NREL
NATIONAL RENEWABLE ENERGY LABORATORY

NREL: A Year in Clean Energy Innovations

A Review of NREL's 2010 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 17848

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INTRODUCTION

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

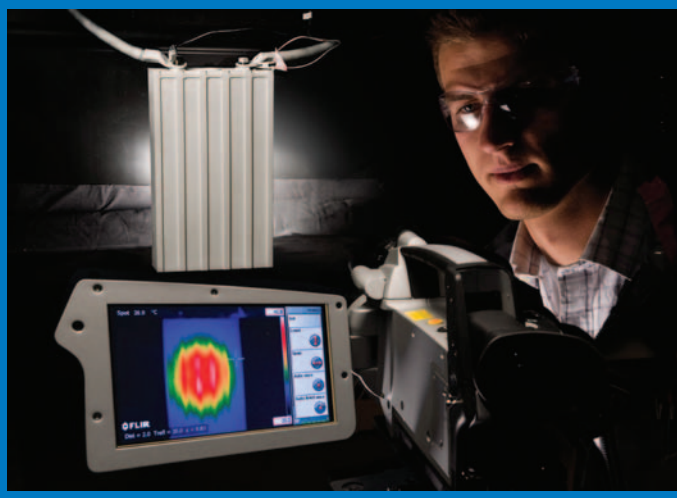
NREL's mission and strategy are focused on advancing the U.S. Department of Energy's and our nation's energy goals. The laboratory's scientists and researchers support critical market objectives to accelerate research from scientific innovations to market-viable alternative energy solutions. At the core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

What follows is a compilation of articles featuring NREL research and development, deployment, commercialization, and outreach activities in 2010. 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 e-mail 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 17820*

NREL BATTERY TESTING CAPABILITIES GET A BOOST



Engineer Dirk Long uses thermal imaging equipment to capture a battery's infrared fingerprint to diagnose its behavior. NREL soon will be ramping up testing as the battery industry uses stimulus funding to enhance batteries used in advanced vehicles. *Photo by Patrick Corkery, NREL/PIX 16952*

Batteries are the heart of today's advanced electric drive vehicles and many manufacturers have their own preference for specific battery geometry and chemistry including their choice of materials for cathodes and anodes. However, all of the manufacturers are concerned about the performance, life, safety, and cost of lithium-ion batteries even though their designs are varied. The U.S Department of Energy (DOE) is looking to help the U.S. battery industry with a simple goal—to mass produce better batteries domestically while addressing safety, affordability, life, and performance.

As a result of DOE's support, more work and funding for battery research is coming to NREL via both indirect and direct avenues thanks to the American Recovery and Reinvestment Act (ARRA). In March 2009, President Obama announced $2.4 billion to help drive the development of the next generation of electric drive vehicles in the United States. As part of that announcement, DOE released a competitive solicitation for up to $1.5 billion in federal funding for manufacturing advanced batteries and related drive components.

"The longer a battery lasts the better the cost efficiency and consumer satisfaction." – Ahmad Pesaran

The funding will spur faster development of batteries for cars with electric powertrains, including hybrid electric, plug-in hybrid electric, all-electric, and fuel-cell vehicles. Battery thermal management is crucial in optimizing the performance and reducing the life-cycle costs for these types of batteries. Once manufacturers start cranking out new and more efficient prototypes, they'll turn to NREL for thermal testing and validation.

"Right now, we already have a back-log of batteries for thermal testing," NREL Principle Engineer and Energy Storage Task Leader Ahmad Pesaran said. "We know that in one or two years, when the battery companies start producing new batteries to evaluate, we wouldn't have been able to keep up without the new investment in equipment."

NREL Garners Big Bucks for Battery Lab Improvements

In the fall of 2009, DOE recognized that NREL would be a key laboratory in the development of these advanced vehicle batteries. So, the lab was awarded $2 million from ARRA for the Battery Thermal and Life Test Facility.

"ARRA has already funded the battery industry to design and build new batteries. DOE also recognized that they needed to equip the national labs to test the new batteries that will be manufactured as a result of the ARRA investments," Pesaran said.

The $2 million dollars coming to NREL will be used to upgrade and enhance the capabilities of the lab with new testing and analysis equipment. Some of the money will also be used to upgrade the utilities and facilities where the researchers perform the testing.

NREL will be purchasing up to 20 new battery testers, which will nearly triple the lab's ability to test batteries. NREL will also purchase two new calorimeters to measure the heat and the efficiency of small and medium sized cells; augmenting NREL's two existing larger calorimeters.

"The team is very excited," Pesaran said. "There have been times where we haven't been able to accomplish all the technical studies that we wanted to do because of lack of equipment. This is going to help resolve that issue."

Pesaran noted that U.S. testing equipment manufacturers also will benefit from NREL's ARRA award because the new testing equipment will be ordered from U.S. suppliers.

Why Better Batteries are Needed

"The longer a battery lasts the better the cost efficiency and consumer satisfaction," Pesaran said. "For cars, it is expected that batteries will last 15 years compared with current lifetimes of only 5-10 years, mainly due to thermal issues."

Batteries are the centerpiece for advanced electric-drive vehicles. Making cars more energy efficient means using less fuel, which helps reduce oil consumption and the nation's dependence on foreign oil. Furthermore, they allow vehicles to drive on electricity, adding diversity to the fuel supply and increasing national energy security.

NREL researchers seek to improve the thermal performance of batteries by studying how heat affects the performance and life of batteries. NREL experts analyze fluid flow (liquid or air) through different types of battery packs to determine how the flow affects the pack's performance and life-cycle costs. Researchers measure and analyze the heat generation,

efficiency, and specific heat of battery modules under specified charge/discharge cycles using the state-of-the-art calorimeters in NREL's energy storage laboratory. Incorporating thermal imaging (still and time-lapse video) helps researchers determine temperature distributions and identify potential hot spots in battery modules and packs.

"Measuring heat generated from a battery tells you how efficiently the battery is operating," Pesaran said. "The data on the heat generation is used by battery companies to determine how much cooling is needed to keep the battery at optimal temperatures because higher temperatures cause the battery to degrade faster.

"It's then up to the battery company to make some decisions. Can they reduce the amount of heat by changing the cell or material design? Or, will they design a cooling system to keep the battery at an optimal temperature. Cooling is easier; but because of the battery size, you need to make the cooling system as small and as efficient as possible without adding weight to the car."

"The data that we generate is going to help us validate the battery models that we have developed." – Ahmad Pesaran

In the end, the goal at NREL is to help industry develop better batteries. And, NREL has lots of companies lined up for future testing, many of which, according to Pesaran, wrote strong letters of support for NREL's ARRA funding application.

NREL Has its Own Testing Planned

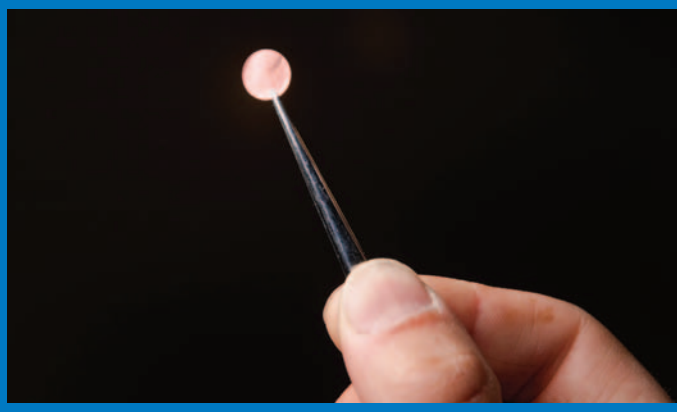
The battery research team will also spend time generating data to be used for validating battery thermal and electrochemical models. Modeling and simulating advanced energy storage systems in vehicles will help designers and researchers accelerate finding solutions for innovative battery designs and best ways to enhance overall vehicle performance.

Pesaran noted that NREL "has leading edge computer models of thermal and electro-chemical battery performance." NREL's team evaluates energy storage devices, such as batteries and ultracapacitors, by constructing computerized representations of energy storage devices and vehicles which simulate real-world driving conditions and environments including temperature changes and driving styles. Researchers then look at the data to determine how much heat was generated under various driving conditions.

"The data that we generate is going to help us validate the battery models that we have developed," Pesaran said. "This is really important because NREL has developed a number of models that are being used for industry, but in some cases we haven't had sufficient data to validate them. So, new equipment is essential to generate the data to validate the models so that industry can use them with greater confidence."

— Heather Lammers (February 5, 2010)

BUILDING BETTER BATTERIES FOR CARS AND SPACECRAFT



This dime-sized coin made of aluminum and copper is used to induce short circuits in lithium-ion batteries. The ability to induce shorts on demand is crucial to finding out how hot a battery can get when it fails while in active use. *Photo by Patrick Corkery, NREL/PIX 17626*

The NASA engineer responsible for the batteries needed for spacewalks now is working at the Department of Energy's (DOE) National Renewable Energy Laboratory (NREL) to help design safer lithium-ion battery packs for sky walkers and automobile drivers alike.

"We at NASA share the same challenges that DOE and NREL have in developing batteries for cars," said Eric Darcy, the battery group leader at the National Aeronautics and Space Administration's Johnson Space Center.

Whether it's "manned space travel or manned automobiles," the hurdles are the same, Darcy said. "Designing a safe, very large and lightweight battery pack for the confined space of manned vehicles is challenging."

In the future, battery-powered automobiles are expected to grab a big share of the market away from gasoline-fueled vehicles.

Lithium-ion batteries are the technology of choice because of their high energy and power densities, Ahmad Pesaran, Energy Storage Group Leader at NREL, said. But the batteries must be able to withstand abuses that could lead to thermal runaway and potentially fire.

Thermal runaway can happen when an increase in temperature changes conditions in a way that leads to a further increase in temperature, a kind of feedback that can lead to catastrophe. The increase in temperature leads to an increase in the reaction rate, which leads to further increases in temperature. The disastrous release of methyl isocyanate gas from a Union Carbide plant in Bhopal, India, in 1984, was precipitated by a thermal runaway.

Researchers in NREL's Energy Storage Group are modeling and testing how well the risk of catastrophic thermal runaway can be mitigated in lithium-ion cell/battery designs. "We're privileged to have Eric working with us for nine months," Pesaran said.

NREL researchers expect the partnership to help them design next-generation battery packs for cars. Darcy's contributions are helping NREL's integrated network model to analyze the qualities of multi-cell battery pack systems and observe their responses to stress, NREL engineer Gi-Heon Kim said. "These kinds of model tools are crucial for car industries to properly perform thermal and safety assessment of their battery pack designs."

Inducing Shorts on Demand

NREL and NASA engineers have invented specially designed small "coins" made of primarily aluminum and copper, that when implanted into lithium-ion cells will induce an internal short circuit on demand. The ability to accurately replicate internal shorts in battery cells is crucial to finding out how hot a battery can get when one of its cells fails because of a rare manufacturing defect. Those defects happen only about one time in 1 million in the field, but because of their catastrophic consequences, NASA and NREL need to lengthen those odds if lithium-ion batteries are to become the workhorses of space walks and automobile transportation.

> "These kinds of model tools are crucial for car industries to properly perform thermal and safety assessment of their battery pack designs." – Gi-Heon Kim

Darcy brings 23 years of experience in putting together batteries for manned spacecraft. With the retirement of the Space Shuttle Program, and the uncertainty of when a replacement will be available, NASA needs a new-generation, longer life spacesuit battery pack that will support dozens of walks based from the Space Station.

"Eric brings the perspective and broad experience base of the aerospace industry," says NREL researcher Kandler Smith. The aerospace industry doesn't share the same cost constraints of the automotive industry, "but the processes employed for battery risk assessment and design for reliability are directly applicable."

NREL researchers have characterized the conditions under which an internal short circuit in a spacesuit battery can lead to a thermal runaway, which can cause a catastrophic explosion.

"Knowing the vulnerabilities of that battery is useful to find a way to mitigate the risks," Smith said.

Safer Spacesuit Battery under Development

NASA has been developing a new spacesuit battery for three years, preparing for the time when the current short wet life battery packs of the shuttle-to-space-station era would require replacement.

"We now need at minimum, a five-year battery, and with that comes a whole new chemistry, lithium-ion," Darcy said.

"That carries with it the risk of it rupture and fire," Darcy added. "That's why we've teamed with NREL to characterize the small range of conditions under which this battery can go into thermal runaway." The Interagency Government Agreement between NASA and NREL was signed in 2008.

The battery under study contains 80 laptop-sized lithium-ion cells, weighs about 15 pounds, and is about 11 inches long, four inches wide and five inches deep. Laptop batteries can last three years if they're treated kindly, albeit they usually aren't, since most of the time they are kept fully charged and operate at high temperatures inside the cramped internal space of a laptop.

The new spacesuit battery will rest inside the backpack on the spacesuit, which packs a lot of thermal insulation, preventing it from getting very cold or very hot. So, even though it will be in the forbidding climes of outer space, it will experience less stress than a battery constantly being charged and discharged on planet Earth.

"I'll come back to NASA a better battery engineer because of what I'm learning at NREL in the areas of simulating battery behavior under abuse conditions." – Eric Darcy

Designed to Last for 50 Space Walks

The battery is designed to endure some 50 multi-hour space walks over its five year life, although typically it would be taken out for about half that many walks.

The lithium-ion battery will power all the life-support systems in the space suit, powering the fans that circulate the air, powering the heat exchanger, the pumps that circulate water through the suit.

Suits will accompany the astronauts on the transfer to the space station, while others will be parked permanently at the station, for the times when the astronauts have to take a walk when there's no shuttle spacecraft around.

NASA is planning more lower-orbit satellites to observe the Earth for climate-change data. The space station is going to be crucial for those close-Earth observations, and that means safe, long-lasting spacesuit batteries will be crucial, too.

Auditing Performance of Lithium-ion Batteries

NASA needs to learn all it can about lithium-ion batteries because the nickel-hydrogen batteries now in use will expire in 2017.

"We're performing audits on the cell production lines" of the lithium-ion batteries, Darcy said.

Tiny latent defects imbedded in cells can be missed if testing isn't done under the strictest conditions. Those defects could cause an internal short circuit and a catastrophic event.

Internal short circuits are rare, but not unheard of. "You hear about these one-in-a-million recalls, when a laptop or a cell phone's battery defect causes it to go into flames," Darcy said.

Early this month, Darcy and Smith audited a lithium-ion manufacturing process. "They had some good processes and some weaknesses," Darcy said. "We made a long list of all those actions they ought to consider correcting to produce a better, safer product."

The lessons learned at the audits can be used by NREL to conduct similar audits on automobile battery manufacturers, Darcy said.

"It's important that they do so, because if an incident occurred on a car battery, it would be a cancer to everyone who uses lithium-ion batteries," Darcy said. "Is mine going to have that same effect?

"They need to know why or why not. What measures can they take to minimize the risk of some kind of internal short inside the cell that can make it blow up?"

Darcy Chose NREL as a NASA Innovative Ambassador

Darcy, a chemical engineer, was one of four NASA employees accepted into the space program's Innovative Ambassador program, allowing him to spend up to a year at another organization.

He chose NREL for its "unique capabilities in the field of batteries." He started at NREL in January and will return to Houston in October.

Darcy has plenty of experience abusing batteries, subjecting them to worst-case conditions, while his new NREL colleagues have ample experience in using mathematical models to predict how they behave when abused.

"That's the mutual benefit of sharing our information," Darcy said. "I can help ground some of the models that NREL is producing. NREL can help me learn how to use the models so I can reduce the development time to a safe and effective design solution.

"I'll come back to NASA a better battery engineer because of what I'm learning at NREL in the areas of simulating battery behavior under abuse conditions," he said.

— Bill Scanlon (July 8, 2010)

NREL HELPS CORPORATE FLEETS GO GREEN

NREL and Coca-Cola Refreshments teamed up for a year-long technology evaluation of their hybrid electric delivery trucks. NREL researchers will provide a comparison of fuel economy and operating costs between the hybrids and the diesel trucks in use. *Photo from NREL/PIX 18337*

With all of the delivery trucks on U.S. roadways, it is easy to see why researchers at the U.S. Department of Energy's (DOE) National Renewable Energy Laboratory (NREL) are focused on evaluating the latest energy-saving technology that is commercially available in the medium- and heavy-duty truck markets.

From the beverage industry to package delivery companies, fleet managers are looking for ways to green their fleets by achieving better fuel efficiency and fewer emissions while maintaining an eye on the company's bottom line. "We focus on a number of factors that affect a company's fleet, from emissions to reliability to cost," Senior Project Leader Kevin Walkowicz said. "Cost is the number one barrier to companies using advanced technologies and commercial fleets are always concerned about maintaining profitability. Companies need to understand if these vehicles are going to save them money, or cost them money, over the long run."

> "After we're done with testing, we try to provide information that is useful to other fleets so they can see who has tried the technology, what the results were, and what the benefits were." – Kevin Walkowicz

Researchers Look for Data, Data, Data

NREL is specifically equipped to tackle this type of research thanks to its Renewable Fuels and Lubricants (ReFUEL) Research Laboratory. ReFUEL is outfitted for testing advanced fuels in heavy-duty engines and vehicles as well as advanced heavy hybrid vehicles. It also was the first independent laboratory in the United States with a heavy-duty chassis dynamometer that was able to accurately measure tailpipe emissions from trucks with diesel engines that meet the stringent 2007 standards set by the Environmental Protection Agency.

"There are three main tools we use when evaluating these types of heavy-duty hybrid vehicles—data provided by the fleet, data we collect at ReFUEL, and data we collect by logging it in the field," Walkowicz said. "After we're done with testing, we try to provide information that is useful to other fleets so they can see who has tried the technology, what the results were, and what the benefits were."

While it sounds like a lot of information, using the three data-stream approach allows researchers to compare how the new vehicles stack up against conventional models in the fleet.

"We test a baseline group alongside a similar number of hybrid vehicles so we can compare the new technology against the old," Walkowicz said. "We are looking for differences in fuel economy, emissions, maintenance, operating cost, and reliability."

Walkowicz also noted that advances in data logging are helping researchers get a valuable real-time snap shot of how these vehicles perform while "on the job."

"We can log into the vehicles remotely, gather everything from GPS to battery temperatures to all of the information available on the vehicles' computer—which can consist of hundreds of channels of digital data being monitored. Data is king—the more data we gather, the easier it is for us to point out a few things to help the operators optimize and use the vehicles more efficiently. Where it can be a trial and error process for the company, we can look at the data and tell them very quickly how these vehicles and advanced technology systems are performing in different operating conditions."

Industry is taking notice of NREL's abilities. In the last two years, FedEx, UPS, and Coca-Cola Refreshments have all teamed with NREL to evaluate their hybrid fleets.

Coca-Cola Takes Diesel Hybrids for a Spin

Just this year, NREL and Coca-Cola Refreshments teamed up for a year-long technology evaluation of their Miami-based, class 8, hybrid electric delivery trucks. At the end of testing, NREL researchers will provide a comparison of fuel economy and operating costs between the hybrids and the diesel trucks in use.

Coca-Cola Refreshments' large hybrid trucks are equipped with the latest generation of a parallel hybrid system manufactured by Eaton Corp. These trucks can weigh in at as much as 55,000 lbs. The system includes regenerative braking and lithium-ion batteries that provide energy storage. Energy that

is normally lost during braking is captured, stored in the batteries, and used to power the electric motor.

The trucks were tested at the ReFUEL facility in August 2010 using drive cycle data obtained from their Miami fleet as guidance for creating the laboratory test plan. Fuel economy and emissions were measured and the test results will be compared to on-road data that is being gathered currently. Final study results will be available in summer 2011.

FedEx Hybrids Reduce Tailpipe Emissions

Also within the past year, FedEx Express, California's South Coast Air Quality Management District, CALSTART, and NREL teamed up to look at FedEx Express' gasoline hybrid electric (gHEV) delivery trucks.

"Performing a field evaluation of gasoline-hybrid delivery trucks in Los Angeles and then testing them at ReFUEL was a unique project because they are using gasoline engines coupled with a hybrid system, rather than diesel," Walkowicz said. "At the time of the study, the gasoline hybrid option was investigated for use in the Southern California location since it was an option that could reduce NOx and particulate matter while maintaining efficiency compared to the diesels available at the time."

> "We are looking for differences in fuel economy, emissions, maintenance, operating cost, and reliability." – Kevin Walkowicz

NREL researchers also tested a conventional diesel vehicle and a gHEV from the FedEx Express fleet at the ReFUEL laboratory. Researchers found the benefit for the gHEVs was indeed in the tailpipe emissions. "The fuel economy for the gasoline hybrid wasn't much better than a diesel so there was not much of a fuel savings," Walkowicz said. "But, when we brought them to the lab, it proved out how much cleaner the hybrids were—the tailpipe emissions were substantially reduced."

The interim report on the FedEx testing was released in May and final results will be published in the coming weeks.

UPS Diesel Hybrids Cut Fuel and Costs

Unlike the second generation Eaton hybrid system that Coca-Cola is testing, in 2009, NREL helped UPS evaluate the first generation hybrid diesel delivery vans powered by an Eaton hybrid system. The vans are one of the first applications of a lithium battery pack put into use in the U.S. market.

Compared to conventional vehicles, NREL testing showed the hybrids improved fuel economy by 28.9% in the field, resulting in a 15% reduction in operating cost per mile. The final report, released in December 2009, details the year-long evaluation, including how the NREL team collected and analyzed fuel economy and other vehicle performance data while the vans stayed in service. The project team also tested a conventional and hybrid delivery van at ReFUEL and documented fuel economy and emissions performance.

After the NREL study, UPS ordered an additional 200 Eaton hybrid vans for its fleet. NREL is continuing to work with UPS into 2011 to evaluate vehicles from the additional order in a UPS fleet in Minneapolis.

As these recent examples show, "Our testing helps NREL, DOE, and industry understand how much progress is being made for these types of vehicles," Walkowicz said. "It also helps us understand the technical and commercial barriers that need to be overcome in order to make these vehicles mainstream products in the industry."

These projects are part of a series of evaluations performed by NREL for the AVTA, DOE's Advanced Vehicle Testing Activity. AVTA bridges the gap between research and development and the commercial availability of advanced vehicle technologies that reduce petroleum use and improve air quality in the United States. The main objective of AVTA projects is to provide comprehensive, unbiased evaluations of advanced vehicle technologies in commercial use.

— Heather Lammers (December 28, 2010)

NREL TO HELP SCALE UP BIOFUELS OPERATIONS

NREL Biomass Partnership Development Team Leader John Ashworth works with NREL's industry partners to develop and prove biomass conversion technologies. Due to recent ARRA funding announcements, NREL has five new partners in the biofuels race. *Photo by Patrick Corkery, NREL/PIX 16942*

When it comes to fostering new biofuels technology during a recession, a big barrier can simply be cash. U.S. Department of Energy (DOE) Secretary Steven Chu recently gave the industry a boost when he announced the selection of 19 integrated biorefinery projects that are eligible to receive up to $564 million from the American Recovery and Reinvestment Act (ARRA) to accelerate the construction and operation of pilot, demonstration-, and commercial-scale biofuel facilities. The National Renewable Energy Laboratory (NREL) is partnering with five of the winning companies—Algenol, Amyris, Clearfuels, Gas Technology Institute, and the Renewable Energy Institute International—to help launch pilot scale and then commercial scale development of biomass based second generation fuels in the United States.

"NREL was approached by approximately 20 companies asking us to partner with them for this DOE solicitation," said John Ashworth, NREL Team Leader for Partnership Development at the National Bioenergy Center. "DOE wanted private firms to be the lead organizations in any proposal, so we partnered with a number of different companies on a variety of projects."

According to Ashworth, DOE has been consciously trying to stimulate innovation in converting non-food biomass into fuels. The government is putting up risk capital to attract private investors to put their money into pushing technologies forward.

"It's a forward thinking approach," Ashworth said. "It's taking risk, but it's working. Billions of dollars are being committed to these scale-up activities, helping cut down the timeline for when these fuels are in the marketplace."

In DOE's request for proposals, companies were encouraged to develop pilot facilities to convert cellulosic mass into biofuels or to use existing small scale facilities to test various processes for using many types of biomass for fuels creation. "DOE deliberately supported a number of different technologies in an effort to move these technologies to the point where they can be tested at scale," Ashworth said.

NREL's Expertise and Tools Add Value

Companies interested in applying for the DOE grants had a variety of reasons for wanting NREL on their team. General themes from the winning proposals included having NREL look at the techno-economics of their proposals to leveraging the existing tools and expertise at the lab.

In the case of techno-economic modeling, NREL examines a company's biomass conversion process to better understand what the economics would look like at scale once they have data from a pilot scale run. "We have very good modeling capabilities at NREL," Ashworth said. "We have some existing models for some processes and for some we will have to develop new models plugging in data from various pilot scale runs to get a better sense of what the resulting fuel would cost."

NREL's tools also are highly valued by the private sector. For instance, companies researching the thermochemical conversion of biomass want to have access to NREL's molecular beam mass spectrometer (MBMS). "There aren't many like it in the world," Ashworth said. "It allows us to look at the gas composition, in real time, to see what's going on inside the reactor." NREL recently developed a transportable version of the MBMS, which NREL researchers can take on the road.

> "It's taking risk, but it's working. Billions of dollars are being committed to these scale-up activities, helping cut down the timeline for when these fuels are in the marketplace." – John Ashworth

Clearfuels (awarded $23 million under the ARRA solicitation) and Renewable Energy Institute International (awarded nearly $20 million) are examples of industry working with NREL by leveraging the lab's tools to improve their technical processes. Specifically, NREL will take the portable MBMS to their operating biomass gasifiers to measure their gas stream in real time and provide suggestions to help optimize their process.

Partners to Explore Varied Technologies

While both companies have a need for NREL tools, their projects are quite different. Clearfuels will produce renewable diesel and jet fuel from woody biomass by integrating

two different conversion technologies. Their facility also will evaluate the conversion of sugar cane bagasse and biomass mixtures to fuels. Renewable Energy Institute International is looking to produce high-quality green diesel from agriculture and forest residues using advanced pyrolysis and steam reforming. The pilot plant will have the capacity to process 25 dry tons of feedstock per day.

Mirroring DOE's desire to explore varied technologies, NREL's other partners are tackling the biofuels challenge in completely different ways.

Algenol ($25 million) is proposing to make ethanol directly from carbon dioxide, sunlight, and seawater using algae. Their facility will have the capacity to produce 100,000 gallons of fuel-grade ethanol per year. "Algenol has a unique process—no one has anything quite like it," Ashworth said. "They have an algae species that produces ethanol and they can take ethanol out of the water or out of the water vapor above their growth chambers." NREL researchers will work with Algenol to remove scientific barriers to help increase the yield and optimize the way the algae process carbon dioxide gas provided by a power plant or industrial user.

Amyris ($25 million) will produce a diesel substitute through the fermentation of sweet sorghum. The pilot plant also will have the capacity to co-produce lubricants, polymers, and other petro-chemical substitutes. In addition to science-based work, NREL also will assist Amyris with techno-economic modeling for their chosen method.

NREL will support Gas Technology Institute's ($2.5 million) unique thermochemical hydropyrolysis/hydroprocessing system by undertaking techno-economic analysis of their process configuration to determine fuel costs from the pilot plant data.

"In all of these cases, our job is to facilitate industry in the scaling up of their technology," Ashworth said. "Our hope is to help drive the industry forward, help get the plants built, and get the technology tested. We are trying to help everyone out as best we can so that they can prove the technology, prove that it is cost effective, and then they can get money to help scale up the technology to commercial size."

> "Our hope is to help drive the industry forward, help get the plants built, and get the technology tested." – John Ashworth

Working with Industry Benefits NREL, Too

The benefit to teaming is not just a one-way street with all of the perks going to industry; NREL also benefits greatly from working with the private sector. The National Bioenergy Center (NBC) at NREL was designed to be a user facility and is charged with helping industry scale up technology. "The great advantage to NBC and NREL is that we get to become a part of the latest technology that's evolving," Ashworth said. "We get to know what industry is working on from the inside out and it helps us broaden our base and the kinds of things we can work on as well. For instance, we will get to work on different feedstocks such as switchgrass, sweet sorgum, or other feedstocks that are going to be important to the future."

— Heather Lammers (January 15, 2010)

HIGH-SPEED PIPELINE REVS UP BIOMASS ANALYSIS

Rob Sykes, a member of NREL's Chemical and Catalyst Science Group, puts a sample of biomass on a carousel for rapid analysis in the new high-throughput pipeline. *Photo by Patrick Corkery, NREL/PIX 17130*

A new pipeline at the National Renewable Energy Laboratory is analyzing 1,000 samples of biomass at a time, finding which one, combined with the right enzyme, most eagerly gives up its sugars to be converted into biofuel.

The deadline is just 12 years away to turn switch grass, poplar trees, or other renewable biomass into 36 billion gallons of fuel for cars and trucks.

The Energy Independence and Security Act requires that the United States produce 36 billion gallons of biofuels by 2022. That would comprise one-third of the annual transportation fuels budget, now dominated by gasoline. In February 2010, President Obama voiced his enthusiasm for the act, saying it would reduce U.S. dependence on foreign oil, cut pollution, boost national security, and bolster good-paying clean-energy jobs.

That's a lot of biomass. And that's a lot of excursions to field, forest and lab to find the trees and plants easiest for enzymes to break down into fermentable sugars. A year ago, it would have taken a week and dozens of overworked graduate students to analyze a handful of trees or plants for their potential as a renewable fuel. Now, thanks to the work done by NREL scientists and their partners, more than 1,000 samples can be tested in the same time it used to take to test just a half dozen. Just as important, NREL's new high throughput pipeline can screen both the feedstock and the enzymes that chew on them to find the combinations that best convert biomass to sugar.

"It's not just about finding the miracle plants, it's about finding a miracle enzyme, too." –Mark Davis

Extreme Analytical Capacity is New, Vital

The high throughput Biomass Recalcitrance Pipeline was created to analyze the large number of poplar, switch grass and other biomass samples being produced by the BioEnergy Science Center (BESC). BESC is a collaboration of 20 university, industrial, and national laboratory partners developing a fundamental understanding of the factors controlling the release of sugar in biomass feedstocks. The BESC was developed under sponsorship from programs in both the Department of Energy's (DOE) Office of Energy Efficiency and Renewable Energy's Biomass Program and DOE's Office of Biological and Environmental Research. Part of NREL's role in the BESC is the daunting task of screening thousands of plant variants for clues to overcome plant cell wall recalcitrance.

The pipeline's extreme analytical capacity, unheard of a few years ago, is important because it's not just a question of finding the right species of poplar tree, but finding that needle in a haystack, a single tree that for reasons of genetics and chemistry, gladly gives up its sugars to enzymes. Find that tree, and a new line of fast-growing poplars can sprout from agri-forests, providing an ongoing harvest for renewable transportation fuel.

To find the juiciest plants, scientists create mini-breweries, employing enzymes to break down plant cell walls so structural sugars are released to serve as microbial food to be converted via fermentation to biofuel.

The stubbornness with which a particular plant resists conversion to sugars is referred to as its recalcitrance. The effort at NREL to find the hidden genes and the underlying chemistry of the least recalcitrant plants has caught the attention of international experts in a half dozen fields. They are turning to NREL and its newly created high throughput process to rapidly and simultaneously analyze the chemistry, genetics and recalcitrance of plants.

So far, even though they've barely begun their search, the NREL researchers and their partners in the BioEnergy Science Center have found an unexpectedly high natural recalcitrance variance of 25% in the first thousand poplars analyzed.

Re-engineered Plate Can Handle Complicated Assays

The key breakthrough at NREL was devising an assay system that could handle the severe temperatures, pressures, and pH conditions needed to screen for recalcitrance, and to do it for hundreds of trees simultaneously, not a handful at a time.

"It's fair to say that this was the Eureka," Jim Brainard, director of NREL's Biosciences Center, said as he held up a 96-well plate the size of a wallet. Typically, such plates are used for dispensing and sampling liquids, but the NREL team found a way to re-engineer it to handle extreme assay conditions and to teach a robot to do the leg—and arm—work of precisely adding the biomass to the wells. The poplar samples from the Pacific Northwest arrive at NREL

as sawdust in small plastic baggies, where a robot grabs a pinch from each and carefully sets it in a well in the plate. The most unique aspect of the NREL plate is that it acts as both the reactor vessel for acid and heat pretreatment of the biomass and as the subsequent reactor for the release of glucose, xylose, and other sugars as the enzymes chew on the samples.

Typically, each of the 96 wells in a plate holds a 5 milligram sample of biomass. Because the plates can be stacked 20-high, almost 2,000 samples can be analyzed at the same time. As the samples pass from instrument to instrument, they are analyzed for how well the enzymes can release sugars and chew into the crystalline cellulose.

Simultaneously, part of each sample is analyzed for cell wall chemistry and genetic characteristics that contribute to recalcitrance, said Mark Davis, principal manager for NREL's Chemical and Catalyst Science Group. When those results are in, and correlated with information on location, environment and other factors, "We can begin to identify what genes are controlling recalcitrance," Davis said.

Milled poplar is loaded into one stage of the high throughput pipeline in order to analyze the components found in the biomass.
Photo by Patrick Corkery, NREL/PIX 17131

Finding Best Enzymes and Plants Requires Genetics, Chemistry

"It's not just about finding the miracle plants, it's about finding a miracle enzyme, too," Davis said. The high throughput assays "will allow us to screen libraries of enzymes that are able to break down the crystalline cellulose and help us develop new enzyme cocktails," Davis said. The goal is to develop screens that can optimize both the biomass feedstock and the enzymes together, as well as finding the plant with the lowest natural recalcitrance.

It is only when the chemistry of recalcitrance is understood that commercial interests can make better than hit-or-miss guesses as to what a planting will accomplish.

Davis's group, collaborating with other university and BESC researchers, has already found elegant ways to identify QTLs, or Quantitative Trait Loci, which are spots on chromosomes that indicate something interesting is going on within about 100 genes in either direction on a 20,000-gene chain of DNA. Once this team of researchers has narrowed down the hot spots, geneticists can take over. They quickly sort through 100 or so genes and find the one that is the true outlier—in this case, the one instructing the plant's cell walls to shamefully give in to the enzymes.

That still leaves the poor graduate students out there getting all those core samples, but while harvesting and sample-prep "used to be the easy part of the experiment, now it's the labor-intensive part," Davis said.

As the scientists in the lab zero in on the genes they likely will find not just ones that promote sugar-friendliness, but those that might link to differences in cell wall thickness or polymer composition. "The real power of this pipeline is that it is so long; extending from plant ecologists and environmental scientists, to plant breeders and molecular biologists, to analytical chemists and enzymologists, to bioinformaticists, to plant cell wall structure experts," Davis said. "Without all of these scientists working together we would not able to do this."

"We're really getting cranked up this year, thanks to the samples flowing in from industry and universities," Davis added. NREL's partners include the Oak Ridge National Laboratory, where tree geneticists analyzed the first 1,000 trees sampled, and companies such as ArborGen that are industrial partners in searching for the miracle tree.

Davis and Brainard say the potential for biomass is huge. "Biomass can concentrate and use carbon dioxide from the atmosphere, thus slowing or perhaps reversing increases in atmospheric greenhouse gases," Brainard said. "It is self-assembling, it is self-repairing, and it regenerates. Yes, there are some issues with water and land use that need attention, but I believe it is the leading candidate for renewable transportation fuels over the next 20 years."

— Bill Scanlon (March 8, 2010)

IMPROVED LABS ENERGIZE BIOMASS RESEARCH

NREL scientist Bryon Donohoe works in the Cellular Visualization room of the Biomass Surface Characterization Lab, looking at different views of ultra structures of pre treated biomass materials. One of the first labs in the Bioenergy Center to undergo a facelift, it is now visually one of the most striking. *Photo by Dennis Schroeder, NREL/PIX 17879*

When you've lived in the same "home" for more than 20 years, a time comes when you need to upgrade your furnishings to keep current and spruce things up a bit. That is exactly what has happened at the U.S. Department of Energy's National Renewable Energy Laboratory (NREL). NREL is home to the National Bioenergy Center where eight of the research labs hadn't been updated in years.

Technologies to convert plants into fuels are on the cutting edge when it comes to helping the United States wean itself from foreign oil. But the old laboratory designs were not helping NREL researchers in their efforts to be as efficient as possible.

"The way that labs are designed today is much different than 20 years ago and the old labs were inadequate to support the capabilities we've developed in research and analysis," said National Bioenergy Center Director Mike Cleary. "The reconfigured labs make much better use of the space and will make us much more efficient in achieving our milestones."

Biomass Compositional Analysis Lab

To successfully produce cellulosic ethanol, you need to know what is in the plant that you are trying to break apart. The team working in NREL's Biomass Compositional Analysis Lab can tell you exactly what you are dealing with. The lab's core work is preparing biomass samples for analysis. The generated data is fed into models for pretreatment, fermentation, and other predictive tools.

"The Biomass Compositional Analysis Lab is the tip of the sword in the ethanol process," said NREL Senior Researcher Ed Wolfrum. "Here we examine the feedstock to see what's in it and how can that be used to make ethanol."

While the idea is a simple one, getting the work done was once a challenging shuffle between labs. "It used to be that we had four labs scattered everywhere throughout the building and samples were moved from lab to lab," NREL Scientist Justin Sluiter said. "We now have a single location where everyone can work together—a place that we can come home."

Being comfortable in their new home is important because the process to analyze biomass can take up to eight days with as many as 15 people working in the lab. "At the end of the day, we have a complete analysis of a biomass sample," Sluiter said. "We know how much glucose, xylose, lignin, ash, protein is in there—we know everything."

Interest in this type of work has grown along with the ethanol industry. "We've gotten a lot busier and the respect for the type of analysis work that NREL does continues to grow," Sluiter added. "People are starting to try to do this type of work themselves but end up coming to NREL because it is a lot harder than it seems and we are really good at it."

Biomass Surface Characterization Lab

One of the first labs in the Bioenergy Center to undergo a facelift now is visually one of the most striking. NREL's Biomass Surface Characterization Laboratory is focused on biomass recalcitrance research. Recalcitrance is the natural resistance of plant cell walls to deconstruction. This natural resistance is a key barrier to the development of next-generation biofuels.

Six different rooms in the Biomass Surface Characterization Lab house a plethora of imaging and visualization equipment including:

- Atomic force microscopy
- Transmission electron microscopy
- Scanning electron microscopy
- Total internal reflectance fluorescence microscopy
- Scanning laser confocal microscopy.

However, the centerpiece of the lab's makeover is the visualization room. The room's bank of monitors and computers provide multiple colorful slices of a biomass sample. To get these images, a microscopic amount of biomass is embedded in resin and then sectioned, nanometers thin, under a specialized ultramicrotome. Before the addition of the visualization room, researchers spent time at the microscopes examining the digital snapshots of the biomass.

"Image processing and image analysis can now be done away from the microscopes, freeing them up for the next person to come in and capture data," said NREL Senior Scientist Bryon Donohoe. "This greatly improves the efficiency of how the microscopes are used."

The new room also allows colleagues to discuss side-by-side images of a biomass sample as seen by different imaging modes. "Small groups of experts will sit here and look at their

fresh-off-the-microscope data but in a way that brings up all of the correlative images at once," Donohoe said. "Bringing these images together helps people understand what really is happening and whether what we did to the biomass is really helping it to break apart and break down into sugars to be converted into fuels."

The visualization room also has proven to be a valuable educational tool for NREL. "Small groups visiting NREL can enter the lab and see a dynamic scientific poster," Donohoe said. "We can show them the real data we generate and how it fits together into a story. Humans are visual creatures and after people see images, they tell us that that they can begin to understand what it is we are doing. Once you have that picture in your mind, it's easier to think more deeply about what the problems are and how we can solve them."

Molecular Beam Mass Spectrometry Lab

NREL's biomass thermochemical conversion technologies and research also got a boost with the updated Molecular Beam Mass Spectrometry Lab. Thermochemical conversion technologies make fuels from biomass using heat resulting in syngas or pyrolysis oil. During this process, a Molecular Beam Mass Spectometry system (MBMS) extracts and analyzes the gases. The lab remodel means that researchers now have access to new equipment and workspace.

"We acquired two new MBMS instruments and needed space to install and use them," NREL's Mark Davis said. "Everything is now centralized, which now allows us to use all pieces of equipment at once rather than one at time. We are able to tailor the experiment that we want to do to the result that we want to get, rather than to the equipment available."

The reason the added equipment is so valuable to NREL is that, according to Davis, "mass spectrometry enables us to have a fundamental understanding of thermochemical biomass conversion." The MBMS gives researchers online, real-time measurements of the gasification processes and also provides rapid readings on plant cell wall and lignin structure.

Other research institutions and private industry also seek this technology. Work done with the MBMS supports the BioEnergy Science Center (BESC), a collaboration of 20 university, industrial and national laboratory partners developing insight into the factors controlling the release of sugar in biomass feedstocks. The two new MBMS systems are being used for all of the collaborative work coming to NREL via the BESC.

NREL also has developed portable versions of the MBMS, which researchers can take to operating biomass gasifiers to measure their gas stream in real time and provide suggestions to help optimize their process.

"Bringing these images together helps people understand what really is happening and whether what we did to the biomass is really helping it to break apart and break down into sugars to be converted into fuels." –Bryon Donohoe

Biomass Catalyst Characterization Lab

Biomass Related Labs Recently Updated at NREL

- Molecular Beam Mass Spectrometry Lab
- Algal Research Lab
- Biomass Catalyst Characterization Lab
- Macromolecular Crystallography Lab
- Robotics and High Throughput Characterization Lab
- Nuclear Magnetic Resonance Lab
- Biomass Compositional Analysis Lab
- Biomass Surface Characterization Lab

Catalysts are used in thermochemical processes to convert tars (a byproduct of gasification) to syngas and then to convert syngas to liquid fuels. In the Biomass Catalyst Characterization Lab, NREL teams are working to understand and enhance the performance of catalysts to help realize the production of efficient biomass-derived fuels.

"The overarching goal of the Biomass Catalyst Characterization Laboratory is to intelligently design, characterize, and evaluate next generation catalysts for the efficient thermochemical conversion of biomass to fuels," NREL Principal Scientist Kim Magrini said. "We have the ability to look at things like surface area, particle size and distribution, and surface and bulk elemental analysis."

Working primarily with metals and ceramics, researchers in the Biomass Catalyst Characterization Lab use high temperatures to convert biomass to fuel. The recent upgrades to this lab gave researchers tools such as:

- New tabletop microscopy equipment that can take a snapshot of the catalyst surfaces and give an elemental readout at the same time;
- Four new high temperature reaction systems with real time product analysis;
- High temperature Raman microscope cells that enable scientists to study catalytic reactions while they are happening;
- Two-dimensional gas chromatography mass spectrometer that tells researchers what is in very complex liquids like pyrolysis oil. That information helps teams come up with ways to manipulate oil chemistry and turn it into fuels.

"Materials development and characterization is at the heart of any industrialized process that takes biomass to fuels," Magrini said. "These new reactors and instruments help us understand how they work and then how we can make them work better."

—Heather Lammers (September 14, 2010)

ALGAE RESEARCH IN FULL BLOOM AT NREL

These test tubes in an NREL algae lab hold a selection of lipids, or oils, that have been extracted from several algal strains. The tubes illustrate the colorful variety of work being done at NREL under a new aquatic species program.
Photo by Dennis Schroeder, NREL/PIX 18070

In a test tube, vibrant green microalgae look fragile, but in reality getting them to spill their lipid secrets to make renewable fuels is a challenge—one that researchers at the U.S. Department of Energy's (DOE) National Renewable Energy Laboratory (NREL) are tackling, again.

From 1978 to 1996, DOE funded NREL's study of microalgae under the Aquatic Species Program. During that time, 3,000 algae strains were isolated from various aquatic habitats. Roughly 50 caught the attention of researchers for their potential use in producing transportation fuels.

Then in 1996, the price of oil bottomed out at roughly $20 a barrel. The estimated cost of algae oil at the time was about $80 a barrel. With those price factors and other budget pressures, DOE stopped funding the Aquatic Species Program. Algae strains were sent to the University of Hawaii for safekeeping and the NREL team summarized nearly 20 years of research in the program's close-out report (http://www.nrel.gov/docs/legosti/fy98/24190.pdf).

"Today we have higher throughput devices that allow us to process samples very quickly. We can actually sort and pick out, at will, individual algae from the water sample and get a pure culture of a single strain of algae." –Al Darzins

Algae Comes Back into the Race

Fast forward 10 years and the Energy Independence and Security Act (EISA) of 2007 is passed by Congress. The 2007 law required that the United States produce and use 36 billion gallons of renewable fuels by 2022. EISA capped the use of starch based ethanol at 15 billion gallons and called for the remainder to be made up by "advanced biofuels"—basically anything else.

Because of its past research, NREL was ahead of the curve. In 2006, an NREL research team began seeking new funding for algae research. "We started another aquatic species program but it is really quite different from the first," said Al Darzins, former NREL principal group manager. "And we have surpassed the old aquatic species program in terms of funding."

In a few short years, the team raised more than $8 million. One of the goals was to diversify program funding said Darzins. DOE is again in the mix, but so is the Department of Defense (for work with the U.S. Air Force Office of Scientific Research) and companies like Chevron with whom NREL has cooperative research and development agreements.

NREL used some funding to retrace work in the old program by bio-prospecting for new strains, but thanks to new technology, the work goes a lot faster.

"We've accumulated almost 400 different algal strains from differing environments—freshwater, brackish, and saline," Darzins said. "Today we have higher throughput devices that allow us to process samples very quickly. Think about it like using tweezers—although it's a little more complicated than that. We can actually sort and pick out, at will, individual algae from the water sample and get a pure culture of a single strain of algae."

Focused on Biology

Once samples are collected, NREL is focused on understanding the biology of the organisms. "If you don't understand the biology and how to grow them, how are you ever going to grow them at a large scale and control them?" Darzins said.

NREL chose a strain of the algal species, *Chlorella vulgaris*, as its model organism. Researchers are trying to get a complete view of its molecular biology and biochemistry. In their opinion, it's a good study subject because it grows quickly and makes a lot of oil.

But, one of the hard parts of dealing with algae is getting the oil out of the cells—this is especially true with *Chlorella vulgaris*. "We typically use some sort of solvent, but even that's not so easy and the cell wall can resist it," Principal Research Supervisor Phil Pienkos said. "NREL is working to find enzymes that can help degrade the cell wall of algae and allow the solvents access so we can more efficiently extract the oil."

According to Pienkos, if an enzyme is found that can easily break down the cell wall, it might be possible to isolate the gene for that enzyme and engineer the algae to produce that enzyme just before it is ready to harvest.

"If you could induce the enzymes so that the cells become weakened on their own then it's possible that the cell could

survive and you could separate out the oil and return the cells into cultivation," Pienkos said. "That would be a real cost savings."

"NREL is looking at the metabolic engineering of algae but only to find out the fundamentals of how these organisms tick," Darzins added. "We are not growing genetically modified organisms outside the lab. By using them only in the controlled laboratory setting, we think it will tell us quite a bit."

Algae to Ethanol

To accelerate the deployment of advanced biofuels, President Obama and Secretary of Energy Steven Chu announced the investment of $800 million in new research on biofuels in the American Recovery and Reinvestment Act. The announcement included funds for research, development, and deployment of commercial algae-to-biofuels processes. Algenol was awarded $25 million to pilot a photo-bioreactor algal biofuel system—and NREL is working with this company to help them accelerate commercial production.

"They have a unique technology using algae to convert carbon dioxide (CO_2) directly to ethanol," Pienkos said. "Their photo bioreactor system allows them to continuously produce ethanol so they don't have to harvest algae."

NREL is working with Algenol on two fronts—a techno economic and lifecycle analysis of their production facility and evaluation of the algae for sensitivity to components in the flue gases used to feed the algae.

"When most people do their small-scale work, they tend to use air mixed with pure CO_2," said Pienkos. "When they scale-up they have to think about using an industrial source of CO_2, which is made up of different components. No one is sure if flue gas will have a long-term impact on algae production."

Using Light to Filter Algae

Whether a company is striving to make ethanol, green diesel, or even jet fuel from algae, the key will be isolating the right algae from the pool of thousands, if not hundreds of thousands of available strains in the environment. Sorting through water samples looking for the right candidate for a project consumes lots of money. NREL is solving that problem by using infrared light to sort out the best oil-producing algae.

"The traditional method to measure the oil content of algal biomass is very cumbersome," Researcher Lieve Laurens said. "It takes a long time—up to two days—and it uses lots of chemicals. We are using near-infrared spectroscopy to determine the oil content in the algae in a matter of minutes."

The process works by shining a broad spectrum light, with wavelengths ranging from the visible to the infrared region of the spectrum, at the sample. Several different detectors measure how much light is reflected versus how much was absorbed by the sample. According to Laurens, different molecules in the algal biomass will have different absorption peaks showing a "fingerprint" for the algae. That fingerprint, along with a mathematical model, is then used to estimate the oil content of that particular strain of algae.

The technique is non-destructive to the cell and, at this point, seems to be species agnostic. "In this case, we can scan the biomass and then continue doing something else with it," Laurens said. This technique has researchers pondering other possible applications. "For example, we could use this technique to screen a large number of algal strains in a culture collection in the search for high oil producers without having to measure the oil content using traditional methods."

Other plans are to apply these infrared methods to growing cultures to see if researchers can do real-time monitoring and determine when a culture is ready to be harvested. In addition, there is an application for crop protection.

"The traditional method to measure the oil content of algal biomass is very cumbersome. It takes a long time—up to two days—and it uses lots of chemicals. We are using near-infrared spectroscopy to determine the oil content in the algae in a matter of minutes." –Lieve Laurens

"In an outside open-pond system, it is likely that other algae will land in the pond and try to out-compete your species so this technique could be handy for monitoring the health of your crop," Laurens said.

What Do You Make with Leftovers?

Once an algal strain is selected, cultivated and the oils are finally harvested, there are leftovers which are referred to as residual biomass. The other question NREL researchers are tackling is what to do with the leftovers. Could they be used to make ethanol or biogas?

To make algae conversion a "two-fuels-for-the-price-of-one" winner, scientists have to understand what makes up the algae biomass. The team is bringing NREL's extensive knowledge in compositional analysis of biomass to the table. "The expertise in the compositional analysis group is a huge knowledge base so we don't have to start completely from scratch when it comes to algae," Laurens said. "There are certain methods we can use and there are some things that will be unique and require some creative solutions. For instance, the carbohydrates in algae are very different compared with those found in biomass like corn stover."

No matter the many new challenges NREL researchers face when it comes to using algae for any variety transportation fuels, the work could really pay off in the end.

"Algae has a lot of potential, and NREL has been doing a good job of not subscribing to all of the hype," Darzins said. "We have been a credible advisor to DOE, industry, and the general research community. Our message has been that for algal biofuels the potential is huge—it could be a game changer. But, the challenges are equally as daunting—and boy, have we got our work cut out for us."

—Heather Lammers (November 3, 2010)

SMART WINDOWS: ENERGY EFFICIENCY WITH A VIEW

NREL research scientist Robert Tenent manipulates an ink-jet sprayer in a glove box at the Process Development Integration Laboratory. Tenant is incorporating thin-film design and manufacturing processes to improve the performance and lower the cost of electrochromic windows. *Photo by Patrick Corkery, NREL/PIX 16937*

Imagine wrapping a giant pair of Wayfarers or Aviators around your house on a sunny day. Wouldn't that be cool?

NREL researchers are trying to do the high-tech equivalent of putting sunglasses on buildings with a new generation of insulated "dynamic windows" that change color to modulate interior temperatures and lighting.

Buildings consume 40% of the nearly 100 quadrillion Btus (quads) of energy the United States consumes annually. Conventional clear windows account for about one-tenth of the buildings' share of that energy load, or four quads. That's because they allow precious heat to leak out on chilly days or allow the incoming sun to warm a room to uncomfortable levels, and building's climate system struggles to adjust.

Using dynamic windows to compensate for some of the electric lighting used inside buildings could save another quad of energy, according to NREL research scientist Dane Gillaspie.

"Combined, a broad installation of these highly insulating, color-changing windows could save about one-eighth of all the energy used by buildings in the United States every year," Gillaspie said, "and about 5% of the nation's total energy budget."

"Combined, a broad installation of these highly insulating, color-changing windows could save about one-eighth of all the energy used by buildings in the United States every year." –Dane Gillaspie

Torture Tested

Color-changing windows have been available for more than two decades. While they have attracted widespread interest—NREL provided a prototype in 1998 for a solar home exhibit at Walt Disney's Epcot Center—they have not become widely available or commercially successful.

Since the 1980s, NREL has tested various window technologies and helped establish technical standards for the industry with the American Society for Testing and Materials.

Researchers put window samples into accelerated weathering chambers for 20,000 light-dark cycles, or the equivalent of 20 years of service. Conditions inside the chamber are calibrated at the intensity of one sun (or the amount of light that typically hits Earth on a sunny day) and 176°F (80°C.)

"We call it our torture chamber," said Erin Whitney, NREL's dynamic window testing coordinator.

Many products and prototypes tested in the NREL chamber have performed poorly and their color-changing properties degraded sooner-than-expected. Among contemporary designs, NREL has verified the performance of one technology developed by Sage Electrochromics—which has a cooperative research agreement with the laboratory. Sage predicts its technology will drop in price by as much as 70% over the next five years as performance improves, volume increases, and production becomes more efficient.

However, today's dynamic windows still cost up to $1,000 per square meter of glass.

"That's a problem," said NREL senior scientist Anne Dillon, who manages the dynamic windows program. "They are too expensive."

How They Work

Insulated windows are made from multiple layers of glass. Typically, the spaces between the panes are filled with a gas. Electrochromic windows are made with a very thin stack of dynamic materials deposited on the outside pane.

The dynamic portion consists of three layers: active and counter electrodes separated by an ion conductor layer. NREL researchers are experimenting with electrode layers made of nickel and tungsten oxides; the ions are lithium.

The window changes from clear to tinted when a small electric field is applied and the lithium ions move into the working electrode layers. The change can be triggered by sensors in an automated building management system, or by a flick of a switch. Electrochromic windows can block as much as 98% of the direct sunlight. Reversing the polarity of the applied voltage causes the ions to migrate back to their original layer, and the glass returns to clear.

Gillaspie said NREL researchers are using metal oxides because light does not degrade them. While current manufacturer warranties typically extend for 10 years, NREL is aiming to develop windows that perform for 20 years or more.

Although electrochromic windows add yet another powered device to a modern building, they should save far more energy than they consume. Powering 1,500 square feet of color-changing glass (about 100 windows) would require less power than a 75 watt light bulb.

And because the windows modulate the building's interior climate, the rest of the heating, cooling, and illumination systems can be smaller, leading to lower construction costs and lower monthly energy bills.

In computer simulations of building performance, the electrochromic windows:

- Reduce electricity consumption for cooling by up to 49%;
- Lower peak electrical power demand by up to 16%; and
- Decrease lighting costs by up to 51%.

"The brilliant thing is that not only do you save energy with these windows," Gillaspie said, "but they allow you to scale back the HVAC, so you save money."

Learning from Photovoltaics

If the dynamic layers of the electrochromic window remind you of an advanced solar cell, it's no coincidence. The entire dynamic stack between the glass panes measures about a micron thick. That's about the same as thin-film photovoltaic cells.

The dynamic layers of electrochromic windows are manufactured with a vacuum deposition process called "sputtering." The process also is used in PV and semiconductor manufacturing because it provides a high degree of control and creates uniform results when depositing materials in ultrathin coatings. However, sputtering is relatively slow and energy-intensive.

NREL researchers are working to drive down high manufacturing costs by creating the dynamic layers using inexpensive printing technologies and metallic inks similar to research into high-volume thin-film PV manufacturing already taking place at NREL.

NREL's smart window engineers will be using some of the same equipment with window manufacturers in the advanced Science and Technology Facility, including the Atmospheric Processing Platform in the Process Development and Integration Laboratory.

NREL researchers also are investigating ways to rapidly make electrochromic films on cheaper, flexible plastic substrates instead of glass. This will allow development of so-called "roll-to-roll" processing methods similar to those currently used to print newspapers.

An electrochromic device made of flexible materials could be retrofit to existing windows, NREL research scientist Robert Tenent said.

Expanding into the retrofit market would expand the windows' use and accelerate energy savings, he said.

"By and large, high manufacturing costs are limiting the implementation of these dynamic materials," Tenent said. "A significant portion of our research efforts are directly focused on eliminating that expense through manufacturing improvements and allowing us to realize the tremendous potential energy savings that this technology holds."

The PV connection doesn't end there. Dynamic windows typically are hardwired into a building's electrical system. But in a wireless version, the power for the color change could come from a small PV cell installed in the window's casement.

When sunlight hits the PV cell, it converts the sunlight to power, which ionizes the electrode layers and darkens the window

Eventually, dynamic windows may produce more energy than they consume so power generation would not be limited to a rooftop PV system.

NREL research supports the U.S. Department of Energy's goal to deploy energy saving windows for residential construction by 2015 and commercial buildings by 2020.

— Joe Verrengia (January 22, 2010)

LIGHT INSPIRES ENERGY EFFICIENT BUILDING DESIGN

NREL Senior Construction Manager Carl Cox demonstrates how the windows will actually open at the RSF as part of the buildings' ventilation system. *Photo by Patrick Corkery, NREL/PIX 17092*

Artists find inspiration in many ways. But for the artists (architects and researchers) working collaboratively to create the most energy efficient office space in the United States, the inspiration was simply light. In fact, light and the access to light turned out to be a top factor when designing the U.S. Department of Energy's (DOE) Research Support Facility (RSF) located on NREL's South Table Mountain Campus near Golden, Colorado.

"One of the most powerful drivers in the project is daylight," Philip Macey, RSF project manager for Haselden, said. "It's the reason why the building is fairly slim from front to back and long. Daylight and solar energy are at the core of the building and the windows are the vehicle that gets the daylight into the building."

> "One of the most powerful drivers in the project is daylight. Daylight and solar energy are at the core of the building and the windows are the vehicle that gets the daylight into the building." –Philip Macey

Scheduled to open the summer of 2010, the 222,000 square-foot RSF will house more than 800 staff and an energy efficient information technology data center. Because 19% of the country's energy is used by commercial buildings, DOE plans to make this facility a showcase for energy efficiency. DOE hopes the design of the RSF will be replicated by the building industry and help reduce the nation's energy consumption by changing the way commercial buildings are designed and built.

Size Matters

To draw as much light into the building as possible, designers looked at a variety of window sizes and glass combinations that would maximize the amount of light, reduce glare and prevent heat from entering and escaping the building.

"There's this push and pull between the size and the construction of the window and getting all of the benefits of daylight into the building," Macey said.

According to Macey, the team spent a good deal of time deciphering which windows would be just the right size. "The south side RSF windows are a little smaller than the north side windows," Macey said. "That was so we could get the light to come into the building in just the right way. On the north side, the glass goes up considerably higher and that's because north light is really gentle. It's soft and diffuse and there really isn't much direct sun. The south side requires a lot more attention because you can get direct sunlight—and it's typically not helpful when it comes to conserving energy.

"The windows are literally the balance point in how the building manages energy. Get the windows too big and you'll get too much heat gain and heat loss. Too small and you won't get enough daylight to light the interior of the building to the middle of the floor plan. You want to have nice even, balanced light across the floor plan."

To help boost the light to the middle of the office space, some of the windows have "light louvers" inside the widow. The light louvers look like a mini venetian blinds hung upside down in the window. The curve of the louver is shaped precisely to catch the light and bounce it deep into the building. By literally helping to toss the light across the room, designers were able to maximize the sunlight increasing its distance from 20 feet to 30 feet inside the office.

The windows in the RSF will also serve double duty as a working part of the buildings' ventilation system. To help cool things down in the summer, employees will get notification to open windows to let cool air in or to shut windows to keep warm air out. While windows that open and light bouncing louvers are elegant solutions for letting light and air into the building, the windows on the west and eastern exposures will employ a different strategy—keeping heat out—to help the building conserve energy.

Windows to Energy Efficiency

"One of the challenges is that although windows let in the daylight, on the other hand, windows are also how you lose most of the energy out of the building," Macey said. "You have to find this really careful balance if you care anything about energy."

Special challenges like this mean looking for new technology. At the extreme ends of the office wings, there will be two kinds of special "dynamic" windows—electrochromic and thermochromic—to ensure energy savings.

"The essence of energy efficiency isn't simply about being 'green'—it's about cost savings and smart resource use," Erin Whitney, NREL's dynamic window testing coordinator, said. "Intelligent solar-managed windows are a simple yet effective way to reduce energy consumption while retaining our Rocky Mountain views and the architectural integrity of the building."

Although it is tempting to take maximum advantage of mountain views west of the RSF, western windows get overloaded with direct sun, even in the winter. When the days are longer in the summer, the windows also could let in a ton of heat thanks to the direct exposure to the sun.

"The windows are literally the balance point in how the building manages energy." –Philip Macey

To keep out the heat, western windows will employ electrochromic technology. Electrochromic windows tint once a small electric current is applied. "When these windows tint, you control the solar radiation that gets in the room by shutting out more of the solar spectrum," NREL Research Scientist Dane Gillaspie said. "These types of windows help to reduce the heating loads—especially the peak heat—which is the most expensive in terms of electricity."

The other advantage to electrochromic windows is the ability to control when the windows tint. "Because the electrochromic windows tint when you apply voltage across the window, they are user controlled, which means they can be integrated into a building control system allowing you to decide when to darken the window," Whitney said.

Another type of dynamic window will be used on the eastern balconies. Thermochromic windows also provide resistance to the transfer of heat by reacting to temperature changes. "During winter days the sun comes up late, isn't high, and doesn't warm up the eastern exposure," Macey said. "These windows have glass resistant to heat transfer that will help us dramatically reduce the heat we would normally lose."

"Thermochromic windows react to changes in the environment so you don't have to wire them to the building, you just put them in," Gillaspie said. "You don't get the fine control of the electrochromic windows but, the thermochromic windows are cheaper and it's a killer technology."

Windows Part of a Living Laboratory

While DOE is looking to the RSF to be a showcase building for energy efficiency, researchers at NREL see the RSF as a living laboratory to study building energy use, which includes the windows. "Part of the test is to see how normal office workers react to the technology," Gillaspie said. "As researchers we'll love seeing it, and other tests have shown people really like the technology—but we'd like to see that for ourselves."

Through the years, NREL has worked with a lot of companies to test window technologies, but seeing products in a real world environment is something that Whitney is looking forward to. "We have no way of simulating how those lab results will transfer to use in the real world so this is a great real-life test of these windows that have not been tested in a building situation.

"It will be an interesting comparison of the two technologies and how well they each respond to different situations." Whitney said.

The RSF was designed by RNL and built by Haselden Construction, under a design-build, integrated project delivery method. Stantec served as sustainable design consultant and mechanical/electrical engineer.

— *Heather Lammers (March 1, 2010)*

NREL FINDS A WAY TO GIVE LEDS THE GREEN LIGHT

NREL's Solar Energy Research Facility is the site of experiments using lasers to probe the light-emitting properties of gallium indium phosphide alloys for making light-emitting diodes.
Photo from NREL/PIX 06353

Light bulbs that last 100 years and fill rooms with brilliant ambiance may become a reality sooner rather than later, thanks to a National Renewable Energy Laboratory (NREL) discovery.

NREL scientists found a way to generate a tricky combination of green and red that may just prove to be the biggest boost for illumination since Edison's light bulb.

Green isn't just a symbol of environmentalism, it is a real color, and a desperately needed one for researchers looking for a way to light homes, streets, and buildings at a fraction of today's costs.

> " We can smoothly control the hue throughout the day like nobody has imagined." –Angelo Mascarenhas

LEDs—light-emitting diodes—are the promise of the future because unlike tungsten bulbs or compact fluorescent bulbs, they deliver most of their energy as light, rather than heat. An extra plus is that they don't contain dangerous mercury.

The era of LEDs is fast approaching. The U.S. Department of Energy expects to phase out tungsten bulbs in four years and compact-fluorescents in 10 years. That will leave LEDs with virtually 100% of the market.

To make an LED that appears white, researchers minimally need the colors red, green, and blue. The white light from the sun is really all the colors of the rainbow. Without at least red, blue, and green from the spectrum, no lighting device will be practical for home or office use.

Red proved easy to generate, and about 15 years ago, Japanese scientists found a way to generate blue, thus providing two of the key colors from the spectrum of white light.

But green has been elusive. In fact, the $10 LEDs that people can buy now are made to look white by aiming the blue light at a phosphor, which then emits green. It works okay, but the clunky process saps a big chunk of the efficiency from the light.

NREL Jumps into LED Research via Solar Cells

Along came NREL, a world leader in designing solar cells, but a neophyte in the lighting realm.

NREL scientist Angelo Mascarenhas, who holds patents in solar-cell technology, realized that an LED is just the reverse of a solar cell. One takes electricity and turns it into light; the other takes sunlight and turns it into electricity.

"We'd been working with solar cells for 30 years," Mascarenhas said. "Could we find some device where we could just reverse the process of making solar cells?"

Indeed, Mascarenhas found it. NREL had won major scientific awards with its inverted metamorphic solar cells, in which the cells are built by combining layers of different lattice sizes to optimally capture solar energy. In fact, an NREL-produced IMM cell set a world record by converting 40% of absorbed sunlight into electricity.

Along the way, "We had already developed some of the know-how to capture sunlight in this green spectral region," Mascarenhas said. They hadn't reached there, because solar cells don't need a green, but they had begun to understand the challenges of getting to a green.

Solving a Decade-Old Conundrum

For a decade, LED researchers had tried and failed to make a reliable efficient green light by putting indium into gallium nitride.

"All signs indicated an impasse," Mascarenhas said. "When you come across an impasse, you don't just bang your head against the wall. You end up breaking your head, not the wall. Instead, you move away from the wall, you find a different path."

He and his fellow solar-cell researchers had dealt with the same problem trying to build a solar cell with gallium indium phosphide. When the lattices created by molecular gases don't match up with the lattices of the layer below, "It can't grow well and the efficiency is very, very poor," Mascarenhas said.

NREL's solar cell experts found a way around that. They put in some extra layers that gradually bridge the gap between the mismatched lattices of the cell layers.

"The approach is to grow a different material with an in-between lattice," Mascarenhas said.

The researchers deposited layers that had lattice patterns of atoms close to, but not exactly matching, the layers below. The tiny gap in size was at the so-called "elastic limit" of the material—close enough that the lattices bonded to each other and impurities were deflected away.

Then, add a third layer, this one again at the precise "elastic limit" of the one below. After about seven microns of layering, the result is a solar cell with a firm bond and almost no impurities.

Why not try that same process, only in reverse, to make a reliable deep-green LED using indium gallium phosphide?

A Deep Green on the Very First Try

Astonishingly, once the concept was understood, Mascarenhas's team produced a radiant deep green on their very first try—without any money backing the effort.

The aim now is to provide a fourth color to make that white light even whiter.

NREL plans to use a slightly deeper red and a lemony green, which would then be combined with a blue and a very deep green made using the gallium nitride based technology.

In three years, NREL should have a bi-colored device that when teamed with blue and deep green can produce a sterling LED with a color-rendering index well over 90, Mascarenhas said.

"It will give you one of the finest color-rendering white lights" and the manufacturing costs shouldn't increase, he said.

"We have a patent on a device that will provide these two colors, as one unit, to industry," Mascarenhas said. "They will arrange them like the mosaic in a fly's eye—our units side by side with the blue and deep green combination, alternating in a pattern."

"From afar, it will look like white. You won't be able to see the individual colors of the mosaic structure."

"We have full confidence that this is achievable," Mascarenhas said.

"This is practical science, not pie-in-the-sky science."

–Angelo Mascarenhas

"The technical things will be solved," he said. "This is practical science, not pie-in-the-sky science."

The resulting white light LED will be intelligent. "We'll be able to electronically control the hue of the lamp," he said. "We can vary the combination of intensities of these four colors on an electronic circuit. By slightly increasing the blue, we can make it more suitable for daylight. By turning down the blue and increasing the reddish yellow, we can make it softer, more suitable for night. We can smoothly control the hue throughout the day like nobody has imagined. "

And, by the way, the move toward all LEDs all the time will save some $120 billion in electricity between now and 2030, the Department of Energy forecasts. Not to mention tens of millions of tons of greenhouse gases.

"This is reality," Mascarenhas said. "This is going to happen."

— *Bill Scanlon (April 5, 2010)*

NATIONAL LABS PARTNER FOR BETTER BUILDING EFFICIENCY

Details matter when it comes to saving energy. NREL Senior Engineer Michael Deru and NREL Mechanical Engineer Ian Doebber examine the night curtains that cover the refrigerated produce at the Whole Foods Market in Golden, Colorado. Covering open refrigerated cases when the store is closed is a proven energy efficiency strategy. *Photo by Patrick Corkery, NREL/PIX 17307*

Commercial buildings use a lot of energy, and building owners and operators foot the bill for that energy. It usually isn't hard to get owners and operators to improve energy efficiency, because the result is reduced operating costs, a healthier bottom line, and bragging rights as good corporate citizens. But energy systems in commercial buildings are complex, and it can be hard to know where to start without expert help.

This is where Commercial Building Partnerships (CBP) comes in. Through this new U.S. Department of Energy (DOE) initiative, commercial building owners and operators can tap the expertise of national laboratories and private-sector technical experts to help them save money and energy across their building portfolios. DOE's National Renewable Energy Laboratory (NREL), Lawrence Berkeley National Laboratory (LBNL), and Pacific Northwest National Laboratory (PNNL) are managing the process, which is funded through the American Recovery and Reinvestment Act.

"This initiative is unique because it demonstrates that it's cost-effective to make buildings more energy efficient, and that energy-efficient buildings are easy to replicate." – Paul Torcellini

Speeding the Transition to Energy Efficiency

To add a sense of urgency to this effort, not only do commercial buildings use a lot of energy, but they use a lot of energy for a long time. Large office buildings, for example, are still in use an average of 70 years after they're built and a third are still in use after 100 years.

By teaming commercial building owners and operators with laboratory researchers and private-sector technical experts, CBP accelerates the deployment of energy efficiency measures into the marketplace. In the process of working through their projects with the building researchers and technical experts, building owners and operators learn about replicable, cost effective energy saving measures that they can apply across their extensive building portfolios. Including private-sector technical experts further speeds the process, because they will share the information and experience gleaned from CBP with other clients.

To reach an even wider audience, publicly available case studies will describe each CBP new construction and retrofit project in detail. This documentation will make it straightforward for building owners and operators outside of the CBP initiative to benefit from the work.

Owners and operators of planned new and retrofit buildings must commit to substantial energy savings in the selected projects.

"CBP participants will create buildings with measured energy savings of at least 50% for new construction and 30% for existing buildings," said Paul Torcellini, group manager for commercial building research at NREL. "This initiative is unique because it demonstrates that it's cost-effective to make buildings more energy efficient, and that energy-efficient buildings are easy to replicate."

A Successful Collaboration

NREL researchers have long experience working with industry to improve energy efficiency. One company NREL works with is Whole Foods Market, a national food retailer.

Whole Foods is well known for its commitment to natural and organic foods. It comes as no surprise that the company also has a commitment to better buildings.

"We've had internal green building standards in place for years, but our work with NREL has helped us focus more specifically on reducing energy use in our stores," said Kathleen Loftus, Global Leader, Sustainable Engineering, Maintenance, and Engineering.

Grocery stores use significant amounts of energy for refrigeration, comfort cooling and heating, and lighting. Whole Foods has additional requirements because of its customer-centric business model and commitment to high quality, attractively displayed merchandise.

Each store works hard to deliver a positive shopping experience through everything from exceptional customer service to displaying "food as art." The challenge is preserving the look and feel of the stores while reducing the energy required to operate them.

"Working closely with local, regional, and national Whole Foods staff, as well as the company's private-sector consultants, we identified energy efficiency measures that reduce energy consumption without compromising the shopping experience," NREL Senior Engineer Michael Deru said.

Both Whole Foods and NREL benefit from this collaboration. NREL researchers learn the importance of considering business sensitivities and constraints as well as technical solutions. If the energy efficiency measures NREL recommends are consistent with the company's business goals, it greatly improves the probability of successful deployment in other stores.

"We identified energy efficiency measures that reduce energy consumption without compromising the shopping experience." – Michael Deru

As a result of their access to NREL technical expertise, Whole Foods has learned how to further reduce energy use and operating costs.

"NREL researchers have expertise in all areas of building energy end use, state-of-the-art efficiency technologies, and renewable energy sources," Loftus said. "And they even understand supermarket construction and energy requirements and challenges, and that's no small feat!"

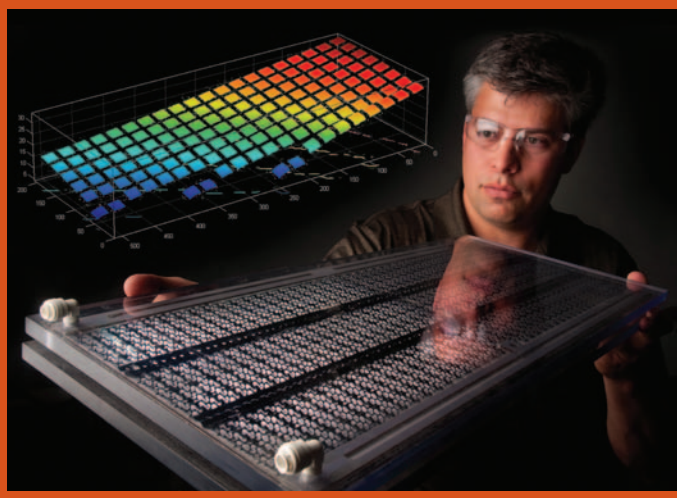
New Opportunities

The three participating DOE laboratories—NREL, LBNL, and PNNL—released a call for projects for commercial building owners and operators and a request for proposals (RFP) from technical experts. The RFP helps retailers, commercial real estate companies, hospitals, educational institutions, and other commercial building owners and operators take advantage of national laboratory technical expertise to improve the energy efficiency of their facilities.

In addition, technical experts interested in helping commercial building owners and operators achieve significant energy savings in their facilities responded to the RFP.

— Greg Stark (April 26, 2010)

ENERGY SAVING A/C CONQUERS ALL CLIMATES



NREL senior engineer Eric Kozubal examines a prototype air flow channel of the DEVap air conditioner, which he co-invented. DEVap, which stands for desiccant-enhanced evaporative air conditioner, is a novel concept that uses membrane technology to combine the efficiency of evaporative cooling and the drying potential of liquid desiccant salt solutions. The graph superimposed on the photo shows how hot humid air, in red, changes to cool dry air, in blue, as the air passes through the DEVap core. *Photo by Patrick Corkery, NREL/PIX 17437*

Ah, the cool, refreshing feel of air conditioning on a sweltering summer day.

Ugh, the discomfort when those energy bills in July, August, and September come due—$200, $400, $600 or more.

Feel miserable, or dig deep into your wallet—not much of a choice for the 250 million Americans who live in climates where heat, humidity or both are a Catch-22 for three to 12 months a year.

A soothing solution may be on its way, thanks to a melding of technologies in filters, coolers, and drying agents.

The U.S. Department of Energy's National Renewable Energy Laboratory (NREL) has invented a new air conditioning process with the potential of using 50-90% less energy than today's top-of-the-line units. It uses membranes, evaporative cooling and liquid desiccants in a way that has never been done before in the centuries-old science of removing heat from the air.

"The idea is to revolutionize cooling, while removing millions of metric tons of carbon from the air," NREL mechanical engineer Eric Kozubal, co-inventor of the Desiccant-Enhanced eVaporative air conditioner (DEVap), said.

"We'd been working with membranes, evaporative coolers, and desiccants. We saw an opportunity to combine them into a single device for a product with unique capabilities." – Eric Kozubal

"We'd been working with membranes, evaporative coolers, and desiccants. We saw an opportunity to combine them into a single device for a product with unique capabilities."

Hot and Humid Climates are Tricky

Evaporative coolers are a lower-cost alternative to A/C in dry climates that don't get too hot or humid—say, Denver, but not Phoenix or Miami. Water flows over a mesh, and a fan blows air through the wet mesh to create humid, cool air.

In humid climes, adding water to the air creates a hot and sticky building environment. Furthermore, the air cannot absorb enough water to become cold.

In Phoenix or Tucson, the evaporative cooler can bring down the temperature, but not enough to make it pleasant inside on a 100-degree day or during the four to eight week moist period known as monsoon season. The cooling bumps up against the wet bulb temperature, the lowest temperature to which air can be cooled by evaporating without changing the pressure. The wet bulb temperature could be 75°F or 80°F on a mid-summer Tucson day. Typically, evaporative coolers only can bring the temperatures about 85% of the way to the wet bulb level.

So, for most of the country, refrigeration-based air conditioning is the preferred way of keeping cool.

Cooling Requires Temperature Drop and Less Moisture

Cooling comes in two forms—sensible cooling, which is a temperature drop, and latent cooling, which comes from pulling the moisture out of the air.

One intriguing product already on the market in arid, temperate climates is the Coolerado cooler. It differs from a typical evaporative cooler by never increasing the moisture content of the supply air. It provides cool air through indirect evaporative cooling. Indirect evaporative systems use a purge air stream that removes heat from the product or supply air stream that is then directed into a building.

That way, the Coolerado can cool the air all the way to the wet-bulb temperature.

"It's a big improvement on evaporative cooling because it doesn't add moisture and still gives you cold air," Kozubal said. However, in a humid climate, it still does not provide cold air or humidity control.

DEVap: Liquid Desiccants, Permeable Membranes

The DEVap solves that problem. It relies on the desiccants' capacity to create dry air using heat and evaporative coolers' capacity to take dry air and make cold air.

"By no means is the concept novel, the idea of combining the two," Kozubal said. "But no one has been able to come up with a practical and cost-effective way to do it."

HVAC engineers have known for decades the value of desiccants to air conditioning. In fact, one of the pioneers of early A/C, Willis Haviland Carrier, knew of its potential, but opted to go the refrigeration route.

Most people know of desiccants as the pebble-sized handfuls that come with new shoes to keep them dry.

The kind NREL uses are syrupy liquids—highly concentrated aqueous salt solutions of lithium chloride or calcium chloride. They have a high affinity for water vapor, and can thus create very dry air.

"It's a big improvement on evaporative cooling because it doesn't add moisture and still gives you cold air." – Eric Kozubal

Because of the complexity of desiccant cooling systems, they have traditionally only been used in industrial drying processes. Inventing a device simple enough for easy installation and maintenance is what has impaired desiccant cooling from entering into commercial and residential cooling markets.

To solve that problem, the NREL device uses thin membranes that simplify the process of integrating air flow, desiccants, and evaporative cooling. These result in an air conditioning system that provides superior comfort and humidity control.

The membranes in the DEVap A/C are hydrophobic, which means water tends to bead up rather than soak through the membranes. Imagine rain falling on a freshly waxed car. That property allows the membranes to control the liquid flows within the cooling core. "It's that property that keeps the water and the desiccant separated from the air stream," Kozubal said.

"We bring the water and liquid desiccant into DEVap's heat-mass exchanger core," Kozubal said. "The desiccant and evaporative cooling effect work together to create cold-dry air."

The air is cooled and dried from a hot-humid condition to a cold and dry condition all in one step. This all happens in a fraction of a second as air flows through the DEVap air conditioner. The result is an air conditioner that controls both thermal and humidity loads.

DEVap helps the environment in many ways. DEVap uses 50-90% less energy than top-of-the-line refrigeration-based air conditioning.

Because DEVap uses salt solutions rather than refrigerants, there are no harmful chlorofluorocarbons (CFCs) or hydrochlorofluorocarbons (HCFCs) to worry about. A pound of CFC or HCFC in refrigerant-based A/Cs contributes as much to global warming as 2,000 pounds of carbon dioxide. A typical residential size A/C has as much as 13 pounds of these refrigerants. The release of this much refrigerant is equivalent to burning more than 1,300 gallons of gasoline, or driving over 60,000 miles in a 2010 Toyota Prius. That's based on the Environmental Protection Agency's fuel efficiency rating for the 2010 Toyota Prius and on the standard of 19.5 pounds of carbon dioxide for every gallon of gasoline burned.

Traditional air conditioners use a lot of electricity to run the refrigeration cycle, but DEVap replaces that refrigeration cycle with an absorption cycle that is thermally activated. It can be powered by natural gas or solar energy and uses very little electricity.

This means that DEVap could become the most energy efficient way to cool your house whether you live in Phoenix, New York, or Houston.

NREL has patented the DEVap concept, and Kozubal expects that over the next couple of years he will be working on making the device smaller and simpler and perfecting the heat transfer to make DEVap more cost effective.

Eventually, NREL will license the technology to industry.

"We're never going to be in the air conditioner manufacturing business," said Ron Judkoff, Principle Program Manager for Building Energy Research at NREL. "But we'd like to work with manufacturers to bring DEVap to market and create a more efficient and environmentally benign air conditioning product."

— Bill Scanlon (June 11, 2010)

MAKING WIND TURBINES BUILDS CAREER INTEREST

Former NREL education science consultant Rick Shin helps Denver West High School student Nicole Nuxoll with her wind turbine. *Photo by Patrick Corkery, NREL/PIX 17127*

The wind turbine that Louis Solis and Jose Santistevan fashioned in about 20 minutes promptly registered a 5.1 on the voltage meter in their Denver West High School classroom, tops in the class.

But Solis and Santistevan, both 17-year-old juniors, were determined they could do better. So, they bent and trimmed the balsa wood, flattened the angles on the blades, and tried again. They flipped on the house fan and, what do you know, the meter read 5.3 volts.

Definitely worth some high-fives.

"This appeals to me," Santistevan said. "To try to find new technology to make renewable energy more accessible and more affordable, that's important. Enjoying your job, having a good time while you're working, that's also important to me."

Rick Shin, former science consultant with NREL's Education Programs, presented the hands-on lesson aimed at sparking interest in clean-energy careers for students who don't necessarily see a bachelor's degree in their futures.

The Energy Workforce Program of Goodwill Industries of Denver sponsored the visit.

Inspiring the Work Force of the Future

"We are well aware of the future challenge of filling such jobs in our nation," said Cynthia Howell, NREL's Education Programs former manager. "We're partnering with education to home-grow such technicians and engineers."

A major goal at NREL is to spark the development of a work force for the renewable energy economy of the future. NREL's Education Programs staff visit local schools dozens of times each year to instruct and inspire.

About 28% of American adults have a bachelor's degree. The remaining 72% vie for a number of jobs that may require specialized training or certification. For example, there are 874,000 electricians and 773,000 hair stylists in the United States.

More education—or at least more training—typically means more income.

According to the U.S. Census, the average American with a bachelor's degree earns about $51,000 a year; those who drop out from high school earn $18,700; and those with a high school diploma but not college degrees earn an average of $28,000.

Of course, there are huge variables in income among those with high school diplomas, the higher-paying jobs going to those with the most marketable technical skills.

Soon the renewable energy industry will be looking for electricians, welders, pipefitters, and turbine installers.

"There are all kinds of good jobs that don't take a lot of education after high school," Shin told the students. "For those jobs, you need about nine months or a year of training after high school."

Most of the students participating in West's Energy Careers class already are determined to pursue a technical career.

> "To try to find new technology to make renewable energy more accessible and more affordable, that's important." – Jose Santistevan

Milynda Montez, 17, sees a huge dichotomy between the dropouts who are on the road to trouble or to dead ends, and her Aviation Careers classmates who are acquiring skills for a technological world. Montez said she plans to enlist in the Air Force—one of nearly a dozen students who are interested in engineering and aviation.

But she sees renewable energy as a promising career choice, too. "It's pretty important and vital to our nation," Montez said. "I know it's a growing problem.

Job Explosion in Renewables Expected

A key part of the new energy future equation is educating students, teachers and consumers. From elementary school mentoring to senior-level research programs, NREL's education opportunities help provide the link to the new energy future. The goal is to engage young minds in renewable energy and support teachers' commitment to excellence in teaching and learning.

An economic model developed in 2009 by researchers at Yale University and the University of California-Berkeley predicted a net increase of 1.9 million green jobs by 2020 in the United States if Congress passes the Clean Energy Jobs Act.

Colorado is a promising location for green jobs if the West High students choose to stay near home. The state has established a requirement of 20% alternative energy by 2020 for major utilities. A bill introduced the current session of the Colorado Legislature would increase the requirement to 30%, with most of that additional clean energy generated by wind power.

"We hope our messages will travel home with the students to their parents," Shin said. The hands-on activities aim to "inspire students to wonder and then seek more knowledge."

Renewable Technologies Are Linked

Training in one renewable energy field often leads to related work.

For example, NREL is working with Xcel Energy to launch a wind-to-hydrogen demonstration project at the laboratory's National Wind Technology Center near Boulder, Colorado. The project links wind turbines to electrolyzers that pass wind-generated electricity through water to split it into hydrogen and oxygen. The hydrogen then can be stored and used later to generate electricity from a fuel cell or an internal combustion engine.

"We're partnering with education to home-grow such technicians and engineers." – Cynthia Howell

Shin talked to the students about the shape of airplane wings and wind turbines, both of which are air foils, and about the increased importance of wind energy in the future.

He showed them a fuel cell that contains precious platinum, a catalyst that makes it easier to use wind energy to break down water into oxygen and hydrogen. They learned that by starting with wind and using water to produce hydrogen, a utility doesn't have to store electricity in batteries. Instead, hydrogen can be stored in tanks, to be used later to make electricity when the wind isn't blowing or the sun isn't shining.

The students' silence during the lecture part of the class had Shin wondering if he had connected with them.

But as soon as they were allowed to use their hands and their brains to model the kinds of wind turbines being tested at NREL, the classroom came alive.

Students used glue guns, balsa wood, dowels, and plastic gears to design wind turbines.

"When we do hands-on, everyone feels more comfortable, working with each other, building something," said Solis. "This is creative. You have to have a creative mind."

John Foden, 17, foresees his interest in mechanics and welding with a job in clean energy. "It's probably a good career," he said. "You never know what's going to happen a few years down the road with the Earth."

Gerardo Espinoza, a senior, changed the blades on his model to make it more aerodynamic. "I'd like to go into mechanics and engineering," he said. "All this, it's like a difficult puzzle to solve. And I like puzzles."

Students not Afraid to Fail

Amber Smith, who teaches the Energy Careers class as part of Career and Technical Training Education at West High, said the NREL program is effective because it exposes the students to real opportunities within their reach and rewards experimentation.

"The hands-on part that NREL provides is just amazing," Smith said. "The NREL educators explained to the students, 'This is what you'll be doing in technical careers.' When they see it and do it, it means so much more to them. They get a lot out of it. They love it, they become engaged."

"Most of the time, children are afraid to fail, afraid to do something wrong. But with the NREL projects, I love that the children didn't mind that the blades didn't spin as fast as they wanted them to. They just said, 'OK, back to the drawing board.' That kind of attitude is hard to replicate in the classroom."

— Bill Scanlon (February 22, 2010)

NREL SCHOLARSHIP GIVES COLUMBINE GRADS A BOOST

Columbine Spirit Scholarship alum Meghan McKee is currently a facility engineer for El Paso Exploration & Production. She splits her time between the company's Denver office and solving problems for the company's natural gas field in Raton, New Mexico. *Photo by Dennis Schroeder, NREL/PIX 18346*

Columbine. It's not often a single word can evoke an enormous spectrum of emotions. But for many, saying that simple word brings back memories of a fateful day—Tuesday, April 20, 1999—when two high school seniors killed 12 students and one teacher. The gunmen also injured 24 others in one of the worst high school shootings in American history.

Like many across the country watching the events unfold, employees at the U.S. Department of Energy's National Renewable Energy Laboratory (NREL) were determined to do something to help. Employees submitted many ideas ranging from giving financial assistance to the victims, to contributing to a memorial site, to investing in the students' futures by creating a scholarship fund.

The scholarship idea was chosen as the best way NREL could honor the victims. With the assistance of the lab's managing partners—Midwest Research Institute, Battelle, and Bechtel Corporation—$35,000 was contributed to Colorado School of Mines to endow the NREL Columbine Spirit Scholarship.

Richard H. Truly, former NREL director, said at the time, "The Columbine tragedy struck me and NREL's employees deeply. We all wanted to do something that would honor the young victims while providing hope for the future, and our future as a community."

Now, more than 10 years later, NREL's investment in the community's future continues to pay dividends as Columbine students embark on bright futures.

Going Places is Just Part of the Job

Columbine Spirit Scholarship recipient Meghan McKee was a freshman at Columbine High School in the spring of 1999, so she was also a member of the last class to graduate after experiencing the tragic events of April 20. "It's different every year how April impacts me," McKee said. "I think I matured quickly, learned to value relationships and the way I treat people."

Relationships have been a key to her success since graduating from Colorado School of Mines with a degree in mechanical engineering. Her professional path has taken her from Colorado to the icy North Slope of Alaska and back.

Shortly before graduating from Mines, McKee accepted a job with ConocoPhillips in Anchorage, Alaska. Her first year was a hands-on introduction to the oil and gas industry during which she rotated into a new position every four months. After a year of learning the ropes, she accepted a job on the North Slope of Alaska at Kuparuk field. Discovered in the late 1960s, Kuparuk boasts one of the largest oil reserves in North America. During long summer days and even longer winter nights, McKee worked two weeks on and then two weeks off as a Drill Site Facility Engineer.

"Oil and gas facilities were what I migrated to because of my mechanical background," McKee said. "You deal with the pumps, compressors, the pipelines—so it was along the lines of what I studied."

Life on the oil fields of Alaska is typically thought of as a man's world, but McKee had no trouble forming relationships and learning from her colleagues.

"After sitting in the lecture hall and you are one of three females, it didn't really strike me as all that different," she said. "It was fun; the guys were top-notch field operators. Some had college degrees and others worked their way up, but they were all really experienced and they taught me a lot."

> "I'm really excited to be able to graduate and go into industry and start making a difference." – Rebecca Silverstein

After her two years in Alaska, McKee returned to Colorado to work for El Paso Exploration & Production as a facility engineer. "I heard a lot about working for independents so I thought it could be fun. Typically in an independent company, you get to see a lot more of the process and you have your hands on a lot more projects."

Working for El Paso means splitting her time between the company's Denver office and a natural gas field outside Raton, New Mexico. Although her experience has been with oil and natural gas, solar may help provide a portion of the power for the work she does outside Raton in the near future.

El Paso's natural gas field is located on Ted Turner's Vermejo Park Ranch. First Solar and Turner Renewable Energy recently announced an agreement to build a multi-megawatt solar project adjacent to the ranch.

Working the natural gas field has provided McKee with yet another unique experience since graduation. "You can drive through the ranch and not see a great deal of visual impact," McKee said. "We've positioned wells behind trees, so the wilderness aspect is still very much there."

After traveling from the frozen wilds of Alaska to the New Mexico wilderness, McKee encourages future scholarship students to "always keep an open mind."

"There were days on the North Slope of Alaska when I thought, 'How did I get here?'" McKee said. "When I look back, it was just awesome. But, it was also a challenge as a young female in the field. You aren't going to like what you do all of the time. You just have to push through and you might realize later that it was one of the best experiences you've ever had and you learned more than you ever thought."

"You might realize later that it was one of the best experiences you've ever had and you learned more than you ever thought." – Meghan McKee

Students Still Helped by the Spirit Scholarship

The NREL Columbine Spirit Scholarship is still helping students not directly impacted by the events of April 1999. Rebecca Silverstein is a recent Columbine graduate in the beginning stages of her college career.

"It's a lot of work being at Mines, but I'm a hard worker and I like to stay busy," said Silverstein.

She is currently majoring in bio-chemical engineering and hoping to find work in the medical field researching new technologies. However, like most students in a tough economy, she is keeping her options open. "What I do will also depend on where I can get a job once I graduate, so I'm not ruling anything out at this point," Silverstein said.

The rough job market means that she will be spending the summer before her sophomore year volunteering and helping her father's company research ways that renewable energy can be used on brownfield sites.

Whether her summer research project will steer her towards renewables remains to be seen. She is, however, certain about the investment she's making in her future, with NREL's help. With no hesitation she said, "I'm really excited to be able to graduate and go into industry and start making a difference."

— *Heather Lammers (July 22, 2010)*

NEW SCHOOLS IN NEW ORLEANS, SUNNIER, GREENER

Students at Craig Elementary School eat lunch in their new cafeteria that benefits from natural light. Craig is one of the schools built in the wake of Hurricane Katrina that is 30% more energy efficient than code thanks, in part, to consultant work by the DOE's National Renewable Energy Laboratory. *Photo courtesy of Joe Ryan*

The kids are back in school in post-Katrina New Orleans, and there's light at the end of the classroom.

Five years after Katrina flushed water through the failed floodwalls, destroying homes, damaging classrooms, and dashing dreams, the opportunity to build green schools that save millions of dollars on energy bills is just within reach for the school districts that serve New Orleans.

Hurricane Katrina knocked out dozens of schools along with thousands of homes, and for quite a while the mission was just to keep education alive and the three Rs solvent. But now, with the help of federal disaster dollars, the school district has launched an ambitious goal to build 40 new schools and renovate 38 others that are at least 30% more energy efficient than required by code.

"Now, the district is requiring architects to include energy modeling as part of the design process for new schools and major renovations." – Phil Voss

The U.S. Department of Energy's (DOE) National Renewable Energy Laboratory (NREL) helped stitch together a blueprint for what the new and renovated schools should become. Now that the first of the new schools have opened, NREL will monitor some schools to illustrate what works well and what opportunities were missed, helping the districts to push new school design teams toward ever more efficient designs.

Things are looking up in New Orleans, which has launched school reform, attracting teacher talent. But even before Katrina, many of the buildings were ramshackle. The 38 schools that require major renovation include those damaged by hurricanes Katrina and Rita, but also many that simply suffered from years of neglect.

New Orleans is humid and often hot, but problems arise at times when temperatures are moderate and humidity remains high. The air that enters the halls and classrooms has to be dried out before it is distributed to the space, compounding the challenge to bring energy efficiency to schools there.

Several studies have shown that students perform better on standardized tests when their classrooms are daylit and the air is comfortable. For example, the Heschong Mahone Daylighting Study found a dramatic correlation between daylit school environments and student performance, including 20% faster progression in math and 26% faster progression in reading. The Greening America's Schools summary report found an average of a 38.5% reduction in asthma in schools with improved indoor air quality. In addition to energy costs, studies such as these were considered when the district set the goal of Leadership in Energy and Environmental Design (LEED) Silver for their new school buildings.

Energy Efficiency Means a Change in Culture

Ironically, the New Orleans schools with the best energy profiles are those 80 to 100 years old that have large windows oriented for natural ventilation and sunlight. The ones built in the past half century, though, weren't built with efficiency in mind, said Phil Voss, senior project leader for NREL's effort in New Orleans. "It was pretty clear to us that the designers didn't have experience with energy efficiency," Voss said. "They had experience in keeping buildings cool and lit, but not in doing it efficiently." In a district chronically underfunded, tens of millions of dollars wafted into the air each year to heat and air condition schools with windows in poor condition, oversized cooling systems, and too little insulation.

In 2007, two years after the destructive hurricane, the DOE signed a memorandum of understanding with the Louisiana Department of Education. The aim was to use the American Society of Heating, Refrigerating and Air Conditioning's Advanced Energy Design Guides so the 40 new schools and the 38 schools facing major renovation would be at least 30% more efficient than code.

Savings Can Run into the Millions Yearly

The potential savings are monumental, amounting to some $75,000 per year per school.

In the United States there are about 100,000 public schools. This year, some $14 billion will be spent constructing new schools—about 750 new schools are built each year—or doing major renovations, according to *School Planning & Management* magazine. If all the new and renovated schools followed green-school designs, the savings would be more than $50 million the first year, compounded each succeeding year.

In New Orleans, making the schools greener will mean an investment of several million dollars over and above what it would cost to build a school merely to code. But the numbers indicate that the schools will break even on the costs versus energy savings in just three or four years. With schools built to last 50 to 100 years, the savings after build-out could amount to tens of millions of dollars per decade, decade after decade.

Or they will, if the blueprints are followed.

In the aftermath of Katrina's destruction, school officials had to take the pragmatic approach, to get children back learning, so energy efficiency wasn't at the top of the list.

"They were understandably under pressure to get designs for the first new schools done fairly quickly," Voss said. "They tried to plug in energy savings where they could, but they missed out on some big opportunities." Some design teams embraced the challenge to incorporate energy efficiency into the design, while others considered the goal an impediment.

NREL: Think about Energy-Efficiency from Day One

NREL brought a way of thinking that was manifest when it designed its new Research Support Facility, which at 222,000 square feet will be among the largest buildings in the world to use no more carbon-based energy than it produces via renewable energy.

For the new school designs, it was essential that the planners consider energy efficiency in the architecture, rather than strictly thinking of efficiency as "a measure of mechanical or electrical equipment in the building," Voss said. "This means the full design team considering how any design decisions will affect energy use from day one."

The school district in New Orleans is developing a position for School District Energy Manager and is paying more attention to not only design, but also ongoing building operation, with energy efficiency in mind.

"Now, the district is requiring architects to include energy modeling as part of the design process for new schools and major renovations," Voss said. "That's a step in the right direction. We're also meeting with the school district on a regular basis to help them get things corrected on the new buildings and document lessons learned to help ensure design intent follows through in how their buildings perform. An energy manager would be another big step."

Joe Ryan, a former NREL employee who lives in New Orleans, is under subcontract to NREL, and is providing most of the direct technical support to the district.

Orientation, High Windows, Zoned A/C All Save Dollars, Greenhouse Gases

NREL also provided energy audit reports for 50 schools to identify opportunities for efficiency and conservation. Those findings will be taken into account for renovations.

For new schools, energy modeling provided strategies that will be effective for all schools in this climate. Foremost is appropriate daylighting, which lowers electric costs by reducing the use of lights and the amount of air conditioning. Daylighting glass is located higher on the wall than glass meant primarily for viewing. The glazing, lighting layout, and controls and any required apparatuses need to be designed according to industry best practices.

Where possible, the schools should be oriented so classrooms are on an east-west axis, with north- or south-facing windows, Voss said.

The humid outdoor air should be pre-conditioned rather than overcooling the entire airflow to deal with humidity.

Ventilation should be demand-controlled so spaces that aren't being used—say, auditoriums, gyms, or cafeterias—aren't getting blasted with humid outdoor air that has to be treated or cooled.

Often, the administrators are the only ones in the school during certain hours or certain days. Using small, efficient HVAC systems zoned only for those offices can avoid the wasteful habit of cooling the entire school when only a handful of people are inside.

Learning from Experience, Eager for More Efficiency

Langston Hughes Charter Academy, one of the newly built schools being monitored by NREL, is a school where students dress sharply in red polos and appear to take their education very seriously. The $27 million building for K-7 students opened in August 2009, and is the first new school built since 2003.

Langston Hughes Academy is situated in a spot that was ideal for natural day lighting but it simply wasn't done properly, Voss said. Windows were supposed to rise to near the classrooms' ceilings to take advantage of natural daylight, but that wasn't done completely.

District officials forced the contractors to go back and make changes, but by then they could only improve natural lighting design into the second floor, not the first. Other design problems at Hughes included fan-powered boxes with electric strip reheat, which are inefficient and will not be used in the schools yet to be built, and large expanses of glass in the cafeteria, library, and atrium without daylighting controls.

But, in an all-too-familiar irony, most of Hughes' wasted energy can be chalked up to inefficient operations. The chiller plant, for example, was operating when no one was in the building. There were times when both the chiller and the boiler were operating simultaneously, one trying to cool things down, the other trying to heat things up.

School officials say they are learning from problems found via the NREL monitoring of Hughes, and are determined to correct the issues to make existing and future schools operate more efficiently to meet their goals and keep operating costs manageable.

— Bill Scanlon (October 11, 2010)

SUN SHINES BRIGHT FOR NREL'S ENERGY EXECS

Jason Richard, left, and Paul Besaw, both with Encore Energy Services, install new solar panels on the roof of the Sangre de Cristo Arts and Conference Center in Pueblo, Colorado. Energy Execs grad Greg Severance is hoping to help make Pueblo the solar capital of Colorado. *Photo by Dennis Schroeder, NREL/PIX 18226*

The 2010 Executive Energy Leadership program at the U.S. Department of Energy's National Renewable Energy Laboratory (NREL) recently minted 19 new "Energy Execs" ready to pursue renewable energy projects at their businesses, governments and other organizations.

The five-month leadership program gives decision makers an in-depth look at an array of renewable energy and energy efficient building technologies, as well as economic and analytical tools. Briefings by NREL technology experts, research laboratory tours, and visits to field applications are part of the monthly experience.

Energy Execs Go National

Since the inception of the Energy Execs program, participants have been solely from Colorado. The 2010 class included participants from across the United States.

"The Energy Execs team worked to expand this Colorado-based pilot program to one sharing NREL's renewable energy and energy efficiency technologies on a national scale," NREL Manager, Corporate Relations Janice Rooney said. "As a national laboratory, we launched this unique forum to provide a dynamic learning opportunity for a diverse group of business, government and organizational leaders. It's exciting to see the impact our grads are having at their businesses and in their communities."

Before graduation, execs must present a viable project using renewable energy or energy efficiency that could be implemented by their organization. Although the execs get broad exposure to many renewable energy technologies, solar solutions are piquing many leaders' interest.

Pueblo County Looks to Take a Solar Lead

Located along Interstate 25 in southern Colorado, Pueblo County is an economic hub for southeastern Colorado. Home to the city of Pueblo, also known as "Steel City," it is one of the largest steel-producing counties in the United States. But, if Pueblo County Public Works Director Greg Severance has any say, Pueblo will also adopt the moniker of solar capital.

"Our goal is to make Pueblo County the solar capital of the state," Severance said. "The wind doesn't blow hard enough down here, but the sun sure shines."

Severance attended Energy Execs in 2009 and left the program with not one, but three goals in mind:

- Install up to 1 megawatt (MW) of solar panels on Pueblo County buildings
- Contract with a company to perform energy audits and retrofits on all 26 county buildings, yielding an estimated minimum energy savings of $300,000 per year
- Work with local utilities to make Pueblo the renewable energy and solar capital of Colorado.

In less than a year, Severance was able to check two of the three items off his list.

Recently, the county commissioners completed a 20-year power purchase agreement (PPA) with Main Street Solar to install 750 kilowatts (kW) of solar on nine county facilities. Estimated savings from the solar panels will fall in the range of $30,000 to 60,000 a year but Severance is looking more toward the future. "We've already had a 10.5% cost increase from Black Hills Energy (BHE) to repair old infrastructure, another 20% increase is projected in the next year and a half to pay off a new natural gas fired power plant BHE is currently building. Project those numbers into the future and the dollars start to add up significantly," Severance said. "Under our 20-year power-purchase agreement, in year 20, we will still be paying 2.8 cents a kilowatt-hour for our 750 kW of installed solar. Imagine what the BHE electricity costs of that energy will be in 2030?"

Getting to 750 kW of solar for the county took some ingenuity. After the initial assessment of county buildings, it was determined that of the 26 buildings, only five roofs met the criteria for solar (with the needed structural support and south facing roof slopes). Since that would not get Severance close to his goal, Main Street Power stepped up and is building carports to put the added photovoltaic (PV) panels over existing on-grade parking areas.

Severance's second goal—contracting to do energy audits and retrofits on all 26 county buildings—is also complete. The county hired Johnson Controls to analyze energy use in all 26 county buildings at a cost of $4.2 million. Under the contract, the company will look at all of the building systems and do many needed retrofits to improve energy efficiency.

"The cost of that audit is guaranteed to be paid in energy savings or the company will absorb the difference," Severance said. "We have 15-year, $5.6 million energy savings guarantee. They have to pay the difference on an annual basis. Why every governmental agency statewide is not doing this is beyond me."

With two goals accomplished, Severance has turned his focus to goal number three—working with local utilities to make Pueblo the renewable energy/solar capital of Colorado. Although the utilities have been a tougher nut to crack, Severance has been busy spreading the solar message to other community groups, and the idea is catching on. According to Severance, since Pueblo County announced its solar endeavor, the local school district is planning a 1.2 MW solar project, the YMCA is installing 500 kW, the regional building authority is adding 60 kW, and the library is installing a 42 kW PV system. "It's spreading," he added.

Despite the fact that Xcel Energy rejected a proposed partnership for a utility scale PV project in Pueblo County two years ago, Severance believes other opportunities will be forthcoming and when the day comes, he says he's laying the ground work to get as many solar companies as possible to submit bids for projects in Pueblo County.

"Pueblo is home to Xcel Energy's 1,410 MW coal-fire Comanche power plant and that electricity is already being shipped to Denver so we know it is possible to ship renewable energy from Pueblo to Denver," Severance said.

Bringing Solar to San Diego's International Airport

2010 Energy Execs grad and Senior Project Architect Christine Murphy is looking for ways to bring solar to San Diego's airport, but she has a few challenges to overcome. "Solar was identified as one renewable energy resource that is feasible in our area, but available unused land at the airport is nonexistent," she said.

When Murphy says there is no land, there is no land. "San Diego is a postage stamp sized airport yet it's the busiest single-runway airport in the United States and second busiest single-runway airport in the world," Murphy added. The San Diego airport sits on a mere 661 acres. For comparison, Denver International Airport, the largest international airport in the United States, has a site that spans 53 square miles and the Hartsfield-Jackson Atlanta International Airport has more breathing room than San Diego with 4,700 acres.

No worries, just put solar on the terminal roofs, right? Not so fast says Murphy. "The terminal roofs at the airport are all reaching the end of their lifespan. Placing solar on top is not a feasible solution until the terminals are re-roofed."

What the San Diego airport has is parking—lots of on-grade parking. Murphy is looking to enter into a PPA with a company that will build raised solar panels over the existing parking, providing 2.3 MW of renewable energy along with a little shading for the cars beneath.

Business Modeling for Solar to Hydrogen Energy Storage

One of the issues with using renewable energy such as wind and solar is being able to store the energy created on bright or windy days and then use it on the not so bright or windy days. Two members of this year's class—Sanjeeva Senanayake , vice president, HSH Nordbank, and Jason Coccia, associate, Booz Allen Hamilton, Inc.—teamed up to see if proposals for using hydrogen to store solar energy from photovoltaics could bring returns for investors. Visit NREL's Wind to Hydrogen Program Web site (http://www.nrel.gov/hydrogen/proj_wind_hydrogen.html) to see the project that inspired Senanayake and Coccia.

"There are a lot of things you need to think about when trying to decide if this is an economically viable technology," Coccia said "It's the efficiency of the system, it's the cost of the components, and the capacity that you want to think about."

The good news is that after crunching the numbers, they found good potential ROI as costs for PV continue to improve. "Given today's market, today's cost and efficiency numbers, the returns are pretty low," Senanayake said. "The key take away from this model is that as PV panel costs come down, the integrated PV-to-hydrogen storage system will make sense. We think there is tremendous business opportunity here."

Dairy Farmers Look to CSP and Wind

David B. Johnston, corporate project engineer for Dairy Farmers of America (DFA), admits he had an advantage when he began his first Energy Execs class in 2010. "I cheated. I already had my project in mind before I signed up for the class," Johnston said. "A year ago, our management came to our team looking to build a new facility for milk condensing. So I just got really fired up about the idea of using renewable energy at this facility."

Dairy Farmers of America is a farmer-owned for-profit marketing cooperative that has experience leveraging renewable energy to boost its bottom line. Examples include:

- Members use methane digesters to turn cow manure into natural gas that can be used to power homes and equipment
- DFA offers consulting service to its members interested in incorporating wind or solar energy on their operations
- DFA works to optimize transportation routes and is using idle-monitoring technology to conserve fuel.

The plant Johnston's team is looking to build will receive 2 million pounds (or about 40 truckloads) per day of raw milk for processing at a location in western Kansas. Because of the demands that trucks be sanitized on site and then turned out to get a new load along with the milk to be pasteurized, approximately 100,000 gallons of hot water storage and 45,000 pounds per hour of steam generation also is built into the facility plans.

Between the location in windy western Kansas and the hot water storage already on site, Johnston is investigating two opportunities for using renewable energy at the new plant—concentrating solar power and wind energy.

"You look at the solar and wind energy resource maps on the NREL Web site and we are definitely in a hot spot for renewable energy," Johnston said.

Learn more about the NREL Executive Energy Program on the Web site (http://www.nrel.gov/energyexecs/) where updates will be posted about the application process. To contact the program, e-mail energyexecs@nrel.gov.

— Heather Lammers (October 19, 2010)

ENERGY DATA AVAILABLE ANYWHERE, ANY TIME

NREL's Debbie Brodt-Giles was a key developer of the Virtual Information Bridge to Energy Efficiency & Renewable Energy its sister Open Energy Information. *Photo by Patrick Corkery, NREL/PIX 16946*

Having rapidly established itself as a "go-to" site for transportation and other related energy information, the Virtual Information Bridge to Energy Efficiency & Renewable Energy (VIBE) is expanding its reach to attract new users across the widest range of energy issues. A sister site to VIBE, called Open Energy Information (OpenEI), has been launched to allow organizations around the world to both post their own energy data and download data, for free.

At the National Renewable Energy Laboratory (NREL), VIBE is known as a state-of-the art presentation studio. Its walls are covered with flat-screen monitors aglow with widgets, home pages, Web links, and sundry visual cues of the virtual world, all smattered among scores of more conventional pie charts, myriad bar graphs, and a plethora of energy datasets.

To the world beyond the laboratory, VIBE and OpenEI contain that same treasure trove of information and a lot more—with every tidbit of data just a mouse click away from any internet-connected device, anywhere.

DOE Selects Platform for Internet Information Sharing

In recent weeks, the potential of VIBE has become apparent across the nation and around the globe.

In December 2009, OpenEI was selected by the U.S. Department of Energy to fulfill the Administration's commitment to open up the workings of the federal government through the Internet. DOE hailed OpenEI as the way to make energy information "transparent, participatory, and collaborative."

"This information platform will allow people across the globe to benefit from the Department of Energy's clean energy data and technical resources," Energy Secretary Steven Chu 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."

Through VIBE and OpenEI, NREL is putting information and data at everyone's fingertips, to use, download, build on, and spur needed new analysis. The ultimate goal is to make the most relevant knowledge about energy issues available to anyone at any time, so that decision makers in both the public and private sectors can help the nation achieve its clean energy goals.

Together, these digital assets provide worldwide access to NREL's valuable analytical capabilities, and thus help transform energy markets, policy decisions, and technology investments.

Gateway to Allow International Exchange

OpenEI also was seized on by the teams representing the United States at international climate negotiations in Copenhagen and the Major Economies Forum (MEF). A new gateway was created specifically for MEF on the OpenEI platform, allowing participating countries to share data, information, resources and tools, including real-time activity tracking. It also will facilitate open participation and input via a "wiki" type collaborative system.

OpenEI, it is hoped, will leverage a wealth of data to allow MEF countries to share best practices and successful implementation strategies, facilitate collaboration with other nations and international organizations, provide global resource maps and information on hot-spot development, make available a portfolio of analysis tools to encourage sustainable energy development, maintain data about the status, characteristics and impacts of clean energy technology deployment, and accelerate development of clean energy through worldwide access to information.

> "This information platform will allow people across the globe to benefit from the Department of Energy's clean energy data and technical resources."
>
> – Energy Secretary Steven Chu

Over time, the plan is to expand the OpenEI portal to include on-line training and networks of technical experts. The portal is co-funded by the International Energy Agency, United Nations Industrial Development Organization and many other international organizations.

Another new gateway that showcases the work of the entire Department of Energy national laboratory complex already is available on the OpenEI platform. That gateway, U.S. OpenLabs, was highlighted at the Copenhagen Climate Conference in December 2009.

VIBE and OpenEI will continue to evolve to support greater knowledge of energy issues and options, and strengthen sound decision-making for policy makers, researchers, technology investors, venture capitalists, and market professionals across the United States and around the world.

— Gary Schmitz (January 8, 2010)

RENEWABLE ENERGY AT WORK IN WAR ZONES

Lt. Col. Brian Stevens of the Texas National Guard, second from right, meets with an Afghan elder in southeastern Afghanistan to discuss the future of sustainable agriculture including possible wind and solar power applications. *Photo courtesy of Capt. Charles Peters*

Ever since Don Quixote tilted at wind mills, warfare and renewable energy have had a rough relationship.

It's tough to erect wind turbines or solar panels when the enemy keeps blowing things up.

Still, Lt. Col. Brian Stevens of the Texas Army National Guard is determined to try.

Stevens leads a group of 66 soldiers who want to help bring sustainable agriculture and renewable energy to rural Afghanistan.

A self described military brat who "grew up all over the world," Stevens was in the 2010 Energy Executives Leadership Program, an initiative of the U.S. Department of Energy's National Renewable Energy Laboratory (NREL).

Energy Execs are leaders who want to learn about renewable energy to help guide the future energy decisions of their companies, organizations or communities. In 2010, 20 Energy Execs gathered at NREL once a month for energy education sessions.

"There's no national power grid in Afghanistan," Stevens said during a break in the education sessions. "Power is generated where it's needed, usually using a diesel generator."

Stevens hopes to change that, knowing that the task is formidable.

"There's a little bit of micro-hydro power, a little bit of wind, a little bit of solar already in Afghanistan, built by Coalition units, the Afghan government, and non-government organizations," Stevens said. "Unfortunately it's usually not very sustainable by the Afghan government. In most cases, they don't have the trained people, the supplies, or the means to continue the operations. As soon as the sponsors pull away, the installations typically don't survive very long.

Education Key to Sustaining Renewable Projects

"Any projects that we would build directly would become lucrative targets of the Taliban," said Stevens, who enlisted in the Army as a young man, served eight years, got a college education and has been with the Texas National Guard for more than 20 years.

So, instead of immediately erecting devices that will catch the wind or the sun's rays, his National Guard unit will focus on education and how to integrate these capabilities into the agricultural sector.

"We're hoping to work with the Afghan government to implement a curriculum at the college, then build a demonstration plant that the university would own," Stevens said. "They could use it as a hands-on solar and wind power learning experience. That way you'd have educated young people able to sustain projects and build bigger projects down the road, while they also develop suppliers and experience."

The Taliban and Al Qaeda can blow up things and chase the population away, but "they can't take that knowledge out of their heads," Stevens said. "Eventually, they'll get some traction out of that."

> "We'll also try to work with the Afghan government and universities to teach and train more efficient irrigation techniques. Renewable energy will be a component of that." – Lt. Col. Brian Stevens

Stevens has worked on rebuilding projects before in Iraq and Afghanistan, as a civil affairs officer and adviser. He thinks the technical knowledge he learns at Energy Execs will help his newest idea succeed.

"The folks we've met at NREL, to a person, are remarkably enthusiastic and excited about what they're doing," Stevens said. "That optimism and enthusiasm … you can see that, too, in a successful military unit."

He's already learned that NREL, Stanford University, and some other partners have put together curriculum packages for renewable energy. "We're looking to see how it can translate over in Afghanistan," he said.

His unit wants to improve refrigeration in arid, temperate Afghanistan. It won't be refrigeration like Americans know the term. "It will still be in cellar-type rooms underground," he said. "We'll be applying some dehumidification techniques and some minor cooling. That's about the most we'll be able to hope for."

"We'll also try to work with the Afghan government and universities to teach and train more efficient irrigation techniques," Stevens said. "Renewable energy will be a component of that."

Making the Most of Windy Months, Sunny Months

Most of all, Stevens wants to avoid doing something counterproductive, such as building wind farms where the wind isn't strong enough, or putting up solar panels where there is too much shade.

So far, the most successful renewable energy program in Afghanistan has used micro-hydro, generating power from the substantial spring melt off of snow running down the mountains.

Afghanistan has a four-month windy season in the spring, the same time of year when micro-hydro has the greatest potential. In the summer, it gets hot and dry in many places, ideal for generating solar energy.

"I don't know yet how we sustain it in the winter, when they get cold, snow, and more cloud cover," Stevens said.

"But we have a great, great team, super motivated, almost all of them volunteers, from security guys to agricultural experts, to mechanical engineers and leadership," Stevens said of his Army National Guard command.

"Everything we do will be with and through the Afghan government," Stevens emphasized. "If we help them develop an increasing capacity to supply services to the people, it increases their legitimacy and allows them to continue to lead."

Stevens said the West has made several mistakes in Afghanistan over several decades, often by "applying a western solution to the problem. We fix it and then we walk away. It's not something they can maintain."

The university in his province has a partnership with Texas A&M University. "Hopefully, that will impel relationships that endure beyond us," he said.

Still, "In Afghanistan, even the easy stuff is hard, politically complicated," Stevens said. "And you have the Taliban and anti-government forces. Some of them are just criminals, opportunists wanting to get their cut. So they don't want to see this (reconstruction success) happen.

"But the Afghan people by and large are awesome. There is the extreme element in every country. But most of the Afghan people want the same things we do—security, drinking water, they want their kids to be able to go to school. There is an element that wants to establish a functional government, and an extremist element that wants power and control to further their objectives. We want to help empower the government to increase its ability to provide reliable security and services to the people. By doing this, we can help protect the Afghan people and prevent the extremists from attacking our country again.

"We want to help empower the government to increase its ability to provide reliable security and services to the people." – Lt. Col. Brian Stevens

"Generally, the Afghans are great people, very hospitable and gracious. They just don't have many of the great opportunities that we have, yet."

— *Bill Scanlon (August 5, 2010)*

GREATER ENERGY EFFICIENCY COULD REDUCE RISKY FUEL-TRUCK TRIPS

NREL engineer John Barnett discusses his trip to Afghanistan where he made several recommendations to improve expeditionary self-sufficiency. *Photo by Patrick Corkery, NREL/PIX 18339*

Scientists and engineers at the U.S. Department of Energy's National Renewable Energy Laboratory (NREL) haven't hesitated to fly to war zones when the military calls on them to assess the potential for energy efficiency and renewable energy at Marine, Army, and Air Force bases.

John Barnett arrived at a U.S. base in Helmand Province, Afghanistan, in September 2009, part of a Marine Corps team asked to find ways to reduce the number of truck trips needed to supply American troops.

Convoys of trucks carry diesel fuel, bottled water and other supplies to U.S. military bases in southern Afghanistan, across rugged roads controlled by Taliban forces and tribal chieftains.

Fewer convoys rolling across the dangerous roads means cost savings and, more important, reduced risk to Afghan and American lives. Retired Brig. Gen. Steve Anderson, who served as Gen. David Petraeus's senior logistician in Iraq, estimates that more than 1,000 Americans have been killed in Iraq and Afghanistan hauling fuel to power tents and buildings. Fewer truck trips would save millions of dollars and the lives of the truck drivers, he said.

Cutting Down on Truck Trips Can Save Lives

"The convoys are obvious targets," says Barnett, who works in the Integrated Applications Office at NREL. "Private Afghani contractors bring supplies to the main bases, making their way through hostile areas with the help of convoy crew members representing local villages and tribes. U.S. troops then provide transport to outlying bases, the most dangerous and expensive part of the supply chain."

The Marine Corps team noted that about half of the cargo in these life-risking convoys was bottled water. But it turned out that every base visited had good potential for water wells. The team recommended that commanders take advantage of the local water, test and certify the supply at each base and eliminate the need to import bottled water in convoys.

Much of the rest of the cargo in those truck convoys is diesel fuel to power the bases—from lights to refrigeration, computers to air conditioning and heating.

In the necessary urgency to get bases up and running early in a war, electrical loads are hooked up to generators without much attention to efficiency, Barnett said. "The generators we saw tended to be loaded at 25% or less of their capacity," he said. "But loading around 75% is best for efficiency and lifetime.

"Increasing the load on individual generators could immediately save around 40% of fuel used to generate electricity at one large base—and they could turn half their generators off."

Blazing Sun in Afghanistan Can Power Lights, Batteries, Hot Showers

Barnett next turned his attention to the potential for renewable energy.

"The solar resource in Helmand Province is outstanding," Barnett said. "Solar water heating is a great option, and could improve conditions for soldiers who often seem to run out of hot water for showers. And there are plenty of rooftop and land-based options for photovoltaic (PV) arrays. Incorporation of renewables in a smart-grid controlled, multi-source power system can support today's military operations and provide an opportunity for positive engagement and training of local populations."

Barnett also noted the potential for waste-to-energy generation at large bases. "At the big bases, tons of garbage is produced every day, and until recently it was just burned in an open pit," he said. "That's electricity waiting to be made."

And the benefits of renewable energy are no less important for small bases. "With their modest power requirements of several kilowatts, the smallest bases should be able to become energy self-sufficient—producing as much energy as they need using local renewable resources," he said.

Air Force Bases in Qatar and Afghanistan Can Save Fuel

Mike Helwig was a naval officer for 20 years and a defense analyst for three years before beginning work at NREL. In early 2010, he was asked to go to Al Udeid Air Base in Qatar, and Kandahar Air Base and Bagram Airfield in Afghanistan to make recommendations about how to save energy for the U.S. Air Force as part of an eight-person assessment team.

The final written report of the Air Force energy assessment team includes recommendations for more efficient use of airplane fuel. Helwig also found that in Qatar, the local utility was charging the U.S. Air Force base 49 cents a kilowatt hour for electricity. At that price, renewable energy options can be extremely attractive.

"It's perfect for solar there," Helwig said. "There is plenty of sunshine and the ground is flat. My major renewable energy recommendation for Al Udeid Air Base was that we should give large-scale solar a shot.

— Bill Scanlon (August 5, 2010)

ISLAND BREEZES, SUN PERFECT FOR RENEWABLES

Wind turbines such as those pictured here on the northern tip of the Big Island in Hawaii near the town of Hawaii will be a more common sight. NREL is helping Hawaii meet an ambitious goal of getting 60% of its energy from renewable sources by 2030.
Photo courtesy of Hawaiian Electric Light Company (HELCO)/PIX 14697

Islands have beautiful sunsets, slumbering volcanoes, soothing trade winds, outrageous energy prices.

In other words, they have all the ingredients for a daring dip into renewable energy.

The U.S. Department of Energy's National Renewable Energy Laboratory (NREL) is helping islands around the world craft polices and infrastructure for a future fueled by the sun, wind, waves, seaweed, and lava. It's an initiative of the international Energy Development in Island Nations project.

Why islands? First, consider the prices paid for energy on islands from the Caribbean to the South Pacific. The energy structure on typical islands was designed in the age of cheap oil, says Adam Warren, who heads NREL's Energy Development in Island Nations program in the U.S. Virgin Islands. Many, if not most, islands depend on imported oil for all of their energy needs. And with prices at $75 a barrel—plus shipping costs—island populations are faced with some of the highest costs for electricity in the world. And, they're vulnerable to wild swings in the price of oil.

"Each island is different, but our goal is to be able to take from all our experiences and have a playbook that is useful for any island in the world." – Adam Warren

In 2008, Hawaii's average electricity rate exceeded 30 cents per kilowatt-hour (kWh); and the price of electricity in the U.S. Virgin Islands was greater than 50 cents/kWh—that's more than five times the U.S. average. With wind energy plunging to as low as 5 cents/kWh, and solar energy dropping to as low as 18 cents/kWh, there's plenty of space for renewable to help the bottom line.

Many of the renewable energy and energy efficiency technologies that have a difficult time competing with the direct cost of coal can easily beat the high cost of electricity on islands.

Islands also are particularly vulnerable to the effects of global warming. Bleaching of coral reefs, rising ocean levels, and strengthening storms all put islands at disproportionate risk—and combine to make clean energy particularly attractive on the isles, keys and atolls.

Clean Energy There for the Taking

Happily, islands have the raw material for renewable energy in abundance. Consistent trade winds are an excellent source of energy, as are the sun's rays and the hot lava deep inside volcanic islands.

NREL recently finished a solar index for the U.S. Virgin Islands, based on satellite data. "Our data has confirmed that they have a good resource of solar," Warren said. "That will be even better confirmed once we install our wind and solar measurement stations."

Geothermal power is a huge, largely untapped, source of potential power. In 2008, Iceland produced one-quarter of its power from the heat of the Earth.

Iceland has joined with the United States and New Zealand in helping island nations measure renewable energy's potential and lay the groundwork for policy changes.

Islands Are the Canaries in the Coal Mine

Critically, islands can be the guinea pigs for the nations stuck on continents. "All the things we have to figure out as a nation, they need to figure out right now," Warren said. Some argue that we, in the continental U.S., have time to react to climate change. "But it's an acute need for islands. They can be leaders by example."

For example, islands can provide a unique testing ground for the smart-grid solutions of the future. A vexing problem is how to get wind, solar, or geothermal power onto the grid in a way that is efficient—and how to store that power for the hours when the sun doesn't shine or the wind doesn't blow.

Because many forms of renewable energy are intermittent, the electrical grid of the future must be able to handle a variable supply for electricity while servicing the always-varying demand. An open question for tomorrow's smart grid is, "how do we deploy renewable energy at high penetrations while maintaining low cost and reliability for customers?"

Before large countries make huge investments in thousands of turbines, the task of integrating wind onto the grid can be

figured out on the islands—be it battery storage, fly wheels, or more effective electrical grids.

Islands' limited size and isolated grids provide a means for developing and proving systems in the real world at a reasonable cost. A few wind turbines, and suddenly the island gets 30% of its power from wind energy.

"Each island is different, but our goal is to be able to take from all our experiences and have a playbook that is useful for any island in the world," Warren said. "We can say, 'Here are the challenges. Here are the opportunities. Here is a process to develop a plan.'"

While Iceland has focused on volcanic islands in the Caribbean, and New Zealand on several Pacific island nations, NREL researchers have been working with the U.S. Virgin Islands, Hawaii, Guam, and several islands in Micronesia.

U.S. Virgin Islands Partnership Shows Promise

The partnership with the U.S. Virgin Islands is fortuitous because the governor and lawmakers there recently passed a law mandating standards for utilities and efficiency targets. It calls for an integrated approach, combining renewable energy with energy efficiency. The governor of the U.S. Virgin Islands also has signed a memo of understanding with the U.S. Departments of Energy and Interior. In his signing statement, Gov. John P. de Jongh, Jr. committed to reducing fossil fuel use by 60% by 2025. That calls for steep rises in the use of wind, solar, and biomass, as well as sharp increases in energy efficiency.

"It's all about building relationships and bringing stakeholders together." – Misty Conrad

The U.S. Virgin Islands is an American territory where most of the population has electricity, but where the 35-cent/kWh cost is crippling on an island with an average household income of $22,000 a year.

Most of the islands households have cisterns to catch rain water, but it's not always enough for their needs. "They burn diesel move their vehicles, to produce their electricity, and to desalinate their water. Right now, the people of the U.S. Virgin Islands are almost 100% dependent on imported fuel," Warren said.

Besides the recently completed solar forecast, NREL is doing a wind forecast to illustrate how reliable and accessible the wind may be. "The local trade winds ought to provide excellent wind resource, but we have to obtain accurate data before someone can go to a bank and ask them to finance wind turbines," Warren said.

"We're doing groundwork on the policy side, finding what policies need to be in place," Warren said.

The landfills on the U.S. Virgin Islands are having trouble complying with Environmental Protection Agency regulations. NREL is helping the islands evaluate systems that turn trash into electricity. The aim is to take out metals and other things that can't burn, compress the remainder into pellets, burn the pellets in a boiler that has pollution controls in it, and produce electricity.

Warren was last in the U.S. Virgin Islands just in time to see his rental car get slammed by a tree uprooted by Hurricane Earl. "We lost electricity. We hunkered down for the day and pulled the shutters down," he said. "You really understand the value of electricity and water when you have neither."

Islands Around the World

Every island has different needs and different potential.

Barbados, for example, has a head start because most families there already use solar water heaters.

NREL and Iceland are double-teaming Dominique in the Caribbean. NREL is measuring the prospects for wind energy, while Iceland is helping that island with its geothermal potential.

Hawaii's Clean Energy Initiative calls for a 70% decline in fossil fuels by 2035 through a combination of renewable energy and energy efficiency. The big push in Hawaii is to build wind farms totaling 400 megawatts on the sparsely populated islands of Molokai and Lanai, then ship the energy via undersea cable to Oahu, where most of the people live, said Dave Corbus, NREL laboratory program manager for electricity systems.

This spring, the governors of Guam, American Samoa and the Commonwealth of Northern Mariana Islands toured NREL, and later signed executive orders establishing energy steering committees that would bring in all stakeholders to discuss energy issues.

"We've been supporting these steering committees, working with them toward putting an energy plan together," said Misty Conrad, Technical Assistance Program manager at NREL.

Conrad went to Guam in mid-October to steer an assessment of solar, wind, and geothermal potential, and opportunities for energy efficiency.

"It's all about building relationships and bringing stakeholders together," Conrad said. Guam has excellent solar potential, quite good geothermal potential, and fairly good wind potential, she said.

Unfortunately, "both Guam and the Northern Marianas are in 'typhoon alley'," she noted. "We have to consider equipment that can stand these types of winds and typhoons. We have to realize that every once in a while everything could get knocked down."

Still, opportunity can spring from national disaster. A year ago, a tsunami tore through American Samoa, knocking out power generators. The American territory is getting assistance

from the Federal Emergency Management Administration and "they're looking at doing more with renewable energy than ever before," Conrad said.

"If they're going to have to rebuild, they want to do it more efficiently," Conrad said. Currently, American Samoa, Guam, and the Northern Marianas all rely 100% on diesel fuel.

Changing to compact fluorescent light bulbs, using more efficient air conditioning and replacing old appliances are the three quickest ways to get more energy efficient on the islands, Conrad said. "There is no green design or efficient design in the buildings, which tend to be mostly cement blocks," she said.

Phil Voss, senior project leader in NREL's Technology Applications Center, is working with scientists from New Zealand and Iceland to help islands with geothermal potential.

Geothermal energy from volcanic vents, such as this one on the Big Island of Hawaii, is an abundant potential source of energy on many islands. *Photo from NREL/PIX 13101*

The islands on the east edge of the Caribbean plate—St. Lucia, St. Kitts, Nevis, Granada, Trinidad, and others—all have excellent geothermal potential.

But geothermal demands high up-front costs, and if an island only has about 50,000 residents, it can be a steep per-capita investment.

NREL is looking at connecting some of those islands with a geothermal resource to other islands via undersea cable. That way all the residents of those islands can share the costs and benefits.

Another study is looking at erecting a big wind farm in Puerto Rico, then transporting the electricity it makes to the U.S. and British Virgin Islands and all the way down the eastern Caribbean chain. The waters are shallow enough to make it worth the investment.

Warren is working with the Organization of American States to create low-carbon communities in the Caribbean.

"Energy efficiency has to be an important part of the overall plan," Warren said.

On St. Lucia, even though electricity is a steep 35 cents/kWh, "there is still a lot of low-hanging fruit on the efficiency side," he said. Islanders use diesel not just to air-condition their homes but to desalinate their water.

An important task is finding spots on the island that are suitable for wind turbines or solar arrays—suitable in the topography, but also not so close to population centers that locals or tourists object to the intrusions on paradise.

"Beauty is in the eyes of the beholder," Warren said. If a wind farm is hard on the eyes for a typical tourist, it might be just the thing to attract the eco-tourist. St. Croix, one of the U.S. Virgin Islands' main islands, has good winds, enough to generate perhaps half of the electricity needed. A tweak to the marketing brochures, and St. Croix might attract green-minded vacationers from North and South America.

— Bill Scanlon (October 26, 2010)

BALANCING RENEWABLES AND NATURAL RESOURCES

Newly installed solar panels at NREL's National Wind Technology Center face skyward to follow the sun. NREL biologists are experimenting with native seed mixes to reestablish plants and wildlife habitat on the graded site. *Photo from NREL/PIX 16995*

NREL's newest source of clean energy—a 1 megawatt solar array—is supplying laboratory researchers with more than carbon-free electricity. It's also an opportunity to examine a sensitive topic—the potential environmental impacts of large-scale renewable energy projects.

That a solar array might raise environmental concerns seems ironic.

Three-quarters of the states in the U.S. have adopted aggressive renewable energy mandates to reduce carbon emissions and diminish the environmental damage from more than a century's reliance on fossil fuels.

But utility-scale renewable energy installations also can be significant construction projects—some proposed sites in California and the desert Southwest may cover up to 5,000 acres apiece.

In the West, the U.S. Bureau of Land Management alone has at least 31 renewable energy projects under "fast track" permitting review. And recently, the Secretary of the Interior identified proposed Solar Energy Study Areas where photovoltaic (PV) and solar thermal projects in six Western states are the subject of a special interdepartmental review known as the Solar Energy Development Programmatic EIS.

Some of the nation's best locations for renewable energy are in open, sunny ecosystems such as deserts and shortgrass prairies. These are arid areas where, once disturbed, the vegetation and wildlife may be slow to recover.

"Most plant species in the West have evolved to grow in direct sunlight, and that's where the best resource is for generating solar power," NREL Senior Biologist Brenda Beatty said. "We need to know how shade from PV panels may affect native plant growth and whether those effects will impact wildlife."

Collaborating on a Sustainable Installation

At NREL, where construction of both buildings and renewable energy systems is occurring at a rapid pace, environmental experts, construction engineers, and security staff are collaborating to meet NREL's commitment to sustainability and environmental stewardship, while still advancing the U.S. Department of Energy's (DOE) goals to develop and deploy renewable energy technologies.

PV array fields typically are graded flat and the vegetation removed before installation begins. Soils under PV arrays frequently are sterilized to prevent weed growth, a step that not only introduces chemical agents into the environment, but also prevents the natural revegetation of native plants that could minimize erosion and provide wildlife habitat.

Alternatively, installers spread gravel beneath the solar panels to inhibit weed growth. But gravel can trap heat, which not only can reduce an array's operating life, but also can stress any plants that might grow there.

NREL's newest PV array at the National Wind Technology Center (NWTC) near Boulder, Colorado, is an opportunity to study how ecosystems respond to renewable energy development and develop best management practices that re-establish habitat, minimize weed invasion, prevent erosion, and protect wildlife.

The steps also may help PV companies and utilities reduce long-term operating and maintenance costs.

"The NWTC array field provides a unique opportunity to study ways in which renewable energy and natural resources can co-exist," Beatty said.

> "We need to know how shade from PV panels may affect native plant growth and whether those effects will impact wildlife." – Brenda Beatty

The NWTC's 1 MW array sits on nearly eight acres near the center's western boundary for which DOE has provided an easement to SunEdison. NREL purchases the electricity from SunEdison through a Solar Power and Services Agreement. It's the laboratory's third sizeable solar array—NREL also has a 94 kW array on the roof of the Science and Technology Facility and a 720 kW array on South Table Mountain, near the lab's Golden, Colorado, campus.

Combined, they are forecast to produce 2.738 gigawatt-hours per year, or about 15% of the electricity that NREL is expected to use in fiscal year 2010. The solar renewable energy certificates (RECs) are sold by SunEdison to Xcel Energy to meet Xcel's Renewable Energy Standard solar requirement; NREL purchases replacement RECs, helping NREL to exceed the Energy Policy Act of 2005's goal of 7.5% of a federal facility's electricity coming from renewable sources by 2013.

More than a Meadow

At the NWTC, most of the vegetation is native shortgrass prairie that includes grasses such as big bluestem, blue gramma and various wheat grasses, forbs such as blanket flower, gayfeather and Penstemon, and shrubs such as, wild rose, hawthorn, and chokecherry.

By studying previous vegetation surveys and walking the site, Beatty and others realized that the NWTC also contains other habitat types that provide critical food and cover for native wildlife species. As part of NREL's sustainability and environmental stewardship commitments, some of these habitats are part of NREL's Conservation Management Area, and are protected from development activities. For example:

- At the northwest corner of the NWTC, there's a thin ridge of Ponderosa Pine and other montane vegetation typically found at higher elevations.
- Closer to the array field, a teardrop-shaped seep where groundwater rises and rainwater collects nurtures cattails, rushes, and other wetland plants.
- On the south edge of the site, there is even a small patch of remnant tallgrass prairie. Only one-tenth of one percent of original tallgrass prairie remains in central North America.

Site engineers and Beatty collaborated on ways to adjust the array's layout to avoid these sensitive areas.

In the center of the eight-acre array field, construction crews also left a total of two acres ungraded. This parcel of intact vegetation is meant to serve as a natural source of native seeds, which should help revegetation efforts.

Crews also will manually reseed graded areas beneath the solar panels in early spring with a blend of native grasses. The composition of the seed blend was formulated to include plants that can tolerate some shading, to help curtail erosion and weed invasion, and to be somewhat fire-resistant.

To develop a clearer understanding of the types of plants that can successfully be grown under solar panels, NREL's Solar Energy Technology Program, in coordination with the Strategic Energy Analysis Center, provided funding to create vegetation test plots under the solar array. Under Beatty's supervision, an independent botanist will establish one acre of test plots beneath solar panels, as well as two control plots on similar land away from the solar panels. Data from the test plots will be used to evaluate vegetation success under varying conditions of moisture, seed mixes, mulching, and other treatments.

"The experiments will begin to give us a handle on how PV installations and operations affect vegetation in our portion of the arid West, and the information obtained may be useful for other NREL projects, and for revegetation efforts at other solar installations," Beatty said.

Wildlife Considerations

The plant communities at the NWTC attract a variety of animal life from rodents to raptors, including bald and golden eagles. Deer and coyote are the largest mammals commonly found roaming the site, but records show black bear and even mountain lion have appeared at the adjacent Rocky Flats National Wildlife Refuge.

Before the array's installation, Beatty supervised the humane relocation of a black-tailed prairie dog colony from the southwestern corner of the NWTC to another onsite location, in prairie habitat. The relocation was conducted in collaboration with DOE, SunEdison, and other stakeholders.

The prairie dog is a keystone species whose activities are critical to the health of the shortgrass prairie; its burrowing stimulates plant growth and attracts other wildlife, and the colonies provide food for predators.

An independent biologist spent several days mapping the colony and recognizing family groups among the 70 animals. At the new colony, the biologist created artificial burrows by digging trenches four feet deep and 20 feet long, and installing irrigation piping to serve as tunnels. After backfilling with dirt, the animals were relocated in family groups. The biologist provided food and water during the two weeks it took the prairie dogs to become acclimated to their new site.

PV isn't the only renewable energy technology drawing the attention of NREL biologists.

At the NWTC, the recent installation of the two largest wind turbines ever tested at the center—a 1.5 MW General Electric and a 2.3 MW Siemens—have prompted a study of whether individual wind turbines and meteorological towers have an impact on birds and bats there. The program includes weekly bird surveys, surveys of nesting and breeding birds and weekly searches for dead birds or bats.

At the laboratory's main campus in Golden, Colorado, NREL senior biologist Tom Ryon is collaborating with stakeholders to establish a wildlife corridor. Such a corridor would allow wildlife to safely move from the top of South Table Mountain to a water source in Lena Gulch, located south of the campus.

Solar Power at the Wind Site

- **System Size:** 1.16 MW DC/ 1 MW AC
- **Characteristics:** Single-axis tracker photovoltaic, ground-mounted
- **Location:** National Wind Technology Center
- **Land:** 8 acres
- **Start of Operation:** December 2009
- **Modules:** 6,000
- **Tracker Posts:** 2,500
- **System Ownership:** SunEdison financed, built, owns, operates, and maintains the system
- **Solar Power and Services Agreement:** 20 years with SunEdison, Western Area Power Administration, NREL, and DOE.

— Joe Verrengia (February 12, 2010)

FIRST EARTH DAY ORGANIZER BULLISH ON RENEWABLES

Denis Hayes fit in with the ethos and dress styles of the era when he organized the first Earth Day in 1970. *Photo courtesy of The Bullitt Foundation*

Earth Day Founder Denis Hayes had a roller coaster ride as head of the Solar Energy Research Institute 30 years ago, but today he says the drive toward renewable energy is "unstoppable."

"The only question is whether the United States or China or Europe will lead the way," said Hayes, who was director of the Solar Energy Research Institute (SERI), the predecessor of the U.S. Department of Energy's National Renewable Energy Laboratory, from July 1979 to June 1981.

Forty years after he and former U.S. Senator Gaylord Nelson put together the first Earth Day, Hayes took some time to reflect on his time in Golden, Colorado.

"Back in the early days of SERI, we had a huge lead over the rest of the world," says Hayes, who now runs the green-oriented non-profit Bullitt Foundation in Seattle. "Now we're trailing Europe and China. The question is whether we'll catch up and pass them. I think we can."

Solar researcher Larry Kazmerski, who was at SERI then and remains at NREL now, remembers Hayes well.

"Denis was a director far ahead of his time," Kazmerski said. "He just knew the value of renewable energy—and had an outstanding respect for science and technology."

Finding His Environmental Calling

Hayes was backpacking around the world in the 1960s when he made an observation that would fundamentally change him and set him on his life's work. He was in southern Africa, in a sleeping bag watching the butterflies and primates, when it occurred to him that humans were the only animals not playing by nature's ecological rules.

They'd abandoned the sun as a means of heat, turning to fossil fuels, "substituting energy for human ingenuity."

Hayes returned to the United States and got a degree from Stanford University.

He was doing graduate work at Harvard when former U.S. Sen. Gaylord Nelson of Wisconsin picked Hayes to organize the first Earth Day—April 22, 1970. Two thousand colleges participated, as did 10,000 elementary and secondary schools. Since then, Earth Day has become an annual international celebration, continuing Hayes' and Nelson's vision of a day of education, contemplation, and celebration.

Later, Hayes was the driving force behind the 1992 Earth Summit in Rio de Janeiro, and he remains active today in building sustainable cities in the Pacific Northwest.

Solar Energy Becomes a National Priority

He looks back on his time at SERI as a tilt-a-whirl of highs and lows.

SERI was opened in 1977 during the Carter administration. After SERI's first director, Paul Rappaport, became ill, Carter picked Hayes to take over.

For a while, "It was like Project Apollo or the Manhattan Project," Hayes recalled of the priority given to SERI those first few years. "Each year, Congress doubled our budget."

> "The only question is whether the United States or China or Europe will lead the way." – Denis Hayes

SERI focused on research, but also on spending money to promote solar energy as the fuel of the future.

Hayes recruited top scientists from the best universities in the world. They gladly gave up tenure for a chance to do world-leading research in solar energy.

There was some resistance, though, in the form of a report that "purported to prove that whatever you did with photovoltaics, you would never be able to provide cost-effective energy, for any purpose," Hayes said. He credits Energy Secretary James Schlessinger, whose background was nuclear energy, with being open-minded when Hayes met with him to try to refute the report.

"Schlessinger was a smart, fair guy," said Hayes. "He always insisted on making decisions based on the best evidence." So, Schlessinger set aside the report and let SERI keep hiring the best in the field.

In the final year of the Carter administration, "SERI was employing more Ph.D.s and obtaining more intellectual property than the rest of the world put together," Hayes said.

Carter's goal was 20% renewable energy by the year 2000. "We would have made it, the math says we could have done it," Hayes maintains.

Layoffs, Budget Cuts, a Raucous Speech

Then, Ronald Reagan was elected, world oil prices plummeted, and the emphasis shifted back to fossil fuels—and away from using SERI dollars to promote solar energy.

During the first summer of the new administration, the cuts at SERI came like waves.

"They fired almost half our staff," Hayes recalled. "They reduced our $135 million budget by $100 million. They terminated all our contracts with universities—including two Nobel Prize winners—in one afternoon."

In the midst of the layoffs, Hayes says he "decided to deliver an impromptu going-away speech." He called a meeting of all the remaining staff at a building in the Jefferson County Fairgrounds in Golden, Colorado.

"I remember coming in—and it was packed," Kazmerski said.

Hayes aired his frustrations, sealing his fate.

Later that day, Hayes called Kazmerski into his office to ask him to help search for his successor. But as Kazmerski remembers it, "Denis didn't even last the rest of the afternoon."

Hayes, thinking back on his notorious speech, said: "I pretty much guaranteed that I would never again run a federal lab."

At Bullitt, Hayes is trying to make the Pacific Northwest a model of sustainability, applying the lessons nature is teaching about the precariousness of the environment. In the face of lower snowpack from the Cascades, and more drought in late summer, he is focusing on smart buildings to sustain a post-carbon world.

"We have a six-story building in cloudy Seattle that generates through photovoltaics as much energy as it uses," Hayes said. "We capture rain water on the roof, and that water is available for drinking in August and September. We have compost toilets, everything we can think of that makes cost-effective sense. We're trying to get some of the models replicated for ecological communities and green cities."

Renewables Again in the Forefront, but Will U.S. Prevail?

For the United States to keep or regain the world lead in renewable energy, several things have to happen, Hayes maintains.

"We've still got wonderful research facilities and probably the best colleges and universities in the world teaching photovoltaics," he said. "And we have an enormous entrepreneurial and venture-capital community that maintains interest."

But the United States needs to commit to renewable energy for a longer time than between election cycles, he said, not just until a new party controls the White House or Congress.

"We need to make a serious national commitment to provide a stable environment to allow companies to make the necessary investments to drive down costs," Hayes said. "We need a guaranteed market to encourage production. Instead of extending the tax incentive for two or four years, we need to do it for 10 or 15."

Hayes said there also needs to be "a real emphasis on the cutting-edge research that NREL does along with a number of colleges and universities."

> "We need to make a serious national commitment to provide a stable environment to allow companies to make the necessary investments to drive down costs." – Denis Hayes

He is especially enthusiastic about the potential of high-efficiency thin-film solar cells, "the stuff you can coat a building or a roof with. Wherever you have a photon, it gives off an electron."

"I'm confident NREL will play an important part as long as it's supported within the administration," Hayes said.

He said current Energy Secretary Steven Chu, a scientist from the Lawrence Berkeley National Laboratory, "understands the field. And so does Assistant Secretary Cathy Zoi, who has a strong background in venture capital."

Young people today know more about the perils humans can do to the Earth than any generation has before, he said. "We have young people talking about electric cars, the smart grid. They're creative, they don't know what they can't do. They're very solutions-oriented."

Still, he worries that only a slice of the generation has gotten a good science education. "We haven't done such a good job in the place we used to be strongest—K-12. Science education today isn't what it should be."

Nonetheless, Hayes is optimistic. "It's a generation that gives you an awful lot of hope."

— Bill Scanlon (April 19, 2010)

BROWNFIELDS' BRIGHT SPOT: SOLAR AND WIND ENERGY

NREL engineer James Salasovich checks his SunEye, a device that analyzes shade to help determine a site's solar energy potential. It can distinguish between trees, clouds, and shaded contours. *Photo by Patrick Corkery, NREL/PIX 17509*

Wind turbines are rising from abandoned toxic industrial sites.

Solar panels are catching rays over contaminated landfills.

America's eyesores are becoming the hot places to install renewable energy for electric power generation.

The land is cheap, often abandoned, close to such necessary infrastructure as power lines and roads, is often properly zoned, and no other developers are rushing to erect anything on them.

The U.S. Department of Energy's National Renewable Energy Laboratory (NREL) is evaluating sites for renewable energy potential on behalf of the Environmental Protection Agency (EPA).

"The big driver is using land that otherwise couldn't be used," said James Salasovich, an NREL engineer who has evaluated so-called landfill "brownfields" in Puerto Rico and Wisconsin.

"Google Earth will tell us the area of the landfill, but to get a good idea of where the hills and shading obstacles are, you really have to visit the site," he added.

Photographing the Full Sky for its Full Solar Potential

Salasovich and other traveling NREL engineers start with a device called a SunEye that has a fish-eye lens to take a photo of the sky above the landfill. "We point this thing south and take a photo," he said. "It puts out a spherical graph and shows you where the shade will be by what time of day and what time of year." An algorithm built into the SunEye can detect differences between, say, the sky and a tree.

For a site with wind potential, the NREL engineers install a meteorological tower with instruments to read wind speed and direction, said Joseph Roberts, an engineer with the National Wind Technology Center at NREL. After 12 months of measurements, they can get a read on the average wind speed, seconded by data from nearby airports. The NREL crew members also check the distance to the nearest roads and transmission lines, evaluating the sites' potential for using renewable energy, and making it work economically.

Ugly Ducklings Bring Power to Schools, Senior Centers

Potential sites are culled from the EPA's list of Superfund and Brownfield sites—and Resource Conservation and Recovery Act (RCRA) sites.

In some cases, the renewable energy apparatus going up is powering the ongoing clean-up efforts at the sites.

In other cases, the wind turbine, solar array or hydro power is bringing power to nearby schools, senior centers, offices, and cities. That's most feasible if the site is close enough to transmission wires to tie into the grid. There are some 11,000 sites in the United States with some past or current environmental contamination problem that may hold potential for renewable energy, said Gail Mosey, senior energy analyst in NREL's Strategic Energy Analysis Center.

It's a great opportunity to reuse these lands for power generation—with no help from fossil fuels, she said.

Erecting Devices without Disturbing the Contamination

Some sites, particularly Superfund sites, are so contaminated with toxic chemicals and heavy metals that the earth ought not be disturbed, Mosey said. "But there are a lot of others that can endure a slight intrusion. There are workable solutions for installing renewable energy on the surface or outside the contaminated area."

Solar arrays can fit comfortably atop the two feet of dirt and liner that typically top a condemned landfill, for example.

There are even wind turbines supported by guy wire and a surface mounted concrete footing that can generate energy without burrowing down into the muck of a Superfund site.

"These are places where you wouldn't necessarily want to put a housing development, to pour a foundation or to have people plant backyard gardens," Mosey said. "But they present as excellent sites for renewable energy."

Brownfields could be former industrial sites abandoned when the owners went bankrupt. There might have been paint or fuel spills there, among other possible insults, but the exact source of contamination may not be known. Superfund sites, by contrast, usually have a responsible party identified.

Brownfields run the gamut from being ready for redevelopment to needing a great deal of remediation.

Renewables Power Clean-up Efforts at Some Sites

In the case of Superfund sites, the NREL people are sometimes working on the site even before the final Record of Decision has been issued. In those cases, NREL suggests options. For example, there is a groundwater cleanup effort at the Leviathan Mine in California, with trucks hauling petroleum up the mountain roads to power the cleanup operations. "We told them they could be cutting back their trips if they installed a wind turbine or PV," Mosey said. "This solution can be factored in the decision."

A brownfield or other contaminated site "can be a blight on a community, land that nothing else can be done with for a number of years," Mosey said. "It's a constant reminder of what the former use was on that site. Rather than just let it sit there fallow, this presents an excellent opportunity for power generation."

> "These are places where you wouldn't necessarily want to put a housing development, to pour a foundation or to have people plant backyard gardens. But they present as excellent sites for renewable energy." – Gail Mosey

There are more than 4,000 brownfields in the United States, totaling 37,000 acres—the equivalent of 28,500 football fields.

Add in RCRA and Superfund sites and abandoned mine lands and there are more than 11,000 sites, totaling over 14 million acres.

That's enough room to power a big chunk of America with wind turbines and solar energy.

Of course, not all those acres are suitable for renewable energy. They could be too sloped, too shady, too contaminated to be useful.

That's where the NREL team is valuable, assessing the properties at sites across America, applying screening criteria and then conducting feasibility studies.

NREL developed criteria that must be met to become a high-potential site. What is the renewable energy resource potential? Is it close enough to transmission lines to feed the grid? Is it near enough to graded roads for renewable energy installation to be feasible? How large is the site and how sloped is the land?

"Not only do you need technical feasibility, but you have to consider economic feasibility," Mosey said. "If it isn't near transmission, at a million dollars a mile to build transmission lines, that's just cost-prohibitive."

Clean-up Often Sparked by Passionate Residents

Mosey and her teammates have seen the best of human nature emerging from some of the ugliest of landscapes.

"We have citizens who are single-handedly making it happen," Mosey said. "They're trying to make good out of bad."

In the anthracite coal region of Pennsylvania, Peter Haentjens, a descendent of the family that tried to pump water out of a huge coal field, is leading the effort to bring hydro power to the notorious Jeddo Tunnel.

The Jeddo Tunnel was dug in the late 1800s to try to move water out of coal formations. The attempt backfired, sweeping dangerous heavy metals down with the acidic water. Today, the Jeddo Tunnel drains 33 square miles of coal basins—bringing 60 million gallons a day of contaminated water to the Little Nescopeck Creek watershed.

"You get this orange residue out of the rock if the water is picking up iron," Haentjens said. "You get gray if it's manganese and white if its aluminum."

"It kills most of the aquatic life in the streams for 17 miles," Haentjens added. "Aluminum, especially, is pretty toxic.

All that flowing water can help run a downstream pump station for a sewage treatment plant, as well as power a school and a senior home, he said. And it can do that even while engineers work on a long-term solution for the contaminated water—and try to find money to pay for it.

When the tunnel was built more than a century ago, the dirt that was dug was set on either side. That same dirt could help build a dam to raise the level of the water some 35 or 40 feet, Haentjens, who is with the non-profit Eastern Middle Anthracite Region Recovery group, said. "We could get pressure to make 150 kilowatts. That could bring in $120,000 of revenue per year.

"It's mostly wetlands so it's not really developable," Haentjens added. "We'd like to make an environmental park out of it. There would be an educational component for hydroelectric energy, as well as a history of the tunnel and the acid drainage and its effect on the environment."

"The NREL people are looking at the economic justification of doing that—of how much we can sell the energy for and the cost of building the dam. The focus is to create economic value and at the same time improve the environment," he said.

"The guy is just on a mission to solve this thing," Mosey said of Haentjens.

Next Step: Expansion to the U.S. Forest Service, Bureau of Mines

In 2008, the EPA awarded NREL $650,000 to conduct feasibility studies at 13 different projects, including one in Puerto Rico.

Mosey hopes to expand the program so NREL can evaluate contaminated sites for other federal agencies such as the Bureau of Mines, the Bureau of Reclamation and the U.S. Forest Service.

"In a lot of cases, the land is cheap, maybe even owned by the state," Mosey said. "They're just happy to have some positive re-use and some sort of revenue-generation on it."

— Bill Scanlon (June 14, 2010)

WIND AND SOLAR ENERGY POWER POLAR RESEARCH

NREL researchers are experimenting with adding wind and photovoltaic solar energy systems at the Amundsen-Scott Research Station at the South Pole. The new station originally was supposed to include renewable energy systems, but construction delays and other factors cut them from the project. *Photo by Owen Roberts, NREL/PIX 18538*

While the Eastern Seaboard sears under triple-digit temperatures, clean energy systems certified by the U.S. Department of Energy's National Renewable Energy Laboratory (NREL) are supplying ice-bound research bases at the bottom of the world with critical power during the frigid darkness of the Antarctic winter.

Other systems being tested by the NREL engineering team are expected to generate power during the endlessly bright polar summer months.

The combined results, along with energy conservation measures, will contribute to new renewable energy and energy-efficient construction standards in Antarctica and other remote locations, where both environmental protection and reliable energy supplies are critical to the success of scientific missions.

The projects also will serve as distant, but powerful reminders that if renewable energy systems can succeed in ferocious conditions, they should have widespread application in more temperate locations.

"There is no design standard for minus-100°F," said NREL senior mechanical engineer Ian Baring-Gould, who leads the laboratory's work in polar environments. "If wind and solar energy systems can work in Antarctica, then certainly they should work in places like Kansas."

NREL and NSF: a Natural Partnership

Remote polar stations operated by the National Science Foundation (NSF) offer NREL a natural opportunity to extend both the reach of renewable energy and the laboratory's expertise.

The stringent international environmental regulations that govern polar activities make renewable energy systems an obvious choice. The 47-nation Antarctic Treaty declared the White Continent a reserve for science and peace. Parties are obliged to "limit adverse impacts on the Antarctic environment."

But because the environment is so uniquely and unrelentingly hostile, and help is so far away—New Zealand is a 5- to 7-hour flight when conditions allow—any energy system used there must be extremely reliable and relatively simple to repair.

Even the systems' constituent materials must be tested. That's because typical metals and plastics can become brittle in extreme cold.

"The conditions in Antarctica leave no margin for error," said Baring-Gould, who works in NREL's National Wind Technology Center and Deployment and Industry Partnerships Group. "NSF needs to know everything it can both about the system and the natural resources that we're harnessing for energy."

Then there is the issue of energy cost.

Antarctica's research stations rely primarily on diesel fuel for heat, lights, and transportation. Every year, NSF ships huge volumes of fuel to locations so remote and barren than NASA uses them as simulators for Mars.

The costs are daunting. A tanker flight delivering 3,000 gallons of diesel to the South Pole costs $100,000—or about $33 per gallon.

"At those prices, you have to manage your energy very carefully," Baring-Gould said. "Every gallon of fuel you can displace with renewable energy makes a real difference to the program budget."

McMurdo Station: Antarctica's Hub

The most extensive use of renewable energy in Antarctica is at McMurdo Station, the primary hub for U.S. science operations on the continent. The station's population swells to more than 1,000 residents during the polar summer. Energy demands continue around the clock as scientists squeeze years' worth of research into a few months of continuously available sunlight.

McMurdo now shares a 1 megawatt wind farm with nearby Scott Base, which is operated by New Zealand. The new wind farm is between the outposts on Ross Island's Crater Hill.

While it is not Antarctica's first permanent wind farm—Australia's Mawson Station installed two turbines on the continent in 2003—it is the southernmost wind farm in the world and the largest installation in Antarctica.

Baring-Gould and NREL's Owen Roberts commissioned the new wind farm in January. It includes three Enercon E33 turbines installed by New Zealand's state-owned Meridian Energy. They were built on specially-designed pads that had to be shipped to the site in sections. That's because Antarctica has no concrete manufacturing facilities or sources of fresh water or aggregate.

The system includes a flywheel that can supply power for 30 seconds to maintain the system's stability in case of sudden wind changes while improving general power quality overall.

And, a special electrical grid of ground-laid cables had to be installed between the bases and the wind farm, as well as a static frequency converter, because power at McMurdo operates at 60Hz while the New Zealand base operates at 50Hz.

The wind farm is expected to meet at least 20% of the electricity needs of both bases and cut diesel consumption by at least 125,000 gallons per year. It will reduce carbon dioxide emissions by an estimated 1,242 tons per year as well.

"During a recent high-wind event, the power system demonstrated that more than 70% of McMurdo's energy needs could be provided by wind with the existing system configuration," Baring-Gould said. "But we need to make sure that the system works with diesel generation so there is no interruption of power or instability."

NSF also is testing electric vehicles in McMurdo, to reduce fuel needs and pollution from the base's extensive fleet of diesel trucks, snow mobiles, and buses.

For fiscal year 2011, NSF is requesting $3 million to fund wind and solar energy upgrades at the nearby Black Island telecommunications relay facility that serves McMurdo. The agency also is seeking $2 million to support new smart grid metering and networked direct digital controls to monitor and manage McMurdo's power, lighting, heating, and water use.

"NREL's expertise has proven particularly helpful in systematically changing the energy profile of the United State's McMurdo Station and New Zealand's Scott Base," said William Colston, director of NSF's Division of Antarctic Infrastructure and Logistics.

"We have already realized over a million gallons of fuel savings annually," Colston said "Together, our two organizations have advanced the United States' environmental stewardship in Antarctica."

South Pole Challenges

The NREL team also is testing renewable energy technologies at the Amundsen-Scott South Pole Station, but the scale of the renewable energy systems there is experimental. That's because the Pole represents a significantly more difficult challenge.

While McMurdo is on the coast with relatively warmer temperatures and even some bare ground, the Pole station is 800 miles inland and rests at an elevation of 10,000 feet atop an ice cap nearly two miles thick.

In summer, the high temperature typically stalls at minus 20°F.

In 2008, NSF dedicated a new $153 million elevated polar station to replace the iconic, but obsolete, geodesic dome station. The new station was designed with integrated photovoltaics (PV) on its roof, but during its extended construction the PV system was eliminated by budget constraints and project delays. Today the new station is served by diesel power; fuel tanks are located in ice caverns below the station.

Adding PV to the station's roof now would be prohibitively expensive, Baring-Gould said. And, engineers would have to drill through the station's high-tech cocoon of insulation, exposing occupants to potentially catastrophic leaks.

Instead, NREL is focusing on property a few hundred yards away nicknamed Summer Camp. Rows of Quonset huts shelter the overflow of researchers and maintenance workers during the polar summer. Because the sun never sets during the polar summer, PV could generate power around the clock for the small huts, as well as nearby toilets, laundries, and other facilities.

The NREL Buildings Group has performed computer modeling of energy-efficient designs for a new generation of Summer Camp dormitories, which could be started in 2012. PV panels would be integrated into the roofs of these new huts, along with passive solar heating systems.

The lab team in collaboration with staff from Raytheon Polar Services, the operating contractor for all NSF operations in Antarctica, already is conducting field tests with small installations—six PV modules and a small 2.3 kW wind turbine. Testing of solar thermal technology will start next year. The wind turbine tests will continue for at least one more year, while the PV panels will capture at least two years of seasonal data.

The combination of technologies appears favorable. Like many places, generating large amounts of renewable power in Antarctica with a single technology is unlikely. Fortunately, polar winds blow during the winter months when the sun does not shine.

"Right now we're testing so we can really understand the energy protocols of the site," Baring Gould said. "It looks promising because the two renewable resources—solar and wind—coincide with the change of seasons. And when the power demand is high during the summer, you'd have solar 24/7."

But remember, this is Antarctica, where the unexpected happens and people's survival can be measured in a few hours—or minutes—without power.

"That's why," Baring-Gould said, "you have to put a unit out there, record the data, and see how it works."

Renewable Energy in Antarctica

- Black Island Telecommunications Facility, the primary downlink relay station for Antarctica, has been partially wind-powered for more than 10 years. A new 1 megawatt wind farm on Ross Island was certified in 2010.
- Australia's Mawson Station installed two wind turbines in 2003. They provide more than 70% of its power needs, saving nearly 160,000 gallons of diesel fuel per year.
- Britain's Rothera station on the Antarctic Peninsula uses solar photovoltaic panels.
- Japan's Syowa base uses solar PV, too.
- Belgium's Princess Elisabeth station in East Antarctica became the first outpost entirely operated on renewable power in 2009.
- A Northern Power wind turbine was tested for two years at the South Pole in 1997-98; solar panel testing was launched in 2009 and continues today.

— Joe Verrengia (July 15, 2010)

PUTTING THE FORKLIFT BEFORE THE HORSELESS CARRIAGE

Forklifts capable of operating in hot or cold conditions are ready for use at a Sysco warehouse in Houston. NREL engineers are analyzing the operation and performance of these fuel cell forklifts and others elsewhere. *Photo from NREL/PIX 18347*

Forklifts hoist, stack, and stow a big chunk of the nation's goods, and have been doing so for 90 years, powered by gasoline and electricity.

Hydrogen fuel cells are much newer, yet already proving themselves in early markets, with the goal of one day providing clean, safe renewable energy to the nation's and the world's transportation fleet.

Warehouse workhorses of the 20th century meet the most intriguing fuel of the 21st.

In warehouses across the nation, hydrogen fuel cells are being tested in forklifts, to see how the emerging technology fares compared to conventional batteries in cost, performance and safety.

How well hydrogen fuel cells perform in forklifts and in other early-market applications such as backup emergency power, stationary power, and portable power is a key step. If they prove themselves, that will accelerate the development, manufacturing and cost-reduction necessary for their widespread use the automobile industry and elsewhere.

The U.S. Department of Energy's National Renewable Energy Laboratory (NREL) is playing a crucial role, as the independent, third-party assessor of the performance of the early fuel cell market demonstrations funded by DOE.

Indispensable to that effort is the Hydrogen Secure Data Center (HSDC) at NREL. A team of NREL engineers is gathering data from a dozen early users of hydrogen fuel cells, assessing how well the fuel cell systems fare in the real world, with a focus on performance, operation, and safety. They began analyzing data from fuel cell vehicles in 2005.

The testing is such a priority of the Department of Energy that a year ago in April 2009, it offered approximately $42 million in American Recovery and Reinvestment Act money for sites to install and operate fuel cell units in real world applications.

The dozen companies selected for the grants collectively put up $51 million of their own money, making it a $93 million project.

The project awards include four that are testing forklifts, four that are testing backup power, one that is testing combined power and heat, one that is testing auxiliary power and two that are testing portable power.

The NREL group is working with fuel cell and hydrogen developers as well as end users across the country.

Hydrogen Keeps Forklifts Moving

Some 90,000 new forklifts are manufactured yearly and delivered to warehouses from Maine to Hawaii. Their average cost exceeds $15,000.

Electric-powered forklifts are a big improvement over the gasoline-powered lift trucks of the 1940s and 1950s—just ask the operators who breathed gas fumes trapped in narrow warehouse aisles.

But there are some performance limitations of battery forklifts, such as voltage sag as the batteries' state of charge decreases. Early in the shift, there's plenty of power in a fully charged battery, but the forklift slows down as the battery drains. When the performance gets too slow the battery has to be changed. That means keeping a battery always in reserve, and it means about 20 minutes of downtime while the switch is made.

Efficiency-driven companies such as the food-supply giant Sysco lose money each minute a forklift is down.

Hydrogen fuel cells, by contrast, deliver a constant flow of energy. Refueling takes about three to five minutes, versus the 15 to 20 minutes it takes to change out a battery, says Jennifer Kurtz, team leader for NREL's American Reinvestment and Recovery Act (ARRA) Early Fuel Cell Market Demonstration and Validation Project.

NREL's data analysis helps Sysco and the other companies understand how the fuel cell and hydrogen units are performing along with comparisons with competing technologies.

Productivity Equals Profit in the Forklift Business

A forklift-intensive warehouse "looks like chaos" to an outsider, but the operation is effectively organized for productivity, Kurtz said. "They have productivity measures, such as how much material is moved per eight-hour shift," Kurtz said. So, a forklift that doesn't slow down as the hours pass, or a

forklift that can be refueled in four minutes, rather than have its battery replaced in 20 minutes, can have a positive impact on productivity.

"Even if it comes down to one minute of productivity gain, that's a noticeable improvement for warehouses where forklift use is really maxed out," Kurtz said.

"It's been a great partnership," said Katrina Fritz Intwala, vice president of business development and government relations for Plug Power, which sells fuel cells for forklifts, stationary power, and other uses.

"NREL is very collaborative, we have meaningful back-and-forth discussions on their data that is very useful for us to see how our units are operating in the field. They gather information on how our units are fueled, when they're filled, what's the run time on the fuel, how long our units run between fuelings, and to what pressure are they fueled. We're able to get a better understanding of how our customers are using our products and how they're performing."

"We're able to get a better understanding of how our customers are using our products and how they're performing." – Katrina Fritz Intwala

Also useful for Plug Power is seeing how their fuel cells compare to battery packs or internal-combustion engines.

Fuel Cells for Emergency Backup Power

The fuel cells also are being tested by organizations that have crucial needs for backup power such as telecommunications and emergency responders.

Typically, that backup power is supplied by diesel, but organizations are eager to explore the advantages of fuel cells.

Mark Cohen, director of product management for ReliOn, said the NREL data "provides more credibility to a customer" than merely having the manufacturer produce its own data to extol the virtues of the product.

He said the partnership, together with the ARRA money, will help accelerate the rate at which his company's hydrogen fuel cells are deployed for backup power in critical communications settings, "while clearly demonstrating the performance and environmental benefits of the technology."

Indispensable Information while Guarding Secrets

NREL's HSDC had to find a way to deliver useful information to the companies without betraying their internal secrets.

"We protect the proprietary data by creating composite data projects," Kurtz said. The HSDC results are online at: http://www.nrel.gov/hydrogen/proj_fc_market_demo.html. "The data are aggregated across all the project partners." That way, each company can see its own data, and how it compares with the aggregate data, but can't hone in on a competitor's specifics. "It's a way of having commercially sensitive data reported on, without revealing a company's proprietary information," Kurtz said.

If fuel cells prove efficient and are adapted widely in transportation and emergency services, they are expected to generate tens of thousands of jobs in manufacturing and maintenance.

They also will help end dependence on foreign oil and keep hundreds of millions of tons of carbon dioxide out of the atmosphere.

— Bill Scanlon (June 3, 2010)

HYDROGEN BUS LETS LAB VISITORS GLIMPSE FUTURE

DOE recently funded the leases for 12 hydrogen-powered shuttle buses to demonstrate market-ready advanced technology vehicles. NREL was the first facility to receive one of the leased buses, which it currently uses at its campus in Golden, Colorado, for tours of the site. *Photo by Dennis Schroeder, NREL/PIX 18290*

Imagine making fuel for your vehicle by simply using water and the wind or sun, filling your tank and driving to your favorite weekend vacation spot before looking for a fueling station. It is not a chapter out of a "green" science fiction novel, but technology being demonstrated in a "big" way on the campus of the U.S. Department of Energy's (DOE) National Renewable Energy Laboratory (NREL) in Colorado.

DOE recently funded the leases for 12 hydrogen-powered internal combustion engine (H2ICE) shuttle buses, which are being placed at federal facilities across the country to demonstrate market-ready advanced technology vehicles. NREL was the first facility to receive one of the leased buses, which it currently uses for tours of its Golden, Colorado, campus.

"NREL's unique twist to this demonstration is that we are fueling our shuttle bus with hydrogen made from wind energy up at our National Wind Technology Center near Boulder," Hydrogen Technologies & Systems Director Robert Remick said. "So, the hydrogen in our shuttle was literally wind energy blowing off the Rocky Mountains last week."

> "The hydrogen in our shuttle was literally wind energy blowing off the Rocky Mountains last week." – Robert Remick

Tweak to an Old Engine

The H2ICE shuttle bus in use at NREL was manufactured by Ford, one of the first automakers to develop commercially available H2ICEs. The shuttle uses the same basic technology as a conventional gasoline-powered engine but runs on the hydrogen fuel created at NREL's Wind to Hydrogen (Wind2H2) Project. The Wind2H2 project links wind turbines to electrolyzers, which pass the wind-generated electricity through water to split it into hydrogen and oxygen. The hydrogen can then be stored and used later to generate electricity from an internal combustion engine or a fuel cell.

The bus has a 6.8-liter supercharged Triton V-10 engine. Only modest design adjustments were needed to switch the basic gasoline-powered engine to a hydrogen-powered engine. Those modifications included using specially designed spark plugs and alternate materials for valve seats and other parts that may become brittle when exposed to hydrogen.

NREL's shuttle is up to 25% more efficient than similar gasoline-fueled passenger vans and can run 175-250 miles (depending on usage) before staff refuels. The lab outfitted its "green" hydrogen dispensing station with cascading storage tanks, which decreases the time required for refueling. This is particularly beneficial for vehicles with large onboard storage systems like the H2ICE bus, which can take up to 30 kilograms of hydrogen in a single fueling. Because NREL's fueling station has a 130 kg storage capacity at 413 bar (6,000 psi), filling the bus takes 20-30 minutes; however, refueling time is lower at other commercial hydrogen stations.

NREL is studying hydrogen use at the Wind2H2 site to gain practical experience operating and maintaining complete systems and to understand hydrogen's interaction with the shuttle and the storage system. "In addition to the fueling station, we are storing more than 200 kg of hydrogen at the Wind2H2 site," Keith Wipke, NREL senior engineer and group manager for Hydrogen Analysis said. "It allows us to capture intermittent renewable energy and both fuel the vehicle and put energy back on the grid at times when there is high demand for electricity."

Although making hydrogen from renewable resources and using it in an H2ICE shuttle bus is a step in the right direction, it is an incremental step for the use of hydrogen in vehicles.

"Fuel cells are the most efficient way to use hydrogen in vehicles," Wipke said. "So, this type of passenger bus utilizing an internal combustion engine is less efficient than a fuel cell, but is a good stepping stone to get the technology into the market and provide an alternative to fleets while the infrastructure for hydrogen fueling stations develops."

Industry Ramps Up for 2015

Hydrogen fueling station are springing up across the United States, with approximately 60 locations already in operation and 20 more slated for construction. "Infrastructure for hydrogen fueling stations is starting to happen," Wipke noted. "The recession has caused a bit of a delay, but California recently awarded funding for 11 new fueling stations, and this is on top of seven new stations that are currently under construction."

Although a commercial sized passenger bus is the technology currently being demonstrated at NREL, Wipke expects

hydrogen vehicles to claim a piece of the personal car market as well. DOE set a target goal for hydrogen fuel cell passenger vehicles to hit the market in 2015 and many of the major players—GM, Daimler, Honda, Toyota, Nissan, and Hyundai-Kia—are targeting a 2015 launch for their larger hydrogen fuel cell market entries. DOE recently announced that 70 Mercedes Benz B-Class fuel cell vehicles will be deployed in California by 2012.

"You look at the auto industry after this recession, and the pruning that you would have expected, the fact that hydrogen is still very strong is a huge vote of confidence for this technology," Wipke said.

There are many benefits keeping hydrogen vehicles in play for the auto industry including very low tailpipe emissions of criteria pollutants and greenhouse gases, and increased economic competiveness and jobs in the United States.

"Fuel cells are the most efficient way to use hydrogen in vehicles." – Keith Wipke

Wipke also believes that although fuel cell cars may start out as a small part of the passenger vehicle market, they won't be relegated to niche-market status. Consumers will be able to purchase fuel cell vehicles that can go up to 300 miles on a single fill-up and refuel in three to five minutes. Drivers seeking larger multi-purpose vehicles, such as trucks and SUVs, will also be able to tow trailers and recreational equipment using fuel cell vehicles.

Hydrogen Has Potential

NREL analysts noted in a 2007 report, "Potential for Hydrogen Production from Key Renewable Resources in the United States," that approximately 1 billion metric tons of hydrogen could be produced annually from wind, solar, and biomass resources in the United States with the potential to displace gasoline consumption in most U.S. states.

NREL's research in hydrogen and fuel cells will get a boost in the coming years as a new laboratory—the Energy Systems Integration Facility comes online in 2012 and provides new lab space for hydrogen and fuel cell related research.

"We are also looking to do more research on fuel cell vehicles as manufacturers get ready to launch their next line of demonstration cars," Wipke said. "We will be able to demonstrate the path of source renewable energy all the way through to the vehicle."

Hydrogen Facts

- Hydrogen can be made from a wide variety of domestic, renewable resources such as solar, wind, biomass, and geothermal energy.
- Enough hydrogen is produced in the United States every year to fuel 34 million fuel cell vehicles. Right now, the hydrogen is used primarily for commercial purposes such as cleaning up gasoline and processing certain foods.
- Hydrogen is neither more nor less hazardous than more common fuels like natural gas, propane, or gasoline.
- Compared to conventional gasoline engines, hydrogen-powered engines have very low criteria emissions and near-zero greenhouse gas emissions when the hydrogen is produced from low carbon or renewable resources.
- Hydrogen is up to 25% more efficient than gasoline in conventional spark ignition engines and around 100% more efficient in fuel cell power trains.
- Only modest design modifications to standard combustion engine technology are needed, so the engine technology is familiar to mechanics and fleet personnel.
- With very few cost and technical issues limiting commercialization and deployment, H2ICE vehicles can help create the demand needed to support the build out of a hydrogen infrastructure.

— *Heather Lammers (December 14, 2010)*

IKEA GEOTHERMAL SYSTEM COULD INFORM OTHERS

NREL senior geothermal analyst Erin Anderson examines a heat sensor to make sure it's in working order before the wire attached to the sensor descends 500 feet under the IKEA store construction site in Centennial, Colorado. *Photo by Patrick Corkery, NREL/PIX 17907*

It will take less energy and money to make the IKEA store opening in suburban Denver feel pleasant when the sun bakes or when the snow drifts, thanks to 130 holes dug into the Earth, where the temperature remains about 55°F all year round.

IKEA, the Swedish home furnishings retailer, has teamed with the U.S. Department of Energy's National Renewable Energy Laboratory (NREL) to showcase and study the advantages of a geothermal heating system currently under construction in Centennial, Colorado.

It will be the first IKEA store in the United States to be built with geothermal heating and cooling, said Douglas Wolfe, IKEA project construction manager for the store expected to open south of Denver in the fall of 2011.

The holes, each 500 feet deep, will be directly below the parking garage that will be just below the store.

Geothermal heat pumps use 25-50% less electricity than conventional heating or cooling systems, a potential saving of several billion dollars a year if projections for geothermal growth prove true. The Environmental Protection Agency says geothermal heat pumps (GHP) can reduce energy consumption—and corresponding emissions—up to 72% compared to traditional electric resistance heating and standard air-conditioning equipment. Geothermal cooling and heating also improves humidity control by maintaining about 50% relative indoor humidity, making GHPs very effective in humid areas.

> "By collecting actual live data on the performance of systems, you have better insight on what needs to be improved." – Erin Anderson

Data Could Lead to Better Models

The IKEA/NREL project could be the benchmark for a credible standard for geothermal installation in large-scale retail stores nationwide. NREL's data base will be open to researchers around the world to use for their models, Erin Anderson, a senior geothermal analyst at NREL, said.

"We're trying to collect data on how it actually performs," which could prove invaluable to future projects. "By collecting actual live data on the performance of systems, you have better insight on what needs to be improved.

"We'll be able to say with confidence, 'if you do it this way, it will work this well.'"

The sun could be frying eggs on sidewalks, or the bitter cold could be freezing tongues to flagpoles, but a few feet underground the temperature generally is moderate and pleasant, summer or winter.

Miners know that well. In well-ventilated underground mines, they can wear light jackets all year round, because from about four feet underground to hundreds of feet underground the temperature stays fairly constant at about 55°F.

This is because of thermal inertia, the propensity for soil to heat up or cool down much slower than air or water.

The trick is to run a liquid in a loop down to that pleasant temperature and bring it back up to help keep things cool in the summer and warm in the winter. When warm air at the surface is passed over the cool pipes, the air gets cooler. When the air is cooler than the liquid, it is warmed as it passes over the pipes.

Now, It's Just Dirt, Trenches and Holes

At the site of the Colorado IKEA store there are several tracts of dirt at different levels, bulldozed flat; some trenches holding pipe; several earth-movers; and a tall drilling rig boring those 500-foot holes.

A counterweight attached to the rig helps drive hose loops through the mud, down the 5 ½-inch diameter holes.

Anderson was at the site recently to take measurements. She sends a sensor attached to hundreds of feet of wire down one of the three holes to be tested. "We're monitoring three points in each hole," Anderson said, "at the very bottom, and at 250 feet on either side of the pipe.

"Imagine two straws," she said. "The fluid is flowing through them, descending down one, rising up the other. We want to see if the supply temperature and the return temperature are different.

"We're trying to determine what the temperature is all the way down as a way to achieve a comfortable temperature in the store," Anderson added. "We have this ground that is pretty steadily cooler in the summer when you want cool air and warmer in the winter when you want warm air."

As the fluid rises to the surface, a heat pump compresses the air, increasing the pressure.

"It's the same way your refrigerator works," with a compressor to extract the heat, Anderson said. "You put a hot chicken in the fridge, and three hours later it's cool. But the back of the fridge is hot. The refrigerator is taking the hot from the food and rejecting it to the outside."

"We have a much larger cooling load than we do a heating load," Wolfe said. "Believe it or not, even in the dead of winter we will be cooling on some days more than heating just because of the number of people who will be in the store. All those customers and co-workers generate a lot of heat—that, along with all the lighting, the heat generated by the restaurant and other equipment throughout the building—increases the cooling load," Wolfe said.

In fact, even with 130 holes 500 feet deep and a maze of hose below the building carrying all that cool-but-not-cold water, the store is going to need an extra chiller. An ice-storage system will provide additional cooling during the warmest days of summer.

A concrete driveway on the north side of the store will be another good place to reject heat, Anderson said. "They're taking warm air from the building and rejecting it to the outside to help melt ice on the parking lot during inclement winter days."

Load Determines Depth

The drillers hired by IKEA are making 5 ½-inch diameter holes and going down 500 feet. Why?

"It's based on the amount of fluid we need in the piping system," Wolfe said, noting the 415,000-square-foot, two-level store will be atop two stories of parking. "We'll be transferring that fluid into our pumping system to provide the heating and cooling. We need that much volume of water and glycol to satisfy the heating and cooling load."

The cost of digging 130 holes 500 feet deep and filling them with loops of pipe will be paid back in energy savings within a reasonable time, Wolfe said. "And we expect the system to last as long as the building lasts.

"We looked at soil conditions and thermal conductivity tests to determine how many wells we would need and at what depth they would have to be," Wolfe said. The numbers bore out. "This approach is consistent with our commitment to using sustainable building practices whenever feasible."

The drillers are encountering "a lot of shale, some layers of sandstone, a lot of sand," said Matt Lungerich, drill crew leader for Rocky Mountain GeoDrill of Centennial. "Here and there we hit some gravel, usually at the top." The end result is a huge pile of grayish rock, from baseball-size to mere dust, which is hauled away by a front-loader.

It usually takes about four or five hours to drill a 500-foot hole, but if they encounter some difficult rock or if the rig breaks down, one hole can take all day.

IKEA, NREL Partnership Boosts Both

Once the geothermal system is in place, it only can be tweaked from the surface. "We'll monitor the energy use of the heat pumps, the temperature in and out of the heat pumps and the flow," Anderson said. "We're also going to look at what the temperature is in terms of climate control."

> "We're very excited about working with NREL. The partnership has turned out to be very beneficial for both of us." – Douglas Wolfe

NREL's monitoring and data will help IKEA make decisions about adding different mixtures to the liquid, tempering the flow, adding more pumps, or adding an additional cooling system to reject more heat.

"We launched an internal energy-efficiency initiative several years back that included evaluation of geothermal programs for construction of new stores," Wolfe said. "We looked at doing geothermal at a couple of other U.S. projects in the past, but this is the first project where the timing, the economics, and the geotechnical aspects all make sense."

The geothermal heating and cooling system "is something that globally IKEA has been considering for a number of years," Wolfe added. "We're very excited about working with NREL. The partnership has turned out to be very beneficial for both of us. It is providing both of us with useful information about operating such programs." Seeing the information in real time "will allow us to determine and manage the efficiency of the geothermal system in Centennial" as well as planning for "future operations at this location as well as at other IKEA stores."

When Anderson heard that IKEA planned to drill holes and install pumps for geothermal energy, she didn't hesitate. "We've been interested in monitoring commercial sites," she said. "I got in touch with the designer and asked if they wanted to be a part of this monitoring system.

"Geothermal is a technology that has been around forever," Anderson said. There is evidence that Stone Age people tapped the Earth to keep their caves and hovels warmer in winter, cooler in summer.

"It works when it's designed correctly and installed correctly," Anderson said.

— Bill Scanlon (August 19, 2010)

GREEN COMPUTING HELPS IN ZERO ENERGY EQUATION

NREL IT managers and supervisors from Haselden Construction eye the spot where the racks will be positioned in the data center of the new Research Support Facility. *Photo by Patrick Corkery, NREL/PIX 17290*

It's a daunting challenge, attempting to erect the largest net-zero-energy office building in the world.

It's especially daunting when that building will be full of people computing, teleconferencing, and generating teraflops of information about renewable energy.

The National Renewable Energy Laboratory (NREL) aims to generate as much energy as it uses in the new 222,000-square-foot U.S. Department of Energy Research Support Facility (RSF) on the NREL campus. When completed in the summer of 2010, it will house more than 800 people and a data center that stores and manages mountains of information on computer servers.

A net-zero energy building produces as much energy as it consumes.

To get there, "every watt has to count," Craig Robben, Information Technology project manager for the RSF says.

The RSF can't get to net-zero without getting credit from some of the energy produced via the sun and wind at its Golden, Colorado, campus.

But neither can it get there if the actual energy use in the new building gets above about 250 watts per person. "That's four or five light bulbs per person—for everything—computers, servers, building systems, the exercise room, everything," Robben told a roomful of employees at a recent informational gathering.

The engineers and scientists from NREL's Building Technology Program set the energy criteria and the energy design strategies that are making it possible for the RSF to use no more carbon-based energy than is produced by renewables.

Even just a couple years ago, there would have been no hope for per-capita energy use being that low in a modern office building. The electrical needs of desktop computers, servers, scanners, printers, and more would have mushroomed above those numbers.

Still, Robben is confident the RSF will meet those goals, with a big boost from smarter use of information technology.

Smart Cooling, Virtualized Servers Key to Energy Savings

Plans to get RSF there employ an intelligent cooling system, natural lighting, virtualized servers, and common-sense measures to conserve, switch off, and think twice.

"We're wasting a lot of energy going out the back of the desktops as heat," he said. "Desktop computers are not supposed to be space heaters."

So, employees will be encouraged to continue the switch to laptops, which only average about 35 watts—about a third the average wattage of desktops. And laptops are getting so powerful that they exceed the needs of most users. Newer mobile processors now include the ability to 'ramp-up' their processing speeds as more number crunching is required.

Only LCD monitors will be going into the RSF, and a good portion of those will use the more energy-efficient LED-backlight. LCD's have always been more energy efficient than the cathode ray tube monitors, but manufacturers are stepping up with new technologies to be even more efficient. As time goes on, Robben expects other new display technologies, such as Organic LED (OLED) displays, to replace LCD's.

"The building has been designed from the beginning to take advantage of our environment." – Craig Robben

All-in-One Printer/Copier/Scanner to be the Norm

There will be very few, if any, local or group printers in the RSF. Scanners, copiers, and fax machines will grow all but extinct. New all-in-one devices that can fax, scan, print, e-mail, and copy in one unit will save huge amounts of energy, Robben said. The new protocol will be just one or two of those units per wing, compared to the current situation, in which there are some 600 printers for 1,800 employees, plus hundreds of other devices to scan, fax, and copy.

The new units can print up to 50 pages per minute, print in high-resolution color on both sides of up to tabloid-sized paper, and perform high-resolution color scans that can be e-mailed.

Phone calls will be made via the Voice-over Internet Protocol system, which uses less energy, even while affording more

functionality. The phone system gives users the option of turning the computer into a virtual handset. "Your computer becomes your phone," Robben said.

RSF employees will be encouraged to switch to motion-detector or similar "smart" power strips that will sense when someone isn't in the office, and then switch off the devices that aren't needed—say, the label printer or task lights.

"It's scary how much power is wasted there," he said.

Cooling Down the Teraflops

The greatest challenge is achieving net-zero energy in a building that has a large data center.

Typically, servers rest in racks, chomping up and spitting out information. Cool air blows through, trying to keep the processors from frying.

"Technology continues to provide us with the tools we need to make IT energy efficient." – Craig Robben

To create all that cool air, data centers typically employ chillers, basically big air conditioning units that sit outside on pads. The chillers are running all of the hours of the day, pumping chilled water into the building. The cool liquid passes over a big radiator and fan unit cooling the air that passes through the data center and to the servers.

The RSF will employ several strategies to dampen the energy needs of the data center including taking advantage of Colorado's climate and some ingenious engineering to minimize the hours the chillers must run.

"The building has been designed from the beginning to take advantage of our environment," Robben said.

Underneath the RSF is a labyrinth of concrete looking like a Rube Goldberg mousetrap, storing thermal energy. That labyrinth becomes a giant "battery," storing cool air during the summer nights and warm air during the winter days.

Air will circulate through that concrete maze constantly. The cold high-altitude air captured at night will remain in the labyrinth during the warm hours of the following day. During the winter, the hot air from the data center will be dumped into the labyrinth to aid in heating the building.

Meanwhile, efficient evaporative chillers, running cold water over pads, will cool the servers when needed. And for the rare occasion when outside air is too hot and humid for evaporative chillers to work effectively—estimated to be fewer than 10 hours per year—a more traditional central chilled water plant will cool the data center. Right now the data center chillers operate 24 hours a day, seven days a week.

The Key: Running Many Virtual Servers on One Physical Server

In the RSF's data center, the individual rack-mount server will go the way of dinosaurs.

Each of the rack-stacked servers plugs into its own power supply, and must be switched on even if during most hours it is just handling, say, 5% of its processing capacity. A humming, albeit underused, server still piles up the wattage.

Blade servers are game-changers, though. They're smaller, more streamlined and still packed with great capacity. And they'll be the work horses of the RSF.

Sixteen blade servers can fit in the space taken up by a few older servers. More important, all 16 are in a single blade chassis, sharing power supplies, cooling fans, and circuit boards.

Along with blades, virtualization is the biggest energy saver at the server level. "Virtualization is taking multiple logical servers and running them on a single physical server," Robben said. "We're averaging 20 virtual servers per blade. We can run so many virtualized systems on one blade because most systems are only running at about 5% of their potential. With that kind of load we could potentially run 320 servers" off a single chassis fully loaded with blades.

Any virtualized server can be moved from one physical system to another without impacting services. That means that underutilized servers can be moved and their physical server can be put to sleep until it is needed again.

"Technology continues to provide us with the tools we need to make IT energy efficient," Robben said. "The RSF will demonstrate how using these methods, standards, and tools in an office environment can help a building reach net-zero."

Haselden Construction and RNL built the 222,000 square-foot Research Support Facility building, which is designed to be a model for sustainable, high-performance building design, and provides DOE-owned work space for administrative staff occupying leased space in the nearby Denver West Office Park. The RSF was designed by RNL. Stantec Consulting served as the project's engineering consultant.

— Bill Scanlon (April 14, 2010)

SUSTAINABLE SOLUTIONS ABUNDANT IN NEW OFFICES

More than 19,000 linear feet of wood from trees killed by bark beetles was used to decorate the lobby of the new RSF. The curves and tilts in the wall make it a work of art.
Photo from NREL/PIX 17404

When it comes to designing an interior decorative feature for one of the most energy efficient office buildings in the world, very few would consider bringing in a beetle to do the job. But that's what happened at the U.S. Department of Energy's (DOE) Research Support Facility (RSF) located on the National Renewable Energy Laboratory (NREL) campus.

In June 2010, the RSF will become home to more than 800 workers from DOE and NREL and building visitors will be greeted with a soaring, two-story high wall entirely covered with wood harvested from the bark beetle infestation that has killed millions of pine trees in the Western United States.

But, the use of beetle kill wood is just one example of the resources being leveraged to make the RSF a model for sustainability and one more step toward NREL's goal to be a net-zero energy campus.

"The designers specifically looked for regional materials that allowed for creative expression within the RSF." – Philip Macey

Beetles Bring Destruction and Beauty

The swath of devastation brought about by the little black bark beetles began in Colorado in the mid-1990s. Since then, bark beetles have killed pine trees on more than 3.5 million acres in Colorado. The beetle invasion also plagues pine forests from Wyoming to South Dakota.

But, for the architects and designers working on the RSF, the bark beetle infestation meant an abundant source of wood close to the construction site that fit numerous project constraints.

"The designers specifically looked for regional materials that allowed for creative expression within the RSF and were within the budget of this project," Philip Macey, RSF project manager for Haselden Construction, said.

Harvested within 500 miles of the RSF, the 19,000 linear feet of beetle kill wood covers an entire side of the RSF atrium. But this is no ordinary wall. As it climbs through the lobby space, the wall tilts in and out giving it a 3-D look all its own. Architectural firm RNL "designed it as a wood wall," Macey said. "But the subcontractors made a piece of art. It's arguably the best wood working that I've ever seen on a project."

Although the unique wood graining found in beetle kill pine brings a slice of Rocky Mountain beauty indoors, it also brings another real concern—fire danger.

"The wood was a point of apprehension from a safety perspective," Macey said. "DOE gives safety a high priority. Contractors had to prove to DOE that the wood could be fire treated and finished in an environmentally friendly way."

Contractors for the RSF went so far as to take a sample of the finished, fire-treated wood to the lab to have it tested with a live flame. They even videotaped the process to demonstrate the safety of the pine wall.

To make the wall even more fire resistant, the bottom four feet is covered in a rugged cement board. "What you see isn't just beautiful, but also very safe," Macey said. "The bottom four feet is essentially non-flammable. If there was ever a bad day and a fire started along the bottom of the wall or the floor, the chances it would ignite the wall are practically zero."

Beetle Kill Isn't the Only Fashion Statement

Other unique and environmentally friendly décor can be found throughout the RSF. "The RSF reception desk top is created from a visually surprising material," Macey said. "It's made from sunflower seeds that come from commercial production. The composited sunflower seeds are bonded together in an environmentally friendly clear adhesive."

According to Macey, the effect is sure to raise eyebrows and garner curious stares since it doesn't really look like wood, it somewhat resembles stone, but then again it doesn't look like any stone you've ever seen.

The flooring in the RSF lobby is stone, also a made from commercial scraps—granite. The large flooring tiles are made from waste granite chips that are the leftovers from fabricating big slabs of granite. The chips are fused together with ceramics creating a sturdy tile.

"It again speaks to a deep respect for the planet in using waste materials in innovative ways that we used to previously just send to a landfill," Macey said.

Not the First Time NREL has Used Beetle Kill

In 2008, NREL brought online its Renewable Fuels Heat Plant (RFHP). "The RFHP is a wood burning boiler that we get comfort heat from using chipped beetle kill wood, and it has the potential to reduce NREL's natural gas usage by 75%," NREL Director of Sustainability Frank Rukavina said.

This plant provides heat to more than 500,000 square feet of laboratory and office space through NREL's district heating system. In 2009-2010, the RFHP burned 850 tons of wood chips displacing 10 billion BTUs of natural gas. And, equipment upgrades this summer will substantially increase wood consumption.

"It again speaks to a deep respect for the planet in using waste materials in innovative ways that we used to previously just send to a landfill." – Philip Macey

The wood chips, which are about half of the cost of natural gas, are sorted for over-sized chips and then automatically fed into the furnace's combustion chamber. Combustion is controlled using an oxygen sensor to ensure optimum air-fuel ratio and temperatures exceed 1,700° F. The system produces less than 1% ash by volume and the ash is recycled by a landscape mulch company. The RFHP's efficient combustion process allows the facility to meet state requirements while burning biomass to reduce the NREL's carbon footprint.

RSF Highlights Sustainable NREL Efforts

"NREL's sustainability focus is how do we operate to be as effective as possible with the smallest footprint and impact on future generations?" Rukavina noted.

According to Rukavina, characteristics of a sustainable campus include minimizing use of resources including energy, materials, and water—along with balancing environmental, economic, and human impacts. In the case of the RSF, the focus also is on attaining LEED Platinum status from the U.S. Green Building Council.

"Our goal is to have the RSF function as a LEED Platinum net-zero energy building, with our long-term goal being a net-zero energy laboratory," Rukavina said. "We are doing that by buying and installing as much renewable energy as possible as well as through power purchase agreements."Net-zero energy means a building—or campus—makes as much energy from renewable resources as it consumes in a year."

The RSF will go a long way in helping NREL boost the amount of renewable energy generators on its South Table Mountain campus.

"We currently have photovoltaics installed on the mesa top and buildings known as the S&TF (Science & Technology Facility) and SERF (Solar Energy Research Facility). But RSF 1 and RSF 2 will have PV on the roof tops along with a visitor parking lot and parking garage covered in PV," Rukavina said. "Our current PV and planned construction of PV means that NREL's South Table Mountain campus will get 32% of our energy usage from the sun."

NREL is also using wind to offset energy use at its National Wind Technology Center (NWTC). The NWTC is already at net-zero energy, with wind turbines and a PV array currently producing all of the NWTC's power needs.

Other sustainability highlights in the RSF include:

- The RSF will use 50% less energy than if it were built to current commercial codes.
- The RSF will increase NREL's campus square footage by 60% but increase energy use by a mere 6%, with the intent to offset that demand with PV cells on the building and adjacent parking lot.
- Twenty percent of the material in the building will be made from recycled content. This includes the aggregate in the foundations and the concreted slabs, which came from the demolition of Denver's Stapleton airport. In addition, recycled natural gas pipes are used as support columns and recycled translucent plastic panels are part of the interior office spaces.
- Countertops in lunch areas and coffee areas are covered with rolled linoleum made from natural materials like jute and cork that have been pressed together.
- Approximately 42 miles of radiant piping runs through all floors of the building, using water for heating and cooling instead of forced air.
- Approximately 75% of the construction waste will be recycled by the time the building is complete.

The RSF was designed by RNL and built by Haselden Construction, under a design-build, integrated project delivery method. Stantec served as sustainable design consultant and mechanical/electrical engineer.

— Heather Lammers (May 24, 2010)

NEW LOW-ENERGY BUILDING A LANDSCAPE LEADER, TOO

Newly planted irises reach for the sun in the courtyard of the new Research Support Facility located on the NREL campus. NREL is part of a team helping to develop a national rating system for landscaping projects. *Photo from NREL/PIX 17515*

Hitting rocky soil while digging for a new building wouldn't cause many contractors to think twice. The rocks would be hauled to a landfill and forgotten. But, when you are excavating for one of the world's greenest buildings, rocks suddenly become a resource. And, clever landscape designers turn that resource into gabion walls as part of an overall landscaping plan that is as environmentally friendly as the building itself. In fact, the landscaping for the U.S. Department of Energy's (DOE) Research Support Facility (RSF) located on the NREL campus already has been selected to help shape a rating system that will be the nation's first for green landscape design, construction, and maintenance.

"We were able to mix really nice landscaping features with the walls and used a lot less energy." – Frank Rukavina

Rock Walls—a Cornerstone for Landscaping

Gabion walls—essentially wire cages filled with rocks—were developed in the Middle Ages, and in modern times are used to provide landscape retention without the use of mined or quarried stone. By using onsite material, such as the rocks found at the RSF site, the walls greatly reduce the need for other materials and eliminate transportation costs and associated fuel consumption.

"Gabion walls provided the foundation for starting our landscaping," NREL Director of Sustainability Frank Rukavina said. "We were able to mix really nice landscaping features with the walls and used a lot less energy than if we'd used a high-energy material like concrete."

"We looked for a retaining wall solution that would use the on-site materials," Brian Nicholson, landscape designer for RNL, added. "Gabions are used in the Southwest, so we found a company that makes the wire baskets from 100% recycled steel. We ended up harvesting 1,000 cubic yards of rock that would have normally been headed to the landfill and putting it to use as retaining walls."

As with the RSF building, the use of recycled materials also is found throughout the landscaping plan. Recycled concrete is used as road base and as a drainage layer under the parking lot, sidewalks, and pavers. Recycled concrete building material is used as the decorative rock skirt surrounding the RSF. The wood mulch is composed of tree trimmings, paint-free lumber, and residential yard waste. Recycled glass is used in the storm water catch basins as to slow flow.

Water-Sipping Plants Provide Color, Texture

"Water flows off the roof, into the downspout and then into catch basins lined with crushed glass." Nicholson said. "The water running through those troughs waters the trees and plants as it goes. In Colorado we can't capture water, but we can use it as it flows through the site."

Stormwater provides supplemental water to the RSF vegetation, but it can't be the only source of water for plants blossoming during Colorado's dry summers.

"Because we are in an arid climate, we have to look at using water as a resource," Nicholson said. "We looked at what we could do to slow down the water on the site and then we wanted to find the most water-efficient irrigation system possible."

The team found an irrigation controller that collects data from weather stations in the region. Using that data, the controller calculates how much water loss there has been from sun and wind and then the controller figures out how much supplemental watering is needed. By using this type of "smart" controller, the landscape team believes a 30% reduction in water use can be achieved.

As the design works down to the plants, trees, and shrubs, Colorado native and adaptive plants are being tapped to provide color and texture to the outside spaces at RSF. The NREL plant palette provides food and habitat for local wildlife while eliminating the need for mowing and applying chemicals such as pesticides and herbicides. The use of native species also promotes biodiversity on the NREL campus.

The plants are zoned according to climate, which means a different plant palette is used on the north versus the south side of the building. Native prairies grasses and rabbit brush are being used to transition the native plants found on the surrounding mesa to the adaptive plants used in RSF courtyards.

"We wanted to also provide a sensory experience with lavender, Russian sage, and other flowering perennials, including roses, all of which are very close to the native plants," Nicholson said.

RSF Pilots New Landscape Rating System

The RSF was selected as one of 150 other projects from 34 states as part of an international pilot project to evaluate the new Sustainable Sites Initiative (SITES), a rating system for sustainable landscaping.

SITES is a partnership between the American Society of Landscape Architects (ASLA), the Lady Bird Johnson Wildflower Center at The University of Texas at Austin, and the United States Botanic Garden. "One area we will be judged on is our ability to cut back on the average water use for landscaping in this area of the country," Rukavina said. "It will be an exciting challenge to be part of the newly formed program."

"It will be an exciting challenge to be part of the newly formed program." – Frank Rukavina

RSF joins other projects that include academic and corporate campuses, public parks with hundreds of acres, transportation corridors and private residences of less than one acre. SITES will use feedback from this and the other selected projects during the pilot phase to revise the final rating system and reference guide by early 2013. The U.S. Green Building Council plans to incorporate the guidelines and performance benchmarks into future versions of its LEED Green Building Rating System.

"We are really looking forward to helping shape the SITES rating system and provide feedback on our design, which centers around an ultra-efficient building and helps to reinforce what's going on inside the RSF," Nicholson said.

The RSF was designed by RNL and built by Haselden Construction, under a design-build, integrated project delivery method. Stantec served as sustainable design consultant and mechanical/electrical engineer.

— Heather Lammers (July 1, 2010)

NREL SOLAR TECHNOLOGY WILL WARM AIR AT 'HOME'

NREL's Craig Christensen and Chuck Kutscher stand next to a wall at the RSF that uses their award-winning transpired air collector technology. *Photo by Dennis Schroeder, NREL/PIX 17659*

Sometimes the way back home isn't straightforward. But once you find your way, you know you'll be welcomed with open arms. Transpired solar air collector technology, developed at the U.S. Department of Energy's National Renewable Energy Laboratory (NREL) in the 1990s, recently "found its way home" and is now an integral part of the comfort heating system of the new Research Support Facility (RSF).

"The solar collector is really important to the building." Philip Macey, RSF project manager for Haselden Construction, said. "It's the way we get free pre-heated warmed air."

Commercial and industrial buildings in the United States have a specific need when it comes to ventilation systems and heating. Although having fresh air inside a building always is desirable, drawing fresh air into a building on a crisp winter day can mean huge amounts of energy is required to heat that air to make it feel comfortable. In fact, 13% of the energy used in the United States goes to heating residential and commercial buildings.

Air Collectors Are Simple, Elegant Solutions

By using a dark-colored, perforated metal plate on the south side of a building, three NREL scientists have perfected a way for buildings to pre-heat the air coming in, reducing the need for additional heating energy.

The basic concept of a transpired solar air collector is for the perforated plate to be warmed by the sunlight hitting the south side of a building. A fan added to the building's existing ventilation system slowly draws warmed ventilation air into the building through the plate. The solar energy absorbed by the dark plate is transferred to the air flowing through it. This process can efficiently preheat the air going into a building like the RSF by as much as 40°F.

"We knew we needed to create pre-warmed air for the RSF and we found a product and kind of had to chuckle when we realized this was going to be perfect—the technology was made by NREL," Macey said. "That's one of those moments when you realized you are obviously going in the right direction when things line up like this."

Unlike previous technologies for flat panel solar collectors, NREL's transpired solar collector does not require glass. Glass covers were typically required to prevent heat loss to the air and could be expensive and reflect some of the solar radiation needed to heat the air. Design refinements identified by NREL research and computer modeling significantly boosted the amount of available solar energy that the transpired solar collector can capture.

"These tend to be very efficient solar collectors," Chuck Kutscher, principal engineer and group manager of the Thermal Systems Group, said. "These collectors can get 75-80% of the energy of the sunlight striking the collector absorbed into the ventilation air." Kutscher was one of the researchers who originally worked on the transpired solar collector for NREL. His research was the subject of his Ph.D. thesis and also provided thesis work for NREL's Craig Christensen and former employee Keith Gawlik.

The developments that NREL brought to this technology were so exciting that the transpired solar collector was recognized by Popular Science and Research and Development magazines as one of the most innovative technology developments of the year.

"Researching the transpired solar collector was a really fun project for us for a couple of reasons," Kutscher said. "We did a wide breadth of research, we covered a lot of different areas, and it was a much more comprehensive study of the technology than we would typically do. It was a totally new concept and we had to develop new equations to understand how it would work. Yet it is a simple and elegant technology that is inexpensive and highly efficient."

Not the First Solar Collector at NREL

"We were gratified to find out the transpired solar collector would be used on the RSF," Kutscher said. "But it's actually the second to be installed at NREL."

In the 1990s, NREL placed a transpired solar collector on its waste handling facility. Because the facility stores waste chemicals, it uses expensive electric resistance heating and requires a large amount of ventilation.

"The Waste Handling Facility was an ideal application," Kutscher said. "We put instruments on that wall, and then studied and reported the results as part of an International Energy Agency task. So it's the second collector at NREL, but the first one to be on an office building."

The RSF was designed by RNL and built by Haselden Construction, under a design-build, integrated project delivery method. Stantec served as sustainable design consultant and mechanical/electrical engineer.

— Heather Lammers (July 30, 2010)

SOLAR SYSTEM TOPS OFF EFFICIENT NREL BUILDING

More than 1,800 solar panels are being installed on the roof of the RSF to help the building generate as much electricity as it uses. *Photo by Dennis Schroeder, NREL/PIX 17848*

When a new office building is constructed on the campus of the U.S. Department of Energy's (DOE) National Renewable Energy Laboratory (NREL), it only makes sense that much of its energy should come from solar power.

The Research Support Facility (RSF) embodies the ideals of energy efficiency, renewable energy, and sustainability that have been advocated by NREL researchers for more than 30 years. While the RSF adds 222,000 square feet of office space to the NREL campus, the building's energy use only increases NREL's overall consumption by 6%. It's this remarkable achievement in ultra energy efficiency and the use of renewable energy that makes the building a shining example of NREL's mission and desire to "walk the talk."

That's a Lot of PV

To help the RSF achieve its goal to produce as much energy on-site as it uses, a 1.6 megawatt (MW) photovoltaic (PV) system is being installed on the NREL campus. The roof system comprises more than 1,800 panels soaking in 240 watts each of the Colorado sun. But the roof alone doesn't zero out the energy equation. Additional PV will be installed on the RSF expansion (currently under construction) and on a nearby garage and parking lot.

"It expands energy reduction and environmental performance requirements for federal agencies so that they will take the lead in creating a clean energy economy." – Frank Rukavina

The PV panels glistening on the roof are the "icing" on many other layers of energy efficiency and sustainable technologies that already make the RSF a model for super energy efficient office buildings. It's these layers—the siting of the building on the land, day lighting in office spaces, energy efficient work stations, and use of recycled materials—that also make the building a candidate for the U.S. Green Building Council's Leadership in Energy and Environmental Design (LEED) Platinum Certification.

Installing 1.6 MW of PV factors into the overall cost of the building and could have affected the other energy saving features at the RSF. To mitigate that up-front cost, DOE turned to a conventional option—the power purchase agreement (PPA).

Energy Partnerships Equal a Win-win

"Third-party financing agreements, such as a PPA, are a popular way to infuse renewable energy generating products into the marketplace without requiring the owner to absorb the system's first costs," said Randy Dins, federal project director for DOE's Golden Office.

Through a competitive selection, DOE and NREL partnered with Sun Edison and successfully responded to a Request for Proposal under Xcel Energy's Solar Rewards Program. Xcel Energy is required by the State of Colorado to generate a certain percentage of power from renewables. The utility was looking for new renewable energy installations from which the renewable energy credits (RECs) could be purchased and that made a PPA a win-win solution for everyone.

Under the PPA, Sun Edison finances the first cost of the RSF PV system. Then Sun Edison sells the RECs generated from the system to Xcel Energy. This investment also generates a monthly revenue stream from DOE to Sun Edison based on a formula of kilowatts per hour generated; the agreement lasts for 20 years. Dins added, "It's the confluence of these two revenue streams that makes the business case palatable for Sun Edison and its investors."

"It's a win for DOE and NREL because the federal government does not incur the upfront costs of purchasing the PV system," Dins said. "We can accurately budget for a fixed price for solar electricity for a fixed period of time."

The PV system is constructed, owned and serviced by Sun Edison, but NREL has the opportunity to purchase the system at the end of the agreement.

Sustainable Before It Was 'Cool'

A financial boon to the taxpayers and NREL's desire to showcase sustainability are just a couple of reasons that PV is being used to generate power for the RSF. A third motivator is Executive Order 13514, "Federal Leadership in Environmental, Energy, and Economic Performance," from the President of the United States to all federal agencies.

"The new executive order is often referred to as the sustainability order," said NREL Director of Sustainability Frank Rukavina. "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 addresses:

- Increasing energy efficiency in federal buildings
- Measuring, reporting, and reducing green house gas (GHG) emissions
- Designing, constructing, maintaining, and operating high-performance sustainable buildings
- Strengthening the vitality and livability of communities in which federal facilities are located
- Conserving water resources, eliminating waste, recycling, and preventing pollution.

NREL's sustainability program has been in place for more than a decade. "To borrow from country music vernacular, NREL was sustainable before sustainability was cool," added Rukavina.

"A standard sustainability model is to meet today's needs without compromising future generations. Because of our mission, we go a step beyond that. At NREL we're meeting today's needs for the benefit of future generations." – Frank Rukavina

What is new to the Sustainable NREL Program is that the team is currently developing goals for GHG emissions for 2020. "Putting PV on the RSF helps NREL meet our green house goals by reducing the amount of power that must be bought from the local utility and by lowering our transmission and distribution reporting requirements," Rukavina said.

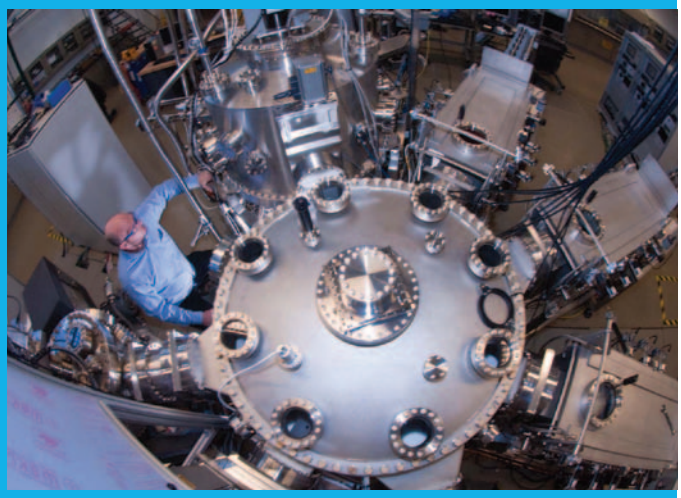
He also noted that by the time that the RSF expansion is complete along with the garage and parking lot, NREL will be producing 32% of all of its energy for the entire South Table Mountain Campus (not just the RSF) from PV.

"A standard sustainability model is to meet today's needs without compromising future generations," Rukavina said. "Because of our mission, we go a step beyond that. At NREL we're meeting today's needs for the benefit of future generations."

The RSF was designed by RNL and built by Haselden Construction, under a design-build, integrated project delivery method. Stantec served as sustainable design consultant and mechanical/electrical engineer.

— *Heather Lammers (September 29, 2010)*

NREL'S NEW ROBOTS SCRUTINIZE SOLAR CELLS



NREL engineer John Scharf sits at the hub of the robot in the Process Development and Integration Laboratory that works with solar cells using Copper Indium Gallium diSelenide (CIGS). The NREL researchers like to equate the robot's capabilities to a jukebox, shuffling in and out tools to grow and analyze solar cells. *Photo by Patrick Corkery, NREL/PIX 17161*

The race to build a better solar cell is looping through the National Renewable Energy Laboratory where new robots are fabricating thin-film cells and analyzing glitches faster and with more precision than ever before.

How much faster? The robot working with silicon can build a semi-conductor on a six-inch-square plate of glass, plastic or flexible metal in about 35 minutes. It pivots and dishes like a point guard, sifts like a master chef, analyzes like a forensics expert, and does it all while maintaining a vacuum seal on the entire process.

Simultaneously, it can analyze glitches and measure light absorption, while preparing the next half-dozen plates.

"It used to require us to go to, let's see, one … two … three … four … five labs to do the same thing," NREL scientist Ingrid Repins said.

And the silicon robot is one of just six such robots in six bays in NREL's Process Development and Integration Laboratory (PDIL), the place where industry is starting to turn to test their newest cells.

The bay that uses silicon as the semiconductor for solar cells was the first to begin operating and holds all the speed and performance records so far.

Next to go on line were bays devoted to stand-alone characterization, integrated characterization, and atmospheric processing.

The latest bay to start operating is the one that uses Copper Indium Gallium diSelenide (CIGS) as the semi-conductor in solar cells. Still being installed is the final bay, which will work with cadmium-telluride cells.

In each bay, the central transfer robot is the hub, operating like a jukebox, delivering the plate to chambers that can deposit micron-thin layers of chemicals to build the semi-conductors, or test and measure the growth of the crystals that make the cells.

Solar Companies Can Test Samples, Use Their Own Tools

Solar companies will be able to hook their own tools to the central robot and discover how their newest formulas compare. A vacuum transport tool can take the sample plates to the different, yet compatible, bays to see how an unusual process might bolster the power of a cell.

Solar companies know how to make solar cells in a dozen different ways—as shingles, as windows, as fanny packs, as attachments to space vehicles—but they constantly are searching for ways to lower costs and gain efficiency.

"The whole goal is dollars per watt," Repins said.

President Obama has set a goal that solar energy become cost-competitive with coal and other fossil fuels by 2015.

"The gap is closing," Repins said. "We're getting closer. Already, First Solar is saying that for a large installation in southern California where electricity prices are relatively high, they are at parity now."

NREL scientists are hoping their PDIL facility will help industry close that gap sooner by bringing lab-like precision to industrial-type processes.

R&D Agreement with Climax Molybdenum

For example, in February 2010, NREL signed a cooperative agreement with Climax Molybdenum of Empire, Colorado, which wants the lab to help test a new process of building sodium into the molybdenum layer of solar cells and then sputtering that sodium onto the CIGS layer.

Traditionally, the sodium leaches into the solar cell from the glass plate, but that's not really a good way to do it because there is little quality-control in the glass-making procedure, Repins said.

For Climax Molybdenum, NREL will measure how well the company uses its tools to sputter the sodium from the molybdenum into the semiconductor, and how precisely it gets there.

"The assumption is that there will be more control getting sodium from the molybdenum than from the glass," she said.

If it's perfected, that's another step toward lowering the cost of solar energy.

Solar cells are like mini-batteries, with three layers of thin films representing the two terminals and the current in between. The three layers together are about one-seventh the thickness of a human hair.

The middle layer, which absorbs the sun's rays and acts as the current, is where the action is.

Some companies are sure CIGS will emerge as the best semi-conductor; others pin their hopes on cadmium telluride or the venerable silicon.

World Record; Now, How to Transfer It to Industry?

In 2008, NREL set a world record for the efficiency of a thin-film solar cell, when its CIGS cell was able to convert to electricity 20% of the energy it absorbed from the sun. The record for a cadmium-telluride cell is 16.8%.

Today's roof-top solar panels typically are able to convert about 10-11% of the sun's energy, although there is a large range of between 8% and 20% efficiency.

Now, the challenge is to be able to layer a film of CIGS on commercial-sized solar panels without dropping down much from that 20% pinnacle.

Repins envisions that with the 20% formula as the template, in a few years companies can roll out kilometer-long sheets of solar cells and still achieve 16% efficiency—even as they strive to use the least expensive materials and put an emphasis on speed.

The difference between 11% and 16% is huge, because the cost savings multiply on each other, she said.

It means solar panels can be smaller and generate the same amount of energy, and that means lower materials costs, lower factory costs, and lower installation costs.

Getting there—to reach a 16% efficiency level while making miles of thin-film cells a day—is the goal of the one-of-a-kind testing facility at NREL.

Sensors Can Read How Cells Are Growing

In the brightly lit PDIL on NREL's campus in Golden, Colorado, scientists simulate the processes industry will use. The goal is to answer previously unanswerable research questions, while controlling and characterizing the surfaces of the cells, developing new techniques and devising new structures.

"The old way we used to do things, each layer required a different machine," Repins said. "We would take out the substrate and put it into another machine." Each time the plate was removed, humidity could weaken the cell and there were issues of cleanliness and contamination.

Now, the goal is a process that is seamless, spotless, and transparent.

In each bay, lasers shine light on the cells and sensors can read how the cells are growing.

PDIL's ultra-high-vacuum environment lets researchers study the role of impurities and defects, said NREL senior scientist Miguel Contreras. "We can do basic R&D at the material level. We can also develop analytical tools on site to test new plates and to test for quality."

What combination of heat, metals, chemicals, and time can grow the crystals to form the perfect cell? At one step excess copper is needed; at another, just enough sodium needs to leach into the middle layer.

The goal of all the depositing, analyzing, and measuring is to be able to tell industrial partners why the cell isn't growing as well as it should and what can be done about it.

It means solar panels can be smaller and generate the same amount of energy, and that means lower materials costs, lower factory costs, and lower installation costs.

"We do a post-mortem," Repins said. For example, "'We got 14% efficiency with these materials, why are you only getting 12%?'"

Companies want to know how they can turn the knobs to get the ultimate performance out of the cells. "This helps take that step toward telling them what to do in the process," she said. "We can tell them, 'this is what the sodium content should look like,' for example. It's one more clue."

Bill Nemeth, a scientist in NREL's PDIL facility, says he doesn't have to wear a lab coat at work "because everything revolves around maintaining a vacuum," and the researchers never come into direct contact with semi-conductors.

"We have the capability that no other place can duplicate," Nemeth added. "This encourages cooperation."

Goal: Fewer Impurities, Better Efficiency, Better Yield

The CIGS PDIL tool also was designed to do basic research and development on materials. The ultra-high vacuum environment allows scientists to study the role of impurities and defects, as well as what happens when the metals are deposited at the fast rate demanded by industry. That knowledge will help researchers develop analytical tools for quality control and to test for new plate materials.

"The system was designed to allow us to do things we could not do before, such as get a better look at impurities and the quality of materials, the different layers that compose the CIGS cell," Contreras said. "It's helping us understand better what is limiting our efficiencies, as well as learning how to improve industrial productivity.

"This gives us more insight into the physics and materials science of CIGS-based solar cells," Contreras added. The fundamental research will "lead to better solar cell efficiency, process control, improved uniformity, and improved yield."

— Bill Scanlon (March 22, 2010)

CHEAPER, BETTER SOLAR CELL IS FULL OF HOLES

A silver wafer reflects the face of NREL research scientist Hao-Chih Yuan, before the wafer is washed with a mix of acids. The acids etch holes, absorbing light and turning the wafer black.
Photo by Dennis Schroeder, NREL/PIX 17852

A new low-cost etching technique developed at the U.S. Department of Energy's National Renewable Energy Laboratory (NREL) can put a trillion holes in a silicon wafer the size of a compact disc.

As the tiny holes deepen, they make the silvery-gray silicon appear darker and darker until it becomes almost pure black and able to absorb nearly all colors of light the sun throws at it.

At room temperature, the black silicon wafer can be made in about three minutes. At 100°F, it can be made in less than a minute.

The breakthrough by NREL scientists likely will lead to lower-cost solar cells that are nonetheless more efficient than the ones used on rooftops and in solar arrays today.

R&D Magazine awarded the NREL team one of its R&D 100 awards for Black Silicon Nanocatalytic Wet-Chemical Etch in 2010. Called "the Oscars of Invention," the R&D 100 awards recognize the most significant scientific breakthroughs of the year.

Howard Branz, the principal investigator for the project, said his team got interested in late 2006 after he heard a talk by a scientist from the Technical University of Munich. The scientist described how his team had created black silicon by laying down a thin gold layer using a vacuum deposition technique. Quickly, NREL senior scientist Qi Wang and senior engineer Scott Ward gave it a try.

"We always ride on the shoulders of others," Branz said. "We started by replicating the Munich experiment."

Packets of Light, Golden Holes

Think of light as coming in little packets. Each packet is a photon, which potentially can be changed into an electron for solar energy. If the photon bounces off the surface of a solar cell, that's energy lost. Some of the light normally bounces off when it hits an object, but a 'black silicon' wafer will absorb all the light that hits it.

The human eye perceives the wafer as black because almost no sunlight reflects back to the retina. And that is because the trillion holes in the wafer's surface do a much better job of absorbing the wavelengths of light than a solid surface does.

It's roughly the same reason that ceiling tiles with holes in them absorb sound better than ceiling tiles without holes. Scientists by the late 19th century had already done experiments to show that what works for absorbing sound also works for absorbing light.

The team from Munich used evaporation techniques that require expensive vacuum pumps to lay down a very thin layer of gold, perhaps 10 atoms thick, Branz said. When a mixture of hydrogen peroxide and hydrofluoric acid was poured on the thin gold layer, nanoparticles of gold bored into the smooth surface of the wafer, making billions of holes.

The NREL team knew right away that the vacuum pumps and evaporative equipment needed to deposit the gold were too costly to become commercially viable.

NREL's Goal: Simplify the Process, Lower the Cost

"Our thinking was that if the goal is to make it cheaper, we want to avoid vacuum deposition completely," Branz said.

In a string of outside-the-box insights combined with some serendipity, Branz and colleagues Scott Ward, Vern Yost, and Anna Duda greatly simplified that process.

Rather than laying the gold with vacuums and pumps, why not just spray it on? Ward suggested.

Rather than layering the gold and then adding the acidic mixture, why not mix it all together from the outset? Dada suggested.

In combination, those two suggestions yielded even better results.

The scientists put a suspended solution of gold nanoparticles, called colloidal gold, on the silicon surface, and let the water evaporate overnight to leave just the gold, which then etched into the wafer. The wafer turned nearly as black as with the evaporated gold.

A Lucky Accident

And then, as is often the case with important scientific breakthroughs, serendipity entered.

NREL technician and chemist Vern Yost noticed after a time that he wasn't getting such good results, and assumed it was because an old batch of colloidal nanoparticles had somehow clumped together. So he tried to separate them with aqua regia, a highly corrosive mixture of nitric acid and hydrochloric acid. Aqua regia is Latin for regal water, and refers to a liquid that can dissolve the royal metals such as silver and gold.

The aqua regia treatment got the process working better than ever, and a little investigation found that the aqua regia had reacted with the gold to form a solution of chloroauric acid.

Voila! Chloroauric acid is less expensive than colloidal gold and actually is the chemical precursor that industry uses to make colloidal gold.

Could the same black-silicon etching result be achieved by substituting the inexpensive chloroauric acid for costly colloidal gold, and then mixing it as before with hydrogen peroxide and hydrofluoric acid? Yost and Branz wondered.

Yes, it worked. "Chloroauric acid is much cheaper than colloidal gold," Branz said. "In essence, by skipping a few steps, they were able to make gold nanoparticles from the chloroauric acid at the same time as they were etching holes into the silicon with the gold they had made."

Once the concept was understood and the mix of materials solved, the actual making of a black silicon wafer became quite simple.

"You take a beaker, put a silicon wafer in, pour in the chloroauric acid, pour in the hydrofluoric acid and hydrogen peroxide, and wait," Branz said.

As little as 20 seconds later, the silvery silicon wafer turns black.

"Our method gives a blacker silicon and would replace an expensive vacuum deposition system with a single, cheap, wet-etch step," Branz said.

Cheaper Process Also Makes a Better Material

They tested their black silicon and found that the much-lower-cost recipe containing chloroauric acid quickly reduced the unwanted reflection to less than 2%. The more costly approach using conventional silicon nitride anti-reflection layers stalled out at about 3-7% reflection. As an added bonus, black silicon prevents reflection of low-angle morning and afternoon sunlight far better than the conventional antireflection layer.

To understand why their inexpensive approach worked so well, the team brought in NREL optics expert and senior scientist Paul Stradins and NREL electron microscopists Bobby To and Kim Jones. The trio found that the black silicon squelched reflection so well because the holes were smaller in diameter than the solar wavelengths.

That's crucial, because if the holes were as big as these light wavelengths, the light rays would recognize a "sharp interface," just as they would if they encountered a stainless steel counter. Any sharp interface causes the light from the sun to reflect from the surface before it can enter the solar cell and be changed into electricity.

Another reason the sunlight never feels a sharp interface when it hits the silicon is that all those trillions of holes are bored to different depths, because of the randomness of the etch rate of each nanoparticle. Because of the variable depths of the holes, the rays very gradually move from air to silicon. The light never encounters an abrupt change from air to solid surface, so it doesn't bounce off the wafer.

But Will it Work in a Solar Cell?

Next was the formidable challenge of using the technology to make a workable solar cell.

Hao-Chi Yuan, a postdoctoral researcher, was added to the team to figure out how best to work this new kind of silicon into a solar cell, make the solar cells and determine the strengths and weaknesses of this new kind of cell. Yuan, along with Yost, Branz, and NREL engineer Matthew Page worked to determine the ideal depths and diameters of the holes if the goal is to turn photons into electrons.

To keep a solar cell at or near the record 16.8% efficiency rate they'd achieved, they realized the holes had to adhere to the "Goldilocks" principle. The holes must be "just right": deep enough to block reflections, but not so deep that they spoil the solar cell.

Specifically, they found the best results occurred when the trillions of holes were on average about 500 nanometers or half a micron deep, and their diameters just a little bit narrower than the smallest wavelength of light. (How small? The diameter of 40 holes, added together, would be the thickness of a human hair.)

If the holes were much deeper, the solar cell would have trouble pulling all of the solar-generated electrons out. Efficiencies would be so low no one would want to put the cells on their roof.

Happily, that combination of depth and diameter can be achieved with a 3-minute wet-etch soak at room temperature.

Industry's Acutely Interested

Though they will be cheaper to manufacture, NREL's best solar cells are still a few tenths of a percent less efficient than the conventional type. But the low reflection means a jump in photovoltaic efficiency of at least 1 percentage point could be achieved. The team is still working to wrest a bit more efficiency from the black silicon cells. The solar cell world has become a game of inches, Branz said, so "even half a percentage point bump in efficiency at reduced cost would be huge."

Solar cell companies are interested in licensing the technology from NREL.

"We've had several companies come visit here to learn more about it," Chris Harris, associate director of licensing in NREL's commercialization and technology transfer division, said. "The interest is high.

"This is certainly a significant advantage in an industry where everyone is competing for market share and the cost per watt is a key selling feature," Harris added. "Black silicon provides an added benefit on top of any other improvements in efficiency a company can get."

Al Goodrich, a senior cost analyst for NREL's PV manufacturing division, found that making the black silicon wafers requires about a third less energy than adding the conventional anti-reflection layer to the finished solar cell.

The one-step process also is a lot easier on the environment.

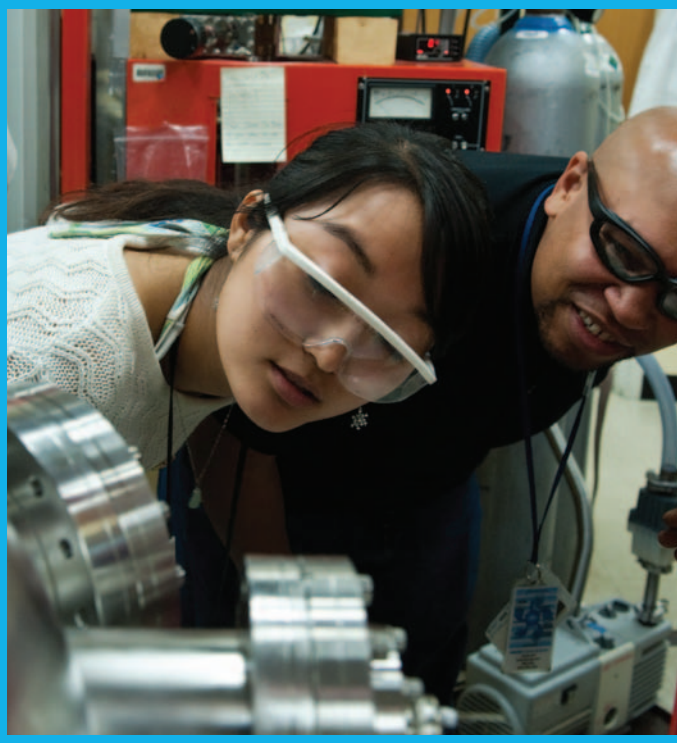
The technology would replace a process that uses dangerous silane gas, as well as cleaning gases such as nitrogen trifluoride, which has 17,000 times more punch than carbon dioxide in contributing to global warming. A switch to the black silicon wet etch technology would mean huge reductions in greenhouse gases, and improvements in the energy payback for resulting PV devices. It also reduces the capital costs of starting a factory line by about 10%, because it replaces several expensive vacuum vapor tools with a simple wet bath, Goodrich said.

NREL estimates that the black silicon can reduce processing costs by 4-8%, resulting in overall savings in manufacturing a solar cell of 1-3%.

"That's big," Goodrich added. "The people who are interested in this technology recognize that that difference is valuable real estate."

— Bill Scanlon (September 2, 2010)

NREL SOLAR SCIENTISTS EPITOMIZE TEAMWORK



NREL scientists Ki Ye and Joe Berry peer into the glass siding of a deposition instrument to view the latest results of an experiment with a new material. *Photo by Dennis Schroeder, NREL/PIX 18317*

A Colorado carpenter's son, an African American from Indiana, a post-doctoral researcher from Senegal, and a young woman from China are working together to solve one of the most important problems in solar-cell efficiency.

When they're not laughing with each other, or meeting with a group of 20 to share strategies, the foursome of scientists at the U.S. Department of Energy's (DOE) National Renewable Energy Laboratory (NREL) is trying to control semiconductors' band gaps to make solar cells less expensive and more efficient. And along the way they're attempting to solve fundamental scientific questions about the nature of new optoelectronic materials.

They're the new face of science—collaborative and diverse, living proof that the age of the solo scientist shouting "Eureka!" has been replaced in the 21st century by multi-disciplinary teams with complementary skills.

David Ginley, the son of a carpenter who grew up in suburban Denver near NREL's Golden, Colorado, campus, leads the team.

He is joined by Joe Berry, a senior scientist, who hails from Indiana; Yi Ke, a graduate student from China who is doing her doctoral dissertation work at Colorado School of Mines and is experimenting with materials in NREL's Pulse Laser Deposition (PLD) lab; and Paul Ndione, the postdoctoral researcher who oversees the PLD.

NREL Team Searching for Better Top Layer

Despite tremendous gains made in processing and developing solar cells, most arrays on individual rooftops or in grid-connected solar fields still operate well below the nearly 30% theoretical conversion efficiency possible for a single absorber device. There are many opportunities to significantly improve the existing efficiency, sometimes while reducing the cost.

That means any breakthrough to add a percentage point or two to that efficiency is huge, and a big step toward making clean solar energy competitive with fossil fuels.

Most solar photovoltaics are composed of an active semiconductor absorber that absorbs the light, a junction to turn photons into charge carriers, and contacts to efficiently remove the carriers without blocking light. To accomplish this, the top layer, the one facing the sun, needs to be both transparent and able to conduct electrons with very little loss.

It's that top layer that is the subject of the NREL team's work. Lately, solar manufacturers have been using indium tin oxide for that transparent conducting oxide layer. However, indium is difficult to extract and is very expensive. So, scientists are searching for alternatives.

Zinc oxide is a promising candidate because it is both highly transparent and conductive, as well as being much more abundant, Ke said. It is also about 1% of the cost of indium tin oxide.

Ginley and his team want to add magnesium to the zinc oxide to improve its transparency and then to dope the ZnMgO with another material to boost its conductivity, all in the name of developing more efficient and more cost-effective solar cells.

Searching for an Elusive Element

They're rarely without their deluxe-model periodic tables called up on their iPads or iPhones, searching for that elusive element that can best pair with zinc oxide and magnesium to boost the number of electrons that can conduct electricity. This impurity only need be present at less than 1% and should not significantly change the structure of the ZnMgO, but it adds the electronic carriers (doping) that are so critical to getting the photogenerated charges out of photovoltaic (PV) devices without significant loss.

In the transparent conductive semiconductors, most electrons (carriers) are in the conduction band, which means they're free to move and carry an electric current. The valance band in the material is a lower energy state in which carriers are not as mobile

Between the conduction band and the valence band is the energy gap, or band gap. It's this gap that is so intriguing to scientists, who think they can change the size of the band gap and simultaneously but independently control the electronic conductivity by doping with an appropriate impurity.

Ginley, Berry, and Ke are looking for the best doping agents to push electrons from the atoms in the ZnMgO material to the conduction band of the semiconductor, where they would be in a free electronic state and can help improve the efficiency and lower the cost of PV devices.

When the NREL team finds a promising material, as with the addition of magnesium, the resulting semiconductor layer has a larger band gap and would be more transparent. However, the materials that dope the ZnO do not add electronic carriers to the Mg substituted materials as well. So, this drives the search to look for new dopants.

"As you crank that gap open, you basically make something that is increasingly transparent," Berry said. "That means you can look through it, and for solar that's what you need.

"The fact that you can change the sensitivity to color at which this thing responds means you can make a detector or window that's selective for a particular wave length," Berry said. "Being able to tune that gap is useful in terms of optoelectronics."

The trick is to get the electrons moving without changing the fundamental nature of the semiconductor material.

"What's cool in this system, you can crank substantial amounts of magnesium into ZnO and it basically stays zinc oxide," Ginley said. "You change the electronic properties, but nothing else changes. It gets much more transparent and its electronic properties are better."

To explore these systems the group uses pulsed laser deposition. Inside the PLD chamber, they aim lasers at ceramic targets containing the chosen material, inducing tremendous energy in the atoms on the surface. What erupts is a plasma plume of partially ionized gas that knocks out some atoms and moves some of the electrons from those atoms to a higher energy state.

Imagine a Water Pistol and Some Mud

A bright light forms in the plasma plume, as those excited electrons release energy while relaxing back into a lower energy state.

Meantime, the fast-moving ions and atoms in the plasma stop abruptly when they run into the plate (or substrate) for the materials being deposited. They solidify into a thin film suitable for incorporation into a next generation of solar cells.

A down-to-earth analogy? "Imagine using a powerful water pistol to shoot at a mound of mud," Ke said. The resulting slurry "sprays on your beautiful clothes."

The water pistol is the laser, the clothes the substrate. The slurry of mud and water is akin to the plasma of atoms and ions, "except the plasma is much more gorgeous and interesting," Ke said.

"For a dopant we're looking at yttrium, scandium, and titanium as possible replacements for the conventional aluminum used to dope zinc oxide," Berry said. "In the magnesium-substituted materials, the question is can you restore the critical ability to dope by going to new dopants."

"If you can control the band gap, while controlling the doping, you can have a huge impact on organic photovoltaic, organic light emitting diodes, silicon, copper indium gallium, PV as a whole," Ginley said. "It would have an immense applicability." A number of other technologies such as flat panel displays and transparent electronics also depend on these same materials, Ginley said.

"We look for people with outstanding potential who have good communications skills and some indication of being able to be team players." – David Ginley

Forming a Scientific Team

Ginley says one if his major duties is hiring good people.

"You should hire people that scare you, they're so good," Ginley said. "People who are more likely to replace you than anything else. You shouldn't be timid when you hire. With grad students, we look for people with outstanding potential who have good communications skills and some indication of being able to be team players.

"The era of the lone scientist is over," Ginley said. "The kinds of problems we deal with, you just don't have the horsepower to do it by yourself. That's an increasing realization nationwide. Look at the Energy Frontier Research Centers. These new centers are a reflection of that. People are realizing that big problems take critical-mass teams.

"We don't know enough on our own," Ginley said. "It's that shared knowledge base and experience base that makes things go faster."

Joe Berry, the African American son of a professor, whom Ginley plucked from the National Institute of Standards and Technology (NIST) up the road in Boulder, concurred. The breadth of the solar cell project, together with the collegiality of the team, gave him a new enthusiasm for his work. "When I was at NIST, I was doing something by myself at a bench," he said. "But the number of people who cared about what I was doing, or who would be impacted by what I was doing, was equally as large."

From China with Aspirations

Ke got her undergraduate degree in China, majoring in electrical engineering. "I started feeling enthusiastic about solar cells" during her college years, she said. "They're things that can really help humans, can give utilities the power to solve a lot of problems. I figured out I could have a great career trying to move that along."

Ke applied to graduate school in the United States because "it has the best higher education in the world," she said. "I feel so fortunate to be here and working with NREL. They have the best scientists, the best mentors ever. Graduate work here is more challenging that in China."

The chance to work at NREL was the main reason she applied to the Colorado School of Mines, Ke said. "I got accepted at Stanford, but my advisor at Mines talked about the possibility of joining this group and working at NREL. He mentioned Dave, I looked him up and I came here for an interview. I was very lucky to get it."

Ke would be very content working in photovoltaics and renewable energy the rest of her career.

"I really want to be a person who understands the science and the R&D," she said. "But also someone who can apply the technology to industry so I can make some difference. To let people use this and become less dependent on fossil fuels."

She sees herself living part time in the United States, part time in China. "A greener future in both America and China can lead to cooperation between the two countries."

Senegal to France to Quebec to NREL

Ndione, the postdoctoral researcher who hails from Senegal, earned his undergraduate degree in Bordeaux, France, and got his doctorate in Quebec, Canada.

Just a thin slice of Senegal's population is college-educated, and to specialize in certain specific areas, a Senegalese has to leave the country. "Now, there are more opportunities for scientists in Senegal," Ndione said. "But to specialize in a field that includes semiconductors and lasers is difficult. We have to go abroad to do it.

"This is what I love," Ndione said, while setting up for another experiment. "The aim in the future is to adapt this technology to our realities in Africa and also, to promote intensive collaboration between the USA and Africa in the field of renewable energy."

"I feel so fortunate to be here and working with NREL. They have the best scientists, the best mentors ever." –Yi Ke

Finding a Life of Science

Berry got his undergraduate degree at Goshen College in Goshen, Indiana, where his father was a political science professor.

Science and math always suited Berry. It might have suited his father as well, but the elder Berry grew up in the segregated south, the first in his family to get a college degree. "Back then, it was one thing for an African American to learn how to read, quite another to learn how to do trigonometry or calculus," Berry said. "I don't think he ever had the opportunities to do that. He might have been inclined."

The son took the next step, cultivating his love for the sciences. Berry's dad helped him with his homework until high school chemistry, after which he was on his own.

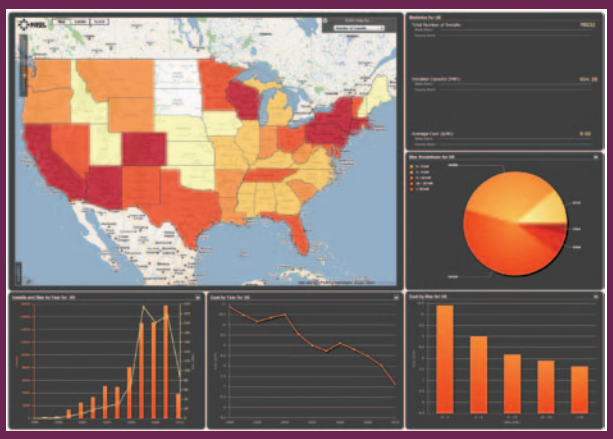
Berry went on to get a doctorate at Pennsylvania State University in condensed material physics, specializing in photon detection.

"These kinds of band-engineering things are meat and potatoes to a semiconductor device physicist," Berry said. "But they're much more challenging than the ones we considered challenges in graduate school.

"NREL being NREL, there's this balance between what we do on the fundamental level and the need to find a way to produce these things at low cost and at scale," Berry said. "NREL is one of those places you always think that it would be nice to work here. I didn't know whether I had the appropriate skill set. But there was an opening and I applied. Dave in his infinite wisdom decided I'd be a reasonable fit for his group. It's been four years. I've been happy as a clam ever since."

— *Bill Scanlon (December 22, 2010)*

TOOL THAT TRACKS SOLAR INSTALLATIONS IS OPEN TO ALL



Open PV's Map Maker lets the user sort through a variety of graphs from the national to the zip code level.

The photovoltaic (PV) market now has an eye-popping, interactive bevy of maps and charts that can let anyone know where PV panels are being installed, how big they are, how much they cost, and how fast the industry is booming.

Interested in where PV is installed in the United States and how it has grown over time? Go to the National Renewable Energy Laboratory's Web site, openpv.nrel.gov, and find a dynamic time map showing PV installation activity in the United States from 1998 to 2009.

Want to know how fast the cost per watt is plunging in Wisconsin or California? Push "Explore" on the Web site to open the PV Market Mapper application and call up any state in the nation to see graphs on the number of PV installations, cost, and capacity over time.

Want to know if your old friends from Kalamazoo or Kokomo ever got around to installing PV on their roof? Zero in by zip code and neighborhood and you can probably find that out, too.

NREL Geographers Conceived an Open PV Community

The Open PV database is the brainchild of geographers in the Data Analysis and Visualization Group within the Strategic Energy Analysis Center at NREL.

"We're building a community of users who are willing to share information about PV installations," said Christopher Helm, a Geographic Information System (GIS) developer and project manager for the Open PV project. "The project is a living, breathing, dynamic database that people can use to explore the U.S. PV market in essentially real-time."

He and Ted Quinby, GIS developer and fellow Open PV project team member, are accepting data uploads from utility companies, local and state governments and the public.

"A big focus in getting this up and running is to spur more data-sharing," Quinby said. "We want to foster the development of a community around collecting and maintaining this data."

So far, Open PV has catalogued more than 64,000 systems with a total capacity of about 733 megawatts.

They know there are more systems out there (there must be more than one system in Illinois, for example) but are confident the numbers will soar as the data-sharing phenomenon catches hold among installers, government officials and utility companies.

Solar Trade Groups Embracing OPEN PV

The two largest solar trade groups, the Solar Energy Industries Association and the Solar Electric Power Association, are fans of the Open PV project and are encouraging their members to use the maps and graphs as tools to grow their businesses.

Installers can use the data to examine their positions in the market and, when they share data, can benefit from the name-recognition that goes with it.

"If people want to see the three or five top installers in their neighborhood, they'll be able to zoom in and find that out," Quinby said. "If they want to know the installers in their region, they'll be able to find that too."

Users Can Explore National, Local Trends

Open PV's Market Mapper launches the user into a kind of time-space continuum.

Users can click on their own state to see how it compares to other states or the nation as a whole in such variables as cost, number of installations and growth. They can do the same for counties or zip codes within each state.

"The idea is that you can drill down to this very specific level," Quinby said. People will soon be able to add comments and even upload photos of their systems.

> "Look at how much we've come down from in just five years," Helm added. "We have a ways to go, but in a few more years, we'll be there." – Christopher Helm

Users can click on counties or zip codes. "We can show that Louisville, Colorado, has 42 installs," Quinby said. "When we have address-level data, we map that as well."

Using the project's new search tool, users can ask complex questions, such as: How many systems of 10 kilowatts or more are in the state of New Jersey and where are they? They can surf through data from several states and find they have

questions of their own, such as how Massachusetts enjoyed such a steep plunge in cost-per-watt, from $15 in 2002 to about $7 in 2009.

"We've built a database that varies in space and time, to really understand the PV market and how it fluctuates," Helm said.

Those who want to contribute data can create an account and visit the "Share Data" page: http://openpv.nrel.gov/share.

An installer might upload the information that he has put PV on 200 homes, or perhaps a county energy commission will report the total installations for a three-month period.

Recently, the state of Massachusetts uploaded information on 1,500 PV installations without any solicitation from NREL.

"It's starting to snowball," Quinby said. "We're not having to go out and ask for data as much as we did initially. People and organizations are now coming to us with their data."

Zeroing In on Systems, Data

California alone has more than 50,000 PV installations recorded in Open PV project, more than three-fourths of the nation's total.

New Jersey is second with 3,192, then Massachusetts, New York, Arizona, and Connecticut.

"People want to zoom in and see their own system," Helm said. "It's a great tool for doing that, but really it's meant to be more of an aggregate look at data, viewing it on bigger-picture scales."

Open PV captures steep cost decline

Open PV's graphs usually show the per-watt cost of a solar installation falling as the size of the project increases.

One of the graphs on the site uses bars to show the rather sharp decline in average cost per watt to install PV systems from 2000 to 2007.

President Obama has set a goal for solar energy to be competitive with fossil-fuel-based energy by 2015. "This tool can be a mechanism to track progress toward grid parity," Helm said.

"Look at how much we've come down from in just five years," Helm added. "We have a ways to go, but in a few more years, we'll be there."

The Open PV project went on line in October 2009.

"The overall reaction has been positive," Helm said.

"The beauty of the site is that it has positioned itself to be the primary repository of PV data such that future PV installations will be more easily tracked and recorded," Helm said. "The PV market should be gaining steadily. We should see a lot of installs over the next several years."

"The beauty of the site is that it has positioned itself to be the primary repository of PV data such that future PV installations will be more easily tracked and recorded." – Christopher Helm

Helm and Quinby hope to create other open data bases for wind, solar, hot water and geothermal installations—across technologies as well as across space and time.

— *Bill Scanlon (March 12, 2010)*

NREL HELPS DOE PROMOTE CUTTING-EDGE TECHNOLOGY

NREL's Senior Vice President for Commercialization & Deployment Casey Porto, Vice President of Commercialization and Tech Transfer Bill Farris, and Technology Commercialization Program Manager Matt Ringer review features of the DOE/EERE Technology Commercialization Portal, which NREL helped create.
Photo by Patrick Corkery, NREL/PIX 18340

Technology seekers know that finding that new "aha" technology can be like finding a proverbial needle in a haystack, especially considering that there have been more than 7 million U.S. patents granted covering everything from ordering online with a mouse click (patent owned by Amazon.com) to Samuel Hopkins' method for improving the production of potash, which was the first U.S. patent signed by President George Washington.

Today's technology seekers interested in breakthroughs in renewable energy and energy efficiency can leverage a new Web site to quickly access patents and patent applications developed by U.S. Department of Energy (DOE) laboratories and other research institutions funded by DOE.

DOE's National Renewable Energy Laboratory (NREL) developed the Technology Commercialization Portal for DOE's Office of Energy Efficiency & Renewable Energy (EERE). Through streamlined searching, the portal whittles down the more than 7 million patents and patent applications at the United States Patent and Trademark Office (USPTO) to a more manageable 14,000—all funded by DOE.

The idea for the Technology Commercialization Portal came about as The Alliance for Sustainable Energy, LLC, was bidding on a contract to manage NREL for DOE. "DOE said if you want to run NREL, tell us what are you going to do that's new and innovative when it comes to commercializing technologies," Vice President of Commercialization and Tech Transfer Bill Farris said. "There is a lot of science and technology going on at NREL and other national labs, but to have the maximum market impact you need to be able to move those technologies out of the lab."

"DOE funds billions of dollars in research and you can't find all of that technology advertised and described in one place," Senior Vice President for Commercialization & Deployment Casey Porto added. "The Alliance felt that this was something we needed to take on, if we were going to tout 'commercialization' as a key differentiator for NREL. Fortunately, DOE/EERE quickly embraced the idea and provided funding, so that the project could be fast tracked."

Focus on Available Clean Energy Technology

The Technology Commercialization Portal gathers patent data by tapping into the USPTO database and searching the millions of entries for anything funded by DOE. Content administrators from NREL or any of the other participating national labs, using a simple content management system, can then add marketing summaries to help businesses interested in licensing the technology understand its potential uses.

"A patent is a legal document written from a legal perspective—what we wanted to do was create and include the marketing summaries written by the labs that tout the technology features, potential applications in the market, advantages, diagrams, and contact info," Technology Commercialization Program Manager Matt Ringer said. "You won't see one of these summaries for every patent; rather we wanted the laboratories to be able to highlight the technologies they wanted to focus on, so that technologies seekers could find them."

Portal users can:

- Search thousands of clean energy related patents available for licensing as well as patent applications
- Browse marketing summaries of clean energy technologies available for licensing organized into 14 technology areas
- Identify the total number of patents and technology marketing summaries contained on the site

Sign up for e-mail updates

Link directly to the DOE laboratories that developed the available technologies to get more information.

"You want to maintain each lab's identity and ability to market their own technologies, licensing, and do their own business," Ringer said. "But there is a tremendous amount of value in being able to go to one place to find the information you are looking for. That's what the portal gives all participants—focused searches on clean energy technologies, the ability to look at new technologies created through DOE funding, and licensable from the owners."

Future Enhancements in the Works

From concept to launch, the Technology Commercialization Portal came about quickly. The beta version was tested in May 2009 and a final version with a Web-friendly interface launched in February 2010.

EERE Technology Commercialization Portal Participating Labs:

- National Renewable Energy Laboratory
- Argonne National Laboratory
- Brookhaven National Laboratory
- Idaho National Laboratory
- Lawrence Berkeley National Laboratory
- Lawrence Livermore National Laboratory
- Los Alamos National Laboratory
- Oak Ridge National Laboratory
- Pacific Northwest National Laboratory
- Sandia National Laboratories

"There is a tremendous amount of value in being able to go to one place to find the information you are looking for. That's what the portal gives all participants." – Matt Ringer

"Because of the enthusiasm this portal has generated we will be looking to grow the site features," Ringer said. "The main goal is to enhance the marketing summaries, to help EERE broadly market technologies they have created."

Other features under consideration include:

- Social media features that would allow networking and interaction between technology managers
- Expanding the data to include other federal agencies that are researching clean energy, such as EPA and NASA
- Ways for technology seekers to find complementary technologies for licensing.

"The ultimate success is when a technology seeker creates a 'bundle' where he takes technology from two different labs and creates a product," Ringer said. "We're looking forward to making that happen."

— *Heather Lammers (May 4, 2010)*

NREL, 3M LAUNCH TECHNOLOGY PARTNERSHIP

NREL Principal Investigator Dan Schell holds a flask of "beer"—a lignocellulosic ethanol broth—that represents a middle stage in the process of making high-grade ethanol fuel from non-edible biomass. *Photo by Patrick Corkery, NREL/PIX 17375*

The U.S. Department of Energy's National Renewable Energy Laboratory (NREL) and 3M, the St. Paul, Minnesota-based technology company, have embarked on research and development partnerships in three key areas of clean energy innovation: thin-film photovoltaics, concentrating solar power, and biofuels.

The work ranges from jointly identifying and developing critical aspects of renewable energy technology to accelerated testing of 3M designs and scaling-up successful prototypes for commercial production. The partnerships are covered in three cooperative research and development agreements, or CRADAs, which last for at least one year. The total combined value of the shared research and development covered by the agreements is $7.33 million.

With $23 billion in annual sales, 3M employs 75,000 people worldwide and has operations in more than 65 countries. It is one of the laboratory's largest commercial partners.

"CRADAs like these with 3M are critical for achieving the marketplace impact that is the goal of NREL's work in renewable energy," NREL Senior Vice President of Commercialization and Deployment Casey Porto said. "Not only do they help shift the nation to clean energy, but they also establish and expand important partnerships for product development through technology transfer."

"3M's wide-ranging expertise and commitment in these fields makes this a key partnership for the laboratory because this type of partnership enables the creation of clean energy breakthroughs that can become products," she said.

"3M is excited for the opportunity to tap into NREL's expertise and understanding of a variety of solar modules and the interplay between the materials and systems," said Mike Roman, general manager and vice president of 3M Renewable Energy Division. "Also, NREL has pilot plant capabilities, which allow valuable application testing of 3M's biofuel separations technologies in a controllable and scalable environment."

Thin Film Solar Cells

3M and NREL will work to develop and test new moisture barrier films and flexible packaging for thin film solar cells made of semiconducting layers of CIGS, or Copper Indium Gallium Diselenide.

CIGS cells have achieved a record efficiency of 19.9% at NREL. But to become commercially successful, manufacturers need to both increase module performance and reduce manufacturing costs.

The solar cells are expected to work effectively for 20 years. That means they will need to be encapsulated in a flexible material that is transparent to light, but also provides durable protection—and doesn't add significant costs.

NREL will conduct accelerated stress tests, including temperature, humidity and irradiance tests, to establish failure barriers on as many as three types of 3M CIGS designs. The laboratory and 3M will jointly interpret the results with the aim of establishing module standards for a 20-year lifetime.

Principal investigator Mike Kempe said much of the testing will revolve around measuring the rate of water vapor transmission in moisture barrier samples.

"We test their moisture barrier materials to determine if they give adequate protection to the CIGS cells," Kempe said. "They want expert eyes looking at these materials before they go to the PV industry."

Concentrating Solar Power

3M is developing highly reflective silvered polymer mirror reflectors as low-cost replacements for glass mirrors in Concentrating Solar Power (CSP) systems. Investors want solar reflectors that are as durable as glass and that meet increasing performance standards.

It's work that started 25 years ago with a 3M reflective coating known as ECP305+. Principal investigator Cheryl Kennedy was new to the laboratory's CSP staff when she shared a patent on the reflective coating.

Today 3M is working with Kennedy again to develop a new version of the solar mirror film. The original solar mirror film was supposed to work reliably for 10 years, but in field tests it is still maintaining its reflectance after at least 15 years of outdoor exposure.

In a second related effort, 3M and NREL will develop a durable, cleanable hard-coat surface for the top layer of the metalized polymeric mirror films.

"At first people thought coatings to prevent CSP mirrors from getting dirty was too futuristic," Kennedy said. "Now the CSP market is taking off. They are looking for coatings that will help mirrors remain highly reflective for 30-50 years with minimal scratching and cleaning. That's how long a coal-fired power plant stays online generating electricity, so CSP systems need low-cost mirrors that maintain high specular reflectance for extended lifetimes outdoors in order to be competitive."

In a third related effort, 3M and NREL will test the new polymeric mirror films and compare the performance using a service lifetime model first developed with the original ECP-305+ reflector. NREL will characterize the new film's optical performance and durability by conducting tests in accelerated weathering chambers that use xenon arc lamps to simulate extreme and accelerated conditions of light, temperature, and humidity at about seven times typical outdoor exposure.

Additionally, samples will be exposed in a new ultraviolet (UV) concentrator, which has the capability of concentrating natural sunlight 100 times in the UV portion of the solar spectrum. Samples will be exposed for the equivalent of 1 year of concentrated UV exposure with temperature and humidity control.

"NREL has pilot plant capabilities, which allow valuable application testing of 3M's biofuel separations technologies in a controllable and scalable environment." – Mike Roman

Ethanol-Biofuels

A new 3M prototype liquid-liquid separations technology uses a membrane to significantly increase the concentration of ethanol extracted from a fermentation broth. The new method does not rely on heat to evaporate water in the broth and reduces the distillation energy required to separate water and ethanol.

3M wants to test and scale-up the new technology for both the existing conventional corn-based ethanol industry and for the emerging lignocellulosic ethanol industry, which produces ethanol from the tougher parts of plants—like stalks, cobs, and leaves—that are not part of the food supply.

Archer-Daniels Midland is the among the largest U.S. corn ethanol producers, and will test the 3M prototype in one of its pilot plants.

"The membrane technology has to be cheaper than the standard distillation method of recovering ethanol," said principal investigator Dan Schell. "We're trying to be more aware of separation as a unique step in the process and take advantage of it."

— Joe Verrengia (May 11, 2010)

NREL BRIDGING THE GAP FOR ENTREPRENEURS AND VCS

Presenting entrepreneurs at NREL's Industry Growth Forum have just 10 minutes to impress skeptical judges with sound business plans that will attract investors to their clean energy innovations. *Photo by Patrick Corkery, NREL/PIX 18341*

PowerPoint? Check. Business plan? Check. Elevator speech? Check.

Breath mints, aspirin, and antacids? Triple check.

Everything was ready for the 23rd Industry Growth Forum held in Denver on October 19, 2010, by the U.S. Department of Energy's National Renewable Energy Laboratory (NREL).

Entrepreneurs at the Growth Forum take the stage under hot lights to make their best pitches to panels of discerning judges—venture capitalists (VCs), public officials, and fund managers—who have seen and heard it all before, often in more promising economic times. All the while, a digital clock reminds them that time is running out.

It sounds a lot like the cleantech version of "America's Got Talent," without the sequins and singing, but the judging is just as tough.

"In this economy, the judges look for more innovation, a game-changing technology," said Lawrence "Marty" Murphy, Forum chairman and NREL's manager of Enterprise Development.

"There isn't as much capital available now as in years past, so when VCs make an investment they want to make a bigger investment that could result in large returns," Murphy said.

> "In this economy, the judges look for more innovation, a game-changing technology."
>
> – Lawrence "Marty" Murphy

Premier Event for Clean Energy Start-Ups

NREL's Industry Growth Forum has grown into the largest national venture event focused exclusively on companies developing clean energy products to serve the electricity, buildings, and transportation infrastructures.

The Forum is the premier event for innovative clean energy start-up companies to meet venture capitalists, corporate investors, and strategic partners.

In 2010, 200 clean energy entrepreneurs applied. Their products and plans were scored by 135 investors and other experts, and 34 were selected to compete as presenting companies. Since 2003, presenting companies have collectively attracted $3.4 billion in capital.

Among the 34 finalists, this year's emphasis is energy efficiency, energy management software, thermoelectric, smart grid, and building technologies. In contrast to previous years, there will be relatively fewer presentations on solar, wind, and biofuels.

"A few years ago people were seeing a lot of deals on photovoltaic (PV) technologies," Murphy said. "So if you have a PV company at the Forum this year, you'd better have a pretty innovative idea."

Emerging companies have 10 minutes apiece to make their case.

Then comes the hard part—answering the judges' questions and absorbing their critiques. The winners were announced at the concluding luncheon on October 21.

The top prize was the $25,000 Best Venture Award, which included $10,000 in cash and NREL in-kind services valued at $15,000. The 2009 Best Venture was Ecovative Design, which grows and forms biodegradable packing materials.

Two Outstanding Presentation awards, each valued at $15,000 in cash and in-kind services, also were announced.

The prizes were sponsored by Wilson Sonsini Goodrich & Rosati.

Deliberate Dialogue

A new opportunity in this year's schedule was a One-on-One Partnering and Pitch Session on October 19, the first day of the forum.

The session provided scheduled, facilitated meetings between investors and entrepreneurs, as well as potential partners and government officials. The One-on-Ones were open to all registered Forum attendees. Innovators and companies that applied to compete as presenting companies received initial consideration for slots on the investors' schedules.

Investors range from small venture capital firms to large corporations such as Honda and Chevron.

"The big companies are looking to invest in a late-stage project as a strategic partner," Murphy explained.

The forum is part of NREL's broader strategic efforts to accelerate the commercialization of clean energy innovations and assist entrepreneurs in their search for investment capital and other resources.

Each year, the applicants provide the laboratory with an indication of early cleantech trends which helps officials gauge how they can better serve the entrepreneurial sector and foster new companies based on NREL technology.

"We want to grow clean energy talent based on the most innovative ideas and the best business plans." – Robert Writz

"We want to grow clean energy talent based on the most innovative ideas and the best business plans," said NREL Robert Writz, an NREL commercialization project manager who coordinates events at the Forum. "By the end of the event, we see strategic partnerships and investments emerging."

A Crash Course for Entrepreneurs

NREL launched the Forum in 1995 as a way to facilitate discussion about new technologies by venture capitalists, public officials and clean energy entrepreneurs face-to-face.

Many early stage clean energy firms were failing because they were unable to make the leap from public sector financing to private sector funding. Young companies needed assistance developing a business pitch and to be schooled in the expectations, requirements, and processes for raising private sector capital, Murphy said.

Similarly, the clean energy investment sector needed realistic information about the emerging technologies, time-to-market, and the associated risk profile.

Instead of following the trend of five minute tête-à-têtes popularized during the dotcom financing boom of the 1990s, Murphy said the Forum deliberately tried to be more about relationship-building and capacity growth.

"There was an information gap between the entrepreneurs and the investors that was a 'valley of death' for new products and companies," Murphy said. "A lot of good technologies were not getting commercialized. The Forum bridged that gap and it continues to do so."

Even if entrepreneurs are not selected to present at the forum, Murphy says applying to the event and attending the sessions can be a crash course in entrepreneurship and provide extensive networking and partnership opportunities.

The Application Process – For many entrepreneurs it's the first time they have articulated their goals, business model, and elevator pitch to someone other than family and friends. "When they see the remarks of the reviewers, it's a wake-up call," Murphy said.

Preparing for the Forum – Each presenter is mentored by an expert to refine the presentation, business case, and elevator pitch with an eye toward attracting investment.

The Forum Pitch – The entrepreneurs learn in a few minutes whether judges think they did their due diligence in anticipating what judges—and investors—need to know. "There's no substitute for this real-time feedback," Murphy says. "This format allows the clean energy community to clearly hear the concerns and interests of the investment community."

Since 2003…

- Presenting companies have cumulatively raised a total of $3.4 billion
- Within a year of presenting, companies have raised $635 million
- Within two years, companies have raised $1.12 billion.
- 53.2% of the presenting companies (91 of 171) have received capital investments
- 25 strategic partnerships have been formed
- At least five Forum companies successfully completed an IPO, merger or acquisition.

— Joe Verrengia (September 22, 2010)

GIANT WIND TURBINE TEST TAKES A HEAVYWEIGHT

A coupling of giants: Samsung's 2.5-megawatt wind turbine drive train meets the National Wind Technology Center's 2.5-megawatt dynamometer. Samsung's drive train weighs 90 tons and is the brains behind its 2.5-megawatt wind turbine that can supply electricity to 1,800 homes. *Photo from NREL/PIX 17398*

In a coupling of giants recently, the 2.5-megawatt dynamometer at the U.S. Department of Energy's (DOE) National Renewable Energy Laboratory (NREL) blasted 12.6 million inch pounds of torque at Samsung's 185,000-pound wind turbine drive train.

The King Kong of wind turbines battled the Godzilla of dynamometers to a draw.

It was the greatest amount of power ever measured at NREL's dynamometer lab, and the largest full-scale dynamometer test of a wind turbine drive train ever done in the United States.

Samsung officials wanted to learn how well their 250-foot-high wind turbines would survive 25 years of gales, gusts, rain, rust, cyclones, and dust.

They turned to NREL because its dynamometer can simulate worst-case wind conditions 24 hours a day. In a few months of testing, a manufacturer can learn whether its gear boxes, bearings, and cog wheels will stand up to real-world conditions.

NREL's 2.5-megawatt dynamometer is outfitted with a powerful 3,550-horsepower electric motor coupled to a three-stage epicyclic gearbox. The motor can produce speeds up to 30 revolutions per minute, simulating everything from soft breezes to back-breaking gales.

Decades of Data in Two Months of Testing

"If we tried to get this information out in the field, it would take years to acquire this kind of data," Ed Overly, master research technician and dynamometer gatekeeper at NREL's National Wind Technology Center (NWTC), said. "We run the turbine under test conditions for 24 hours a day, seven days a week at 2.1 megawatts. We can monitor how all the fluid and bearing temperatures equilibrate at their maximum points. We see how well the inverter operates under different load conditions to detect if there are any unknown faults."

"Doing this test with Samsung has given us the experience of testing a very large machine at the Dynamometer Facility, which we've never done before," Overly said.

Samsung already has a similar sized (2.5-megawatt) wind turbine running in Lubbock, Texas, that can provide electricity for 1,800 homes, said In-kyu Kim, manager of the Wind Turbine Development team at Samsung. But the company had never tested one of its turbines above 600 kilowatts.

Jaedoo Lee, manager at Samsung Heavy Industries, said his company chose NREL "because we needed to test for performance and we know NREL is prestigious. We like to simulate and test all the tough and extreme conditions that would happen in the real world."

"We wanted a third-party test for quality," Lee added. "NREL is the perfect test facility for us. We'd like to keep working with them as we develop wind turbines for off-shore uses."

Moving 185,000 Pounds: A Herculean Endeavor

How did the huge wind turbine drive-train make its way into the dynamometer's test bay?

"It was a monumental task," Overly said. "We had to move 200,000 pounds of equipment out of here and clean up the whole high bay, then move in the Samsung turbine—within a week."

A 185-foot-long, 19-axle rig hauled the drive train and electrical equipment from Houston to the NWTC. Then a 400-ton crane moved the drive train onto a track and cart system, temporarily laid just for the move. "We off-loaded it and brought it into the dynamometer in one piece," Overly said. It's the largest piece of equipment ever installed in the Dynamometer Test Facility.

The software used by NREL and Samsung tells the dynamometer what kind of torque it should give the drive train.

"We want to provide an accurate reproduction of loads the drive train will see in the field," NREL senior engineer Robb Wallen said as the dynamometer put the Samsung drive train though its paces in April 2010. "The tower, rotor, and blades are represented by computer models which interact in real-time with the drive train and turbine control system just like their real counterparts."

Using a virtual wind-speed profile the computer model calculates what the main shaft torque should be and sends the torque commands to the dynamometer. "The end result is the drive train responding to a variety of wind conditions as it would in the field," Wallen said. "It's a very sophisticated test and it's never been done here before."

The tests, which ran for a couple months early this year, "accelerate the startup, the actual checkout, as well as spotting any kinds of deficiencies," Overly said.

NREL is the only place in the nation where "you can run a wind turbine under load conditions, watch it operate real-time, be standing near to it and hear how it operates," Overly said. "You can't accomplish that up in a wind turbine in the field."

Meanwhile, NREL is taking the next giant step—designing a 5-megawatt dynamometer that will be capable of testing most of the large turbines expected to roll off humungous assembly lines in the next decade.

— Bill Scanlon (May 17, 2010)

WIND TURBINES WHIP UP EXCITEMENT, SCHOOL PRIDE

Blades of a Southwest Windpower Skystream turbine are silhouetted by the sun at NREL's National Wind Technology Center. Forty-two of the turbines are spinning at schools in 11 states as part of the Wind for Schools project.
Photo by Dennis Schroeder, NREL/PIX 18237

They're about 50 feet high, whirl like pinwheels and instill an excitement in students and a pride in a community that is hard to match.

They're wind turbines installed in schoolyards around the west, whipping up energy to help power the schools, and whipping up enthusiasm for next-generation scientists and engineers.

The Wind for Schools project of the U.S. Department of Energy's (DOE) National Renewable Energy Laboratory (NREL) is churning, having installed 42 Southwest Windpower SkyStream 3.7 turbines so far, with a goal of five new turbines each year for the 11 states already part of the program. Eventually, 35 states are expected to participate.

That's enough critical mass, say the researchers, for the idea to catch fire, and for states and school districts to take on the installations themselves. And when that happens, there will be such a groundswell of informed eagerness for wind energy among young people that the fear of shortages of skilled labor for the wind industry might subside.

"It's a great fit for our area in that wind is something we deal with all of our lives around here," Kyle Hebberd, superintendent at the Walsh School District in southeast Colorado, said at the dedication ceremonies for the wind turbine at Walsh High School. "It's great to see it finally put to some productive use."

The students at Walsh walk by their wind turbine every day, get some of their electricity from it, and can incorporate the energy data into their math and science classes.

More than that, the turbine at the high school blows excitement all over town.

Turbines Educate, Point to Future Jobs

In November 2010, the students in the upper grades at Walsh Elementary School crafted their own mini-turbines in what teacher Janet Chenoweth calls the Blade Challenge. It's embryonic in Colorado, but huge in Maine, where more than a dozen high schools compete to design blades that will create the most power.

Chenoweth, who teaches science to fourth-, fifth-, and sixth-graders, became a Wind Senator through the KidWind project and is becoming an ambassador for wind-energy curriculum in southeast Colorado.

"Oh my gosh, they're excited," Chenoweth said. "Ever since the wind turbine went up there, my kids have been saying, 'When can we do wind energy?' If we can get them excited over here, the science teachers in the high school can take it from there."

The idea began in Colorado, where NREL has its headquarters.

"We used rural Colorado as our sandbox to see what rural school officials were interested in," said NREL engineer Larry Flowers, the national technical director of Wind Powering America.

After meeting several times with rural officials, "We decided a simple, low-cost package with a curriculum, sited, and installed in collaboration with university engineering students and the local electric co-op was the ticket."

NREL Director Dan Arvizu agreed to buy green energy certificates for the projects as part of NREL's sustainability program.

Former Colorado Gov. Bill Ritter said the school wind turbine projects are an important example of how Colorado is participating in the "New Energy Economy."

"Educating today's young people about the benefits and mechanics of renewable energy prepares them for a wealth of future opportunities," Ritter said. He said the Wind in Schools program also demonstrates the crucial role rural communities can play.

"It's a great way to introduce wind energy to communities in a not very threatening, educational way," said Ian Baring-Gould, senior research supervisor for wind technology deployment at NREL's National Wind Technology Center. "It allows the community to take a more active role in their energy future."

It needs to happen because DOE envisions the United States getting as much as 20% of its electricity from wind power by 2030, the year today's toddlers graduate from college, eager to establish careers in forward-looking industries.

DOE expects 500,000 wind-related jobs by 2030 if the 20% scenario comes to pass. That would be a six-fold increase in wind-related jobs from today.

Wind Turbine Pride Contagious in Rural Areas

The idea is to make the wind turbines points of community pride, especially in rural areas. The rural electric companies that brought electricity to the towns are enthusiastically helping to sponsor the installations. Wind energy can be a way to keep young adults in town, with the prospects of interesting jobs, rather than seeing them flee to the cities.

Once a school gets a turbine, the school down the road wants one, and so do the local car dealership and other businesses.

In late January 2010, NREL and the DOE's Wind and Water Power Program announced that five more states had been selected to receive $60,000 each in support of the Wind Powering America's Wind for Schools Project

In each state, university students will help install the turbines and deliver lessons to younger students through local Wind Applications Centers. The new partnerships are: Appalachian State University in North Carolina, James Madison University in Virginia, Northern Arizona University, Pennsylvania State University, and the University of Alaska. The original six states are Colorado, Idaho, Kansas, Montana, Nebraska, and South Dakota.

"What this program is addressing is the bottleneck in brainpower," said Todd Haynes, Boise State University's Wind for Schools coordinator. "That's why wind in the schools is all about education."

"Educating today's young people about the benefits and mechanics of renewable energy prepares them for a wealth of future opportunities." – Gov. Bill Ritter

Schoolyard Turbines a Symbol of Future Employment

Wind Powering America is about renewable energy, but it's also about jobs.

"We had identified the need for a skilled workforce" for wind energy even before DOE's 20% by 2030 report (http://www.20percentwind.org/) of two years ago, Baring-Gould said.

"We're really talking about a paradigm shift" with the expected surge in wind energy, Baring-Gould said. "The last time we went from zero to a significant amount was with nuclear energy in the 1950s and 1960s."

Baring-Gould notes that there are universities with huge programs devoted to nuclear energy, but nothing comparable for wind energy.

With fewer middle-school students expressing an interest in science, the prospects of there being enough skilled young adults to enter the growing wind-energy field, was looking like "a train wreck," he said.

So, the idea of Wind Application Centers at land-grant universities was born. College students would take classes in wind applications, then be assigned to elementary or secondary schools where they would oversee the installations and talk to pupils about wind energy.

"We're kind of feeding the pipeline, training engineers, and getting the kids to think about science," Baring-Gould said.

The 2.5-kilowatt turbines, with rotor blades 12 feet in diameter, are big enough to power about a third of the electricity needed for a single-family home, so they produce just a slice of what a school needs.

Still, they generate about $400 worth of electricity a year and in about five years can offset the $2,000 the school is asked to contribute to the upfront costs of the turbine.

Turbines Propel Classroom Excitement

The school gets more than green power. There are a curriculum on wind energy and a guide for the classroom teachers. And, data from the turbines is online, giving the teachers and students a chance to play with the numbers in nearly real time.

"How much energy did the turbine produce last night?" students will ask in the spirit of intra-town competition. "Did we produce more energy than they did?"

The mania is already on display.

Zach Parker let the middle-school students "turn the wrench a few times" when he was assembling a SkyStream 3.7 at the middle school in rural Jerome, Idaho.

"When the turbine was raised to its final height, the students were all saying, 'Look, I built that,'" Parker, a 2009 graduate of Boise State University, said. "I explained to them about power and energy, they helped put the bolts in. They were excited about the whole process."

By the time the rotors started moving, "They were jumping up and down, they were bringing their parents over."

On dedication day, Parker helped the math teachers on a lesson on the mode, mean and median wind speed of the turbine. "I'd never seen a math class where the kids were that engaged. Usually there are a couple who are just too cool for math. But that wasn't the case that day."

The turbine project excited Parker, too. In October, he started work for Gamesa Energy, one of the largest wind-turbine manufacturers in the world.

Recently, a wind turbine was being installed at a school as afternoon crept to evening. Cars started arriving in the parking lot, filled with students and parents. When the installation was complete, "lights started blinking, horns were honking, it was a total community event," Becki Meadows, senior engineer for NREL's Wind Technology Deployment, recalled.

— Bill Scanlon (November 23, 2010)

National Renewable Energy Laboratory
1617 Cole Boulevard, Golden, Colorado 80401-3305
303-275-3000 • www.nrel.gov

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