process to produce a quality product that people can use to see if there are any other energy savings they can squeeze out of their buildings."

—Heather Lammers (March 8, 2011)

Nationwide Utility Rates Now on OpenEI

Utility rates from cities all across the United States are now available in one place—the U.S. Department of Energy's (DOE) Open Energy Information platform, or OpenEI.org.

Am I paying too much for electricity? Does it make sense for me to put solar panels on my roof? Should I lease my land to wind-farm developers?

Consumers and businesses are asking, and OpenEI provides the answers. Developed by the DOE's National Renewable Energy Laboratory (NREL), OpenEI is where energy officials and consumers alike can go to boost their energy IQs and make better decisions.

The free site blends elements of social media and Wiki-based technology with robust and previously unavailable information on energy sources and prices. The result: a powerful, collaborative platform that is helping government and industry leaders around the world define policy options, make informed investment decisions, and create new businesses.

"Remember the end of Raiders of the Lost Ark, when the Ark was hidden away in a warehouse?" said Debbie Brodt-Giles, NREL's supervisor of the site. "Many websites are like that—taking something with the power to transform the way we see the world and locking it away. OpenEI is about more than collecting data. We're about sharing data in ways that transform understanding."

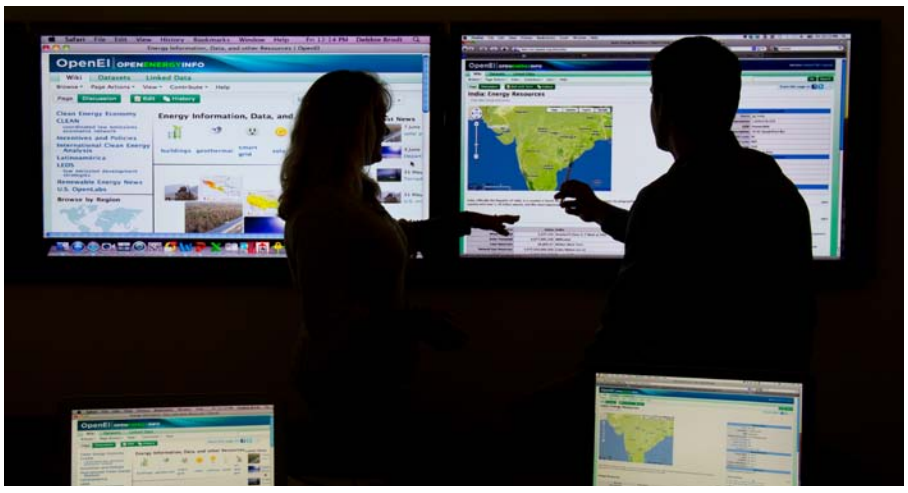
Transforming the way we see the energy world is the point behind OpenEI, which NREL launched late in 2009 in response to the White House's effort to promote the openness, transparency, and accessibility of the federal government.

Crowd-Sourcing Uses the Power of Numbers to Boost Reliability

The site uses the power of crowd-sourcing to make energy information ever more robust and more accessible. In addition, maps and other visualization tools transform raw data into displays that are easily understood.

"The more people, the more experts, we have contributing data and using the site, the better the site is going to be, the richer the experience is going to be," Brodt-Giles said. "To have a platform to openly share information that is typically hard to access is a big plus."

"OpenEI's unique quality is that it is so open, collaborative, and transparent," NREL's Graham Hill said. "The new Utility Rate Database is a great example. We've taken information that is typically disparate and difficult to find and we've made it easy for anyone to access and understand."



NREL researchers examine some of the Web pages available to the public through OpenEI.org, a new site where consumers, scientists, and utility representatives can get information on energy. *Photo by Dennis Schroeder, NREL/PIX 19433*

The new information allows anyone with Internet access to compare kilowatt-hour rates in dozens of cities and zero in on such variables as time-of-use rates, demand charges, and tiered rate structures.

For household consumers, that could mean getting wiser about whether to install rooftop solar panels or finding other ways to lower their energy bills. A farmer in rural Iowa can assess potential profitability of leasing land for wind development.

Energy investors could use other tools to determine how many turbines could be installed on the same property. They can analyze information on rates, sunshine, wind speed, and incentives to inform their decisions. With OpenEI, decision makers can reduce missteps and save time and money.

The new utility rate data show average consumption rates in the cities. The data illuminate, for example, that air-conditioner-revving warm-weather cities Tucson and Atlanta consume far more energy than cooler-weather cities such as Boston, Denver, and Milwaukee.

Since the launch of OpenEI, the site has had more than 450,000 visits from 190 countries. It now holds more than 600 data sets and has created more than 54,000 wiki-content pages.

Valuable Information for Consumers, Developers

What are these visitors creating and finding? Among other things:

- For anyone contemplating heating homes or buildings with geothermal energy, the National Oceanic and Atmospheric Administration provides research about how warm it gets as holes are drilled deeper into the earth
- Information on how to qualify for local, state, and national incentives for renewable energy systems is accessible thanks to contributions from North Carolina State University
- Developers can access solar radiation data to find out precisely how much sun they can expect to hit their panels in different locations around the country
- Where to purchase ethanol
- State-by-state rankings of wind, solar, and geothermal energy production.

> "OpenEI's unique quality is that it is so open, collaborative, and transparent."
>
> **—GRAHAM HILL,** *NREL Analyst*

Utilities typically put their rates somewhere on the internet, but OpenEI ensures that those rates are easily accessible by consumers and in data sets that compare costs across a range of cities.

OpenEI Going Global

OpenEI also is international.

Visit http://en.openei.org/wiki/India for example, and you'll find among many other nuggets that India is not only the world's most populous democracy, but ranks eighth in the world in solar potential, just 120th in wind potential and has more than 66 million short tons of coal reserves.

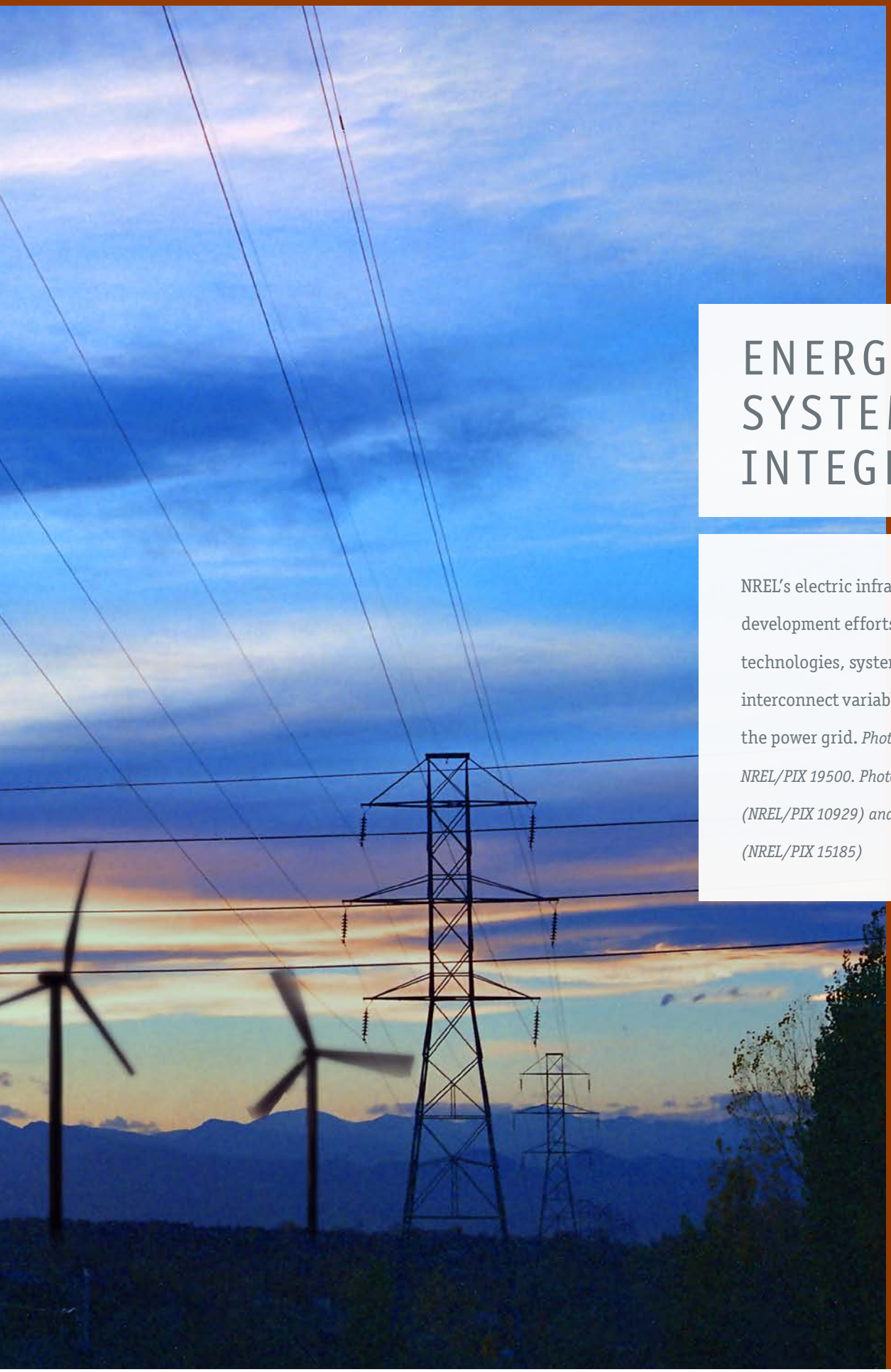
OpenEI.org has a collaboration with the Centro De Energias Renovables in Santiago, Chile. NREL and the Chilean renewable energy lab are hoping to extend a network across South America, using OpenEI as the platform to link national labs.

A new Google translator feature makes OpenEI available in 20 languages, so its helpfulness matches its global reach.

The ultimate benefit of OpenEI.org is the acceleration of energy technology research and the transformation to a clean, secure energy future.

When Energy Secretary Steven Chu announced OpenEI.org, he said: "The true potential of this tool will grow with the public's participation—as they add new data and share their expertise—to ensure that all communities have access to the information they need to broadly deploy the clean energy resources of the future."

—Bill Scanlon (September 6, 2011)



ENERGY SYSTEMS INTEGRATION

NREL's electric infrastructure research and development efforts involves developing technologies, systems, and methods to interconnect variable renewable energy with the power grid. *Photo illustration by Ray David, NREL/PIX 19500. Photos from Warren Gretz (NREL/PIX 10929) and Iberdrola Renewables Inc. (NREL/PIX 15185)*

A Better Way to Connect Solar, Wind to the Grid

The sun makes sidewalks hot enough to fry eggs, the wind blows hard enough to tear fences, but if solar and wind energy can't be converted to the 60-hertz alternating current (AC) standard in the United States, it can't be connected to the grid for use in homes or offices.

That's where the inverter fits in, a device that takes that distributed energy and turns it into grid compatible AC power.

If the United States is to generate a significant amount of the nation's electricity from clean energy, the inverter must be smarter, more flexible and a whole lot cheaper.

The U.S. Department of Energy's National Renewable Energy Laboratory (NREL), with industrial partner Semikron, and with funding from the California Energy Commission, has developed a prototype of a 50-kilowatt (kW) inverter. Inside is a 50-kW modular power block the size of a microwave oven that can be included with a photovoltaic array, small wind turbine, battery charger, fuel cell, or flywheel and control the flow of energy onto the electric grid.

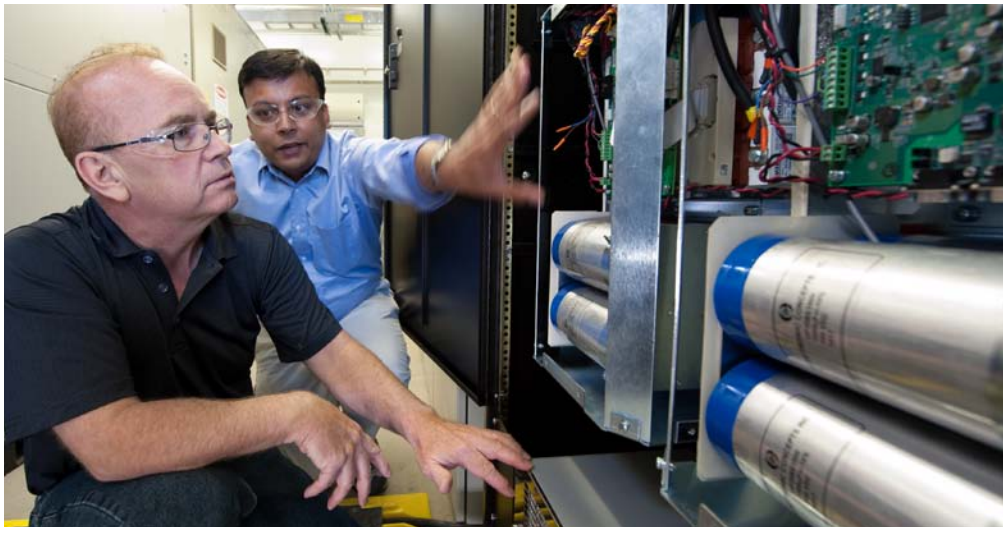
Besides being the most versatile, the integrated 50-kW modular power block is more reliable, more durable, lighter, and should cost significantly less than other power blocks of its wattage. A reliable power block suitable for multiple applications such as photovoltaics (PV), wind turbines, and batteries should sell in high volumes, and that's when the big savings should kick in. When the power block is produced in volume, the price is expected to be just one-third of the cost of other integrated power electronics of the same rating.

At 16 inches wide, 8 inches tall and 12 inches deep, the flexible power block should be a workhorse in the electricity industry as it adapts to integrating more PV, wind, and battery power. The power block includes electronic switches, sensors, direct-current (DC) bus filtering, a heat sink, a driver, and a controller board.

It will be packaged inside a 6-foot by 2.5-foot inverter, which also will contain inductors, capacitors, sensors, contactors, pilot relays and a DC power supply, along with protective devices to suppress surges, protect against ground faults, and ensure emergency shut off.

Digital Controller Allows User to Modify Algorithms

A digital controller in the brains of the power block allows the user to modify control algorithms to allow it to work with different technologies, Ben Kroposki, leader of the Distributed Energy Systems Integration group at NREL, said. Used in an inverter, "the power block will allow utilities to let more renewable energy come online."



NREL engineers Sudipta Chakraborty and Bill Kramer examine the design of the power block at a laboratory at NREL. *Photo by Dennis Schroeder, NREL/PIX 19357*

By combining off-the-shelf high-volume, high-quality components from Semikron, with a flexible controller and software module from NREL, the power block combines reliability, flexibility, and cost savings.

"It's in its final prototype stage," NREL's Bill Kramer, the principal investigator, said. "After one more redesign, we'll get a dozen or so of these into the hands of industry across different disciplines to get their feedback. We hope they start using these components in their designs to lower their costs."

"This is a building block for multiple applications," said NREL electrical research engineer Sudipta Chakraborty, the lead researcher on the project. "It doesn't matter what renewable energy application you're using, this will be the heart of the power conversion."

Partnership with Semikron, California Energy Commission

"We worked with Semikron to make the power block cheaper," Chakraborty added. "By putting all the parts in an integrated package, the power block can be tested for some of the stringent quality controls to make it more reliable than if you just put the discrete components together," Chakraborty said.

The 50-kW power block is modular, so the same power block can be used for multiple technologies. It's also scalable, so two or more can be connected to create a larger power converter without having to redesign a system. It also doesn't need any external DC filtering capacitors, further lowering the cost. "It makes the inverter a lot cheaper for many technologies, because you don't have to custom-design the DC filtering," Kroposki said.

"The manufacturer can easily build an inverter based on our power block," Kramer said. "They just have to integrate the power block into their product. Until now, the inverter manufacturers have to build every inverter from scratch. They still have to add filters and protections and so forth, but we give them a large part of the inverter that is already integrated and tested."

NREL has a cooperative research and development agreement with the California Energy Commission (CEC). The CEC is using NREL's algorithms developed on the 50-kW power block as a way to help lower electric bills for California customers.

> "It doesn't matter what renewable energy application you're using, this will be the heart of the power conversion."
>
> **—SUDIPTA CHAKRABORTY,**
> *NREL Research Engineer*

The power block is designed to use in various power converters such as DC-to-AC (alternating current), AC-to-DC, or DC-to-DC converters.

In the case of PV systems—those that convert the sun's photons into electrons for electricity—the power block acts as a DC-to-AC converter. A large PV system must convert the variable DC output—it varies because the sun's intensity varies—into reliable 60-hertz AC power that can be accepted by the grid. Once it's on the grid, any consumer or business can use it.

If the task is battery charging, the power block converts AC power from the electric grid to DC to charge the battery.

Conversely, if the task is battery discharging, the power block acts as a DC-to-AC converter so the battery can provide AC power back to the grid.

For a small wind turbine, two power blocks can be used back-to-back so that the first one converts the variable AC power from a wind turbine generator to DC. The second block then converts that DC to 60-hertz AC power acceptable to the grid.

For systems that aren't intended to go on the grid, the power block can be used as an islanded inverter to supply off-grid loads.

Designed for High Reliability Using High-Volume Parts

With NREL's guidance, Semikron pulled together off-the-shelf components to build a low-price package. NREL developed the software to control the power block. "We developed the

control algorithms so that the same piece of hardware can be used for multiple applications, just by changing the software," Kroposki said.

To verify the operations of the new power block, NREL also designed an inverter platform that consists of a cabinet housing the power block, filters, air cooling, and protection. In addition to the basic inverter operations, new control algorithms are being developed and tested using this platform.

For example, NREL has demonstrated that control algorithms can be easily modified so inverters can supply both active and reactive power or can even be used to regulate voltage. It has been known that inverters could supply such advanced capabilities, but "we're showing that in the future, when regulations allow it, there is an easy way to implement them," Chakraborty said.

Companies that buy the power block can use the built-in controller board, or swap it out and use their own controllers. Start-up companies that have smaller R&D budgets are expected to use the entire power block package—the controller and NREL's software.

The power block is the right size to be used in a power system that could bring electricity to, say, an apartment complex or a group of about 10 houses. The scalability to use multiple power blocks in parallel will be useful for larger installations.

Most power converters fail faster than the renewable energy systems themselves. They have to be replaced more often than the wind turbines or photovoltaic arrays designed to last 20 or 30 years. With the power block, because all the small components are integrated and tested as a single system, reliability grows.

> "We developed the control algorithms so that the same piece of hardware can be used for multiple applications, just by changing the software."
>
> —**BEN KROPOSKI,** *Leader of NREL's Distributed Energy Systems Integration group*

The power block was designed to be highly reliable and to use high-volume parts, Kramer said. "The goal from the beginning was to develop a modular inverter that could be used in many applications so it can be produced in high volume, thus reducing the cost for renewable applications."

As the country focuses on developing more clean energy, this new power block and its advanced functionality will allow for higher penetrations of renewable energy to be interconnected to the electric grid, Kroposki said.

—Bill Scanlon (July 29, 2011)

New Lab to Help Utilities 'See' Grid of the Future

With the simple flick of a light switch, you are connected to "the machine."

The North American electric grid—the world's most complex transmission and distribution system—also is referred to as the world's largest machine. That same machine has run reliably on coal, natural gas, and nuclear energy for decades.

Now, it's time for a tune up. Newer power generation technologies such as wind and solar are gaining market share, while at the same time they are introducing an uncertain wrinkle into the old reliable power grid—variability.

The new Energy Systems Integration Facility (ESIF) at U.S. Department of Energy's (DOE) National Renewable Energy Laboratory (NREL) is tackling the challenge of keeping the power grid running reliably while at the same time introducing a host of new technologies into an already complex system.

According to NREL's center director for Electricity Resources and Buildings Integration, David Mooney, the grid has operated essentially the same for more than 50 years. Utilities know how to predict energy demand by looking at the day of the week and the weather forecast. Then, utilities dispatch generating sources (usually from coal or natural gas) to meet expected demand.

"It was a pretty orderly way to operate a system," Mooney said. "Today, there are a lot of technologies coming online—including wind and solar—that are going to require a transformation in the way this orderly system gets operated. Now instead of only having variability in the electric demand, we are also introducing technologies that make the generating supply variable as well."

Renewable Energy is Already Connected—Or Is It?

For the homeowner with photovoltaics (PV) on her roof, or the technician working a wind farm in Texas, this may seem moot. Their technologies already are connected to the grid and the electrons seem to be flowing seamlessly.

However, these types of renewable energy systems still make up a small fraction of America's overall energy generation. According to the latest data from the U.S. Energy Information Administration, power generation from renewables such as biomass, geothermal, solar and wind have so far accounted for less than 5% of the total U.S. power generation in 2011.

Connecting that small amount of renewables into the power grid is not a big deal. "If you have 1,000 homes and five to 10% of those add solar, the variation and the output of the PV is in the noise of the grid," Mooney said. "Right now, utilities view PV systems in small numbers as a demand reduction technology—no different than people switching to compact florescent bulbs. But, if 50% of those 1,000 homes have a PV system, then the

Power generation technologies such as wind and solar are gaining market share, while at the same time they are introducing an uncertain wrinkle into the old reliable power grid—variability. *Photo illustration by Ray David, NREL/PIX 19500. Photos from Warren Gretz (NREL/PIX 10929) and Iberdrola Renewables Inc. (NREL/PIX 15185)*

output could start to look more like a generating technology to the utility. Once it reaches those kinds of numbers, the utility has to start worrying about things like variation in cloud cover that cause PV output to vary."

"As all of these new technologies become cost effective, they are starting to get used a lot more and utilities ask, what's the best way to integrate these variable technologies while maintaining a safe and reliable electric power system?" NREL's Director of Energy Systems Integration Ben Kroposki said.

ESIF is the first significant DOE laboratory designed specifically to deal with the integration issue. NREL's researchers will be able to configure electric systems the way they would appear in the field and operate them at the same level of power as the utility uses.

> "Today, there are a lot of technologies coming online—including wind and solar—that are going to require a transformation in the way this orderly system gets operated."
>
> —**DAVID MOONEY,** *NREL Center Director for Electricity Resources and Building Systems Integration*

"We all know how we react when the power goes out, and the local utility usually bears the brunt of the PR problems associated with an outage," Mooney said. "So it is understandable that they are very conservative in how they go about adopting new technology. That is why the ESIF is so important for reducing that risk. The utilities will be able to operate new technologies in an environment that mimics the real system so they can work out all of the bugs of introducing new technologies beforehand and maintain the high reliability standards that we have all come to expect."

ESIF also will be a plug-and-play environment for industry. "ESIF is set up so that partners can bring in technologies—like a PV inverter or battery system—and we will have on hand the other equipment that the technology being tested would connect to. They don't have to go and try to find these complete systems," Kroposki said.

ESIF also will loop the utilities' hardware into a simulation environment so they can look at new technologies operating in a combination of real world, real power and simulated or virtual environments to see the impact that these new systems are going to have on the reliability and quality of the power.

"Once they try it all out in the ESIF, we believe the utilities will be much more inclined to adopt the technology," Mooney added.

A Smarter Grid

Another challenge for NREL researchers will include looking for ways to improve the grid itself. "For mostly economic reasons we can't build up a new grid and then switch over to it," Mooney said. "ESIF will enable us to look at how we can make the grid 'smarter' and more flexible to be able to receive technologies in a way that can maintain or even enhance the existing grid."

Many of the technologies on the grid are antiquated, and can be up to 50 years old. A "smart grid" has three components that the current grid doesn't have:

- **Sensors** as part of the grid so that power quality is being measure in real time
- **Communications** that relay data coming from the sensors back to utility operators so they can look at it and make decisions
- **Controls** that allow changes in the operation of the system from a central control room.

"People are surprised to learn that most utilities still don't know about a power outage until they get a call from a customer," Mooney said. "If we had a smarter grid, we would have sensors on transformers and power lines that would allow utilities to act preemptively if problems in power quality were arising so they could keep the power on. However, if the power did go out, utilities would be able to see it immediately and dispatch crews to minimize down time."

> "The utilities will be able to operate new technologies in an environment that mimics the real system so they can work out all of the bugs of introducing new technologies beforehand and maintain the high reliability standards that we have all come to expect."
>
> —**DAVID MOONEY,** *NREL Center Director for Electricity Resources and Building Systems Integration*

As the utilities put smarter technologies onto the grid, another avenue for energy savings is to have the grid communicate with a home energy management system so a home can work with a utility to manage power needs.

"The smart grid will offer the possibility of frequent, likely automated communication between a utility and a customer," Mooney said. "As a consumer, you will likely be able to know when the power is cheapest, for example, and have a plan with the utility that tailors your power consumption accordingly."

The foundations for a smarter grid are being laid today. In June, Secretary of Energy Steven Chu announced that more than 5 million smart meters had been deployed thanks to Recovery Act-funded efforts to accelerate modernization of the nation's electric grid.

"To compete in the global economy, we need a modern electricity grid," Secretary Chu said. "An upgraded electricity grid will give consumers choices and promote energy savings, increase energy efficiency, and foster the growth of renewable energy resources."

—Heather Lammers (December 6, 2011)

ESIF FAST FACTS:

- Cost: $135 million
- Square feet: 182,500
- Office space for approximately 200
- State-of-the-art electric systems simulation and visualization
- Component and systems testing at MW-scale power
- Integration of functioning systems with utility system simulations for real-time, real-power evaluation of high penetrations of renewable energy
- Fifteen laboratories
- Four outdoor test areas
- Construction complete: fall 2012

OTHER KEY SERVICE AND SUPPORT FEATURES:

- Research Electrical Distribution Bus
- High Performance Computing Data Center
- Hardware-in-the-Loop Prototyping at Megawatt-scale Power
- Collaboration and Visualization Rooms
- High Bay Control Room

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 from Dennis Schroeder, NREL/PIX 19089*

Small Improvements to Make Big Difference

Old memo from the boss: Your goal for 2010—build one of the most energy efficient office buildings in the world on the campus of the U.S. Department of Energy's National Renewable Energy Laboratory (NREL). New memo from the boss: Your goal for 2011—repeat 2010 goal and increase energy efficiency by 17%.

Fortunately for NREL, these goals are being achieved thanks to $39 million in funding for the new RSF wing from the 2009 American Recovery and Reinvestment Act (ARRA). The ARRA funding allowed a planned 138,000 square foot expansion of the Research Support Facility (RSF) to get underway shortly after the finishing touches on the first phase of RSF were complete. Accelerating the building of the second phase of RSF means that NREL will finish the building years earlier than expected as well as provide a unique opportunity for research and contractors.

"A general rule of thumb for projects is you do something, you learn from it and then your ability to apply what you learned is limited by the next project that you get to do," Philip Macey, division manager, High Performance Buildings for Haselden Construction said. "Buildings are individually unique. You almost never get to apply what you just learned as is the case with the RSF expansion project. This has been an amazing opportunity for everybody."

Once the expansion is complete, visitors to the RSF will not see two different projects. In the end, the RSF will look and feel like one building.

Same ... but Different

"The overall goal is one building. However, one of the biggest differences between the initial project and the expansion is the ease of constructability," NREL Senior Research Engineer Shanti Pless said. "You don't often get to take everything you've learned in one building and immediately replicate it and improve it."

Even though the first phase of the RSF used many of the best construction practices and energy efficiency technologies available, both Macey and Pless have been impressed by the improvement in commercially available building systems for the RSF expansion.

"I've been surprised by how many things have gotten incrementally better—energy performance, thermal performance, and windows. That's usually tough when you are out there on the edge of what is commercially available," Macey said.

"As the design firm, we relished the opportunity to specify improved products for the RSF expansion," added Wendy L. Weiskopf, interior design project manager for RNL. "The product improvements that occurred during the short time since the

This artist's rendering shows how the Research Support Facility looks now that the ARRA-funded expansion project is complete.
Illustration from RNL, PIX 18471

completion of the project's first phase are truly impactful. Given the RSF's status as one of the nation's most energy efficient office buildings, increasing the efficiency for the project's expansion was a welcomed challenge."

Once of the more significant changes in the RSF expansion project is the windows. However, those changes won't affect the day-lit work spaces.

"The first RSF project had one of the most advanced window framing systems available," Pless said. "But, they can still get cool, especially on the north side of the building on the coldest days."

What design teams discovered while working on the RSF expansion design was two-fold. First, they could make the windows slightly smaller and not hurt the day lighting yet still help the thermal performance. Second, the thermal breaks could be improved to further slow cold air getting into the building from the windows.

"It's down to really fine details," Macey said. "In the first set of windows, there was a 'key' that hooked the windows together and it was a piece of structural plastic. For the RSF expansion, it's a much larger 'key', this time made with specially engineered fiberglass. It's that critical place where there's more material that acts as a big washer and stops the thermal transfer."

But according to Macey, small design changes such as this have a lasting impact when multiplied over the nearly 600 windows in the RSF expansion wing.

Solar Air Collector Shoulders More Work

"The transpired solar air collector on RSF has been amazing," Macey said. "We modeled it for a 35°F change in air temperature. It has regularly produced a 50°F change in temperature when it heats the outside air being drawn into the building. It has become so reliable that it is a big piece of the expansion project."

Although the transpired solar air collector has exceeded expectations, it wasn't needed too often thanks to a mild Colorado fall and winter. In the first six months the RSF was in operation, the data center provided enough waste heat so that the transpired solar collector has kicked on mostly for the sunny and really cold, sub-zero days. But there is no data center in the expansion, so the transpired solar air collector is doing all of the work to warm the need fresh outside air.

> "You almost never get to apply what you just learned as is the case with the RSF expansion project. This has been an amazing opportunity for everybody."
>
> —**PHILIP MACEY,** *Division Manager, High Performance Buildings for Haselden Construction*

A significant, but not visible, change is the one made to the thermal storage battery in the RSF basement—also known as the labyrinth. There are no interlaced structural concrete grade beams for thermal transfer in the crawl space of the RSF expansion.

"We were really conservative with the labyrinth design for the first phase of RSF because there was no commercially available software to tell us how to design one," Macey said. "We knew intellectually that warm air will transfer energy into something massive. What we found after we had it operating is that the energy transfer is direct and happens much faster than we imagined. So, there is no labyrinth in the RSF expansion. Instead, it has a large open concrete crawl space."

Users Make All the Difference

"Due to the flexibility designed into the first phase, office workspaces stayed very much the same in the RSF expansion," Weiskopf said.

Talking to engineers and designers alike, one theme stands out. Any building can be incredibly energy efficient, but if the staff does not "walk the talk," the energy savings will be diminished.

"We are studying how well the various occupants in RSF are using energy," Pless said. "We've got energy monitors in 12 work stations throughout the building to understand how people are using the energy efficient work stations.

"Occupant education has been key in all of this. People should understand that it is important for them to put their computer in standby mode when they leave. It is the easiest thing they can do to help save energy."

The great news is that the NREL staffers in the RSF so far are sticking to their "energy budget," which works out to only 55 watts per workstation. The staff has been doing a phased move in over the last few months. Soon the first RSF wings will be completely filled giving researchers an accurate picture of how the computer energy model matches real life.

"Our models have proven to be amazingly accurate so far, especially on the lighting," Pless said. "One interesting note from the computer energy modeling is that people are at their desk less than anticipated. They appear to be in meetings, in conference rooms, or on travel. The model assumed we had people sitting at their desk pretty much all day."

But then again, collaboration is an integral part of life in the RSF.

"The design team was able to cost-effectively add additional conferencing space in the RSF expansion, including the including conference rooms that enhance digital collaboration, which are proving to be a much needed and very successful space for employees," Weiskopf said. (See table below.)

The RSF will serve as a "living laboratory." The expansion includes the following technology and design improvements and enhancements:

- More efficient solar panels were purchased at a lower cost
- Less window area, while still fully day lighting office spaces
- Better thermal breaks in the window frames, leveraging the latest in commercial windows and aluminum frames, driving down energy consumption and increasing comfort
- Hand crank operable windows, increasing user friendliness
- Automatically controlled outlets, simplifying energy savings for staff
- Displacement ventilation in conference rooms, improving thermal comfort
- Natural passive cooling in stair wells vs. mechanical ventilation in the RSF
- Triple pane east/west curtain walls, as compared to double glazing in the RSF
- More flexible lighting controls with more lighting zones, allowing easier reconfiguration and enhanced user experience
- Additional use of LEDs, further reducing the installed lighting power density
- Simplified labyrinth design and reduced costs through enhanced thermal modeling
- True vacancy sensors rather than switched occupancy sensors, simplifying lighting controls and occupant understanding of controls
- Day lighting controls in day-lit stairwells, allowing enhanced energy savings during the day

—Heather Lammers (January 26, 2011)

PROJECT COMPARISONS

	RSF – First Phase (completed in June 2010)	RSF Expansion (to be completed late 2011)	Total
Cost	$57.4 M (construction) $64 M total	$34M (construction) / $39M total	$91.4 (construction) / $103M total
Square feet	222,000	138,000	360,000
Cost/sq ft.	$259 (construction cost only)	$246 (construction cost only)	$254 (construction cost only)
Energy use	35.1 kBtu/sf/yr	33.2 kBtu/sf/yr	34.4 kBtu/sf/yr
Occupants	800	525	1325

At NREL, Even the Ones and Zeros Are Green

Data is something computer users often take for granted. As you type, an unimaginable quantity of ones and zeros fly through networks and cyberspace and are parsed together into documents, photos, music, websites, and more.

All of those ones and zeros have to live somewhere and their "home" often is business data centers. Like any home, data centers use energy—and lots of it. The current estimate is that data centers account for as much as 3% of the nation's energy use. In 2006, the EPA published a report forecasting that by 2011, "national energy consumption by servers and data centers could nearly double … to more than 100 billion kWh, representing a $7.4 billion annual electricity cost."

The data center for the U.S. Department of Energy's National Renewable Energy Laboratory (NREL) recently benefited from an "extreme home makeover" as it moved from leased office space to the lab's ultra energy efficient Research Support Facility (RSF). The lessons learned will help data centers around the world green up their ones and zeros.

How Good is Your PUE?

Power usage effectiveness (PUE) is a key metric for determining how green a data center is and it shows how effectively a data center uses power. PUE is the ratio of the total amount of power used in the data center divided by the amount of power to the computer equipment. The best score a data center can earn is 1.0.

"Our PUE has gone from 3.3 in our old location to 1.15 at the RSF; last month our average was 1.12," NREL IT Strategist, Chuck Powers said. "A data center is typically considered world class when the PUE reaches 1.3—we've redefined world class. We had a lot to live up to and we've been successful."

Like most projects related to NREL's RSF, the beauty of the energy solutions are in their simplicity. While NREL had the advantage of building the data center from the ground up, the practices applied can be used in data centers new and old including:

- Managing air flow—optimizing it and reusing it
- Using energy-efficient cooling techniques
- Increasing operating temperatures
- Upgrading power back-ups.

Managing Air and Reusing It

Airflow management is very important to greening a data center. "The back of a server rack often looks like a bowl full of spaghetti noodles," Powers said. "All of those cords everywhere impedes air flow and keeps the hot air from being blown past the cables. We are very careful to organize the cables in back of the cabinets."

NREL's data center is arranged with hot aisle containment. As the server equipment is cooled, it pulls air from the room through the front of the cabinet and blows warmed air out the back of the equipment air into the containment aisle. *Photo by Dennis Schroeder, NREL/PIX 19216*

At NREL, it might be said that the lab has taken aggressive measures to manage airflow, including setting up the aisles so that the cool air and warm air do not mingle.

The data center is arranged with hot aisle containment. As the server equipment is cooled, it pulls air from the room through the front of the cabinet and blows warmed air out the back of the equipment (warm aisle). The RSF data center has the backs of server rows facing each other and the aisle has a ceiling over it and vents to capture the warm air.

"Because of the way we've contained the heat, we are able to use the heat from the data center to heat the RSF," Powers said. For the first Colorado winter in the RSF, the data center provided a significant amount of heating for the 222,000 square foot facility.

"The hot air from the hot aisle in the data center is 80°F all winter," NREL Senior Research Engineer Shanti Pless said. "In the winter, we used this waste heat for heating of the RSF's outdoor air during the day, and at night when the RSF ventilation system is off, it goes to heating the thermal mass in the labyrinth, so that this otherwise wasted heat is available the next day. It is a simple, yet elegant solution that utilizes the building's concrete structure as a thermal battery."

> "It is a simple, yet elegant solution that utilizes the building's concrete structure as a thermal battery."
>
> —**SHANTI PLESS,** *NREL Senior Research Engineer*

Hot air used to be the bane of data centers, but not anymore. Walking into a 1980s server room often required adding a sweater because the facilities were kept cool to keep the machines from over-heating. "Today's servers can tolerate more heat, with a recommended temperature range of 60–80°F with less than 60% humidity," Powers said. "Increasing the operating temperature to 80°F means you need significantly less cooling and energy. We are continually monitoring our data center temperature to get that number up as high as possible, without impacting our servers."

> "You really have to take an inventory of the natural resources available and leverage those resources to help reduce the cooling, or the power load, for your data center."
>
> —**PHILIP MACEY,** *Division Manager, High Performance Buildings for Haselden Construction*

Mother Nature has a Cool Role

A warmer data center means that in cooler climates like Colorado, Mother Nature can provide natural air conditioning for most of the year.

"You really have to take an inventory of the natural resources available and leverage those resources to help reduce the cooling, or the power load, for your data center," Powers said. "In Colorado, 70% of the year we can just use direct, filtered air to cool the data center. Roughly 30% of the year, we can use an energy efficient evaporative cooling to cool the air a little further. There is only an average of 33 hours a year where we see a combination of high heat and humidity that require chilled water to cool the air."

Colorado also has the advantage of an average of 300 days a year of sun. Photovoltaics (PV) are installed on the roof of the RSF and related parking structures. The combined 2.5-megawatt system will offset the annual energy usage for the entire RSF, the parking areas, and the data center.

Boosting Equipment Energy Efficiency

Moving the data center provided NREL with the opportunity to replace equipment to increase its energy efficiency.

"I had two years to begin the whole replacement cycle before our data center moved to RSF," Powers said. "We replaced traditional servers with blade servers—that saved us 30% on our power. We also were able to virtualize, or take the workload that used to run on 20 or more servers and put it on one energy efficient blade. We went from 302 watts per server to

10.75 watts per server at a 20:1 ratio, a significant reduction in power requirements for servers."

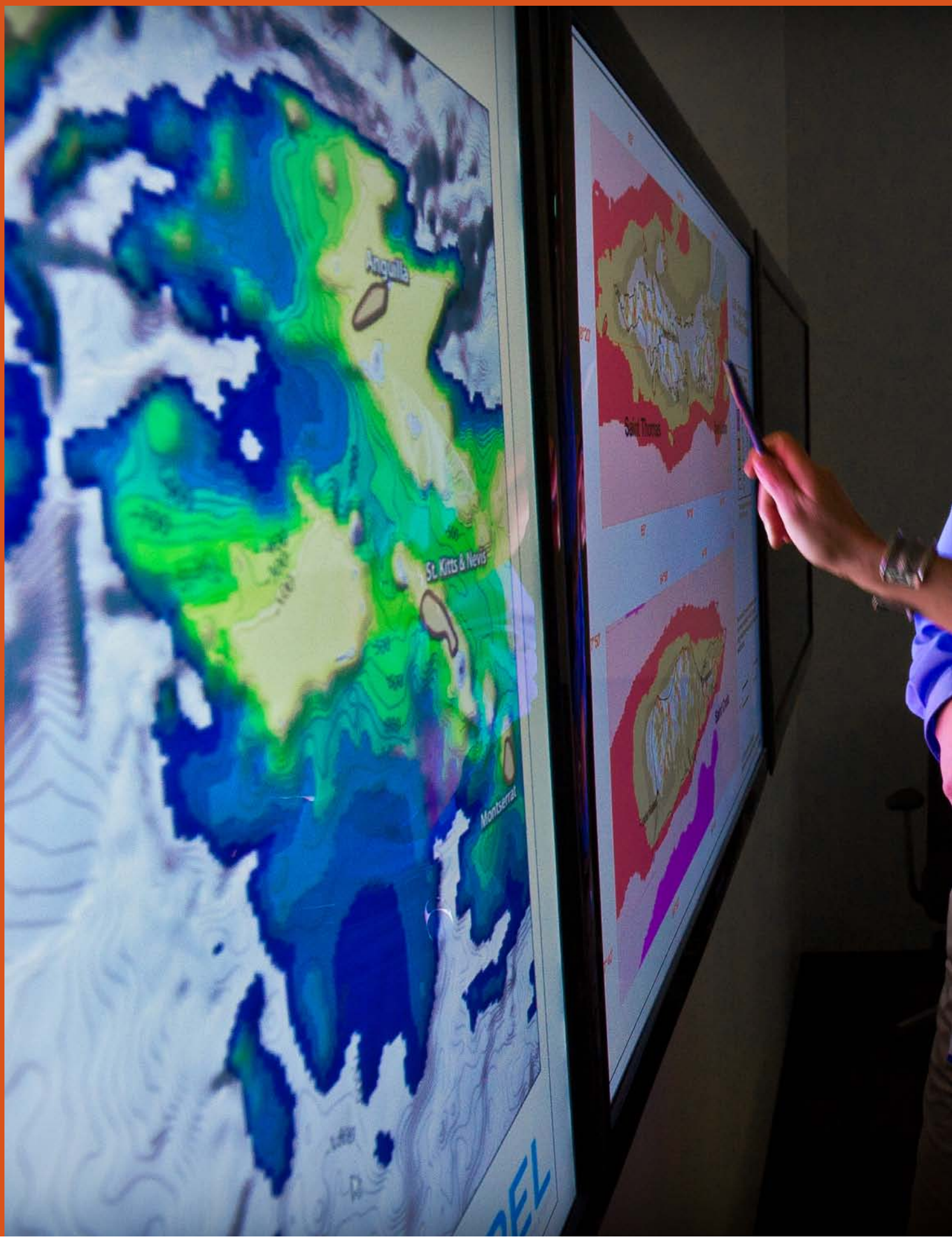
Another major energy savings for NREL was found in the data center's UPS, or back-up Uninterrupted Power Supply. NREL's old UPS was 80% energy efficient and the new one is 97% efficient.

"On a 100 kilowatt (kW) load, right off the top we saved 17 kW, or a 17% reduction in energy consumption," Powers said. "The old UPS produced an additional 20 kW of heat that needed to be cooled. We are experiencing a 19% reduction in our total data center power requirements by replacing the UPS with one that is ultra energy efficient."

The new data center has reduced NREL's annualized carbon emissions for data by almost 5 million pounds per year and operating costs by $200,000 per year.

Much of what was done at NREL can be repeated in any data center. "There is tremendous opportunity here for retrofits as well," Powers said. "NREL is now being asked to help other organizations optimize their data centers. A lot of what we have done can significantly improve the energy efficiency in existing data centers, and many of the practices can be implemented at low cost."

—Heather Lammers (July 6, 2011)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St. Kitts & Nevis
Montserrat
Saint Thomas

NATIONAL AND INTERNATIONAL IMPACTS

NREL facilitates comprehensive energy solutions by helping put renewable energy and energy efficiency technologies to work around the world through a range of capabilities. *Photo by Dennis Schroeder, NREL/PIX 19962*

Biden Says U.S. Will Lead Energy Revolution

America, with its entrepreneurial spirit and innovative national labs, will lead the global clean-energy revolution and reap the economic and environmental benefits that go with it, Vice President Joe Biden vowed in a visit last week to the U.S. Department of Energy's (DOE) National Renewable Energy Laboratory (NREL).

But that will happen only if partnerships between national labs and the most innovative start-ups are encouraged and allowed to blossom, he said.

New initiatives from the DOE are making it easier for small but innovative companies to access technologies developed at the national labs, he said. Now, those licenses are just $1,000, so cost is no longer a barrier, he said.

NREL and other national labs will provide the spark, and private companies will use the efficiencies of the market to commercialize the best clean-energy innovations, Biden told an overflow crowd at NREL's Golden, Colo., campus.

"Now, more than ever, America's future competitiveness depends on our ability to innovate and our capacity to live up to our rich history of technological advancement," said Vice President Biden. "This kind of public-private partnership fosters extraordinary innovation, allows brilliant ideas to develop, and gives businesses the tools they need to bring technology to the market."

Biden prompted a standing ovation from a crowd of scientists and policy makers when he declared that "science is back," as a crucial player in American innovation.

The vice president noted that NREL has in the works such potentially revolutionary technology as a battery that could power a car 1,000 miles between charges, and cost about 5% of today's gasoline costs.

If such ideas are squelched by the faction that would label any government participation as "socialism," rest assured that China or Spain or Brazil or India will lead the clean-energy revolution—with help from their governments, Biden said.

Biden Cites Public-Private Partnerships Going Back 150 Years

Using the government to spark innovation is as American as apple pie, Biden said.

He noted that President Lincoln issued government bonds to help get the Transcontinental Railroad built—and now railroads are a $300-plus billion industry.

President Eisenhower used government aid to help push to the market the innovations from the Argonne National Laboratory that sparked a revolution in telecommunications.

When President Kennedy announced a national initiative to get a man on the moon by the end of the 1960s, neither he nor

NREL Director Dan Arvizu accompanied Vice President Joe Biden on a tour of NREL's Process Development Integration Laboratory (PDIL). The PDIL has six bays where proven and experimental solar cells are made and tested in partnership with private industry. *Photo by Dennis Schroeder, NREL/PIX 20321*

most of the scientists hired for the effort could imagine that the space mission would launch the semiconductor industry, which in turn launched the personal computer, which made possible the Microsofts, Apples, and Googles of the world, he said.

Similarly, no one today can guess at the marvels that will emerge from what is being developed at NREL and commercialized by private industry, he said.

Boulder Firm First to Sign Agreement Under Streamlined "America's Next Top Energy Innovator" Challenge

Biden announced the first option agreement under the DOE's "America's Next Top Energy Innovator" challenge. Boulder, CO-based U.S. e-Chromic, LLC, finalized an option agreement to use NREL technology to retrofit inefficient windows with thin films so that they deflect sunlight in the summer, sharply reducing the need for air conditioning in homes or offices.

"Any of you who've been in an office with direct sunlight know how fast it can make you want to crank up the A/C," Biden said. U.S. e-Chromic CEO Loren Burnett, who was given the honor of introducing Biden, said:

"I'd like to express my sincere appreciation to the Obama administration for creating the Start-up America Initiative, and to DOE Secretary Chu for the America's Next Top Energy Initiative Challenge. Suddenly launching a company around an NREL technology was within our reach."

Buildings comprise about a third of U.S. energy consumption, and windows are a big chunk of the energy drain. So this one technology potentially can lower the nation's entire energy budget by about 1%, Biden said.

NREL's Executive Energy Leadership Program (Energy Execs) participants were special guests at Biden's announcement. Twenty representatives of industry, nonprofit, and government organizations from nine states participated in the 2011 Energy Execs class. The five-month program gives executive decision-makers throughout the United States an in-depth look at renewable energy and energy efficiency technologies.

America has Tough Competitors in Clean-Energy Innovation

America's heterogeneous population and its free-enterprise system have "let us do things no other system in the world has been able to do," Biden said.

> "Now, more than ever, America's future competitiveness depends on our ability to innovate and our capacity to live up to our rich history of technological advancement."
>
> —VICE PRESIDENT JOE BIDEN

But the rest of the world isn't standing still, he said.

"Imagine the first country to create a car battery better and cheaper than batteries today that can store much more energy and go 1,000 miles between charges," the vice president said.

"And imagine the country that doesn't invest in these technologies, that continues to rely on fossil fuels. Some other country will lead us toward these breakthroughs."

The United States "still has the best research universities and the best engineers," Biden said. "And we have 15,000 technologies held by our 17 national laboratories. Each of those technologies now can be developed by private enterprise."

Biden pointed to the DOE-funded, NREL-run SunShot Incubator program, which funds start-ups that have the kind of disruptive technology that can lower the costs of solar energy to be on a par with coal-based electricity.

"The SunShot Incubator program has taken $60 million of DOE money and applied it to 20 start-up companies," Biden said. "Those 20 companies have attracted $1.3 billion in private investment at a time when we are coming out of a recession. They've already added more than 1,000 good clean-tech jobs. And this is just the start."

"The only way to know whether or not these ideas can fulfill the promise that they hold is to give them … to private enterprise to see if they can commercially make them viable," Biden said. "That is not the business of government. That is not our business. … We're in the business of providing the spark."

—Bill Scanlon (May 24, 2011)

Boulder Entrepreneur Rose From Ashes

Loren Burnett lost his business in 2008 when the venture-capital markets dried up in the wake of the banking crisis. About the same time, his wife lost her job.

"The next two years, we continued to search for the next great idea around which to build a company," Burnett, who shared the speaker's podium with Vice President Joe Biden at the National Renewable Energy Laboratory (NREL), said on May 24, 2011.

"We learned about these amazing technologies that NREL was creating," Burnett said. "Clean energy is something vitally important to America, and something I feel passionate about.

"I learned about this groundbreaking research in thin-panel electro-chromic windows."

In January of 2011, Burnett relocated his family from Washington, D.C., to Colorado, "a hotbed for entrepreneurship.

"The challenge for me was that the expenses to license the technology were very high because of the large number of patents," he said.

"That all changed starting in January when President Obama announced the Start-up America Initiative," he said. Then, in late March 2011, The U.S. Department of Energy (DOE) announced "America's Next Top Energy Innovator Challenge," which lowered the financial hurdle for accessing DOE technologies.

Suddenly ground-breaking technology was available to a small start-up.

US e-Chromic, LLC, is just getting started, but the plan is to use technology developed at NREL to make thin films that can be applied to existing windows. The films change colors, so in the summer they'll reflect the sun away, keeping things inside much cooler and dramatically lowering the need for air conditioning.

"It means that you can turn this film on, activate it electronically, so the film actually reflects sunlight and heat away from the building and back to the atmosphere," Burnett said. "We're a brand new company, so right now we're hiring mostly scientists. But after a couple of years, the sky will be the limit. We'll certainly be hiring north of 100 people when we get into full manufacturing."

Vice-President Joe Biden walks to the podium at NREL as Loren Burnett, CEO of US e-Chromic, completes his introduction. Biden delivered a 30-minute speech about innovation and entrepreneurship at NREL. *Photo by Dennis Schroeder, NREL/PIX 18992*

Quicker, Smoother Technology Transfers will Continue

The smooth technology transfer to US e-Chromic is the norm for NREL, Bill Farris, NREL's vice president for commercialization and technology transfer, said. "He came to us, saying he was looking to grow a new business, he wasn't sure what was available but 'here's what I'm interested in.' We started a dialogue with him and it culminated in this transaction. We are rich in technologies, what we need are experienced entrepreneurs like Loren to partner with us and take the technologies to market"

Burnett still has to prove to potential investors that he's the right man with the right business plan, as will others who license innovations from national labs, but technology transfer won't be the big hurdle, Farris said.

"The labs have these technologies, and America has great American entrepreneurs. We must link the two together."

—Bill Scanlon (May 24, 2011)

> "The labs have these technologies, and America has great American entrepreneurs. We must link the two together."
>
> **—BILL FARRIS,** *NREL's Vice President for Commercialization and Technology Transfer*

Clean Energy Top Priority, U.N. Chief Tells NREL

Providing clean, renewable energy to the 1.4 billion people who are living without electricity is the No. 1 priority of the United Nations (U.N.), the secretary general of the U.N. said during a visit on August 24, 2011, to the U.S. Department of Energy's National Renewable Energy Laboratory (NREL).

NREL, through its numerous partnerships with the U.N., is playing a crucial role in making that happen and building a sustainable world, Secretary General Ban Ki-moon told a crowd of researchers assembled at NREL's Research Support Facility. "When we put a priority on renewable energy we address job creation, we address climate change, women's empowerment and food security," Ban said. "Sustainable energy cuts across nearly every major challenge we face today and will face in the future.

"We must work together to realize this initiative of sustainable energy," Ban added, saying the U.N.'s goal is that every village in the world have access to electricity by 2030, and that there is a doubling of renewable energy and energy efficiency by 2030.

"We can create jobs that will stimulate economies and provide universal access to all the people," he said. "That is why the General Assembly has declared next year as the International Year for Sustainable Energy for All."

Ban said that in the past five years he has traveled to both poles, to the Aral Sea, to Mount Kilimanjaro, and other spots around the world seeing evidence of the negative effects of climate change, caused in part by the burning of fossil fuels.

"I'm here at NREL to learn more about how we can work together on international issues, how research communities can help us realize sustainable energy," he told the gathering of NREL employees "I fully support your work."

Ron Benioff, manager of International Programs at NREL, told Ban that NREL is working with 50 countries, ranging from biofuels partnerships with Brazil, to solar work in China and Europe, to helping island nations integrate solar and wind power into their electric grids. Senior Project Leader Phil Voss noted that NREL is working with the Energy Department and

> "We must work together to realize this initiative of sustainable energy."
>
> —**BAN KI-MOON,** *U.N. Secretary General*

NREL Deputy Laboratory Director for Science and Technology Dana Christensen, left, explains the lab's solar testing to U.N. Secretary General Ban Ki-moon as his wife, Ban Soon-taek, NREL Director Dan Arvizu, and Department of Energy Golden Field Office Executive Director for Field Operations Carol Battershell listen. *Photo by Dennis Schroeder, NREL/PIX 19537*

the Department of State to help Haiti emerge from the devastating earthquake with a renewable energy package that will bring electricity to more Haitians than before the disaster. The project has mapped Haiti's solar and wind resources and is working on a plan to turn waste into energy.

NREL Senior Scientist Doug Arent, executive director of the Joint Institute for Strategic Energy Analysis (JISEA), showed Ban an NREL-generated wind resource map of Central America, noting that it helped convince Nicaraguan officials to encourage wind energy development there.

Arent also told Ban that in Nepal an NREL tool generated a quick assessment of the square kilometers available for solar energy in the savannahs and shrub lands, demonstrating that it is an attractive alternative, particularly in rural areas.

NREL Director Dan Arvizu told Ban that the lab's mission is "to be the steward of our national investment in renewable energy and energy efficiency. We have experts from various disciplines, and that allows us to integrate deployment and come up with market solutions for creative ways to speed the deployment of renewable energy," Arvizu said. "And, that drives other agencies to come here for consultation and help with making decisions on visionary policies."

Ban noted that Colorado has the ambitious goal of 30% renewable energy by 2020, and asked what the U.N. could learn from the strategies employed to get there.

Arvizu answered that in the United States a big driver of innovation is economic development. "In a state blessed with many resources, such as Colorado, there is an interest in using the resources in a very sustainable way and in a way that produces new jobs," he said.

"We hope we can demonstrate things locally that can coalesce into national targets," Arvizu said. "Our role here is to be forward thinking on increased use of alternative energy."

Arent emphasized the importance of relying on quality information to make decisions. And he suggested that Ban "embrace the diversity" of resources available in each country, and to realize that each country will have a unique portfolio of challenges and

> "We can create jobs that will stimulate economies and provide universal access to all the people. That is why the General Assembly has declared next year as the International Year for Sustainable Energy for All."
>
> **—BAN KI-MOON,** *U.N. Secretary General*

resources Ban visited NREL's Outdoor Test Facility, where solar cells and panels from many private companies are analyzed for durability, reliability and efficiency.

He was shown flexible solar panels, each of which can provide the electrical needs for a very small house, of which there are hundreds of millions around the world. Executives from Global Solar and Ascent Solar showed Ban low-cost solar panels that are ideally suited for developing countries.

"We put them through a battery of tests and if they perform the way they should, we give them the stamp of approval," NREL Deputy Laboratory Director for Science and Technology Dana Christensen told Ban. "It's that stamp of approval they need so they can go to the banking community and borrow money. The banks know if NREL says it is going to perform, it's going to perform."

NREL computational scientist Jinsuk Lee posed for a photo with Ban and later said it was a thrill. "I very much appreciated that the Secretary General puts so much importance on renewable energy."

—Bill Scanlon (August 25, 2011)

Secretary Chu: We Can Win Clean Energy Battle

Seven trillion dollars are at stake in the global battle to win market share in renewable energy and the United States can win that battle, U.S. Secretary of Energy Steven Chu said during stops in Colorado.

Chu toured a GE-PrimeStar Solar plant in Arvada, Colo., on Nov. 18 that he said was a stellar example of American invention leading to American jobs. Later the same day, he toured the U.S. Department of Energy's (DOE) National Renewable Energy Laboratory (NREL) in Golden, Colo., and spoke to a gathering of NREL and DOE employees.

At PrimeStar, Chu noted that the company adopted technology developed at NREL to build thin film solar panels made of cadmium and telluride. The technology can be more efficient than silicon solar cells and cost much less—because it uses 99% less chemical material than more conventional cells.

GE PrimeStar recently announced plans to build a large manufacturing plant in Aurora, Colo., which will employ about 400 people and build enough modules to power 80,000 homes.

Chu said that if the United States balks at helping private firms invest in the most exciting new renewable energy ideas, there are 50 other nations that will continue to do so within their borders.

In China, Canada, Australia, India, and most of the countries of western Europe, governments are making direct investments or guaranteeing financing—because they know the stakes are so high.

"We can accept defeat and watch the solar jobs go to China, Germany, and other countries, or we can get in the game and play to win, creating jobs in Colorado and across the country," Chu said.

Chu noted that the United States still leads the world in solar innovations—the scientific and research work behind the most important breakthroughs.

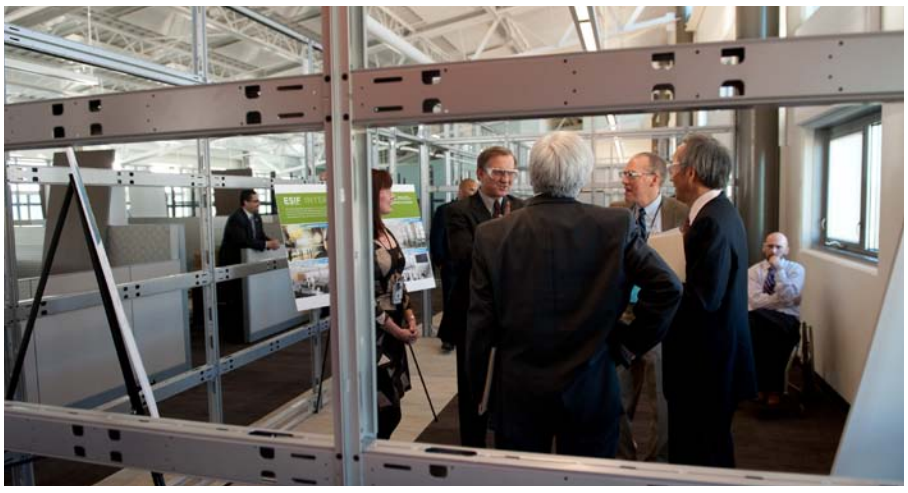
However, the United States lost its lead in exporting solar equipment—China now has a 50% share, while the United States has dropped to 7%.

America Won Back the Lead in Air Transportation

There are precedents in America for technologies that were invented here, usurped by others, and then won back, Chu noted.

The Wright Brothers invented the airplane, but within 10 years, Europe was building better planes and winning the market battle, he said.

"We didn't say, OK, we invented it but now we're waving the white flag," he said. "No, we said, 'we'll win back this technology.' And we did it.



Energy Secretary Steven Chu got to tour NREL's newest buildings during a visit in 2011. *Photo by Dennis Schroeder, NREL/PIX 19823*

"Just like with the airplane, we can and should win back the market lead in renewable energy."

NREL Developed the Solar Cell Technology Employed by PrimeStar

Innovations such as PrimeStar's that are more cost efficient and energy-efficient can make U.S. manufacturing an attractive alternative to shipping that work overseas, Chu said.

In 2007, PrimeStar signed a cooperative research and development agreement with NREL, which had earlier developed the cadmium-telluride technology on which the solar cell is based.

DOE later invested $3 million so the experts at NREL's solar incubator program could help PrimeStar develop the technology to pilot scale.

Now, the largest energy company in the world, GE, has taken a $600 million stake in that technology.

"Global business in renewable energy last year was $240 billion," Chu noted. "It's destined to grow by leaps and bounds. By 2030 it should be $460 billion a year.

"That's $5 trillion to $7 trillion—a huge market potential.

"It's very important that we stay in this game," Chu said. "Is it a game we can win? Absolutely.

"Because of our technological edge, we can be competitive with anyone in the world" if research and development is funded adequately.

At NREL, Chu Talks about Investments, Innovations

Chu toured the PrimeStar plant, then visited NREL in nearby Golden where Colorado Gov. John Hickenlooper introduced him.

"NREL again and again has demonstrated that it is in the forefront of taking ideas and turning them into jobs, and improving the quality of life in Colorado, the nation and the world," Hickenlooper said.

Chu, who won the Nobel Prize in Physics in 1997 when he was director of the Lawrence Berkeley National Laboratory, said wind power now is virtually cost-competitive with fossil fuels, going for about 5 and a half cents per kilowatt hour.

Solar is still more expensive than that, but should reach price parity by the end of this decade or a few years beyond, he said. It will get there because of investments in start-ups such as 1366 Technologies, a company that is using a brand new approach, akin to dipping a strawberry into chocolate, to make solar cells that are thinner and much more cost-effective.

"That's an example of American ingenuity," Chu said. "We don't know if it will work out or not. But it is a good enough idea that 1366 is already getting private investment.

"We haven't lost our stature in terms of our ability to invent and innovate," Chu said. "But when I see what other countries are doing in terms of support … we have to remember: 'Are we in this to win?'"

He says his priority now is to talk to "Democrats and Republicans to make sure we continue our strong investments in energy research. It is so important that we continue this research."

Before taking a look at the construction of NREL's new Energy Systems Integration Facility, where utilities will test their smart-grid capabilities, Chu told the NREL audience that industries as diverse as railroads, telecommunications, semiconductors, and oil and gas survived and prospered because of government investment.

He said when he's asked how long renewable energy should continue to get some subsidies, he reminds that oil has had them for more than a century and jokes that renewables should receive subsidies but, "by no means for more than 100 years."

Some say that with the economic downturn this is not the time to invest in future energy, but Chu says it is the right time.

He noted that in the depths of the Civil War, Abraham Lincoln had the foresight to establish the land grant universities to make agriculture and the mechanical arts more scientific, found money for the transcontinental railroad, and established the National Academy of Sciences to assure that he was getting advice on military and domestic policy from the era's greatest minds.

"Of course, that last one, Lincoln insisted that the scientists give their help for no pay," Chu noted wryly.

"We were a cheap date then, and we're a cheap date now."

—Bill Scanlon (November 21, 2011)

SOLAR

NREL's photovoltaic (PV) research covers the full spectrum from fundamental studies in PV-related materials to commercialization.

Photo by Dennis Schroeder, NREL/PIX 19119

Super-Efficient Cells Key to Low-Cost Solar Power

Thinking big while focusing on small, a solar company and a national energy lab combined talents to develop a solar power concentrator that generates electricity at prices competitive with natural gas.

The Amonix 7700 Concentrated Photovoltaic (CPV) Solar Power Generator, developed by Amonix and the U.S. Department of Energy's (DOE) National Renewable Energy Laboratory (NREL), is the size of an IMAX screen but costs much less than comparable generators, partly because of the efficiency of its small solar cells. It delivers more "energy per acre" than anything yet available in the solar energy world.

The public-private partnership won a 2010 R&D 100 Award at the annual event honoring the greatest breakthroughs in technology, often called "The Oscars of Invention."

NREL's partnerships with industry, such as this one with Amonix, are key to reaching aggressive White House goals including lowering solar energy's installed cost to $1 a watt, which would make America a leader in renewable energy.

The 7700 uses acrylic Fresnel lenses to concentrate sunlight up to 500 times its usual intensity and direct it onto 7,560 tiny, highly efficient multi-junction photovoltaic (PV) cells.

The cells, originally developed by NREL scientists, can convert 41.6% of the sunlight that shines on them into usable electricity in a laboratory setting, a world record. Production cells never work quite as well as cells produced in the lab. But the multi-junction cells on the Amonix 7700 are achieving 31% efficiency at the module level and 27% at the system level in the field, the highest ever achieved for an operating CPV concentrator.

That unprecedented efficiency opened the door to reducing costs and reducing land use—both key for solar electricity to reach cost-parity with fossil fuels.

Seeing the potential for game-changing cost cuts, Amonix, with technical support from NREL's High-Performance PV Project and financial support through DOE and its Solar Energy Technologies Program, redeveloped its flagship CPV system using the multi-junction cells.

A six-inch square silicon wafer in traditional PV panels produces about 2.5 watts of electricity. That same-sized wafer, cut into hundreds of square-centimeter cells in the Amonix 7700, each teamed with a Fresnel lens, produces more than 1,500 watts. It reduces the required area for cells 500 times.

The 7700 already has driven the price of electricity from solar down to the price of electricity from natural gas, according to the California Market Price Referent, which establishes a proxy price for electricity generated by a new state-of-the-art natural gas plant. Solar power is at or near price parity in six other states

A technician at SolarTAC in Aurora, Colo., enters numbers into a laptop as he monitors validation of the Amonix 7700 Solar Power Generators. *Photo by Dennis Schroeder, NREL/PIX 18526*

that share California's sunny and dry climates—Arizona, Nevada, Utah, New Mexico, Colorado, and Texas.

The 7700 also keeps down costs by integrating the lenses, the cells and the mounting structure into a single unit that eliminates most of the parts and costs associated with other concentrator designs. The seven MegaModules that make up the 53-kilowatt system can be hauled on two flatbed trucks, then assembled in the field in hours, rather than weeks.

Low-Cost, Efficiency Attract Interest from Utilities

Those cost-slashing measures, together with the Amonix 7700's large-scale capacity, are catching the interest of utility companies from California to Colorado. Twenty Amonix 7700s, erected on just five acres of desert, can generate more than a megawatt of rated capacity, enough to power 750 homes. That's half the space typically needed to generate that much power.

The Southern Nevada Water Authority and California Polytechnic Institute in California are among those that have purchased the Amonix 7700. The DOE and Amonix are paying for testing of the 7700 at the Solar Technology Acceleration Center (SolarTAC) in Aurora, Colo., to validate the reliability of the system.

Multi-Junction Cells Key to Record-Setting Efficiency

The key breakthrough that lifted the 7700 to a 50% greater power output than previous generations of Amonix generators was the substitution of the multi-junction cells made of gallium indium arsenide and gallium phosphide for the more common silicon cells.

Cells made from gallium, indium, and other elements from the III and V columns of the periodic table are more expensive to produce today, but also can be more efficient at converting the sun's photons into usable electrons for electricity.

NREL scientists had developed a high-efficiency multi-junction indium gallium phosphide PV cell that had been used previously for energy for spacecraft.

DOE, NREL High-Performance PV Project Funded Breakthrough

To offer up the more efficient multi-junction cell as a possible replacement for the silicon cells used in most PV concentrators, NREL issued a request for proposals for projects designed to accelerate multi-junction cell development and their integration into CPV solar systems. NREL awarded Amonix $1.2 million for a project that began in 2004 and concluded in 2008. At the end of the NREL project, Amonix was able to demonstrate close to 31% efficiency for a one-square-meter module—a world record at the time.

> "This could truly shake up the world and add competition to the flat-plate technologies being deployed at utility scale."
>
> —**MARTHA SYMKO-DAVIES,** *NREL architect behind the PV Incubator program*

Martha Symko-Davies, a senior supervisor at NREL, recalled that most concentrator companies could not see the benefits of switching to new-generation solar cells, but Amonix was different, conducting research and development with NREL to overcome stiff challenges.

The first NREL/Amonix project led to a larger award in 2007 from DOE for $15.6 million leveraged by an additional $18 million of investor funds, which helped make the transition to manufacturing of the Amonix 7700 at the company's facility in Seal Beach, Calif.

Amonix has 15 years of experience developing CPV systems, while NREL has a record of more than three decades of research and development in PV technologies. The fruitful partnership, incorporating the high-efficiency multi-junction solar cell with Amonix's flagship CPV system, came about through the High-Performance PV Project funded by the DOE's Solar Energy Technologies Program.

Other DOE-funded support came from the Small Business Innovation Research and Technology Pathway Partnership programs. DOE's Sandia National Laboratories and Brookhaven National Laboratory also facilitated the scale-up of this project.

A conundrum was how to use the highly efficient cells without breaking the bank. Researchers solved that problem by teaming an inexpensive Fresnel lens—at less than $2 a pop—with each of the 7,560 high efficiency solar cells that make up one 53-kilowatt

7700 system. The 500-power amplification of the Fresnel lens allowed the solar cells to be tiny—thus a small fraction of the cost of bigger cells—while still packing record-setting efficiency.

There were other hurdles to clear, too.

Researchers developed a new receiver package of cells and lenses to ensure that the cells would not short out. They solved the distortion problem that happens when a lens doesn't focus all colors on the same convergence point. And they overcame the thermal issues that crop up when a cell has to handle the intensity of 500 suns.

Their efforts were rewarded in the form of $130 million in private equity financing in 2010.

Expanding the Market to Everyone

Solar energy has found a niche on rooftops, especially of green-minded homeowners. But if it is to play a major role in the broader electricity market, it needs to come in at or below the costs of electricity generated from coal, which is projected to cost from 6 cents to 15 cents per kilowatt-hour in four years. The 7700's cost per kilowatt-hour is expected to be well within those price ranges as production and sales continue to grow.

"This development and R&D investment enabled the entire CPV industry," Symko-Davies said. "This could truly shake up the world and add competition to the flat-plate technologies being deployed at utility scale."

The 7700's two-axis tracker can be repositioned throughout the day to follow the sun, but also can be re-positioned to shield the cells from extreme wind, increasing the life of the system. It allows the cells to capture sunlight for a longer time throughout the day and through all seasons of the year. Field tests indicate that depending on the location, the two-axis tracker captures up to 50% more energy than fixed one-axis systems.

Utilities expect their generators to last 50 years. The Amonix 7700 can reach that target with proper maintenance and timely replacement of certain parts, said a spokesman for the company.

Two Axis-Tracker, Modular Design Key to Cost Savings

The two-axis tracker is the only moving component on Amonix's CPV systems and has been designed for reliability and minimum maintenance. The energy needed to move the two-axis tracker amounts to less than 1% of the power output.

> "You simply can't put enough solar systems on rooftops to achieve the scale and capacity necessary to generate electricity in the quantities required by utilities and by society."
>
> —**VAHAN GARBOUSHIAN,** *Amonix's Founder and Chief Technical Officer*

The system has just 12 subassemblies, which are shipped to installation sites for deployment. Once the site is ready, an Amonix system can be installed very quickly, within hours. By contrast, some systems require shipment of thousands of parts to the installation site.

Cost savings were factored in every step of the way—from foundry to grid—said Bob McConnell, who worked at NREL before he left the lab in 2007 to join Amonix and help bring the research to market.

The result is a generator manufactured at about a third to one half of generators using crystalline silicon or thin-film approaches.

Multi-junction cells can operate at higher ambient temperatures than traditional PV cells, making them ideal for sunny and dry climates in the southwestern United States, and ripe for future cost reductions.

The concentrator also is kinder to the environment than most large systems, using no water in its operation. Propped up two feet above the land, it doesn't hinder the movement of wildlife.

"You simply can't put enough solar systems on rooftops to achieve the scale and capacity necessary to generate electricity in the quantities required by utilities and by society," said Amonix's founder and chief technical officer, Vahan Garboushian. "This is a technology that can meet the terawatt (trillions of watts) needs of the world for clean electricity."

—Bill Scanlon (February 16, 2011)

Algorithm Positions Solar Trackers, Movie Stars

Math and programming experts at a federal laboratory took an algorithm used to track the stars and rewrote its code to precisely follow the sun, even taking into consideration the vagaries of the occasional leap second.

Now, the algorithm and its software are helping solar power manufacturers build more precise trackers, orchards to keep their apples spotless, and movie makers to keep the shadows off movie stars.

The Solar Position Algorithm (SPA) was developed at the U.S. Department of Energy's National Renewable Energy Laboratory (NREL) to calculate the sun's position with unmatched low uncertainty of +/- 0.0003 degrees at vertex, in the period of years from -2000 to 6000 (or 2001 B.C. until just short of 4,000 years from now). That's more than 30 times more precise than the uncertainty levels for all other algorithms used in solar energy applications, which claim no better than +/- 0.01 degrees, and are only valid for a maximum of 50 years. And those uncertainty claims cannot be validated because of the need to add an occasional leap second because of the randomly increasing length of the mean solar day. The SPA does account for the leap second.

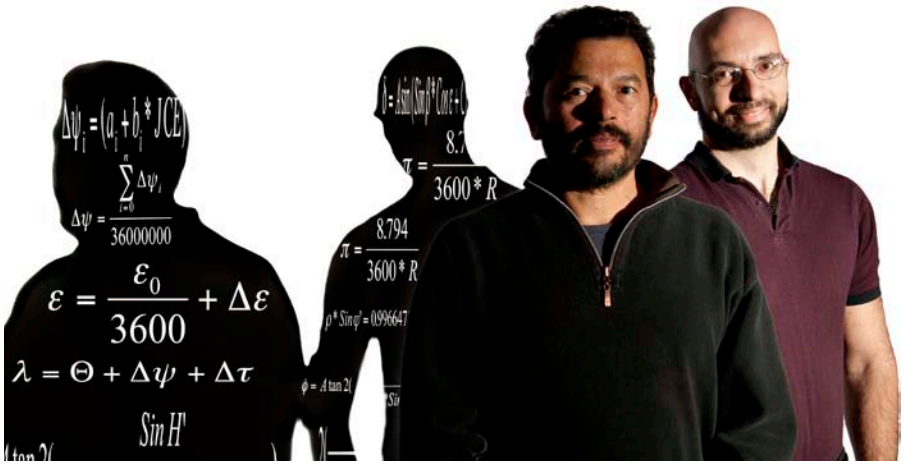
That difference in uncertainty levels is no small change, because an error of .01 degrees at noon can throw calculations off by 2% or 3% at sunrise or sunset, said NREL Senior Scientist Ibrahim Reda, the leader on the project. "Every uncertainty of 1% in the energy budget is millions of dollars uncertainty for utility companies and bankers," Reda said. "Accuracy is translated into dollars. When you can be more accurate, you save a lot of money."

"Siemens Industry, Inc., uses NREL's SPA in its newest and smallest S7-1200 compact controller," says Paul Ruland of Siemens Industry, Inc. "Siemens took that very complex calculation, systemized it into our code, and made a usable function block that its customers can use with their particular technologies to track the sun in the most efficient way. The end result is a 30% increase in accuracy compared to other technologies."

Science, Engineering, and Math All Add to Breakthroughs

An algorithm is a set of rules for solving a mathematical problem in a finite number of steps, even though those steps can number in the hundreds or thousands.

NREL is known more for its solar, wind, and biofuel researchers than for its work in advanced math. But algorithms are key to so many scientific and technological breakthroughs today that a



NREL Senior Scientists Ibrahim Reda and Afshin Andreas developed the Solar Position Algorithm (seen in the background) now used by solar trackers, orchard growers, and movie-camera makers, among others. *Photo by Dennis Schroeder, NREL/PIX 18600*

scientist well-versed in the math of algorithms is behind many of NREL's big innovations.

Since SPA was published on NREL's website, more than 4,000 users from around the world have downloaded it. In the European Union, for the past three years, it has been the reference algorithm to calculate the sun's position both for solar energy and atmospheric science applications. It has been licensed to, and downloaded by, major U.S. manufacturers of sun trackers, military equipment, and cell phones. It has been used to boost agriculture and to help forecast the weather. Archaeologists, universities, and religious organizations have employed SPA, as have other national laboratories.

> "The end result is a 30% increase in accuracy compared to other technologies."
>
> —**PAUL RULAND,** *Siemens Industry, Inc.*

Fewer Dropped Cell Phone Calls

Billions of cell-phone calls are made each day, and they stay connected only because algorithms help determine exactly when to switch signals from one satellite to another.

Cell phone companies can use the SPA to know exactly the moments when the phone, satellite, and the bothersome sun are in the same alignment, vulnerable to disconnections or lost calls. "The cell phone guys use SPA to know the specific moment to switch to another satellite so you're not disconnected," said Reda, who has a master's degree in electrical engineering/measurement from the University of Colorado. "Think of how many millions of people would be disconnected if there's too much uncertainty about the sun's position."

From a Tool for Solar Scientists to Widespread Uses

SPA sprang from NREL's need to calibrate solar measuring instruments at its Solar Radiation Research Laboratory. "We characterize the instruments based on the solar angle," Reda said. "It's vital that instruments get a precise read on the amount of energy they are getting from the sun at precise solar angle."

That will become even more critical in the future when utilities add more energy garnered from the sun to the smart grid. "The smart grid has to know precisely what your budget is for each resource you are using—oil, coal, solar, wind," Reda said.

Making an Astronomy Algorithm One for the Sun

Reda borrowed from the "Astronomical Algorithms," which is based on the Variations Sèculaires des Orbites Planètaires Theory (VSOP87) developed in 1982 then modified in 1987. Astronomers trust it to let them know exactly where to point their telescopes to get the best views of Jupiter, Alpha Centauri, the Magellan galaxy, or whatever celestial bodies they are studying. "We were able to separate and modify that global astronomical algorithm and apply it just to solar energy, while making it less complex and easy to implement," said Reda, highlighting the role of his colleague, Afshin Andreas, who has a degree in engineering physics from the Colorado School of Mines, as well as expertise in computer programming.

They spent an intense three or four weeks of programming to make sure the equations were accurate before distributing the 1,100 lines of code, Andreas said.

They used almanacs and historical data to ensure that what the algorithm was calculating agreed with what observers from previous generations said about the sun's position on a particular day. "We did spot checks so we would have a good comfort level that the future projections are accurate," Reda said.

"We used our independent math and programming skills to make sure that our results agreed," Reda said.

Available for Licensing, Free Public Use

The new SPA algorithm simply served the needs of NREL scientists, until the day it was put on NREL's public website.

"A lot of people started downloading it," so NREL established some rules of use, Reda said. Individuals and universities could use SPA free of charge, but companies with commercial interests would have to pay for the software.

Factoring in Leap Seconds Improves Accuracy

NREL's SPA knows the position of the sun in the sky over an 8,000 year period partly because it has learned when to add those

confounding leap seconds. Solar positioners that don't factor in the leap second only can calculate a few years or a few decades.

The length of an Earth day isn't determined by an expensive watch, but by the actual rotation of the Earth.

Almost immeasurably, the Earth's rotation is slowing down, meaning the solar day is getting just a tiny bit longer. But it's not doing so at a constant rate. "It happens in unpredictable ways," Reda said. Sometimes a leap second is added every year; sometimes there isn't a need for another leap second for three or four years. For example, the International Earth Rotation and Reference Systems Service (IERS) added six leap seconds over the course of seven years between 1992 and 1998, but has added just one extra second since 2006.

The algorithm calculates exactly when to add a leap second because included in its equations are rapid, monthly, and long-term data on the solar day provided by IERS, Reda and Andreas said.

"IERS receives the data from many observatories around the world," Reda added. "Each observatory has its own measuring instruments to measure the Earth's rotation. A consensus correction is then calculated for the fraction of second. As long as we know the time, and how much the Earth's rotation has slowed, we know the sun's position precisely."

That precision has proved useful in unexpected fields.

Practical Uses in Agriculture, Movie Making

One person who bought a license for the SPA software has an apple orchard, and wanted to keep the black spots off the apples that turn off finicky consumers, thus making wholesale buyers hesitate, Reda said.

The black spots appear when too much sun hits a particular apple, a particular tree or a particular row of trees in an orchard.

The spots can be prevented by showering the apples with water, but growers don't want to use more water than necessary.

> "It's vital that instruments get a precise read on the amount of energy they are getting from the sun at precise solar angle."
>
> **—IBRAHIM REDA,** *NREL Senior Scientist*

SPA's precise tracking of the sun tells the grower exactly when the automatic sprinkler should spray for a few moments on a particular set of trees, and when it's OK to shut off that sprayer and turn on the next one. SPA communicates with the sprinkler system so, "instead of spraying the whole orchard, the spray moves minute by minute," Reda said. "He takes our tool and plugs it into the software that controls the sprinkler system. And he saves a lot of water."

Religious groups with traditions of praying at a particular time of day even have turned to SPA to help with precision.

A movie camera manufacturer has purchased the SPA software to help cinematographers combat the precious waste of money when shadows disrupt outdoor shooting.

"They have cameras on those big cranes and booms, and typically they'd have to manually change them based on the shadows," Reda said. "This company that bought it has an automatic camera positioner."

Combining the positioner with the SPA's calculations, the camera can tell the precise moment when the sun will, say, peak above the tall buildings of an outdoor set. "They don't have to make so many judgments on their own about where the camera should be positioned," Reda said. "It gives them a clearer picture."

—Bill Scanlon (March 30, 2011)

Prestigious Cherry Award Goes to NREL Scientist

A physicist from the U.S. Department of Energy's National Renewable Energy Laboratory (NREL) who was a pioneer in multi-junction solar cells for use in outer space and on planet Earth was awarded the prestigious Cherry Award by the Institute of Electrical and Electronics Engineers (IEEE) in 2011.

Jerry Olson, a principal scientist at NREL, received the award at the IEEE's annual Photovoltaic Specialists Conference in Seattle.

Olson pried open the door for multijunction solar cells by showing that a top cell of gallium indium phosphide and a bottom cell of gallium arsenide can capture and convert photons more efficiently into electricity than previous attempts at using other materials.

He and his coworkers showed that the multijunction concentrator cells not only use a fraction of the precious electronic materials used by the thicker flat plate cells, but that they can capture more light through the course of a day.

Olson's breakthrough was embraced by NASA, which uses multijunction solar cells based on his invention to power most space satellites as wells as the Mars rovers Spirit and Opportunity.

To come up with the ideal materials to make a highly efficient solar cell requires an almost slavish attention to the Periodic Table of Elements, as well as a mastery of physics and good instincts.

From Utah with a Saxophone

That those skills were embodied in Olson, who started out college as a music major, is all the more intriguing.

He grew up in Utah playing the saxophone. Even after he switched from music to physics at the University of Utah, it wasn't until years later "that I could even spell 'photovoltaics,'" Olson said.

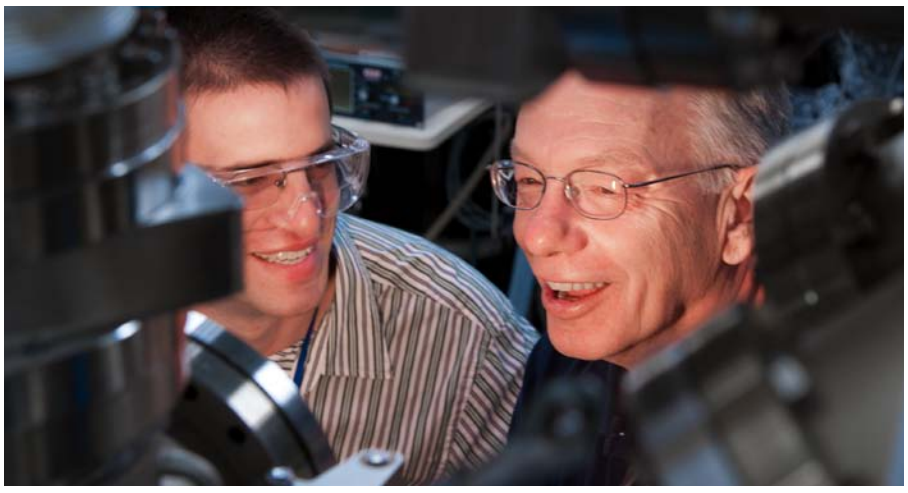
Despite the inauspicious start, Olson in 1978 landed a job at the fledgling Solar Energy Research Institute in Golden, Colo., the precursor to NREL. His assignment: to purify silicon.

He did that for a few years, patenting a new method for refining silicon. Then, in 1982, a change of emphasis switched priorities away from silicon cells and to new materials.

"At first I was kind of miffed that we wouldn't be allowed to develop some promising ideas, but I also know that change is sometimes good," Olson recalled.

Turning Photons into Currents of Electrons

Solar cells work by converting photons into electrons capable of producing electrical power. This can happen in a class of materials called semiconductors. In the dark, most electrons in a semiconductor are confined to the valence band where the electrons are bound to individual atoms and are not free to



NREL Principal Scientist Jerry Olson, right, was honored with the prestigious Cherry Award in 2011. *Photo by Dennis Schroeder, NREL/PIX 19247*

move. Semiconductors also have what is called a conduction band where electrons are free to move. But an electron can only occupy the conduction band if it receives energy from another source, such a photon. The photons must have energy equal to or greater than the so-called band gap between the conduction band and valence band of the semiconductor.

Solar cells convert absorbed sunlight to electrical power such that the current is proportional to the number of electrons that jump the band gap and the voltage is proportional to the band gap energy.

A single-junction solar cell has just one band gap. Scientists try to tune the size of that gap to maximize power conversion efficiency. But this is always a balancing act. If the gap is too wide, the low-energy photons can't make the leap and current is low. If it's too narrow, it's wasting the potential of the high-energy photons, which shed their excess energy as heat when they make the too-easy jump across the gap.

Multi-junction cells, with more semiconductor layers, have more band gaps, and more of an opportunity to fine-tune the size of those gaps.

Still, the enigma was how to choose the perfect combination of materials that matched up in current, lattice, and band gaps so the whole solar cell would maximize efficiency.

The New Kid Finds a New Way

Olson, the rookie in multi-junction solar cells, looked at some papers on the subject and had a brand new thought. Most groups working in the field were looking for band gap combination that would yield maximum theoretical efficiency with less emphasis on the chemical and structural compatibility of the different semiconductor layers.

In essence they were "trying too hard to hit the bull's eye," Olson said.

The key was to set their sights lower and find materials that were compatible (and more likely to be manufacturable) but still had a band gap combination that would give a high, but not necessarily the highest, theoretical efficiency. That combination was a top cell of GaInP with a band gap of 1.9 eV and a bottom cell of GaAs with a band gap of 1.4 eV. These two semiconductors are chemically compatible and they have the same lattice constant, a measure of their structural compatibility.

> "The brilliance of his achievement was partly that he was willing to set that aside even in the face of people telling him that his approach would never work."
>
> —**SARAH KURTZ,** *NREL's Acting Director of the National Center for Photovoltaics*

The first cells in 1985 were fairly anemic with efficiencies less than 10%. But as the understanding and the processes improved, efficiency skyrocketed. The cells set several world records at about 30% in 1994 and 1995. After that, the NREL team and other groups around the world started adding additional semiconductor junctions and the world record steadily increased to where it now stands at 43.5%.

Cherry Award Given for Body of Work

The Cherry Award is named in honor of William R. Cherry, a founder of the photovoltaic community. In the 1950s, he was instrumental in establishing solar cells as the ideal power source for space satellites and for recognizing, advocating, and nurturing the use of photovoltaic systems for terrestrial applications. The William R. Cherry Award was instituted in 1980, shortly after his death. The purpose of the award is to recognize an individual engineer or scientist who devoted a part of their professional life to the advancement of the science and technology of photovoltaic energy conversion.

It is only awarded to scientists who are still actively contributing to the field.

Today's PV concentrators, which can extract 30 to 40 watts out of a small one square centimeter solar cell by using lenses to focus the power of a thousand suns on the cell, are direct descendants of Olson's multi-junction breakthrough.

Olson Could Learn from Other's Mistakes

Sarah Kurtz, NREL's acting director of the National Center for Photovoltaics, joined the lab a couple years after Olson's watershed invention, and the pair has been instrumental in clearing hurdles to ensure that the GaInP/GaAs solar cell remains the top cell for efficiency.

"He told me that he was looking at the (Periodic) Table and noticed that the Gallium Indium Phosphide and Gallium Arsenide would be a good combination," Kurtz said. "At the time the understanding was that combination would separate and produce low-quality material.

"Jerry wasn't dissuaded by things in the literature that might give erroneous directions," Kurtz said. "The brilliance of his achievement was partly that he was willing to set that aside even in the face of people telling him that his approach would never work."

When his first efforts produced a low-efficiency cell, he wasn't discouraged because he knew that the purity of indium could be ramped up quickly if industry could see the advantage.

> "Solar is going to be a very big component of clean energy. It will play an important part in how the world operates in the future."
>
> —**JERRY OLSON,** *NREL Principal Scientist*

"Jerry has always liked looking at the other side of things that people are working on and coming up with the wrong conclusions," Kurtz said.

Ryne Raffaelle, former director of NREL's NCPV, said Olson's work on solar cell materials "established him as one of the true icons of our field."

"It is working with people like Jerry, and the appreciation I have for their tremendous contributions to the field of photovoltaics that make it truly an honor to be associated with our National Center for Photovoltaics."

Olson Sees Bright Future for Solar

Olson now plays the saxophone only at Christmas. He and his wife enjoy bicycling hundreds of miles in places such as northern Spain, Southeast Asia, and Mexico.

The solar industry has made tremendous progress in increasing efficiency and lowering costs, but still faces big hurdles because the cost of energy from other sources are so low, Olson said.

"In the long term, we are going to run out of fossil fuels," he said. "Solar is going to be a very big component of clean energy. It will play an important part in how the world operates in the future."

He believes the future will belong to the PV concentrators, based on the multi-junction solar cells.

"We won't be covering square miles with precious or toxic materials," he said. "Concentrators are going to have a big role. Probably not on roofs, but in subdivisions or in large utilities, especially in sunny areas."

Olson is a principal scientist in the III-V Materials and Devices Group at NREL. The past quarter century, his group has developed and refined the multijunction solar cell, won several patents, and transferred licenses to industry. Besides world records in efficiency, the group has won several awards, including two R&D 100 Awards in 1990 and 2001, a Federal Laboratory Consortium Award for Technology Transfer in 1997, the IEEE Electrotechnology Transfer Award in 1998, and the Dan David Prize in 2007.

The most enduring legacy is the devices based on Olson's original GaInP/GaAs solar cell now being produced by companies around the world for space power and concentrator photovoltaic systems.

—Bill Scanlon (June 20, 2011)

NREL Invention Speeds Solar Cell Quality Tests

To come up with a way to do something 1,000 times faster than it had been done in the past, you have to count on some serendipity—not to mention hard work, collaboration and good timing.

Such was the case with three scientists from the U.S. Department of Energy's (DOE) National Renewable Energy Laboratory (NREL), who somewhat accidentally developed a way to assess the quality of solar cells at a speed that is orders of magnitude faster than had been done before.

The instrument, Real-time QE, licensed and embellished by Tau Science Corp. as FlashQE™, uses light-emitting diodes, high-speed electronics, and mathematical algorithms to measure the quantum efficiency (QE) of solar cells up to 1,000 times faster than had been done before. The technology won a 2011 R&D 100 Award, as one of the year's most significant innovations.

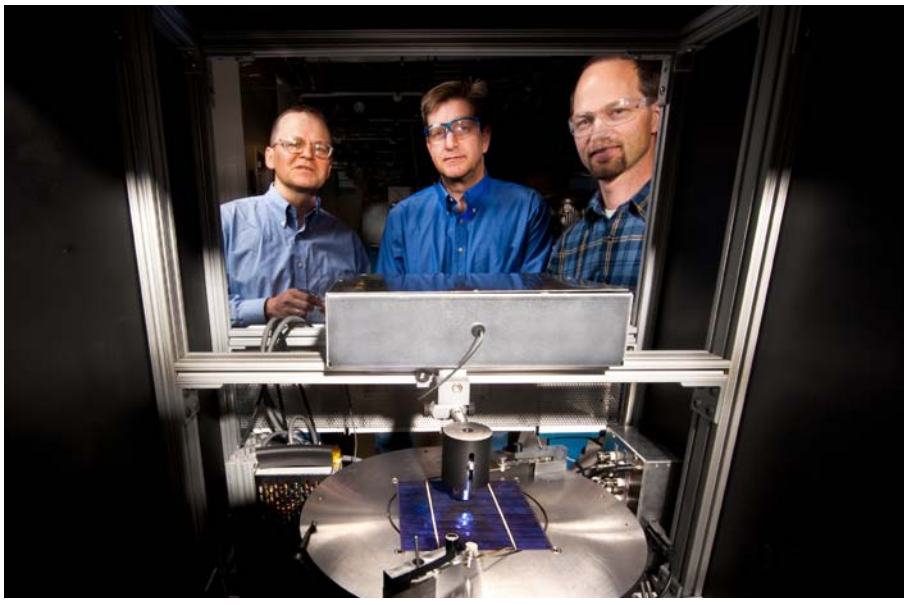
What used to take 20 minutes—and therefore could be done only with random samples of cells—now can be done in a second. That means every single cell on a manufacturing line can be assessed and then sorted into bins so the cells that respond best to, say, red or blue are kept together on the same solar module. That way, a mismatched blue-response cell on a module won't put the brakes on all the work the red-response cells are doing. And that means more efficient conversion of photons into electricity at sunrise and sunset when the red wavelengths predominate.

Speed Means Putting Every Cell to the Test

Quantum-efficiency measurements indicate how well a solar cell converts the various wavelengths of sunlight into electricity. More precisely, QE is the ratio of the number of light-generated charge carriers collected by a solar cell to the number of photons of a given energy that are shining on the solar cell.

Today's solar cell manufacturing lines test each cell to determine useful cell parameters such as how much current and voltage is generated. But those tests give no information about how the cell responds to each color of light in the solar spectrum.

Flash QE's ability to also test for each cell's response to color allows crucial extra information to be fed back into the production line. It does it so fast that cells of the same current and the same response to particular colors can be sorted into particular bins. From these sorted bins, spectrally matched modules can be made to optimize the energy produced throughout a day.



The Real-Time QE instrument, developed by NREL scientists Pauls Stradins, Brian Egaas, and David Young, quickly measures how each solar cell responds to different wavelengths of light. *Photo by Dennis Schroeder, NREL/PIX 18964*

Traditionally, determining how a single cell responds to different wavelengths of light has taken 20 minutes so only about one in 1,000 cells are plucked from the manufacturing process for that extra test.

Flash QE, though, has the speed to supply that extra rich information for every cell.

It likely will mean significant jumps in the efficiency values of future solar modules and arrays that power the fast-growing solar industry as well as much better manufacturing line diagnostics.

FlashQE comes on the market at a time when solar manufacturers are working to weed out any profit-robbing costs from their production lines, boost the conversion efficiencies of solar cells, and move toward DOE cost goals established within the "SunShot" initiative.

> "We just wanted to come up with a real simple way of shining light of different colors."
>
> —**DAVID YOUNG,** *Principal Investigator*

Insights, Timing, and Serendipity

It started in some small labs in NREL's Science and Technology Facility.

"I almost forget what we were originally looking for," principal investigator David Young said, recalling the time seven years ago when he was examining how different wavelengths of light penetrated to different depths in a solar cell. "We just wanted to come up with a real simple way of shining light of different colors."

Enter Brian Egaas, who worked close by and was doing work on quantum efficiency.

"We started looking at LEDs as the source of light, and I remember coming into the lab one day and saying, 'There are enough LEDs now that we can probably get every color of the rainbow,'" Egaas said.

But this work wasn't an official project. So, they went to their group leader, Rommel Noufi, who saw enough promise that he agreed to let them have $1,000 to buy some LEDs.

Egaas found a mom-and-pop shop in Vienna, Austria, that would supply them with LEDs that spanned the solar spectrum—and let them buy just a couple of each color, rather than the hundreds that are bundled together from larger suppliers.

The timing was fortuitous. LEDs spanning the solar cell spectrum wouldn't have been available a year or two earlier, and the computing power to gather all the information needed in parallel wouldn't have been available much earlier than that either.

"This invention came about at the time when it first could come about," Young said. "When enough LEDs were just coming onto the market, and when we had enough high-speed computer capability to get all that data coming out of the cells."

"We mocked it up, and turned on one LED at a time, to make the measurements," Egaas said.

"But there was just too much noise in the quantum efficiency measurement," Young said. "Brian had the whole thing rigged up, and we tried to pick up the speed of each individual measurement, but it was still taking 20 minutes or so to characterize each cell."

Operate It Like the Human Brain

Enter Pauls Stradins, who had a lab in the same corridor, and was keeping a casual eye on progress by Young and Egaas.

"Pauls walks through our lab one day and says, 'Do you realize you can run all those lights at the same time at different frequencies?'" Young recalled.

"When he said that, the light just kind of went on," Young said. "We all realized, 'Oh, yeah, that's the way to do it.'"

"I'd been reading a book on how the brain works," Stradins recalled.

"The brain has many similarities with a computer, but whereas a computer does most things sequentially, the brain has a huge number of parallel channels," Stradins said. "When an image comes in, it doesn't process it 'one pixel, two pixels, three pixels,' it processes it instantly—in parallel."

Applying the brain's parallel approach to the challenge ahead of them—gathering quantum efficiency data from solar cells with a spectrum of encoded LED light colors—proved to be the key.

"We knew there were these mathematical things you can do to filter the processes in real time," Stradins said. "Because computers have so much memory now, we could probably just download a whole chunk for one second and get about a million points."

By arranging for each LED to blink at a different frequency, they could determine how each solar cell generated current in response to certain colors.

"We arranged it so we could take our test cell and run it against a pre-calibrated cell and learn the quantum efficiency of it," Stradins said.

"It was a true collaboration," Egaas said. "There were pieces that everybody had that needed to come together."

Over the next few years, they brought in summer interns to work on a prototype 10-LED device "held together by tape," Young said.

Transferring the Technology to Private Industry

Just in time for a scientific conference, they got the first data that proved that rich quantum efficiency information could be gathered almost instantaneously from a solar cell. Young gave a talk on the instrument at an IEEE Photovoltaic Specialists Conference in San Diego. He realized many in the solar industry were intrigued by the promise of a fast quantum-efficiency tool for analyzing solar cells in the lab and on the manufacturing floor.

The first commercial interest in the product came serendipitously. After being alerted by a colleague that a start-up company was touring NREL trolling for new ideas to market, Young had 10 minutes to write up some notes, then "I gave four guys from Tau Science my off-the-cuff elevator speech."

"They just got it right like that," Young said. "They knew the solar market would eat up a fast QE system.

"They licensed the product and now are selling it."

Tau Science made significant improvements to the instrument, patenting their own ideas for LED optics and handling the vast amount of parallel processed data needed for the technique.

> "It was a true collaboration. There were pieces that everybody had that needed to come together."
>
> —**BRIAN EGAAS,** *NREL Scientist*

"It's been a great collaboration," Tau Science president Jamie Hudson, said, adding that co-founder Greg Horner got to know NREL while he did some post-doc work here.

"Quantum efficiency is an extremely fundamental technique in solar cells, and this is the first time it's been able to be done at speeds to keep up with the line," Hudson said. "It tells you the spectral response of the solar cell and also a lot of information about the front and back surfaces. You're able to look at every sample rather than just one out of 1,000."

Tau Science's first shipment of Flash QE was in early 2011 to Oregon State University, which will use it in its pilot solar-cell production facility.

Fast-Blinking LEDs Illuminate the Cells in Parallel

The FlashQE system uses an electronically controlled full-spectrum light source composed of an array of LEDs. Each LED emits a different wavelength of light. The LEDs illuminate the cell simultaneously, rather than the serial approach of a conventional system. The key to the technology is that all the LEDs are flashed on and off at different frequencies thereby encoding their particular response in the solar cell. High-speed electronics and mathematics cleverly extract the encoded information to reveal a full-spectrum quantum efficiency graph of the cell. A wide variety of information is gathered in less than a second—information about the ability of the front surface of the cell to absorb high-frequency light, the quality of thin-film surface coatings, the ability of the middle region of a cell to absorb a wide range of wavelengths, how well the back surface absorbs lower-energy light, and the ability of the back surface to collect electrons.

For multi-junction cells, Flash QE can detect how each of the layers performs by using the light source itself to "electronically filter" the light to only measure the response of the cell of interest.

Instant Feedback Is a Competitive Edge

Flash QE is the quickest diagnostic tool for the quantum efficiency of solar cells, yielding both a voltage current curve showing the amount of power, and a spectral response gauge, diagnosing how the cells respond to different wavelengths of light.

Manufacturers can get a whole new insight into each of their cells, determining, for example, why they're not getting good responses from their reds.

Or Flash QE can detect that the blue response is slowly getting worse and worse—in real time, soon enough to alert workers that an adjustment must be made to the line.

Flash QE works for silicon cells, and also for multijunction cells that use stacks of materials such as gallium and indium. "With Flash QE, you can look at the individual responses of each of the layers," Young said.

"It's fast enough to do spatial measurement mapping across the cell," Egaas said. "Is the response the same on the edges as it is in the middle? Is there a cooling problem that makes the edge different? They can learn that they have to cool it more slowly, change the process based on the results."

Like Baking With Constant Vigilance

It's like baking bread, Stradins said. Automated bakeries can produce good bread if the parameters are extremely tight, but if anything goes wrong, a huge batch gets wasted.

The family baker, able to take frequent peaks inside the oven, has better quality control. That feedback, with bread or with solar cells, is a powerful tool.

NREL's LED light source also is a stand-alone invention that could be licensed by another company for probing things other than solar cells, ranging from counterfeit bills to skin cancer.

—Bill Scanlon (June 23, 2011)

Speed and Precision Keys to Large-Scale Manufacturing of Solar Cells

When you're making millions of solar cells a week, the process has to be a combination of precision and speed.

That means there has to be a fast way to deposit lightly-doped silicon here while depositing heavily-doped silicon there.

Innovalight's ability to make their Silicon Ink emulsion liquid, without having solids clump together or fall to the bottom, made their product a potential game-changer.

The aim is to moderately dope the emitter between the front grid lines such that most of the sun's light is absorbed in the solar cell's lightly-doped base, while heavy doping in the emitter precisely under the grid lines reduces contact series resistance.

The result is a more efficient solar cell, which means smaller modules can generate the same amount of power. And that means lower costs for the consumer, who can get electricity with a smaller down payment, and lower costs for the manufacturer, who can save hundreds of millions of dollars a year and sharply increase profit.

Dopants Form Negative-Type, Positive-Type Silicon

How does it happen?

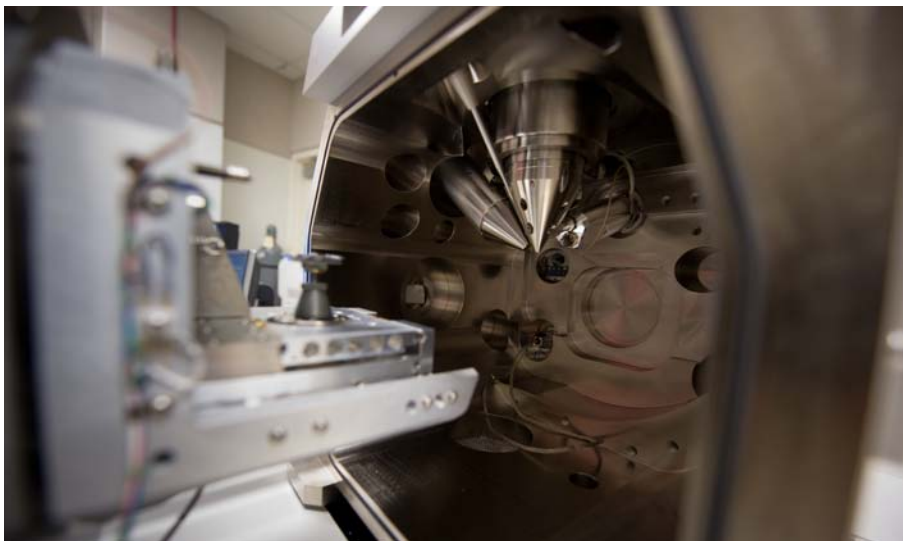
The goal is to make a junction where electrons and holes are in equilibrium but where there is a voltage difference that builds in an electric field. To do that requires two different types of silicon, *p*-type and *n*-type. Each of the types requires different loads of impurities, or dopants.

The dopants or impurities added to the silicon alter the electrical properties. Adding phosphorous produces *n*-type silicon, the "n" standing for free negative electrons. Adding boron produces *p*-type silicon, which produces positive charges or holes. The opposite charges—*n*-type electrons and *p*-type holes—carry the charge in a solar cell when they come into contact at a junction.

To prove that Silicon Ink can accomplish that delicate task of depositing differentiated impurities, Innovalight officials turned to the U.S. Department of Energy's National Renewable Energy Laboratory (NREL).

"They told us what they wanted to prove, so we thought about it and proposed some experiments," NREL Senior Scientist Kirstin Alberi said.

After Innovalight prepared the samples for the experiments, NREL's experts on measurements and characterizations got involved, as did specialists in scanning capacitance, contrast imaging, and microscopy.



The inside of the specimen/vacuum chamber of NREL's FEI Nova 200 dual beam electron microscope used to analyze the topography of materials such as Innovalight's Silicon Ink. The instrument is used to produce site-specific sections for high spatial microstructural analysis. *Photo by Dennis Schroeder, NREL/PIX 19555*

Huge Electron Microscopes Up to the Task

Helio Moutinho, Bob Reedy, Yanfa Yan, Kim Jones, and Manuel Romero started analyzing with huge specialized electron microscopes.

Romero subjected the samples to contrast imaging and, with the aid of an electron microscope, determined both the depths of the dopants and how far they spread laterally.

Using a process called secondary ion mass spectrometry, NREL's scientists sputtered off the atoms and analyzed the mass of elements to determine their exact composition. Then, applying spatially resolved measurement techniques, they created a map to tell them where precisely the elements lie on the sample.

They proved that Silicon Ink can be used to lay down *p*- and *n*-type silicon on the back of a silicon wafer, eliminating the need to have contacts on the front of the wafer.

"They developed the ability to get silicon particles doped in the special way they wanted for *p*- and *n*-type. They could adjust the size of the silicon particle," said Richard Mitchell, NREL's lead investigator on the project.

The contact and emitter design enhancements achieved with Silicon Ink are optimized such that each cell gains a percentage point in efficiency—bumping up from converting, say, 16% of the photons into electricity to 17%. That's actually a 6–7% increase in overall efficiency.

> "They told us what they wanted to prove, so we thought about it and proposed some experiments."
>
> —**KIRSTIN ALBERI,** *NREL Senior Scientist*

The proofs from the tests were enough to attract DuPont, one of the largest corporations in the world, which acquired Innovalight in August 2011.

"It's always good when an industrial capability collects the interest of large corporate financing," Mitchell said. "They certainly did their due diligence, before they decided that this was a good technology to buy."

—Bill Scanlon (September 28, 2011)

Silicon Ink Is Spot On, NREL Experiments Show

Ink can cause a mess, but the Silicon Ink developed by Innovalight behaves itself so well that when it is added to a solar cell it doesn't clump or spill, instead it boosts the cell's power by a startling, profit-boosting 5–7%.

Both solar cells and T-shirts can be enhanced with a screen printer, some ink, and a squeegee.

But it takes a real special ink to suspend silicon nanoparticles so uniformly that it can lay down the precise microns-thick lines needed to dope the silicon emitter exactly under the front metal contacts. Those contacts make a solar cell work.

Innovalight, a small start-up from Sunnyvale, Calif., came up with an ingenious way to suspend silicon in a solution without the tiny particles glomming onto one another or sinking to the bottom of the container.

But could that Silicon Ink prove useful for solar cells?

Researchers at the U.S. Department of Energy's (DOE) National Renewable Energy Laboratory (NREL) proved that the answer is "yes." And the winners could be the solar cell industry and the environment, because Silicon Ink, when added to the manufacturing process, can make solar cells more efficient and save a large plant hundreds of millions of dollars each year.

NREL and Innovalight shared a coveted R&D 100 Award for 2011 for the Silicon Ink technology. Given by R&D Magazine, the R&D 100 Awards are referred to in the industry as the "Oscars of Invention." Silicon Ink's ability to boost efficiency in such a low-cost way prompts some in the industry to label it "liquid gold."

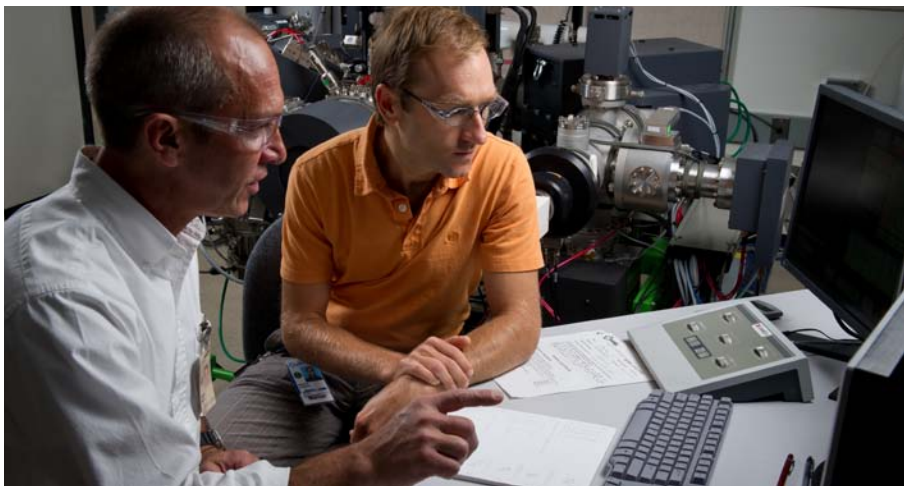
Impurities in Silicon Are Key to Making Contacts, Making Electricity

Silicon is the key ingredient in most of the billions of solar cells made each year worldwide.

Dopants or impurities are used to change the conductivity of silicon and to create the internal electric fields that are needed to turn photons into electrons, and thus, into electricity. One of the great challenges is to distribute the exact concentrations of dopants in precisely the correct locations throughout the device.

Innovalight scored big with Silicon Ink because it found a way to suspend silicon nanoparticles evenly in a solution. Those silicon nanoparticles contain dopant atoms that can be driven into silicon solar cell to form a selective emitter.

What Innovalight's potential customers and investors wanted to know was whether the ink can deliver high concentrations of dopants to extremely localized regions of the emitter and increase a solar cell's efficiency.



NREL's Bob Reedy, left, and Manuel Romero work with a secondary ion mass spectrometer, the same instrument used to analyze dopants and impurities in Silicon Ink for Innovalight. *Photo by Dennis Schroeder, NREL/PIX 19553*

NREL Senior Scientists Kirstin Alberi and David Young listened to what Innovalight wanted to prove and then suggested some experiments that could help them prove it.

"The question was, 'can you print this ink in very well defined lines and drive in dopants only in the material underneath the lines to create a well-defined selective emitter?'" said Alberi, who began at NREL three years ago as a post-doctorate researcher. If so, the increased concentration of dopants right under the contacts would lower the resistance at the metal contact, while the rest of the cell contained low-doped silicon—and that would mean jumps in efficiency and savings of huge amounts of money.

"On some level, you want the emitter to be highly doped so it makes a better contact with the metal," Alberi said. "But if it's too heavily doped elsewhere, that's bad."

That's why a "selective emitter" that is heavily doped only in precise portions of a solar cell is such a promising technology.

The Ink Stays Put, Boosting Efficiency of the Cell

The money question: Can Silicon Ink, using a screen-printing approach, lay down those differently-doped lines without having the ink spread all over the place? If the ink spreads, the spots where silicon is supposed to be lightly doped get the overflow from the spots where silicon is highly doped.

"They needed to prove this to their investors to show that their company was the best at doing this," Alberi said. "They didn't know how to go about proving this, and that's where we were able to help."

There wasn't a "eureka" moment, but the dawning realization that the Silicon Ink was performing exactly as well as Innovalight had hoped was extremely gratifying, Alberi said.

"It was nice seeing that the results were exactly what they hoped they would be," Alberi said.

The scorecard: Silicon Ink, used in a low-cost screen-printing process, delivered a 1 percentage point absolute increase in the efficiency of the solar cells.

If that doesn't sound like much, consider that a typical silicon solar cell array in the field may convert 15% of the photons that hit it into useable electricity. That 1 percentage point increase actually represents a 7% increase in power output for a typical 15%-efficient cell—at a cost that is so low that it basically goes unnoticed at large solar-cell manufacturing plants.

"That's a huge impact for almost nothing," Richard Mitchell, NREL's lead investigator on the project, said.

> "They needed to prove this to their investors to show that their company was the best at doing this. They didn't know how to go about proving this, and that's where we were able to help."
>
> —**KIRSTIN ALBERI,** *NREL Senior Scientist*

A Very Special Ink, a Very Special Screen and Squeegee

In the manufacturing process, the Silicon Ink spills onto a screen, a squeegee pushes it one way as the silicon wafers pass through, then pushes the ink the other way as new wafers appear below the screen. The Ink only reaches the cell at the precise points where a tiny slit in the screen's mask lets it get through. The slits are narrower than a human hair.

Every once in a while, a syringe adds some more Silicon Ink to the screen to ensure the spread is even and the liquid doesn't run out.

The tests proved that the ink stayed put.

Once the silicon and the dopants are where they should be on the unfinished cell, they are heated—not enough to melt them, but just enough to drive the dopants contained within the Silicon Ink into the solar cell.

"Kirstin and the others helped Innovalight prove they can actually get the right kind of selective doping in the areas they need," Mitchell said. "This is the first technology that showed that

exactly where you print is exactly where the cell gets doped—to a precision of a micron."

NREL, Innovalight Partnered on R&D and Overcoming Barriers

The first NREL/Innovalight partnership was a 2008 cooperative research and development agreement, or CRADA, in which Innovalight paid for the expertise of the scientists at NREL, who in return agreed to keep the proprietary technology secret.

Later, Innovalight won a competitive bid to enroll in NREL's Photovoltaic Incubator program in which it had to meet stringent deadlines to deliver improvements in its technology in return for the help of NREL scientists in overcoming barriers.

Innovalight eventually worked out the kinks in its process for using Silicon Ink in an ink-jet application. It showed off the technique to potential customers at a demonstration assembly line at its Sunnyvale, Calif., headquarters.

Customers were unfamiliar with ink-jet printing as it applied to solar cells, so manufacturers balked at making the leap. "But they all had screen printing on their production lines already," Mitchell said. "Adding another screen printer was something their operators would understand."

So, the goals of the Innovalight/NREL partnerships shifted to proving the reliability of Silicon Ink with screen printing.

Chinese Have Signed on to the Technology, United States May Be Next

The manufacturers that have signed contracts for Silicon Ink—all in China, including JA Solar, Hanwha SolarOne, and Jinko Solar—are trying the technology on selected assembly lines. If they get the results expected, they'll likely start using it on all their lines, Mitchell said. If that proves successful, then they might be ready to try Silicon Ink with the ink-jet method, which Innovalight says holds even greater promise to improve cell efficiency and save money.

> "It's a win-win situation where we have access to those resources when we need them. It's good to have those resources in the United States."
>
> —**CONRAD BURKE,** *Founder and General Manager of DuPont Innovalight*

In August of 2011, DuPont acquired Innovalight, a move that could boost the prospects for American solar-cell manufacturing using the Silicon Ink technology.

The partnership with NREL "absolutely was a positive experience from the beginning," said Conrad Burke, who founded Innovalight and is now general manager of DuPont Innovalight, which now has 58 employees.

"There are certain capabilities at NREL that companies of our size, or even larger companies, can't afford to have access to," Burke said. "It's a win-win situation where we have access to those resources when we need them. It's good to have those resources in the United States."

—Bill Scanlon (September 28, 2011)

Breakthrough Furnace Can Cut Solar Costs

Solar cells, the heart of the photovoltaic industry, must be tested for mechanical strength, oxidized, annealed, purified, diffused, etched, and layered.

Heat is an indispensable ingredient in each of those steps, and that's why large furnaces dot the assembly lines of all the solar cell manufacturers. The state of the art has been thermal or rapid-thermal-processing furnaces that use radiant or infrared heat to quickly boost the temperature of silicon wafers.

Now, there's something new.

A game-changing Optical Cavity Furnace (OCF) developed by the U.S. Department of Energy's (DOE) National Renewable Energy Laboratory (NREL) uses optics to heat and purify solar cells at unmatched precision while sharply boosting the cells' efficiency.

The OCF combines the assets that photonics can bring to the process with tightly controlled engineering to maximize efficiency while minimizing heating and cooling costs.

NREL's OCF encloses an array of lamps within a highly reflective chamber to achieve a level of temperature uniformity that is unprecedented. It virtually eliminates energy loss by lining the cavity walls with super-insulating and highly reflective ceramics, and by using a complex optimal geometric design. The cavity design uses about half the energy of a conventional thermal furnace because in the OCF the wafer itself absorbs what would otherwise be energy loss. Like a microwave oven, the OCF dissipates energy only on the target, not on the container.

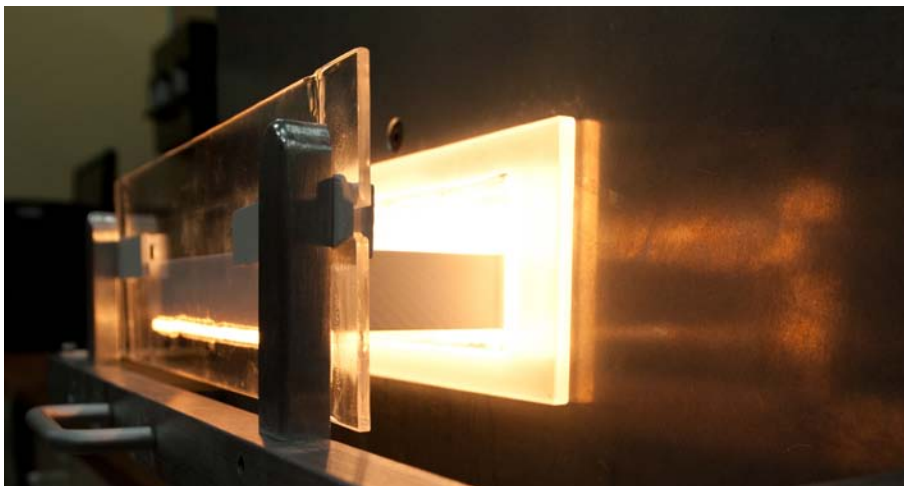
Different configurations of the OCF use the benefits of optics to screen wafers that are mechanically strong to withstand handling and processing, remove impurities (called impurity gettering), form junctions, lower stress, improve electronic properties, and strengthen back-surface fields.

Making 1,200 Highly Efficient Solar Cells per Hour

NREL researchers continue to improve the furnace and expect it to be able soon to hike the efficiency by 4%, a large leap in an industry that measures its successes a half a percentage point at a time. "Our calculations show that some material that is at 16% efficiency now is capable of reaching 20% if we take advantage of these photonic effects," NREL Principal Engineer Bhushan Sopori said. "That's huge."

Meanwhile, NREL and its private-industry partner, AOS, Inc., are building a manufacturing-size OCF capable of processing 1,200 wafers an hour.

At about a quarter to half the cost of a standard thermal furnace, the OCF is poised to boost the solar cell manufacturing industry



The cavity inside the Solar Optical Furnace glows white hot during a simulated firing of a solar cell. *Photo by Dennis Schroeder, NREL/PIX 19755*

in the United States by helping produce solar cells with higher quality and efficiency at a fraction of the cost.

The furnace's process times also are significantly shorter than conventional furnaces. The OCF takes only a few minutes to process a solar wafer.

NREL has cooperative research and development agreements with several of the world's largest solar-cell manufacturers, all intrigued by the OCF's potential to boost quality and lower costs.

R&D 100 Award Winner

NREL and AOS shared a 2011 R&D 100 Award for the furnace. The awards, from R&D Magazine, honor the most important technological breakthroughs of the year.

Billions of solar cells are manufactured each year. A conventional thermal furnace heats up a wafer by convection; a Rapid-Thermal-Processing furnace uses radiative heat to boost the temperature of a silicon wafer up to 1,000°C within several seconds.

In contrast to RTP furnaces, the OCF processing involves wafer heating at a relatively slower rate to take advantage of photonic effects. Slower heating has an added advantage of significantly lowering the power requirements and the energy loss, so it can boost efficiency while lowering costs.

"With all solar cells, optics has a big advantage because solar cells are designed to absorb light very efficiently," NREL Principal Engineer Bhushan Sopori said. "You can do a lot of things. You can heat it very fast and tailor its temperature profile so it's almost perfectly uniform."

In fact, the OCF is so uniform, with the help of the ceramic walls, that when the middle of the wafer reaches 1,000°C, every nook and cranny of it is between 999°C and 1,001°C.

"The amazing thing about this is that we don't use any cooling, except some nitrogen to cool the ends of the 1- and 2-kilowatt lamps," Sopori said. That, of course, dramatically lowers the energy requirements of the furnace.

The use of photons also allows junctions to be formed quicker and at lower temperatures.

As America strives to reach the goal of 80% clean energy by 2035, the White House and DOE are challenging the solar industry to reach the goal of $1 per watt for installed solar systems. To reach that goal, manufacturers need better, less expensive ways to make solar cells. At $250,000, the OCF can do more, do it quicker, and do it at a lower capital cost than conventional furnaces.

Twenty Years of Great Ideas

For more than two decades, Sopori had great ideas for making a better furnace.

He knew that incorporating optics could produce a furnace that could heat solar cells, purify them, ease their stress, form junctions and diffuse just the right amount of dopants to make them more efficient.

"It's always easy on paper," Sopori said recently, recalling the innovations that worked well on paper and in the lab, but not so well in the real world. "There are moments … you realize that no one has ever done something like this. Hopefully it will work, but there are always doubts."

Trouble was, he'd come up with some elegant theoretical solutions involving optics, but wasn't able to combine them with the optimal geometry and materials of a furnace. "We've had a whole bunch of patents (12) to do these things, but what we were missing was an energy-efficient furnace to make it possible," Sopori said.

And then, combining his expertise in optics with some ingenious engineering with ceramics, he had his ah-ha moment:

NREL's OCF uses visible and infrared light to uniformly heat crystalline silicon wafers, especially at the edges, which are prone to cooling or heat loss, at unprecedented precision. The rays heat the sample, but the wafer never physically contacts the lamps.

The OCF is versatile. Each step in the solar cell manufacturing process typically requires a different furnace configuration and temperature profile. However, with the OCF, a solar cell manufacturer simply tells a computer (using NREL proprietary software) what temperature profile is necessary for processing a solar cell.

So, the OCF can perform five different process steps without the retooling and reconfiguration required by the furnaces used today, all the while incrementally improving the sunlight-to-electricity conversion efficiency of each solar cell.

—Bill Scanlon (October 21, 2011)

Light Has Multiple Advantages in Furnaces

Photons have special qualities that prove useful in creating solar cells.

When light is shined on silicon atoms that are bonded electronically to each other it changes their potential. The work by Bhushan Sopori and his colleagues ensures that change is for the better.

The Optical Cavity Furnace (OCF) shines visible and near-infrared light to heat the solar cell, and also shines ultraviolet light to take advantage of photonic effects that occur deep within the atomic structure of the cell material. This combination offers unique capabilities that lead to improved device quality and efficiency.

Iron and other impurities can degrade the silicon quality quickly, noted Sopori, the principal investigator for the OCF, developed by the U.S. Department of Energy's National Renewable Energy Laboratory (NREL) and its private industry partner AOS Inc. "But shining the right light on it can remove that impurity from the silicon," Sopori said. "We've shown that it is possible with the photonic effects to getter these impurities during solar cell fabrication."

Optics can make a lot of things happen at the interfaces in a cell, where, for example, metal can reflect the light and speed the diffusion of impurities, Sopori said.

The lamps in the furnace help fool the impurities in the silicon into moving out of the way, by creating vacancies.

"We call it injecting vacancies," Sopori said. A vacancy is a lack of a silicon atom. "If the atom is missing, you have a vacancy here, an empty space." Those spaces prompt the impurities such as iron to feel much more like moving—and they do so at a much lower temperature than would otherwise be required. The iron moves in with the aluminum, creating an aluminum-iron mix that, happily, is needed anyway as a contact point.

Removing impurities can change a cell's efficiency from 13–17%. What that means is that 17% of the photons that hit the improved cell are converted into usable electricity.

The absence of cooling water and confinement of energy in the OCF proves to be a big advantage for lowering the energy payback time of solar cells.

Other advantages of the photonic approach:

- Silicon cells often have silver contacts in front and aluminum contacts in back. They usually are fired simultaneously as the cell is being formed. The OCF by selectively heating the interfaces of silicon and metal can better control the process, and thus create stronger field surfaces and improved cell performance.
- The OCF uses photons of light to remove weak, cracked wafers from the processing line. Photons can more easily produce a thermal stress in a wafer and screen out bad wafers. The photon process tests the wafers' integrity right after they are cut. The conventional method requires physical twisting and bending of the wafers to test for weakness.

—Bill Scanlon (October 21, 2011)

Bhushan Sopori, a principal engineer at NREL, discusses the capabilities of the Optical Cavity Furnace with colleagues Vishal Mehta and Peter Rupnowski.
Photo by Dennis Schroeder, NREL/PIX 19754

Sun Trackers Gather to Calibrate Instruments

Under a partly cloudy sky overlooking grassy mesas, dozens of cylindrical instruments point toward the sun above the Colorado prairie.

October 2011 marked the 16th NREL Pyrheliometer Comparisons at the U.S. Department of Energy's (DOE) National Renewable Energy Laboratory (NREL), an annual get-together of the most precise radiometers on the globe and the sun-hatted men and women who take care of them.

The instruments, the size of extra-long klieg lights, sit on rectangular tables, carts, wooden boxes, and credenzas on NREL's mesa-top concrete deck, angled south and upward toward Old Sol.

"T minus 10 seconds," time keeper Wim Zaaiman says to the 25 people hunched over computers adjacent to their precious instruments. "T minus 5-4-3-2-1, READ."

At that moment each instrument records a measurement of direct irradiance from the sun. And then 20 seconds later another reading, then another, every 20 seconds until 37 readings have been recorded.

And that's just a sliver of the measurements needed to verify that each instrument is capable of providing honest, reliable measurements of the sun's energy at any moment anywhere on the globe.

Instruments Must Trace Reliability Back to World Standard

"It's all about traceability," NREL group manager Tom Stoffel said during a cloud-inspired break in the action. It's essential that each of these instruments be calibrated to ensure that they're starting from the same reference so that their measures of direct normal solar irradiance, recorded in watts per square meter, can be trusted.

"If I buy 10 pounds of potatoes, I want to make sure that it really is 10 pounds, or the equivalent in kilograms," Stoffel said. "That's why there are international measurement standards.

"We have an international standard for the measurement of the sun, too. The unit of measure is watts per square meter." Accurate solar measurements are important for many applications, including measuring the efficiency of photovoltaic (PV) systems: energy produced divided by available solar energy.

NREL is the only place in the world that holds an annual gathering for radiometers to get recalibrated. Every five years, the instruments and their keepers journey to Davos, Switzerland, home of the World Radiation Center, to ensure that their annual calibrations are on track with the World Radiometric Reference (WRR). So, any agency with a radiometer that gets its calibrations from the annual NREL event has confidence that their instruments are directly traceable to the world standard.

Wim Zaaiman of the European Commission Directorate General JRC holds a new concentrating photovoltaic cell during a calibration event at NREL. *Photo by Dennis Schroeder, NREL/PIX 19759*

"The WRR is the only internationally recognized solar measurement standard," Stoffel said. The yearly instrument comparisons help to maintain the traceability of our solar measurements to this standard, he said.

And that's crucial for researchers and others who track the sun, the solar industry, universities, the radiometer manufacturers, the agencies that are monitoring global climate change and, no less important, the bankers and venture capitalists who decide where to invest in solar energy projects.

> "The goal here is stability and meticulous attention to detail."
>
> —**TOM STOFFEL,** *NREL Group Manager*

Decades-Old Instruments Still Operating Like Clockwork

Some of the instruments have been operating since the 1970s.

The instruments get old and the radiation measures can be affected by paint degradation, changing performance of sensitive electronics or a variety of other factors. But as long as they are calibrated to the world standard, and the adjustments made, they can doing the exacting jobs for which they were made.

"It's not rocket science," Stoffel said, standing next to a 1970s-vintage gold-colored radiometer. The venerable instrument uses a tracker and a pinhole to ensure that the instrument is pointed directly at the sun's center as it moves across the sky.

"We have a simple clock, a pinhole and a target," Stoffel said. "When the sun is out, you'll see the sun's image on this target. That's how you know it is aligned properly." The actual solar measurement is based on the ability to measure the heat generated by the sun as captured by a special purpose optical "cavity." The sensitivity of the cavity is calibrated with a known electrical power before making solar measurements. These instruments are called electrically self-calibrating absolute cavity radiometers.

"The goal here is stability and meticulous attention to detail," Stoffel said.

The gathering at NREL is scheduled for 12 days in the fall each year, during which they can pretty much guarantee they'll have the equivalent of three days of clear sunlight for taking the measurements, and will still have plenty of time for seminars, lectures, and discussions. The talks range from calculating uncertainties to accreditation audits and assessing data quality from solar measurement stations.

A new research focus is to try to be able to forecast what will happen in the next five minutes, hour, or day ahead, so utilities can adjust how much power to generate—welcoming the extra solar energy if it is needed, diverting it if it is not.

It's All About 'Bankability' to Financiers

"Millions of dollars a day can be at stake based on the solar forecasts," Stoffel said. Developing and validating those forecasts depend on the availability of accurate solar radiation measurements. If the radiometers under predict the sun's potential, a promising project could be quashed. If they over predict, the project could face power production deficits.

Precise calculations reduce uncertainty, and that's what financiers want to see before approving utility-scale solar projects, Stoffel said.

Readings from the radiometer can help answer questions such as whether to use concentrating solar power or, say, flat panels, and ultimately whether the financials look rosy enough to give the go-ahead to start construction.

"How do you know when you've leased hundreds of acres from the Bureau of Land Management, and you're proposing a $30 million concentrating-solar-power plant, exactly how much direct sun are you going to get?

"This is all part of due diligence," Stoffel said. "The word is 'bankability,' how bankable are your calibrations? Before the bank actually signs off on it, it's going to want to know if someone came out and measured the fuel supply and whether the radiometer making those measurements had been calibrated properly."

Among the 25 participants at this year's NREL event were people from Lockheed-Martin and NASA, representing the space industry; scientists from Sandia National Laboratories; professors from the University of Oregon; meteorologists from the National Oceanic and Atmospheric Administration and the folks from World Radiation Center in Davos, Switzerland.

"We have most of the key manufacturers of radiometers from all over the world," Stoffel said.

Radiometers Used for Precise Data on Climate Change

Craig Webb, an electronic technician for the DOE's Climate Research Facility in Lamont, Okla.—its Atmospheric Radiation Measurement (ARM) program studies global climate change—was at NREL for the fourth year in a row.

"We have 25 sites in Oklahoma and Kansas, one site in Alaska, two in Papua New Guinea, one in Darwin, Australia," he said. "Our two mobile sites have been to China, Egypt, Germany, and the Azores."

"We look at the sun and do cloud profiling," he said. ARM has 20 years of solar and atmospheric radiation data, currently taken every 60 seconds. They look for changes in particles, dust, water, and vapor, indicators that the climate may be changing.

"They want everybody to be tied to the same base so we can measure accurately the watts from the sun," Webb said. "That's why we're here every year."

Pyrheliometer Pioneer Looks Back

Inside each instrument is a cavity-like detector that traps the photons inside as they rattle around and convert their light energy to heat. The measure of the heat in that cavity elicits the precise radiation per square meter.

One of the men in a sun hat was John Hickey, who is long retired but who made many of the instruments at the 2011 Pyrheliometer Comparisons and who designed the first cavity-type radiometer to go into space.

Hickey, who worked at the University of Rhode Island and then for the Eppley Laboratory, Inc., makes it to NREL every year that his health permits it.

"It's fun being back," Hickey said. "I have friends all over the world but the bulk of them are out here."

Hickey, who is 77, said scientists knew how to take radiation readings by the time he was born; it was just a question of putting all that understanding into an instrument that was reliable and sturdy.

> "Millions of dollars a day can be at stake based on the solar forecasts."
>
> —**TOM STOFFEL,** *NREL Group Manager*

A Quarter Century of Huge Improvements in Precision

Twenty-five years ago, the industry was happy to have daily updates on the sun's radiation intensity in a handful of zones across the country. Fifteen years ago, they were thrilled to be able to get hourly updates on the sun's intensity.

Now, the gold standard is once-a-second updates at the exact spot where the solar installation is envisioned.

NREL has a solar calendar dating back to 1981 with a rich collection of data on the sun's radiation. The main display shows solar radiation for the day, starting with sunrise. They're looking for a smooth, arcing red line, which peaks at mid-day, but which doesn't have the wrinkles and the downturns that happen when water vapor, clouds, and rain get in the way.

The measurements are halted when there are too many clouds in the sky. Even though the radiometers measure energy in all kinds of weather, the actual calibrations of the instruments work best when the photons can enter the radiometers in a steady flow, unshaken by water vapor from clouds.

Stoffel said this year's gathering was a resounding success. "We are pleased to see this year's record turnout," he said, noting that support from DOE's Office of Energy Efficiency and Renewable Energy is what maintains the international solar-measurement cooperation.

—Bill Scanlon (October 31, 2011)

Tiny Solar Cell Could Make a Big Difference

How small can a solar cell be and still be a powerhouse?

How about 600 microns wide—about the diameter of a dot made by a ballpoint pen?

The U.S. Department of Energy's (DOE) National Renewable Energy Laboratory (NREL) recently validated greater than 41% efficiency at a concentration of 1,000 suns for tiny cells made by Semprius—one of the highest efficiencies recorded at this concentration. The energy conversion efficiency of a solar cell is the percentage of sunlight converted by the cell into electricity.

Seed money from DOE, together with the experts at the NREL-based SunShot Incubator Program, lifted Semprius from a small electronics start-up with a novel idea to a real difference-maker in the solar cell world.

Semprius' triple-junction cells are made of gallium arsenide. Low-cost lenses concentrate the sun light onto the tiny cells 1,100 times. Their tiny size means they occupy only one-one thousandth of the entire solar module area, reducing the module cost. In addition, the use of a large number of small cells helps to distribute unwanted heat over the cell's structure, so there's no need for expensive thermal management hardware such as heat fins.

Semprius engineers use the company's patented micro-transfer printing process to allow the micro-cells to be transferred from the growth substrate to a wafer. In a massive parallel process, thousands of cells are transferred simultaneously. This allows the original substrate to be used again and again, dramatically cutting costs. It also provides a way to handle very small cells.

This low-cost approach, which Semprius executives say can cut manufacturing expense by 50%, caught the eye of energy giant Siemens, which took a 16% stake in Semprius in 2011, as part of a $20 million investment from venture capitalists.

SunShot Incubator Program Spurs Private Investment

Since 2007, DOE has invested $50 million for 35 solar start-ups to participate in the PV Incubator program—now the SunShot Incubator—at NREL. Private investment in those firms now totals more than $1.3 billion, a 25-to-1 multiple.

DOE and NREL selected Semprius to be one of their PV Incubator companies in 2010. Incubator companies get $1 million to $3 million to develop their concepts into actual working prototypes or pilot projects. And they also get the expertise of NREL scientists to help overcome obstacles and test for reliability and validity.

Transfer Printing Technology Evolves to Innovative Solar-Cell Use

Semprius' back story, though, begins at the University of Illinois where Professor John Rogers and his team developed the transfer-printing process initially intended for flexible electronics.

Soon, Rogers realized that applying the technology to a concentrated photovoltaic (CPV) design could be much more lucrative.

Semprius grows a temporary layer on the original gallium-arsenide substrate, and then grows the multi-junction solar cell structure on top of that layer. Then, after the wafer is processed,

NREL scientist Keith Emery examines a Semprius solar module at NREL's Outdoor Test Facility. NREL helped Semprius characterize and test its tiny solar cells, which are the diameter of a dot made by a ballpoint pen. *Photo by Dennis Schroeder, NREL/PIX 19946*

the transfer printing process is used to remove the cells from the gallium-arsenide substrate and transfer them to an interposer wafer.

"We're using a completely different approach to what has been practiced," said Kanchan Ghosal, CPV Applications Engineering Manager and the principal investigator for Semprius' PV Incubator Award. "This approach uses micro-cells and transfer printing to significantly reduce the use of materials in highly concentrated PV modules. And it provides a highly parallel method to manufacture the module, based on established microelectronics processes and equipment."

Demand for Concentrated PV Expected to Double Each Year

Semprius broke ground on a manufacturing plant in Henderson, N.C., this year. The state of North Carolina and local agencies kicked in $7.9 million for the 50,000-square foot plant, which is expected to employ 256 people at full build-out.

North Carolina Gov. Bev Perdue cited her state's "investments in education and job training" as the reason the company chose to locate there. The plant is expected to start operating next year, with an initial capacity of 5 megawatts, eventually growing to 35 megawatts.

The available market for highly-concentrated photovoltaics is expected to double or more each year over the next nine years, reaching greater than 10 gigawatts of power by 2020, according to Semprius CEO Joe Carr.

Partnership With DOE and NREL Proves Fruitful

Semprius first looked at using its micro-transfer printing for solar cells in 2007, with the help of a "Next-Gen" grant from DOE's Office of Energy Efficiency and Renewable Energy.

In 2010, Semprius earned one of four spots in what is now the SunShot Incubator, which is funded by DOE and run out of NREL.

Ghosal laughs when he remembers the frantic moments finishing the application for the PV Incubator.

"We barely met the criteria," Ghosal said. "The rules said that you had to have a module ready to be eligible, but we only had small squares with a couple of cells, not a real module."

So, the Semprius engineers "worked feverishly day and night to make our first module."

"Two days before the deadline, we were able to get good results from that first module," Ghosal said. "We applied for the Incubator grant with the results from this module and a scale-up plan."

When Ghosal asked the company's engineers about whether they could meet the hard deadlines and aggressive goals laid down by NREL, "I was met with a lot of apprehension," he recalled. "NREL was asking for a lot of deliverables that had not been done before."

But it all worked out, and Semprius became the latest Incubator company to achieve more than it thought it could via the strict dictates of the NREL contract.

"It looked like a tall order, but we met all our goals," Ghosal said.

Kaitlyn VanSant, NREL's technical monitor for Semprius, said the company is being too modest.

"They actually met the goals a lot faster than originally anticipated," VanSant said. "The goals were definitely aggressive, but they accomplished them quicker than the timeline."

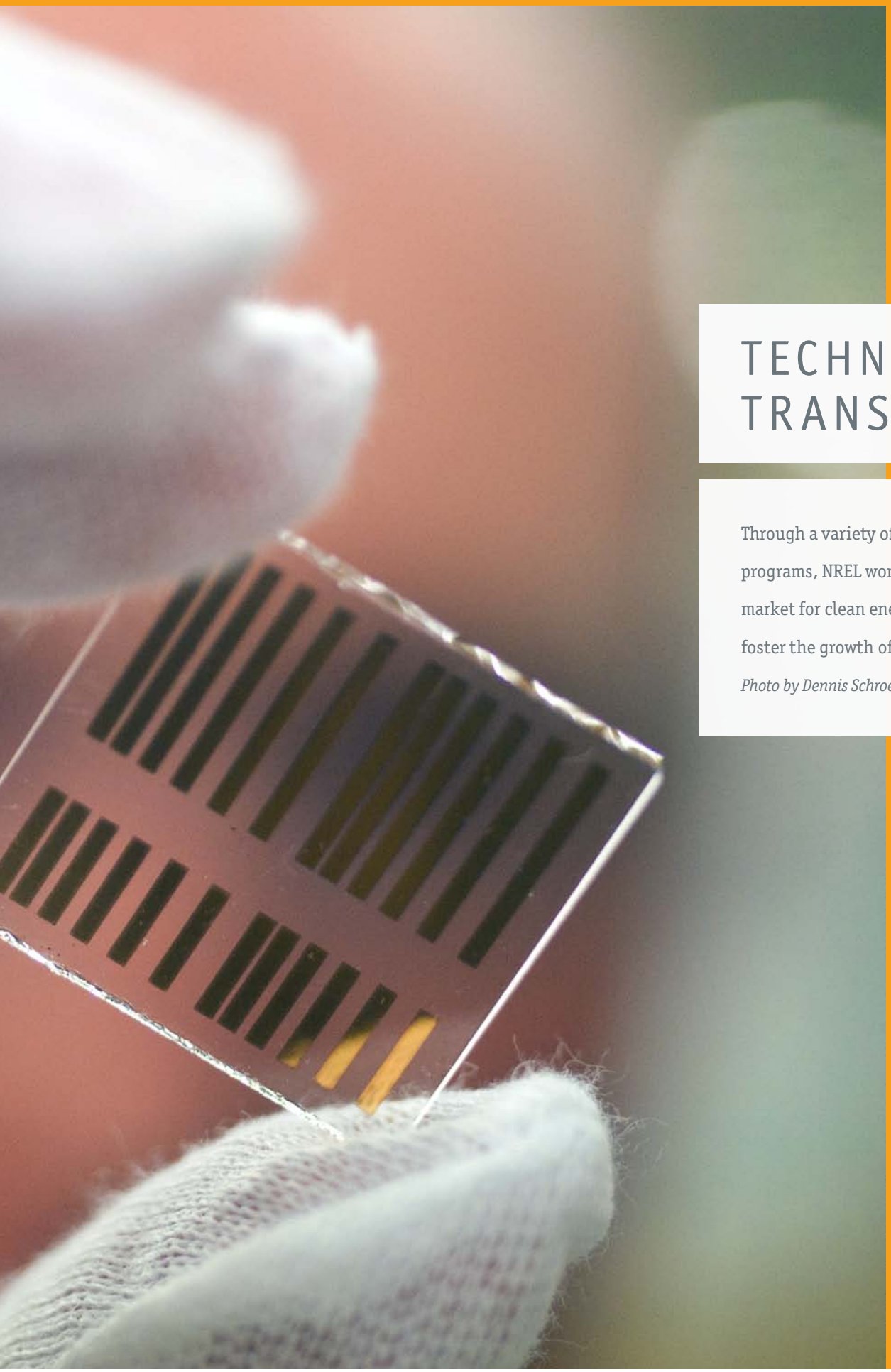
The modules to be made in the North Carolina plant starting next year will be 24 inches by 18 inches, and about 2.5 inches deep, have a concentration of more than 1,100 suns, and an efficiency of more than 31%. These modules would be cost competitive with fossil fuel technology at high volume.

NREL's role was critical, Ghosal said.

"A lot of the early benefits were from the testing NREL could do. NREL has an internationally recognized testing program," Ghosal said. "It's one thing to claim a particular output, but something different to say that it was validated at NREL. It gives that stamp of credibility.

"Also, we learned from NREL how vigorous we had to be in terms of the materials we are using," Ghosal said. "We got an understanding of how it would perform in the field and got some important pointers of what to watch for."

—Bill Scanlon (December 14, 2011)



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/PIX 18302

PV Incubator Pushes Solar Innovations

To catapult America to the global lead in solar manufacturing, the U.S. Department of Energy (DOE) is turning to small start-ups with the kind of disruptive technology that has the potential to lower costs dramatically.

The stale and the satisfied need not apply for the $1 million to $4 million subcontracts awarded through an aggressive photovoltaics (PV) incubator program prodding entrepreneurs to help the United States reach the DOE's SunShot Initiative goal of lowering the cost of utility-scale installations by about 75% to roughly $1 per watt by 2020.

But those with truly disruptive technologies that can greatly change solar-power economics, will find eager, albeit stern, partners in the PV Incubator program, an initiative of the DOE executed through its National Renewable Energy Laboratory (NREL).

By "disruptive" or "differentiated" technologies, scientists or business people are referring to new ways of doing things that overturn the traditional methods and practices, such as the steam engine in the age of sail or e-mail in the age of post-office mail.

The DOE has provided $50 million to small businesses under the PV Technology Incubator program, which started in 2007. The businesses in turn have created more than 1,000 jobs in the United States and have the potential to raise solar-energy capacity in the United States from hundreds of megawatts to thousands of megawatts.

As of March 2011, 20 small businesses had been awarded PV Technology Incubator subcontracts, with DOE's Solar Energy Technologies Program investing about $3 million per company.

The returns on taxpayer dollars have been amazing, said NREL's Martha Symko-Davies, the architect behind the PV Incubator program. The private sector subsequently has invested about $1.3 billion in the companies selected for the PV Incubator program, she said.

"It is even more impressive considering the recent difficult economic times faced by venture capitalists, making them much more selective about funding start-ups," she said. The $1.3 billion "provides clear evidence of the commercial value of these differentiated PV technologies."

NREL Principal Engineer Keith Emery prepares to load three-junction concentrator cells into NREL's High-Intensity Pulse Solar Simulator to test for efficiency. *Photo by Dennis Schroeder, NREL/PIX 18580*

The project represents a significant partnering with U.S. industry to help speed commercialization of PV research and development in the United States to meet the goals of the DOE SunShot Initiative.

"The object is to scale up capacity from prototypes to pilot scale in just 18 months," Symko-Davies said. "We target hard deliverables, firm-fixed price subcontracting. We want to make sure taxpayer money is well-utilized."

Prove Your Concepts or Get Shown the Door

The program works because the companies are pushed hard, Symko-Davies said.

If the companies don't pass a Stage Gate review conducted nine months in, they're dropped, they don't get the remaining half of the subcontract dollars and that money is put back into the pot for the next year's recruits. That happened to three of the 10 companies selected in the first round in 2007. For others, milestones are rewritten or tightened.

President Obama in his State of the Union Address of January 25, 2011, set a goal of 80% clean energy by 2035. A key milestone in the minds of the DOE and the White House is to lower the installed cost of a photovoltaic system to $1 per watt by 2020.

If the installed cost of solar energy can plunge from $3 to $1 in six years, it likely will mean hundreds of thousands of new American jobs and lift the United States to global leadership in both solar innovation and solar manufacturing.

The $3 million or so awarded to the chosen companies often leverages much more, in terms of venture-capital dollars and federal loan guarantees.

The program has helped hatch companies such as Abound Solar of Longmont, Colo., which parlayed a $3 million PV Incubator subcontract and a simpler way to make cadmium-telluride solar cells into a manufacturing process that attracted several times that amount in venture capital money and a $400 million federal loan guaranty. The company expects to employ more than 1,000 when its plants in Colorado and Indiana are at full capacity.

And there's CaliSolar, which attracted venture capital interest after NREL helped it work out the kinks in a process that allows it to use far less expensive silicon in its manufacturing process.

> "The object is to scale up capacity from prototypes to pilot scale in just 18 months. We target hard deliverables, firm-fixed price subcontracting. We want to make sure taxpayer money is well-utilized."
>
> —**MARTHA SYMKO-DAVIES,** *NREL's PV Incubator Program Architect*

CaliSolar now counts its employees in the hundreds and plans to greatly expand manufacturing capacity.

PV Incubator alumnus Solopower, which has a breakthrough electrochemistry process to fabricate copper-indium-gallium-selenide cells at a fraction of the typical cost, recently received a $200 million federal loan guarantee.

Low-Cost, Efficiency Attract Interest from Utilities

The PV Incubator program spun off from DOE's Solar America Initiative, which provided money and expertise to some of the larger American companies.

DOE officials told Symko-Davies that they wanted to encourage game-changing innovations among small start-ups, but wanted to make sure the money was leveraged and spent on the most promising ventures.

Besides the financial resource, the companies get access to the facilities and expertise at NREL, which has been researching solar energy since 1977.

Setting Tough Goals Inspires Harder Work

Early on, NREL helps the companies write a statement of work with tough, specific goals, such as raising the efficiency of their cells to 15% or cutting manufacturing costs in half.

"We hold them to the plan. If you said you're going to produce a cell with 15% efficiency by this date, you had better get it

done," Symko-Davies said. NREL has the best testing facilities and experts to make sure that these companies are successful in meeting their aggressive goals.

"Initially, these companies are very unhappy with Martha, because they think the goals are too aggressive," Mowafak Al-Jassim, an NREL scientist who works with some of the companies, said. "But almost universally, they come back and say, 'you guys pushed us so hard. Without you we wouldn't have accomplished what we did.'"

Symko-Davies and her team of four oversee the program, but at least three or four NREL researchers are brought in to help each company—growing the size of the operation, reducing capital expenses, scaling up the efficiencies. "We're in your face," Symko-Davies said. "If you don't want to accept NREL as your partner, don't apply. But we'll help enable U.S. manufacturing quickly and reliably."

From Concept to Prototype; From Prototype to Pilot Production

Some of the money goes to companies that already have a prototype and need to lift it to a pilot-scale operation. And some of the money goes to companies that only have a concept but want to turn it into a prototype.

The start-ups' proposals are reviewed by an external committee. The most promising ideas warrant a site visit.

"We're looking to verify what they put in their proposals," Symko-Davies said. "Do they actually have a prototype? Sometimes there's a tendency to boost up the proposal. How are they going to get from point A to Z?"

NREL helps the companies overcome R&D hurdles quickly. If a company has a breakthrough technology, but its super-thin wafer keeps bowing or can't make contact with the substrate, NREL experts can help them toward a solution.

Symko-Davies said she is optimistic about the future of solar energy in the United States, "If we do it right, there are companies that can actually make this happen."

She points to PV Incubator graduate Innovalight, which invented a liquid form of silicon, Silicon Ink, which uses an ink-jet approach to depositing layers on solar cells. The innovation dramatically improves the performance of solar cells and can boost profits for a typical American manufacturer by 20%. Five of the world's leading solar cell producers have signed licenses to use Silicon Ink in their production lines.

> "You've got to be doing something that is a game-changer. The ship is sailing. Are you going to be on the ship?"
>
> —**MARTHA SYMKO-DAVIES,** *NREL's PV Incubator Program Architect*

Grants Make the Difference in a Tight Lending Environment

The free-flowing venture capital of a few years ago has dried up.

Four or five years ago, "If you could spell the word 'solar' venture capitalists would give you money," Al-Jassim said. No more.

Today, the $3 million from the PV Incubator program is huge.

Abound, Solopower, and CaliSolar are prime examples of what America needs: startups that can make high-efficient solar cells in a non-labor-intensive way so America can compete with China and other countries in the manufacturing arena, say the NREL scientists involved in the PV Incubator program.

The PV Incubator program wouldn't likely touch a company that proposes to make regular silicon solar cells, for example, because established companies already manufacturing these materials are trying to reduce costs. But if a company has a way to use a fraction of the usual amount of silicon, or simplify the manufacturing process, or use only abundant materials, then it can be a part of a growth-boom in good-paying U.S. clean-energy jobs.

Testing Outside-the-Box Technologies at NREL

The companies make trips to NREL in Golden, Colo., or send samples to NREL's Process Development Integration Laboratory

which has huge bays devoted to different approaches to, or different materials for, making solar cells.

"We work on specific obstacles," Al-Jassim said. "We have sophisticated techniques, especially in measurement, that these guys couldn't afford. We are their seeing-eye dogs. If this cell works, but that cell doesn't, we can tell them why that is the case. We provide the intellectual guidance on why the product isn't working up to par. We show them how they can tweak it."

The companies also take advantage of NREL's state-of-the-art testing facilities, such as the Outdoor Test Facility and the Thermal Test Facility. Quality and reliability are huge issues. The NREL testing instruments can simulate the lifetime of a product by exposing it to several hundred suns of infrared, but not ultraviolet, light. That way, they know in a few months whether they can give their product a five-year or 10-year or 50-year warranty. It gives them and their potential investors confidence that this is a bona fide product that will hold up over the years.

NREL's Keith Emery, who is the manager of the Cell and Modular Performance team, oversees the testing of the PV Incubator technologies.

Without the PV Incubator program, "there would be no place where well-thought-out innovative ideas could be funded," Emery said. "We look for innovative ideas that aren't ready for prime time, that aren't ready for current manufacturing and are a little too high-risk for the venture capital community."

"Almost every successful solar program started at this level, with subcontracts at NREL."

NREL, which announced last month the four companies selected in the fourth round of the PV Incubator program, continues to look only for the most promising cost-cutters and efficiency-enhancers.

"Unless it has the potential of dramatically reducing cost, we're not touching them," Symko-Davies said. "You've got to be doing something that is a game-changer. The ship is sailing. Are you going to be on the ship?"

—Bill Scanlon (March 22, 2011)

NREL Helping the Army Be as Green as It Can Be

"Army green" may lead the average person to think about the color of uniform fatigues or an original Army Jeep their grandfather's garage, but U.S. Department of Energy's (DOE) National Renewable Energy Laboratory (NREL) is helping the U.S. Army with a new program that will have Army installations across the country thinking "green"—all the way to net zero.

Funding from DOE's Federal Energy Management Program (FEMP) is enabling NREL to partner with the Army to jump start the "Army Vision for Net Zero" program. All agencies in the federal government are looking for ways to meet mandates to reduce energy as a result of Executive Order 13514, "Federal Leadership in Environmental, Energy, and Economic Performance."

It expands energy reduction and environmental performance requirements for federal agencies so that they will take the lead in creating a clean energy economy. The executive order calls for new buildings to be net zero energy by 2030, and seeks a 30% reduction in water use and a 50% reduction in waste that goes to landfills.

The National Defense Authorization Act also mandates that the Army produce or acquire 25% of its energy from renewables by 2025. Through the Vision for Net Zero program, the Army will look for ways to manage its installations not only on for net zero energy, but for water and waste as well.

"The first priority is less," Assistant Secretary of the Army for Installations, Energy & Environment Katherine Hammack said. "If you use less energy, you don't have to buy as much—or you don't have to make as much from alternative energy sources or renewable energy sources. So if you look at energy, that is a focus on energy efficiency. If you're talking about water, then that's water conservation. Or even if you're talking about waste, that's reducing the amount of waste we have in the steam."

Let the Challenge Begin

Army installations have nominated themselves to participate in the Net Zero Installation program. On April 19, an announcement will be made at the Army's Installation Symposium and Exposition identifying five bases selected to work toward each of the goals—net zero energy, net zero water and net zero waste. In addition, more than a dozen bases have signed up to achieve all three goals and some will be asked to work toward a triple crown.

At the Army's request, NREL created the application for the Net Zero Installation Energy program. The NREL team currently is evaluating more than 60 applications from installations around the country. Net zero energy attracted the most applications with 53 installation expressing interest, 23 installations signed

Katherine Hammack, Assistant Secretary of the Army for Installations, Energy, and the Environment, gets a tour of NREL's ultra energy efficient Research Support Facility. Funding from DOE's Federal Energy Management Program is enabling NREL to partner with the Army to jump start the "Army Vision for Net Zero" program. *Photo by Dennis Schroeder, NREL/PIX 20005*

up for Net Zero Water, and 24 for Net Zero Waste, with 14 expressing interest in all three.

NREL will whittle down the list to the best candidates and provide recommendations and technical information to Army leadership for final selections.

"NREL is perfectly situated to assist the Army with this project," NREL Senior Vice President Bobi Garrett said. "NREL has done a number of net zero energy assessments and we've written guide for net zero energy at military installations. We bring a great deal of experience that is valuable to the process."

"The Army had this net zero goal and we saw it as an opportunity for NREL to provide support and engagement—thanks to FEMP funding," NREL Senior Project Leader Sam Booth said. "It started with us helping the Army define net zero energy and helping them think about the selection process for the bases interested in joining the program."

Installations provided NREL with information about command level support, their vision for net zero, a history of energy efficiency strategies, and any mission critical needs for moving forward. Once the finalists for the program are announced, NREL will work with bases on net zero energy efforts and Pacific Northwest National Laboratory will work with installations on water conservation and waste diversion.

The game is not over for Army posts that will not be a part of the pilot program. "That doesn't mean that the others are done," Army Net Zero Installation Portfolio Manager Kristine Kingery said. "We are going to look to all installations to pursue becoming net zero—no matter what. We plan to leverage lessons learned at the pilot installations as we expand the program to 25 installations in 2014."

Army Already on Its Way to Net Zero

Beginning in 2008, FEMP, along with primary support from NREL, Department of Defense (DOD) and the Armed Services, engaged in a program looking for potential for net zero installations (NZEI) across all branches of the military. A 2008 report from the Defense Science Board concluded that critical missions at military bases are facing unacceptable risks from extended power losses. To address this concern, DOD intends to establish NZEIs, defined as military installations that produce as much energy on site from renewable energy generation as they consume in their buildings, facilities and fleet vehicles. To achieve NZEI status, an installation must minimize its energy consumption through conservation and efficiency measures, then meet the balance of energy demand with renewable energy. NREL helped identify pilot locations for NZEIs for each of the services. The Army's location is the Pohakuloa Training Area in Hawaii.

"We had some things in the works before the launch of current our net zero installation challenge," Kingery said. "Assistant Secretary Hammack has expanded the program accordingly, looking for ways to better manage our natural resources. We need to do this because it has mission and operational implications and we believe that in the long run it will benefit us financially."

The installations selected for the Army's program likely will need some project support that NREL is uniquely positioned to provide. One of the questions on the NREL-created application simply asks Army staffers, "What additional support do you need?" According to Booth, most of the applications list something—from subject matter experts to contractors to project managers.

Other installations participating in the Army Vision for Net Zero could learn from projects at Fort Bliss:

- Solar daylighting in the dining facility, warehouse and gym
- Photovolatics on a number of buildings including 100 kW on the Dining Facility
- Building envelope renovations such as replacing single pane windows with energy efficient windows
- Utility monitoring and control for heating and air-conditioning systems in approximately 70 buildings with an additional 557 buildings to be completed by 2012
- A study that confirms the technical and economic feasibility of hybrid Waste-to Energy/Concentrating Solar Power plant at Fort Bliss for 90 to 140 megawatts, based on the City of El Paso committing to provide 1 million tons per year of municipal solid waste.

"The Army's net zero vision is a holistic approach to addressing energy, water, and waste at Army installations," Kingery said. "We look at net zero as a force multiplier for the Army that will help us steward our resources and manage our costs."

—Heather Lammers (April 7, 2011)

NREL Partners Take Technology to Market

Data from the U.S. Department of Energy (DOE) show that the National Renewable Energy Laboratory (NREL) leads all DOE national labs when it comes to working with businesses on research and development efforts to commercialize cutting-edge technologies.

Cooperative research and development agreements (CRADA) are used by the labs and collaboration partners to promote technology transfer. Under CRADAs, outside groups can benefit from NREL's research capabilities, technologies, or intellectual property to create or bolster an existing or start-up business.

"We do cutting-edge research here, companies know that and they call us to collaborate," NREL Vice President for Commercialization & Technology Transfer William Farris said. "Each year DOE collects data from the labs about their CRADA activities. When you look at those data, you see that NREL is actively engaged in collaborating on research and moving technologies into the market and we outdo all other DOE labs including labs that are many times our size."

Part of NREL's success is because of the lab's mission to grow and support new clean technology industries. NREL's work runs the gamut from basic science all the way through to applied research in renewable energy and energy efficiency technologies.

"NREL has the basic research capabilities but we are never going to be the ultimate producer of a commercial product. That is the role of the private sector," Farris said. "We may come up with a new and innovative technology, but for it to end up on a utility scale deployment or in the fuel tank of a vehicle; there is a commercialization partner who is going to invest in the business, facilities, sales, support—all of which is done outside of the lab. So, it is an ideal arrangement to couple government investment in new technologies with the commercial drive of the private sector."

According to Farris, most companies do not have the resources to fund research that is 10 years away from a commercial product. He sees a role for the federal government to take on some of the early stage risk, with the investment paying off with an industry that will lead to U.S. manufacturing, jobs, and businesses.

OPXBIO—Making Diesel From Hydrogen and Carbon Dioxide

One example of a company leveraging NREL resources and DOE funds to advance fuels technologies is OPXBIO in Boulder, Colo. Using $6 million in Electrofuels grants from DOE's Advanced Research Projects Agency-Energy (ARPA-E) and adding $2 million of its money, OPXBIO is focused on taking energy from hydrogen and converting it into liquid transportation fuels.

NREL Researcher Grant Balzer cultivates strains of metabolically engineered bacteria for biodiesel production in the bioscience research lab. This work is part of a CRADA agreement with OPXBIO under DOE's ARPA-E program. *Photo by Dennis Schroeder, NREL/PIX 19606*

Electrofuels are fuels derived from electricity or electrons. In this case, the CRADA partners are using a microbial approach.

"We are using our technology to optimize a microbe that will convert hydrogen and carbon dioxide gas directly into diesel," OPXBIO Chief Scientific Officer Michael Lynch said. "NREL has expertise in how you make hydrogen—we are leveraging that in reverse. How a microbes eat hydrogen more efficiently to produce the diesel."

The processing being studied by OPXBIO, NREL and Johnson Matthey, starts with simple hydrogen gas and carbon dioxide (CO_2) gas. The CO_2 supplies the carbon, which is the backbone of the fuel molecule; and the hydrogen supplies the energy. The gases are mixed in a big water tank with the microorganism, and the microorganism takes up the gases and converts those directly to a diesel molecule.

"If we use the fuel directly, the molecule we are making is equivalent to a biodiesel molecule," Lynch said. "We can either use it in biodiesel tanks or we can upgrade it with a … catalyst to produce traditional diesel or jet fuel."

> "We do cutting-edge research here, companies know that and they call us to collaborate."
>
> —**WILLIAM FARRIS,** *NREL Vice President for Commercialization & Technology Transfer William*

For NREL scientists, the chance to work with OPXBIO's microbe is an opportunity to grow research in a new direction. "This project will enable NREL to gain expertise on this unique microbe that can use hydrogen, carbon dioxide to create a new direct drop-in fuel, meanwhile OPXBIO can take advantage of NREL's in-house expertise in microbial hydrogen and carbon dioxide metabolism." NREL Principal Scientist Pin-Ching Maness said.

At the end of the three-year ARPA-E program, OPXBIO plans to be at the stage to produce diesel at pilot scale.

> "NREL has the basic research capabilities, but we are never going to be the ultimate producer of a commercial product. That is the role of the private sector."
>
> —**WILLIAM FARRIS,** *NREL Vice President for Commercialization & Technology Transfer William*

PrimeStar Solar & GE—Commercializing CdTe PV

In February 2007, NREL and PrimeStar Solar, Inc., announced an $870,000 CRADA to transition NREL's cadmium telluride (CdTe) photovoltaic (PV) technology to commercial module production.

"From the day that PrimeStar Solar was founded, we have worked hand-in-hand with NREL," PrimeStar Vice President for Technology Fred Seymour said. "It took some months for us to work through the licensing, but it was very clear from the beginning that NREL wanted to help."

PrimeStar Solar formed around NREL's technology and the desire to make it commercial. "We were the information source for the people at PrimeStar who were going to go after the technology, but they could benefit from our knowledge of thin-film solar cells," NREL Senior Scientist David Albin said. "They used the CRADA to help jump start making a company work."

"Through our CRADA, we have had characterization help from NREL and early on we did interleaving with the laboratory to help us scale up our line and we continue with ongoing consulting work," Seymour said.

Interleaving involves mixing the technologies available at NREL with the technologies available at PrimeStar facilities. "We were taking films from PrimeStar and finishing the processing here," Albin said. "Sometimes we would give them films to finish over there. But, the concept of interleaving was very important to the work."

A key event leading up to the purchase of PrimeStar by GE was a technical services agreement involving Albin spending several weeks at the GE Global Research Center in Niskayuna, N.Y., to help set up a solar cell fabrication line there.

"Getting the CRADA going with PrimeStar and then having GE come in, suddenly brought in that big chunk of how you manufacture things cheaply," NREL Principal Scientist Tim Gessert. "It's likely that GE, with its engineering muscle will find innovative ways to do solar on a large scale."

Verdant Power—Harnessing the Energy of Moving Water

NREL is collaborating with Verdant Power on a CRADA to design and test a new composite rotor for marine-kinetic hydropower turbines.

There are different ways to extract energy from water including: waves, currents, and rivers. The Verdant Power technology is very similar in concept to a wind turbine but with applications for tidal changes and river and ocean currents. Experience with the design, modeling, and testing of similar wind energy systems is why the company turned to NREL for assistance. A critical component of the system is the rotor, which consists of a hub and blades which transfer the kinetic energy of the water to create power generating torque. Optimization of the rotor design can lead to more efficient rotors with increased energy capture and reduction in manufacturing costs.

"NREL has been working with Verdant since 2008 to develop not only an improved hydrodynamic and structural design of the rotor, but also to characterize the fundamental properties of tidal flows and develop the computational tools needed to model and design advanced kinetic hydropower systems," Senior Engineer Scott Hughes said. "We've taken what we know about wind turbines and combined it with Verdant's expertise in marine engineering and marine hydrokinetic systems to help develop new tools for marine applications." The culmination of the CRADA will be a full-scale structural test of an advanced composite rotor blade at NREL's National Wind Technology Center.

"Marine hydrokinetic turbines are installed under water and rotate slowly but steadily thanks to the natural currents of tides and rivers," Director of Marine Current Technology Dean Corren said. "This motion drives a speed increaser, which in turn drives a grid-connected generator, both of which are encased in a streamlined waterproof nacelle mounted on a pylon."

> "This research is important to optimize the cost of marine renewable energy. Robust design tools and validation testing are fundamental to develop reliable products."
>
> —**SCOTT HUGHES,** *Senior Engineer*

To enable the development of the new rotor system, NREL developed design tools for optimizing rotor performance for marine applications. These tools were adapted from a suite of NREL codes which have been used extensively in wind energy applications. The new codes leveraged NREL's code development expertise with the in-water experience of Verdant, enabling a comparison and validation of the codes. Verdant can use this tool to access a variety of rotor tools and airfoil configurations in a very short period.

"This research is important to optimize the cost of marine renewable energy," Hughes said. "Robust design tools and validation testing are fundamental to develop reliable products. If we can demonstrate technology viability, there is a tremendous resource for marine hydrokinetic device deployment near many high density population centers."

In addition to NREL, Verdant Power has partnered with the Sandia National Laboratories and the University of Minnesota's St. Anthony Falls Laboratory.

—Heather Lammers (September 14, 2011)

Growth Forum Boosts Cleantech Startups

A disruptive DC-to-DC (direct current) power conversion technology for semiconductor chips that power microprocessor cores and other mobile technology devices joined an elite group of technologies deemed "Best Ventures" at the U.S. Department of Energy's (DOE) National Renewable Energy Laboratory's (NREL) 24th Industry Growth Forum.

For three days in November 2011, cleantech startups, venture capitalists, banks, and researchers from NREL convened in Denver looking for market-ready innovations to speed the adoption of renewable energy and energy efficiency technologies.

"Creating clean energy options is about working with industry, and working on innovations that really cut through the market barriers, to help us make progress in a definitive way," NREL Director Dan Arvizu said in opening remarks. He also noted that he sees a vibrant global industry with "opportunity space" in the U.S. that companies attending the Growth Forum could capture.

Ready to seek out those opportunities were more than 250 companies applying for 30 presenter slots. Competition is stiff because simply being a presenter at the event can help a company "make it." Then, out of the 30 presenters, only three are bestowed with the Clean Energy Venture Awards—sponsored by Wilson Sonsini Goodrich & Rosati.

And the Winners Are...

The Best Venture Award went to Arctic Sand Technologies of Cambridge, Mass. Arctic Sand is commercializing a groundbreaking power conversion technology that consolidates several broad-level power components into one chip.

"Eighty percent of the energy that is generated in the world gets lost in the form of heat," Arctic Sand founder and CEO Nadia Shalaby said after the awards ceremony. "The culprit is the $60 billion power conversion industry that converts one form of energy into another. Arctic Sand addresses this problem inside of devices. We make DC-to-DC conversion chips and our solutions are 10 times smaller and 75% more efficient at cost parity."

Arctic Sand received $10,000 in cash and added services from Wilson Sonsini Goodrich & Rosati, NREL, and the Cleantech Investors Summit; the total award value is $32,000. But, other benefits may be less tangible. "Winning the Growth Forum is a huge affirmation for us—and NREL brings a lot of name recognition," added Shalaby.

Two Outstanding Venture awards were also presented at the Growth Forum. The first company recognized was ICR Turbine Engine Corporation of Hampton, N.H. ICRTec is developing an innovative gas turbine engine that is a replacement for diesel engines. The ICR engine has both lower emissions and better fuel economy. It also is able to operate on any liquid or gaseous

Kiverdi CEO Lisa Dyson pitches her company, which upgrades waste carbon into oil using a syngas conversion process, at NREL's 24th Industry Growth Forum. *Photo by Pat Corkery, NREL/PIX 19817*

fuel and can switch between fuels while on the move—something not possible with other engines.

The second Outstanding Venture Award went to LimeLite Technologies of Austin, Texas. LimeLite's energy efficient safety lighting technologies optimize the performance of electroluminescent lighting. Already a player in the consumer nightlight industry, LimeLite is looking to expand in to building safety lighting, specifically exit signs.

According to CTO Samuel Kim's presentation at the forum, there are nearly 1 billion exit signs in the world. LED exit signs have a yearly maintenance cost of approximately $34 and the LimeLight solution would bring that cost down to $6.82.

"Exit signs have a very high cost of ownership due to the fact they are on 24/7, 365 days a year," Kim said. "On average, our products are 10 to 16 times more energy efficient, last two times longer, are two to six times more luminous, and have great visibility in smoky conditions."

The award package for both ICR Turbine Engine Corporation and LimeLite Technologies includes $5,000 in cash and added services from Wilson Sonsini Goodrich & Rosati, NREL, and the Cleantech Investors Summit; the total award value is $17,000 per company.

Winning Isn't Everything

Just because a company leaves the Growth Forum without a trophy, does not mean it leaves empty handed. Companies that have presented at the Growth Forum have raised almost $4 billion in investments since 2003. TerraLUX, based in Longmont, Colo., is one example.

"We were actually participants two years ago and got our first round of funding as a result of participating," TerraLUX President and CEO Mark Verheyen said. "We thought it would be a good idea to participate again in the search for a second round."

TerraLUX has created a patented technology that enables the simple integration of energy efficient LED light engines into existing lighting fixtures. According to Verheyen, a TerraLUX unit replaces a traditional light source, such as a 60-watt incandescent light bulb, with an eight-watt energy efficient LED unit.

> "Creating clean energy options is about working with industry, and working on innovations that really cut through the market barriers, to help us make progress in a definitive way."
>
> —**DAN ARVIZU,** *NREL Director*

"It's significantly less power consumption and it also lives 50 times as long," Verheyen said. "The customer doesn't notice the difference because the color and quality of the light source are the same."

TerraLUX hopes to build on the success it had garnering investors after its first appearance at the Growth Forum. "At that time we didn't have the products ready, but we presented the strategy," Verheyen said. "Now we are back showing finished products and are ready to go to market. We're hoping to find one or multiple investors who say that, 'I'm excited about what I've heard, I see the potential and I want to be part of that company,' either for strategic reasons or as a pure VC investor."

NREL Accelerates a Better Built Environment

In 2011, NREL added a new track to the last day of the Growth Forum. The "Partnership Accelerator" brought together businesses and researchers to discuss the challenges, and possible solutions, facing the commercial and residential buildings industry.

"The Partnership Accelerator is about putting together the leading research minds and practitioners in the building space together with companies to help solve technical challenges," NREL Manager for Innovation and Entrepreneurship Richard Adams said. "It's about driving outcomes."

NREL Center Director for Electricity Resources and Building Systems Integration David Money began with an overview of

the challenges facing NREL, and industry, when it comes to energy systems integration. According to Mooney, 30 years of renewable energy R&D technology is entering the market and one of the challenges facing utilities is how to get that energy onto the grid in large quantities while maintaining the reliability and affordability of the nation's energy systems.

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>
> —**RICHARD ADAMS,** *NREL Manager for Innovation and Entrepreneurship*

Mooney also gave the audience a preview of NREL's new laboratory specifically designed to address these energy integration challenges—the Energy Systems Integration Facility (ESIF). "There are a few things about ESIF that make it really unique," he said. "We are going to be able to conduct systems integration experiments at megawatt scale. We are going to be able to bring utility and other partners into the building so they can see these systems operating at real power."

Conversations at the Partnership Accelerator moved from the utility scale to the virtual scale with Google SketchUp's Aidan Chopra discussing Google's easy-to-use 3-D modeling program for buildings. "If you don't have a good 3-D representation of what it is you plan to make, you are hobbled in a lot of ways," Chopra said.

In addition to simply creating a 3-D rendering of a house or commercial space, SketchUp can be a tool for placing solar panels on a building. "People from individual homeowners who are considering PV-to-PV installers are using SketchUp in conjunction with Google Earth to figure out this converging industry. Our level of ubiquitousness in this industry is actually sort of astounding."

SketchUp was a perfect segue into a discussion led by NREL Senior Engineer Nicholas Long about how NREL is leveraging SketchUp and DOE's EnergyPlus to do energy modeling via its OpenStudio product. Together, residential and commercial buildings account for a staggering 40% of energy use in the United States. NREL is developing a suite of tools in OpenStudio to help tame this energy use.

Once a building is constructed, occupant comfort is another area where energy use can hurt, rather than help the owner. NREL Senior Engineer Dane Christensen introduced an NREL innovation known as DEVap. The Desiccant-Enhanced eVaporative air conditioner (DEVap) is a new air conditioning process with the potential of using 50–90% less energy than today's top-of-the-line units. It removes heat from the air using membranes, evaporative cooling, and liquid desiccants in a way that has never been done.

"In humid climate like Houston or Miami, you can't exactly use a swamp cooler, by using DEVap we've actually coupled the evaporative cooler with a desiccant, which is a dehumidifier," Christensen said. "It has allowed us to apply the efficiency of evaporative cooling in a much broader range of climates. In fact, it can be used in any building, in any climate across the country."

All told, 13 speakers presented a wide array of solutions for accelerating the built environment ranging from energy efficiency to advanced windows to whole building controls. The event demonstrated available opportunities that companies, researchers, and investors can all work on to meet the DOE's goal of cutting building energy consumption by 50%.

—Heather Lammers (November 15, 2011)

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/PIX 19897*

NREL Adds Giant Wind Turbine to Research Site

With blades longer than a basketball court and a tower the length of a football field, the 3-megawatt Eco 100 is the latest—and largest—wind turbine behemoth erected at the National Wind Technology Center (NWTC) near Boulder, Colo.

Built by French power-generation company, Alstom, the Eco 100 is being tested at NWTC, part of the U.S. Department of Energy's (DOE) National Renewable Energy Laboratory (NREL), so it can be certified for use in the United States. Its certification will mean good-paying jobs in the United States for years to come, and what is learned during testing will bring the nation closer to DOE's target of 20% wind energy by 2030.

Alstom paid for the project and will benefit from the information the tests provide, but NREL and America as a whole also will benefit, speakers at the April 26, 2011, turbine dedication ribbon-cutting said.

The cooperative research and development agreement signed in May 2010 between Alstom Power and NREL is being extended to include ongoing tests. Later, the two public-private partnership could be extended to include research on offshore turbines.

The partnership will continue to produce results that "will strengthen our ability to harness the wind and power our future with clean, safe, and renewable energy," said John Cohen, Alstom Power's vice president for Government Affairs. He said the "what ifs" at the beginning of the partnership already are coming true. "What if a new technical process for turbine design accelerates expansion of wind power? What if together we make progress to meet tomorrow's energy needs? What if our push for innovation accelerates new clean-energy jobs in the United States?"

Manufacturing Plant in Texas

Alstom is building a manufacturing plant for the nacelles—the cigar-shaped enclosures attaching the tower to the blades—for the Eco 100 in Amarillo, Texas. The plant will open this fall and create and maintain 275 American jobs, NWTC Director Fort Felker said. A single Eco 100 is powerful enough to supply energy to 2,000 homes and, with expected service life pegged conservatively at 20 years, could easily generate revenue in the tens of millions of dollars.

Alstom already has 27 Eco 100s operating in France at wind farms south of Paris.

"Partnerships are in our very blood," said Robert Hawsey, NREL's associate laboratory director for Renewable Electricity and End Use Systems. "We're delighted Alstom chose NREL as a strategic partner."

A worker from Michels Wind Energy prepares to release a harness after the third and final blade was attached to the Alstom Eco 100 wind turbine. *Photo by Dennis Schroeder, NREL/PIX 18890*

The tests are measuring power performance, power quality, noise, and system frequency. Success in those tests already has given Alstom the IEC certification of its 60Hz model it needs to start sales and production in the United States. Ongoing tests will create a sophisticated engineering simulation model of the Eco-100 drive train. The turbine will go through long-term field tests for model validation that could last another several years.

NREL is measuring inflow conditions, including wind speed, wind direction, air pressure, and temperature, on a large meteorological tower at the NWTC. NREL also is measuring voltage and current at 1Hz to establish a power curve—a plot of power versus wind speed. In addition, the tests will measure voltage and current fluctuations for their impact on the power grid. In the spring of 2011, NREL measured turbine noise by placing a microphone on a soundboard downwind of the turbine. Measurements will be taken at a wide range of wind speeds.

Instruments at the base of the tower measure pressure under the foundation and the strain inside the foundation. The tests are aimed at checking the assumptions in the design and optimizing the design of the foundation.

Partnership to Research Reliability

The NWTC is the most extensive wind-turbine testing facility in the nation.

The NREL-Alstom partnership reinforces "how relevant NREL is to the wind industry," DOE's Deputy Assistant Secretary for Renewable Energy Steve Chalk said. The new turbine, together with the recent construction projects at NREL's Golden, Colo., campus, represents "investments that will really pay off down the line. It means NREL will continue to attract the best scientists, and that will lower the cost of renewable energy," spurring greater demand for it.

"We're extremely proud and excited to work with NREL and DOE," Andy Geissbuehler, vice president and general manager of Alstom Power Wind Business North America, said at the dedication ceremonies "We chose the right partner. We would like to continue the partnership and work with NREL on off-shore wind."

The Alstom Eco 100 turbine employs a novel drive-train design that isolates the gearbox from rotor loads, putting less strain on the gearbox. That is a promising difference-maker because the wind industry worldwide has been addressing the problem of gearbox reliability for several years. NREL heads a consortium of turbine manufacturers, utilities, and suppliers, the Gearbox Reliability Collaborative, that examines ways to improve designs and retrofits for gearboxes.

> "Partnerships are in our very blood. We're delighted Alstom chose NREL as a strategic partner."
>
> —**ROBERT HAWSEY,** *NREL's Associate Laboratory Director for Renewable Electricity and End Use Systems*

"This has the potential to greatly improve gearbox reliability," Felker said. "Through this project with Alstom, NREL will develop a comprehensive understanding of this innovative drive-train topology."

Soaring High Over the Prairie

Never has a wind turbine churned wind as high above the ground at the NWTC as the 3-MW Eco 100. How big is it?

At its base, the 300-foot (90-meter) tower is about 14 feet (4.5 meters) in diameter.

The entire turbine weighs about 600 tons, with each of the three blades weighing about 11 tons, said Rodrigo Vallejo Paez, project manager for Alstom. The 33-foot by 16-foot (10-meter by 5-meter) nacelle, which cradles the gear box and other instruments high up on the tower, weighs 95 tons.

When one of the three 160-foot-long (50-meter-long) blades of the turbine is at high noon, the entire structure reaches more than 400 feet (130 meters) above the ground.

To ensure that the behemoth withstands 90- to 100-mph winds blowing from the mountains to the west, the base of the tower was planted into a foundation that required 70 truckloads of concrete.

Alstom hired Michels Wind Energy to install the turbine. Stage-by-stage, one of the largest cranes in the world, lifted turbine

parts above the short-grass prairie of rural Boulder County, Colo., in the shadow of the Rocky Mountains in December 2010.

The crane, from Mullen Crane Services of Soda Springs, Idaho, has a lift capacity of 1,350 tons. The graceful bend in the blades, supplied by LM Wind Power, would look at home in a museum of sculpture. The blades are shaped to have pre-bend in the upwind direction—a reverse camber that hooks into the wind. The aerodynamic forces will bend the blades downwind, ensuring that the blades don't hit the tower under any weather condition.

"People don't appreciate how much power these machines have," Felker said. "It's a tremendous job to install a 3 MW wind turbine."

The 90-meter tower arrived in five giant sections. The 50-meter-long rotor blades were shipped on special trucks. "Meticulous engineering and planning was required to ensure that the project proceeded safely," Felker said. Ironworkers, millwrights, and electricians were among the skilled workers who erected and installed the turbine and its instruments.

Wind energy has been one of the fastest-growing segments of the U.S. electrical system for many years, and will be an essential part of the transformation to clean energy, Felker said.

Jeroen van Dam, NREL's project manager for the Alstom project, agrees. "Wind power is a clean energy source that can be rapidly deployed, is abundant and creates manufacturing jobs," he said. "It is already cost-competitive with fossil fuels in a lot of locations and it doesn't use any water."

> "This has the potential to greatly improve gearbox reliability. Through this project with Alstom, NREL will develop a comprehensive understanding of this innovative drive-train topology."
>
> **—FORT FELKER,** *NWTC Director*

Felker said it's important that the United States commit long-term to wind energy. "Too often in the past, the wind industry has been buffeted by expiring short-term policies. A policy needs to be in place that recognizes that wind energy provides renewable energy at a competitive cost, with no carbon emissions and with the lowest water consumption of any electricity-generating technology."

—Bill Scanlon (April 29, 2011)

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