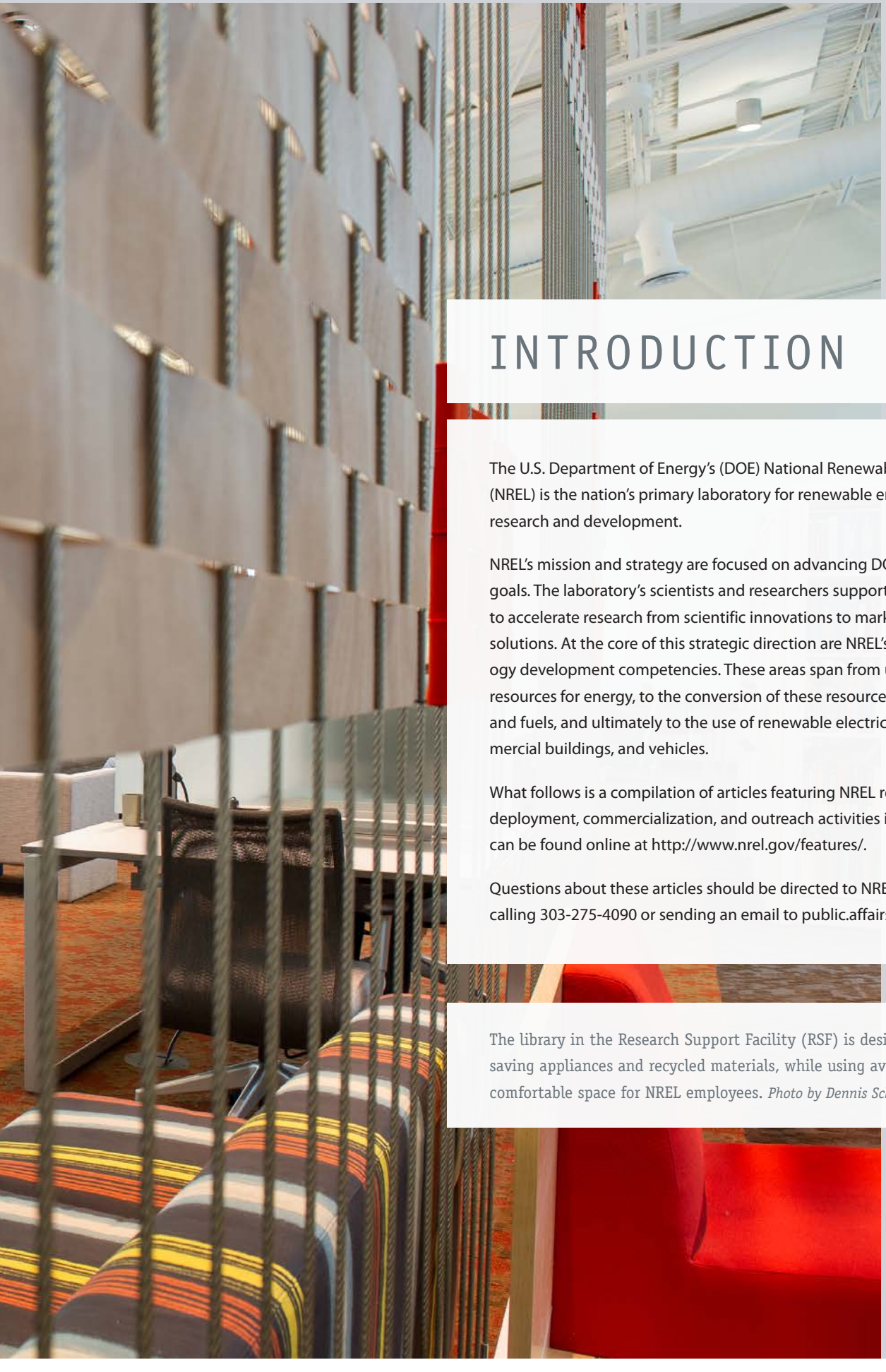
NREL
NATIONAL RENEWABLE ENERGY LABORATORY

NREL: A YEAR IN CLEAN ENERGY INNOVATIONS

A Review of NREL's 2012 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 21548



INTRODUCTION

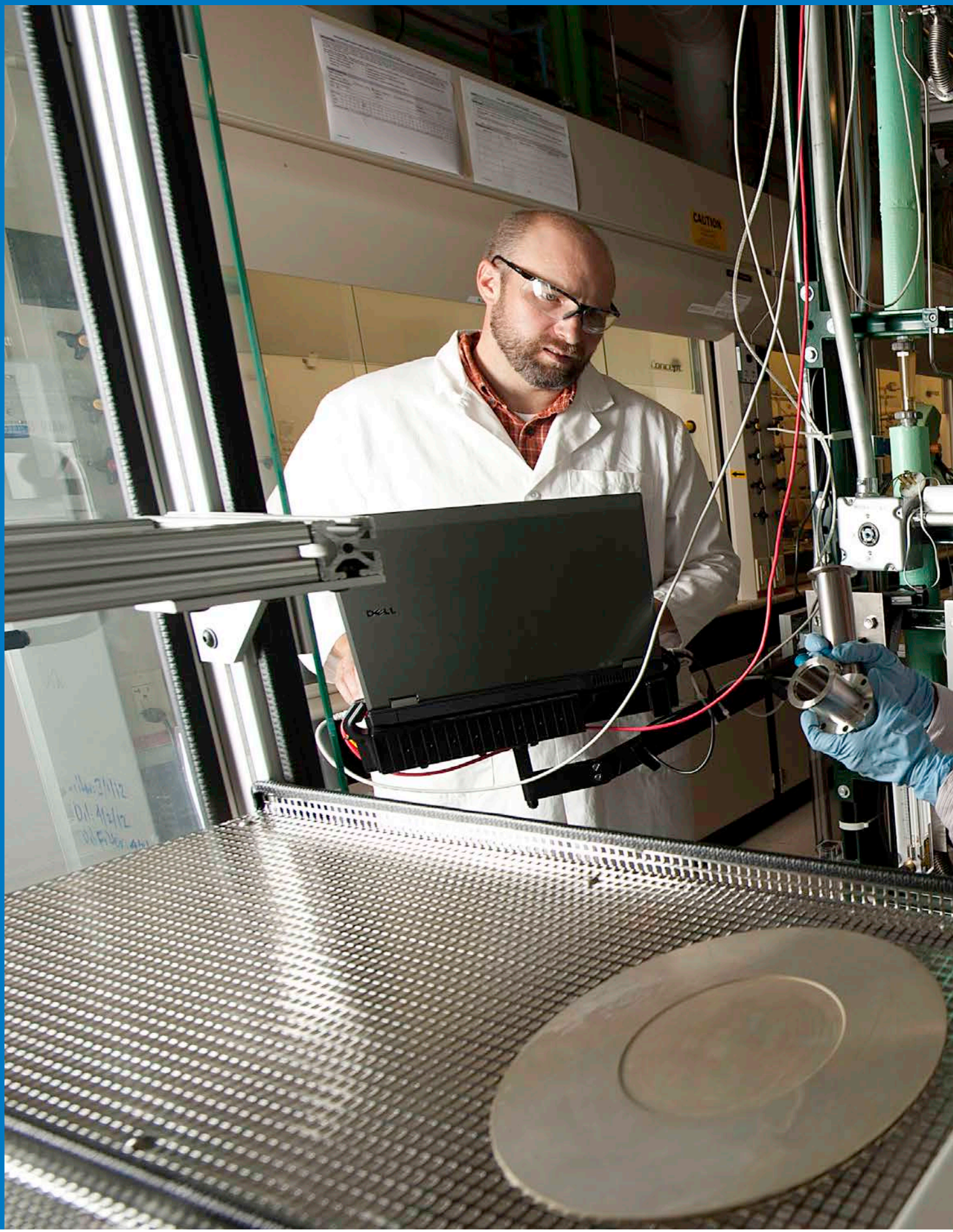
The U.S. Department of Energy's (DOE) National Renewable Energy Laboratory (NREL) is the nation's primary laboratory for renewable energy and energy efficiency research and development.

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

What follows is a compilation of articles featuring NREL research and development, deployment, commercialization, and outreach activities in 2012. The feature stories can be found online at http://www.nrel.gov/features/.

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

The library in the Research Support Facility (RSF) is designed with energy saving appliances and recycled materials, while using available light to create a comfortable space for NREL employees. *Photo by Dennis Schroeder, NREL 23238*


CAUTION
DELL

ADVANCED VEHICLES & FUELS

Working in partnership with public and private organizations, NREL researches, develops, and demonstrates innovative vehicle and fuel technologies that reduce the nation's dependence on imported oil and improve our energy security and air quality. *Photo by Dennis Schroeder, NREL 22951*

NREL Catalyst Brings Drop-In Fuels Closer

We live in a petroleum-based society, and the oil we use comes from plants that were buried eons ago and changed under pressure and high temperatures. As countries across the globe face dwindling oil supplies and the environmental impacts of tapping hard-to-process shale oil, the question arises: is there a greener way to replicate Mother Nature?

Researchers at the U.S. Department of Energy's (DOE) National Renewable Energy Laboratory (NREL) are looking for ways to thermochemically treat biomass to arrive at an end product that is similar to oil. One way to get there is through a process called gasification. Gasification takes biomass and heats it with steam and air to produce synthesis gas, or syngas. Syngas is a mixture of hydrogen and carbon monoxide—the building blocks of fuels and chemicals. After the syngas goes through another catalytic process, it is possible to make almost any type of related fuel or chemical.

But copying Mother Nature is rarely easy. During the syngas process, tars and other undesired components are also created. These tars can foul the refining process and must be removed from the syngas before the fuel-synthesis step. NREL has patented a fluidizable tar reforming catalyst that converts tars into additional syngas to make thermochemically derived biomass syngas ready for fuel synthesis.

"In the end you want to create something that's going to look just like gasoline, with a cost similar to gasoline, but that is derived from biomass," NREL Principal Scientist Kim Magrini said. "There is an added benefit to this process because you are taking biomass, which has carbon in it, and putting it into your fuel, which gets combusted into carbon dioxide—which is food for future biomass. If you look at the life-cycle analysis, it has a greater than 90% closure on the carbon loop."

In fact, thermochemically derived fuels have a number of benefits. The flexibility of thermochemical processes, such as gasification and pyrolysis, provides cost-effective options for manufacturing cellulosic ethanol and advanced biofuels. Often called "drop-in" fuels, these advanced biofuels are compatible with the existing fuel infrastructure, which will speed commercial adoption. And, as Magrini noted, advanced biofuels produced via thermochemical conversion could significantly reduce greenhouse gas emissions.

Hydrogen and Pyrolysis Got the Wheels in Motion

Work on the fluidizable tar reforming catalyst started in NREL's Hydrogen Program, where researchers were looking to produce hydrogen from the aqueous hydrocarbon fractions of pyrolysis oil, also thermochemically produced from biomass, Magrini said.

Pyrolysis is the process of heating biomass in the absence of added oxygen and at temperatures lower than those used in gasification. It breaks down the biomass and produces an oil-like liquid called pyrolysis oil. Pyrolysis oil, with treatment, can also be refined into greener transportation fuels.

"Pyrolysis oil is analogous to petroleum oil, although it is chemically different," Magrini said. "Once you form the pyrolysis oil, you can do a variety of things with it, like upgrade it into fuel-like

NREL Engineer Whitney Jablonski places a quartz reactor tube with a nickel-based catalyst into a reactor at NREL's Thermochemical Users Facility. *Photo by Dennis Schroeder, NREL 20398*

intermediates that can go into the existing fuel structure. Or, you can reform the aqueous phases and get hydrogen. When you do this, you need a catalyst that breaks down the components into hydrogen and carbon monoxide. The problem was that the catalyst that can do this reaction gets fouled in the process.

"Commercial catalysts wouldn't work; they are made for use in a fixed bed, which is a packed bed of catalysts that you run the materials through. We had to find a fluidizable material that moves around in the reactor and provides more efficient contact of the liquid with the catalyst."

The NREL team was successful in creating a catalyst that worked. The next idea was to take this reforming catalyst, designed for getting hydrogen, and see if it could be used to reform the tars that result from biomass gasification.

"The answer was, yes, we could," Magrini said. "It worked quite well. But the problem with this process was that when you gasify biomass, sulfur compounds from proteins are produced from the biomass. Those compounds deteriorated the catalyst because it is nickel on aluminum, and nickel readily reacts with sulfur."

NREL Turns to CoorsTek for Support

Magrini's team, including NREL's Yves Parent, Steve Landin, and Marc Ritland, identified the need for the catalyst to reside on a better support. The commercially available materials NREL tried simply fell apart in the reactor—so NREL staff enlisted the help of a Colorado neighbor, CoorsTek, to further refine the catalyst support so it would work in the fluidized bed of a gasification reactor.

"Almost everything we make at CoorsTek is custom; we engineer solutions to meet people's needs," CoorsTek Research Manager Steve Landin said. "The challenge for our work with NREL was to get the right size, composition, and surface area so the material didn't wear too much in the fluidized bed—it had to be damage tolerant."

The resulting catalyst support is made by taking all the raw materials and grinding them in water to form a high-solids solution. The particles in the solution are approximately one micron in diameter. The solution is spray-dried by atomizing the liquid in really hot air, forming droplets. The tiny droplets are little round pellets of ceramic; each one is formed when numerous particles from the solution adhere together. Then the material is fired, giving it strength, but the porous surface of the ceramic is not totally sealed, so the catalyst components—nickel, magnesium, and potassium—can "soak in."

Once the support structure was identified, NREL created the catalyst by mixing a nickel, magnesium, and potassium salt solution with the support. When this is heated, a chemical reaction occurs and the catalyst components of the solution stick onto the surface of the support.

"So when you take the CoorsTek support and add our patented formulation, we can efficiently clean up the syngas for downstream fuel synthesis," Magrini said. "All that work comprised NREL's material patent because it didn't exist anywhere else in industry."

NREL's decade of work on this process will culminate in the summer of 2012 when a biomass-to-ethanol process will be demonstrated at pilot scale to show that the catalyst is ready for industry.

Rentech's Plans for Commercialization

Just patented last year, NREL's unique solution for a fluidizable tar reforming catalyst has already caught the attention of industry and has been licensed by Rentech, Inc., a Colorado company with an NREL connection.

"One of our engineers developed a new reactor to condition syngas," Rentech Senior Vice President and Chief Technology Officer Harold Wright said. "Our engineer was searching for an attrition-resistant fluidizable catalyst. Through the patent information and some of the articles that Kim Magrini and her coworkers had written, we believed NREL was developing a catalyst that would fit into that configuration."

Rentech was founded in 1981 by engineers from the Solar Energy Research Institute (NREL's predecessor). Rentech has been developing synthetic fuel technologies since the early 1980s and has advanced a technology to convert syngas from almost any biomass feedstock into diesel jet fuel and other drop-in fuels. In 2008, Rentech was awarded $23 million in American Recovery and Reinvestment Act funding from DOE to add a Rentech-ClearFuel biomass gasifier to its facility in Commerce City, Colorado.

"We are still working with NREL on the development of the catalyst," Wright said. "We are also working to build a demonstration-scale facility that would use that catalyst. And we've done pilot-scale work at a university to show the validity of the catalyst.

"For Rentech, this is a part of the commercial deployment of an overall suite of technologies that process any type of biomass feedstock put in to the reactor to produce final drop-in fuels. The combination of the NREL catalyst and our reactor really helps to improve the overall economics of that process."

— Heather Lammers (April 11, 2012)

NREL Helps "Supersize" Butanol Production

The idea of "supersizing" is no longer embraced when it comes to what we eat. But when it comes to creating renewable fuels, supersizing can be a very good thing.

Recently, a team of scientists from Cobalt Technologies assembled at the U.S. Department of Energy's (DOE) National Renewable Energy Laboratory (NREL) to supersize their process for making renewable butanol.

Cobalt had proven in the lab that its anaerobic microorganism could take organic feedstocks and convert them into biobutanol. Butanol is valued as an industrial chemical—used in plastics, paints, adhesives, and inks—and, through a Cobalt-U.S. Navy process, can be made into jet fuel. It is also seen as a drop-in replacement for petroleum-derived fuel blending.

"We've been developing a bacterial fermentation process in order to build commercial biobutanol plants," Cobalt's Senior Director for Research and Development David Walther said. "One of the key milestones is demonstrating our fermentation process at larger and larger scales in order to minimize the risk for ourselves and our partners. NREL has a unique combination of scale and staff capability that we wanted to tap into; it really allowed us to do demonstration work in a timely and cost-effective manner."

Cobalt's team was able to leverage NREL's Integrated Biorefinery Research Facility (IBRF) for their scale-up testing. The facility is unique in its ability to handle a wide range of feedstocks and fermentation processes. The IBRF's equipment can support industry partners looking to evaluate new technologies in a demonstration-size facility. For companies like Cobalt looking to collaborate with NREL, the facility's fermentation capabilities and labs can be reconfigured to meet any project's needs.

"NREL is dedicated to advancing the cleantech industry and continually looks for ways to help firms and research groups leverage their intellectual capital and bring cost-competitive products to the marketplace," NREL's National Bioenergy Center's Team Leader for Partnership Development John Ashworth said. "Our bioprocessing fermentation facilities can be used by non-DOE academic institutions and companies like Cobalt to conduct test trials, prove technology, or even advance and optimize technology processes."

The IBRF's flexibility was key for this project, as this was the first butanol run in the fermentation areas of the IBRF, which were originally designed for cellulosic ethanol.

It was also the first major fermentation work-for-others partnership since DOE had invested $33.5 million in IBRF facility upgrades.

David Sievers, biochemical engineer and NREL's Cobalt project manager, left, and Erin Fetsch, senior scientist for Cobalt, oversee Cobalt's demonstration of its renewable butanol at NREL's Integrated Biorefinery Research Facility (IBRF). Fermentation samples, such as those pictured, exceeded the target yield and other performance metrics for a commercial-scale facility. *Photo by Dennis Schroeder, NREL 20216*

From Small Vial to Really Big Tank

When the Cobalt team first visited NREL, they discussed with NREL staff their procedures for culturing their microorganism so it could produce butanol at larger scales.

"This was something they've never done before," NREL Scientist Andrew Lowell said. "They brought in their lab-scale protocol, procedures, and data, and asked us to help make it work at 9,000 liters."

"It was a close collaboration because they know how their organism works; even when it was in our fermenters, having them alongside us was helpful because there were things we'd never seen before, and they could offer their expertise on how their organism behaves. There are a lot of subtleties when moving from a few liters to several thousand. But in the end, it worked out really well," NREL Senior Research Scientist Nancy Dowe said.

The organism was put in the hands of NREL staff and was grown up from a small vial all the way to being able to inoculate a 9,000-liter butanol run.

Adding another level of challenge to the project was the fact that some of this work was done from computer-modeled data that Cobalt provided for butanol recovery. "We had to adapt our equipment, which was used for ethanol recovery, to butanol. But the computer modeling gave us parameters to work with," Dowe added.

"We found that the scientists at NREL are eager collaborators," Walther said. "This was something different for NREL, so we had to develop and refine some processes we'd done on a smaller scale. The technical capability of the staff at NREL is very high, so they were able to adapt quickly to wrinkles or changes in the process."

Learning at All Levels

Although companies such as Cobalt come to NREL for its expertise—in this case, scaling up biofuels production—NREL scientists also benefit from working with new feedstocks, organisms, and drop-in fuels.

Options for drop-in fuels are a DOE focus. Less than a year ago, the U.S. Departments of Agriculture, Energy, and Navy joined forces to invest up to $510 million, over three years, to produce advanced drop-in aviation and marine biofuels. Cobalt is also working with the Navy to process its bio n-butanol into renewable jet fuel.

"This whole run showcased our expertise and that we are not just a corn-stover-to-cellulosic-ethanol facility," Lowell said. "We can do a lot of different things and can be a very versatile facility."

NREL's versatility and flexibility were proven in that this was the first time that a strictly anaerobic microorganism was put through the IBRF.

"This project stretched us in terms of the type of organism, the feedstock, and the procedures that had to be developed," Dowe added. "Now that we have this under our belt, we've had other companies who have approached us and want to work with us to develop their anaerobic microorganisms."

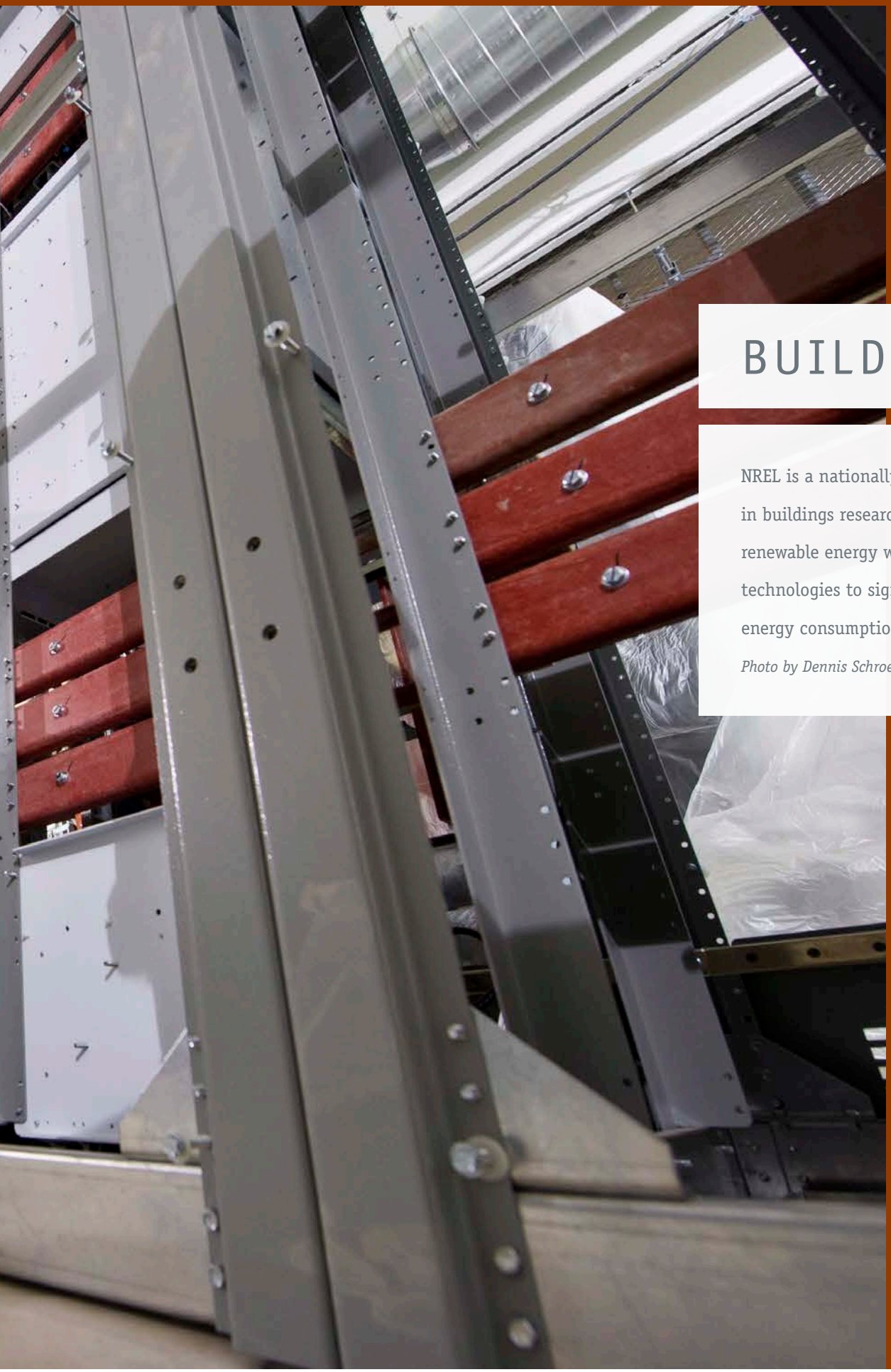
The NREL-Cobalt collaboration was successful for the company, as well. According to Cobalt, the fermentation demonstration validated the ability of Cobalt's organism to achieve commercial performance metrics at larger scales. It also confirmed that their process to produce renewable n-butanol is 40% to 60% less expensive than production of petroleum-based n-butanol.

"We were pleased with the results," Walther said. "We have been conducting demonstrations for our biomass-to-butanol pathways and are moving rapidly toward the construction of commercial-scale facilities. These demonstrations have given our partners some added comfort in the scaling up of the process and production organisms."

This is exactly the type of scale-up story that NREL planned to support with its IBRF facility upgrades—and the lab hopes that more companies will bring their scale-up challenges to NREL so that both sides can learn from the process.

"This is a role that NREL and the IBRF can play for start-ups that aren't able to invest in this kind of equipment," Ashworth said. "We've been working with these types of processes and materials for more than 20 years. We have the ability and staff to do the analytical work, material handling, pretreatment, saccharification, and understand the implications for fermentation. We can save these companies a lot of work if they choose to partner with us, because we have all of this experience in one place."

—Heather Lammers (June 19, 2012)



BUILDINGS

NREL is a nationally recognized leader in buildings research, combining renewable energy with innovative technologies to significantly reduce energy consumption in buildings.

Photo by Dennis Schroeder, NREL 20314

From Townhouse to Green House

Solar panels, solar-powered attic exhaust fan, light-emitting diode (LED) lighting, smart hot-water heater, biofuels fireplace… there's nothing in Kevin Donovan's townhouse that hasn't been analyzed, replaced, or upgraded to give him a better return on his energy dollar.

Donovan, while packing for a recent charity trip to Nepal, said his determination to reach net zero energy is equally about saving money and saving the planet. He's not going to save carbon dioxide just for its own sake—the changes have to make financial sense, too.

Take, for example, the new hot water heater with the smart heat pump recently installed in his two-car garage in Arvada, Colorado. The new heater draws hot air from the garage to make heating his water more efficient.

"It cost me $900 at Lowe's," Donovan said. "I got a $450 rebate from Xcel [his utility] and a $300 federal rebate. I sold the old hot water heater for $100. So, the whole thing cost me fifty bucks." Moreover, it is powered by 100% renewable energy.

Wind and Solar Just Some of Many Ways to Save

Donovan looked at the projected future costs of coal-generated electricity and decided it was time to make some changes. "I started off buying 100% wind credits. So from the first month I was in the townhouse, it has been powered by renewable energy."

Donovan then decided to invest in solar electricity. Right before his trip to Nepal, installers from Lighthouse Solar placed panels on his roof that will turn enough photons into electrons to generate 110% of his average monthly electric bill.

Most of that solar energy will power his own appliances and lights, but some of it will be loaded back into the grid, making it available for others. In turn, when the sun isn't shining, he'll use wind-powered electricity from the grid. Each month he'll come out a little bit ahead. However, instead of receiving a yearly check from his utility company, Donovan has elected to let the credits roll over into the next year, as they do not expire.

When Donovan bought his townhouse, he made sure it was fee simple, meaning he owned the roof and could thus legally install solar panels. This is supported by a recent Colorado law that prevents homeowner associations from saying "no" to owners who want to add renewable energy to their properties.

Donovan's mother started one of the first recycling centers in Texas in the 1970s, so he has been engaging in sustainable practices before it meant what it does today. "The idea of being sustainable before it was a catch-phrase has always been there for me," Donovan said.

Kevin Donovan uses an application on his smart phone to control the thermostat in his townhouse. He has cut his electricity use in half by installing energy-efficient lights and appliances. *Photo by Dennis Schroeder, NREL 20284.*

> “The idea of being sustainable before it was a catch-phrase has always been there for me.”
>
> —KEVIN DONOVAN, *NREL Data Center Manager*

“It goes with my job,” said Donovan, who runs a super-efficient computer data center at NREL.

Energy Efficiency in Every Room

On a tour of his home, Donovan points left, right, up, and down:

“Right here, that’s five 20-watt dimmable LEDs at $30 a piece,” he said. “Some of the bulbs are just $10 when they’re on sale.

“Three 3.5-watt LEDs give you the equivalent of about a 50-watt bulb,” he said. “Here’s a $30 fixture with $30 of bulbs in it.”

The LED bulbs can last up to 20 years, so over their lifetime they pay for themselves in the cost of the bulbs alone, compared to the cheaper, but less durable incandescent bulbs they replaced. The energy savings will be significant because unlike traditional bulbs, the LEDs don’t waste most of their energy as heat.

Donovan’s kitchen is equipped with ENERGY STAR® appliances—even the ceiling fans are ENERGY STAR. The floor tiles include recycled aggregate, and the wood floors are sustainable Brazilian walnut or bamboo.

Recently, he replaced his gas fireplace with one that burns biofuels. And on his smart phone, he has an app that adjusts the house’s thermostat—so he can do it anywhere in the world with an Internet connection.

At night, the thermostat is set to 60 degrees Fahrenheit (°F), and when he’s at work, it stays there. When Donovan is home, the indoor temperature rises to about 68°F.

“I have it time-based for each day of the week, and I can also lock both the thermostat and the hot water heater into vacation mode,” he said.

Donovan’s Nepal trip lasted 17 days, so he set the hot water heater to 50°F for 16 days, with a return to 120°F on the final day. “It was great to come back from traveling and jump in a hot shower.”

Donovan also has a programmable whole-house fan with high-tech actuated louvers that draw cool air from outside during summer evenings and mornings.

“You start thinking of all these little things that take 12 watts off here, 20 watts off there,” he said. “I dropped the watts by half just by changing some habits.”

Indeed, Donovan has cut his base energy load in half, from 500 watts to 250 watts. The 250 watts he does use fuel his power supplies, alarm clocks, appliance LEDs, wall chargers, and other devices that require a constant supply of energy.

— Bill Scanlon (April 3, 2012)

NREL Helps Cut Building Energy Use in Half

The blips of a heart monitor, the hum of an MRI, the intense lights of a surgical room: all can bring both comfort and fear—and all require a lot of power. But new hospitals are being filled with natural, calming light and are leveraging energy from the sun and earth to power the machines, instruments, and tools medical professionals use to help patients recover.

Hospitals use a lot of energy to save lives. In fact, they use more than 836 trillion BTUs of energy every year and produce more than 2.5 times the carbon dioxide emissions of commercial office buildings.

The U.S. Department of Energy's (DOE) Commercial Buildings Program and DOE's National Renewable Energy Laboratory (NREL) are working with the American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) and the buildings industry to find ways to reduce the energy intensity of large hospitals, schools, and retail buildings by 50%.

"The Advanced Energy Design Guidelines [AEDG] series represents the best practices in industry for energy efficiency in buildings," NREL Senior Research Engineer and AEDG Project Chair Shanti Pless said. "Our job is to develop those best practices, along with the professionals in the industry, and put them together in an easy-to-implement guide. NREL created the modeling and optimization software used to determine that what is going into the guides achieves a 50% savings goal."

The NREL commercial buildings team of Pless, Eric Bonnema, and Matt Leach led the development of the Large Hospital, Retail, and School 50% Savings AEDGs. Pless was chair of the project committees of industry experts, and Bonnema and Leach provided efficiency expertise and energy modeling optimization support.

U.S. hospitals spend more than $5 billion annually on energy, often equaling 1% to 3% of a typical hospital's operating budget. "Healthcare is a big opportunity for energy savings," Pless said. "We felt this industry needed resources, and there weren't many out there helping them to achieve 50% savings in energy."

The 50% AEDG series is a new group of publications that builds on previous successes. Collaborators including DOE and NREL published a series of six 30% AEDGs covering structures ranging from small office buildings to highway lodging to self-storage buildings. Between the 30% and 50% AEDGs, there are roughly 450,000 copies currently in circulation. The full series of AEDGs is available as a free download at www.ashrae.org/aedg.

"ASHRAE, a professional organization consisting of 60,000 mechanical engineers who work on energy efficiency in buildings, is an excellent organization through which we disseminate the guides," NREL Principal Lab Program Manager for Building

The Great River Medical Center in Burlington, Iowa, has energy consumption even lower than the 50% savings promoted in the Advanced Energy Design Guide for Large Hospitals. The lake plays an important role in the hospital's energy savings.
Photo Courtesy of KJWW Engineering Consultants, NREL 21237

Energy Technologies Ron Judkoff said. "ASHRAE also maintains commercial building standards for industry."

But Don't Just Follow Code

The building code is the baseline for the least energy-efficient building an owner can construct. Fortunately, there is nothing in building codes to stop building owners and construction companies who want to go for the most energy savings they can find—and that's where the AEDGs can bridge the gap.

"There is a lot of interest out there for 50% energy savings in buildings because just about anyone can do it, if they are paying attention," Pless said. "And it doesn't have to cost more if you are using streamlined design and construction processes."

The AEDGs are written for owners, design teams, and contractors—the professionals who will be constructing these buildings. If they don't have experience in energy efficiency, they can look to these guides for examples and details on how to do it themselves. The guides have recommendation tables for all climate zones in the United States.

AEDG recommendations are also built on technical support documents written by the national labs that accompany the design guidelines. These support documents cover the details of the energy modeling used. For instance, while daylighting works well in almost all climate zones, heating and cooling can require different solutions from zone to zone, especially in hospitals because of the high demand for fresh air.

"Hospitals have strict ventilation requirements, and they bring in a certain amount of fresh air along with a certain amount of recirculated air," Bonnema said. "There is a huge potential for savings if you set up your system differently, since most hospitals are using energy to cool the air and then heat it back up."

Jeff Boldt is the director of engineering for KJWW Engineering Consultants, and he was also a project team member for the Large Hospital AEDG. "It's really interesting when you look at a large hospital energy model; the biggest use of energy is the reheat. It's because you have to dehumidify all the air. For instance, you cool it down to 52 degrees in order to dehumidify it. Then, your boiler comes on to reheat the air. That process is usually the single largest use of energy in a hospital. This guide figures out how to get that reheat for free or cause the reheat not to happen at all."

> "There is a lot of interest out there for 50% energy savings in buildings because just about anyone can do it, if they are paying attention. And it doesn't have to cost more if you are using streamlined design and construction processes."
>
> —SHANTI PLESS, *NREL Senior Research Engineer and AEDG Project Chair*

According to Boldt, the AEDG will help the healthcare industry understand that there are practical ways to design a building that uses 50% less energy. "I like that they are prescriptive because a lot of people aren't comfortable with energy modeling. With the AEDGs, we've done all the energy modeling, and you can hand this to your design team and say 'I want you to follow the items in this AEDG,' and your team can go from a checklist and know what they are getting."

Running those energy models and finding climate-by-climate solutions wouldn't be possible without the computer modeling muscle at NREL. "From our optimization tools to mass modeling capabilities using 16 climate zones and five building types, all running different 'what if' scenarios, we are able to do all the modeling on a pretty condensed timeline," Pless said.

Schools are Ahead of the Class

"Research has demonstrated that the quality of the physical environment affects student performance," Pless said. "An environment that includes appropriate lighting, sound, temperature, humidity, and air quality can help students learn better. In many cases, improving these can also reduce energy use."

Schools can have similar heating, ventilation, and air conditioning (HVAC) issues as hospitals—specifically, decoupling of ventilation air from space heating and cooling. If engineers are able to provide the heating and cooling separately from ventilation, this basically eliminates the issue of reheat in schools.

NREL and the AEDG team have also produced a guide for K-12 Schools that includes:

- Three different HVAC system types that achieve significant energy savings
- Different ways to daylight 100% of the floor area of classrooms, resource rooms, cafeterias, gymnasiums, and multipurpose rooms for two-thirds of school hours
- Recommendations for computers, vending machines, kitchen cooking equipment, walk-in refrigeration equipment, kitchen exhaust hoods, and service water heating.

> "Net-zero makes a lot of sense for schools. They are built to last for 50 years, and a lot of effort goes into making them robust."
>
> —SHANTI PLESS, *NREL Senior Research Engineer and AEDG Project Chair*

The K-12 Schools AEDG was one that NREL chose to do early on because a number of schools are at the 50% energy-savings level, and there were many case studies to draw from. Pete Jefferson, a principal with Denver-based M.E. GROUP, was on the project committee for the K-12 Schools AEDG. He said the guides give professionals a solid starting base for energy design.

"These guides are a great shortcut for anybody who is working on a school. You can jump to the AEDG recommendations and start from there and see how much further you can go as a design professional," Jefferson said. "When we do our energy models, we use the AEDG recommendations as our new baseline to see how we can improve from there."

Some schools are even pushing the envelope to net-zero energy levels—which is something the team hopes to tackle in the next round of design guides. A net-zero energy building is one in which annual on-site renewable energy production is equal to or greater than energy use.

"Net-zero makes a lot of sense for schools. They are built to last for 50 years, and a lot of effort goes into making them robust," Pless said. "There are also teaching opportunities with energy-efficiency features and on-site renewables. So there are net-zero schools popping up, but having a design guide with best practices is key to helping them become widespread."

The NREL team sees a need for a complete net-zero design guide series. "Industry is starting to understand that it can be done," Pless said. "Having a net-zero office design guide is needed. There are examples across the country of offices that are attempting to do this."

The United States adds 2% every year in new buildings and only tears down 1%, which means the nation continues to add to its energy use when it comes to buildings. The AEDG team sees the opportunity to make the new buildings more energy efficient and sees even greater opportunities when it comes to deep retrofits, because the recommendations in the guides can apply to both.

"At these building rates, over the course of 20 years, you've touched over half of the buildings in America through retrofits or bringing new construction to 50% savings," Pless said. "That's measureable impact on the 40% of the nation's energy that gets used in buildings."

Another area where the AEDGs have had an impact is the town of Greensburg, Kansas. After a 2007 tornado leveled nearly the entire town, DOE and NREL helped the town leaders create a newer, more efficient Greensburg. In this case, a whole town was constructed that was able to achieve 50% energy savings. "Greensburg was kind of a demonstration for us that if 50% energy savings can be done here, it can be done anywhere," Pless said. "It exemplifies all the AEDG work that has been done."

— Heather Lammers (July 16, 2012)

Award-Winning A/C Uses Old Idea, New Materials

If thirst is crucial to knowledge, then one crucial step in the evolution of air conditioning was born in the 1970s, when Ron Judkoff was a hot, thirsty Peace Corp volunteer in Kedougou, Senegal, one of the warmest places on Earth.

"That's where I really saw the effectiveness of evaporative cooling," said Judkoff, director of Buildings and Thermal Systems at the U.S. Department of Energy's National Renewable Energy Laboratory (NREL). Judkoff was talking about DEVAP, NREL's Desiccant-Enhanced Evaporative (DEVAP) system that works in any climate and achieves comfortable cooling while saving 40% to 80% of the energy use of a conventional air conditioning (A/C) system.

"The Senegalese would make these clay pots to keep water in," he recalled. "The pots didn't feel wet on the outside, but they were semi-permeable. There was enough porousness in the clay that there was evaporation taking place. You could take a nice drink of cold water—and the water would stay cold in the pot."

That semi-porous clay operated in a similar way to the high-tech membranes in NREL's DEVAP system, which recently received a coveted R&D 100 award—often called the Oscars of Invention—from R&D Magazine.

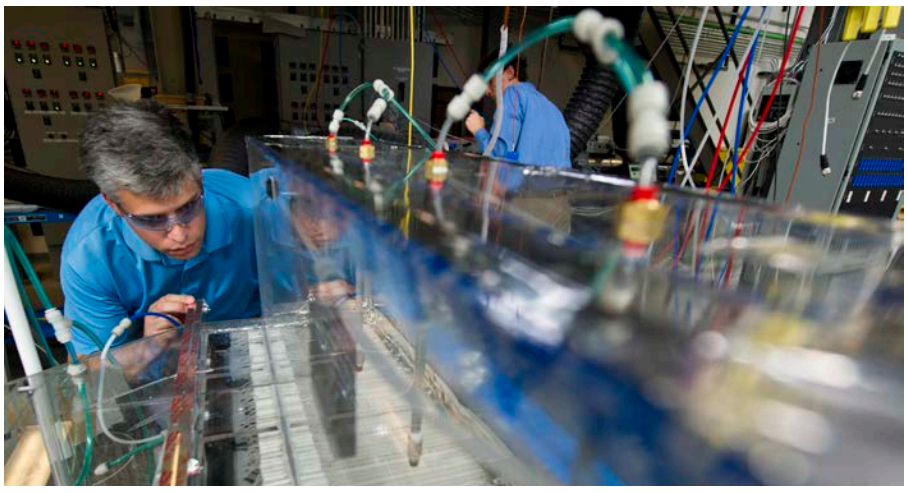
Learning from Indigenous Peoples and the Ancients

During his Peace Corps tenure, Judkoff also noted how indigenous people in Saharan and sub-Saharan climates would effectively cool their buildings with clever use of the spray from fountains and transpiration from plants. He went on to study at Columbia University under James Marston Fitch, a pioneer in bio-climatic architecture, and gained a greater appreciation for the ways ancient peoples and modern indigenous people achieved cooling. They could even make ice in deserts using night sky radiation. They fabricated wind scoops to channel soothing natural ventilation into otherwise stifling buildings.

Later, Judkoff researched desiccants—materials with the capacity to dry out moist air, which are a must if air conditioning is to be comfortable in a hot, humid climate.

In the 1970s, "I had this notion that if we could only combine desiccant and evaporative cooling we might be able to come up with something really important," Judkoff said. "But it was just a notion, because with the materials available at that time, the cost, the weight, the volume—it just didn't look like it would pan out."

Still, Judkoff never completely let go of the idea, and in his early days at NREL he oversaw the first full-scale leap into evaporative



NREL engineers Eric Kozubal, left, and Jason Woods conduct research on a DEVAP prototype at the HVAC Systems Laboratory. *Photo by Dennis Schroeder, NREL 20172*

cooling at NREL's second building, the Solar Energy Research Facility (SERF). In Colorado's dry climate, evaporative cooling by itself can achieve comfortable indoor climates. But it doesn't work in vast stretches of the United States and parts of the world where the air is too humid.

NREL Takes a Different Direction

Other national labs were tasked to try to improve on the elephant in the room—the vapor condensing air conditioner first designed by Willis H. Carrier in 1909. That left Judkoff and his NREL colleagues to look at alternatives to the dominant approach.

A key in combining desiccant drying with evaporative cooling was finding a way to separate the desiccant from the air.

Eric Kozubal, now NREL's principal investigator on the DEVAP cooling system, found a piece of the puzzle in a membrane that mimics the properties of the semi-porous clay. The holes are so tiny that they're referred to as micro-pores. The membrane allows the desiccant to pull moisture out of the air through the membrane while preventing any desiccant from coming in direct contact with the air.

A DEVAP air conditioner typically has a heat and mass exchanger that has hundreds if not thousands of air passages, each lined with a micro-porous membrane. A mixture of fresh air and building return air flows through these passages, and water vapor gets absorbed into desiccant flowing behind the membrane. Because this water vapor travels through the membrane, it is imperative that the membrane have sufficient permeability.

Simultaneously, adjacent air passages are in thermal contact with the flowing desiccant. These air passages are wetted with water, and a working air stream flows to evaporate this water film and thus remove the heat of absorption from the desiccant. This method of integrating indirect evaporative cooling creates a very efficient way to dehumidify the air.

Designing a Heat Exchanger with Four Fluid Streams

"Essentially, we were able to design a heat and mass exchanger with four fluid streams coming into thermal and mass transfer contact," Kozubal said. "We did this in a manner such that none of these streams became mixed with another." This was no simple task, and it was the ability to use membranes to contain the liquid desiccant that enabled such a design.

> "This air conditioner works by adding heat! We can use natural gas, solar heat, or waste heat from many industrial processes to drive an air conditioner."
>
> —ERIC KOZUBAL, *NREL Principal Investigator*

"It wasn't until advances in membrane technology and careful thermodynamic modeling and design that Eric was able to come up with a method to cheaply and efficiently build such an air conditioner," Judkoff said. There is a ticklish problem called droplet carryover, in which some of the corrosive desiccant gets entrained in the air. That air gets into the duct work and corrodes it. It can also corrode metal fan blades, and in rare cases, structural steel. DEVAP's membrane technology solves this problem.

Once the air is sufficiently dried out, a clever indirect evaporative heat exchanger design allows it to be cooled down enough to cool a building. What comes out is air as dry and cool as the air in Colorado on a nice fall day.

Air conditioning currently accounts for 15% of all electricity use in the United States, and can be as much as 70% of use during hot summer days. DEVAP's first iteration will be for the commercial market; later, it is expected to enter the residential realm.

NREL enlisted two companies—AIL Research and Synapse—as partners to build prototypes. The final R&D 100 award winning device incorporated ideas from each.

"We knew we couldn't just slap on any indirect evaporative cooler off the shelf," Kozubal said. "We needed an evaporative cooler that could reduce temperature below the wet-bulb temperature, minimize water usage, and purge air." And they needed to maintain a size and weight similar to conventional rooftop air conditioners for the entire DEVAP package.

Cooling Air with Heat

To cool the air that will enter the building (called the supply air) from the DEVAP system without adding moisture, Kozubal developed a counterflow indirect design. A small amount of the dry supply air is bled off and fed through an adjacent air channel flowing in the opposite direction to the supply air. That channel has wetted surfaces that cool this "bled-off" air via evaporation. The cold, wet channel then cools the adjacent dry supply air via conduction through the channel walls. The supply air is cooled to about 55°F while remaining dry.

To complete the cycle, the liquid desiccant must be dried out to remove the water it absorbed. To accomplish this, heat is added to the desiccant in another specially designed heat and mass exchanger called a regenerator. The heat drives the water out of the desiccant into an air stream that carries away the moisture and vents it to the outside.

"This air conditioner works by adding heat!" Kozubal said. "We can use natural gas, solar heat, or waste heat from many industrial processes to drive an air conditioner."

"I can foresee a time when this approach replaces most air conditioning in the world," Judkoff said.

DEVAP is an Energy Miser, Too

The other huge advantage of DEVAP is that it is an energy miser. A traditional commercial A/C uses 25% of its energy removing humidity, 75% dropping the temperature.

By contrast, DEVAP only uses energy for that first step—removing humidity. The second step is achieved simply by adding a little water.

"As a cooling process, evaporative cooling is incredibly efficient," Judkoff said. "The fact that we have to put a little energy into drying the air is more than made up for out of the efficiency of evaporative cooling. Especially compared to typical A/C, where you have to use electricity to compress the working fluid."

Numerous Advantages over Typical A/C

According to Kozubal, aside from large energy savings, DEVAP has several other advantages over conventional cooling, including:

- There is no need for environmentally damaging working fluids such as the chlorofluorocarbons, hydrochlorofluorocarbons, or hydrofluorocarbons used in vapor compression systems.
- The working fluids in DEVAP are environmentally benign: water and a strong salt solution for the desiccant.
- DEVAP allows independent control of temperature and humidity, something that is not possible with conventional A/C unless an expensive overcooling and reheating process is employed.
- There is no need for a compressor or large amounts of expensive copper coils.
- DEVAP contains fewer moving parts in the form of simple low-pressure pumps and fans.
- Vapor compression A/C has been incrementally improved for over 100 years, so there are few low-cost energy improvements left for that technology.
- As efficient as DEVAP already is, there is lots of "thermodynamic room" for cost-effective efficiency improvements.

A typical air conditioner cools the air and dehumidifies it all at once, but not in a controlled way. The limit to how much drying can be achieved depends on how much water condenses on the evaporator coils as the air passes through.

This so-called "wet-bulb limit" is the reason typical evaporative coolers either can't cool things down enough or can't create a truly comfortable space when there is a lot of heat and humidity in the air.

By contrast, DEVAP can provide cooling in any climate. The first stage wrings out all the moisture in the air. Doing so lowers the effective temperature limit the indirect evaporative cooler can achieve. It has a wet-bulb effectiveness of 125%—a huge boon compared to most current technology that has tried to get as close as it can to 100%.

"Developing a brand-new thermodynamic cycle and an apparatus to accomplish this process was difficult," Kozubal said. Conceptualizing this new device required a lot of ingenuity and breakthroughs in materials to become a reality.

"It took a lot of pondering. I spent a lot of time looking up at the ceiling."

— Bill Scanlon (December 17, 2012)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COMMUNITY OUTREACH

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

Photo by Dennis Schroeder, NREL 22288

Success Comes in Twos at the 2012 Science Bowl

The stakes were high at the Colorado High School Science Bowl, hosted by the U.S. Department of Energy's (DOE) National Renewable Energy Laboratory (NREL), as 27 teams competed for a shot to represent their home state in Washington, D.C., at the National Science Bowl in April 2012. As the day wore on and the competition stiffened, it began to seem as if 'two-of-a-kind' was the right hand to hold.

After a full day answering rapid-fire questions in physics, math, astronomy, chemistry, anthropology, and earth sciences, Cherry Creek High School scored a pair of dramatic victories in the final round to claim the Colorado championship and advance to nationals. Cherry Creek brought one loss into the final round of the double-elimination tournament against an undefeated Cheyenne Mountain High School team that appeared unstoppable. In order to claim victory, Cherry Creek had to beat Cheyenne Mountain twice.

Team Proud to Be Returning to Nationals

"Wow, that was intense," Cherry Creek team captain Rajeev Vishwamitra said. "We went up there with a lot of jitters. We knew how good they were, but we also knew that we could win. To beat them twice would be very difficult. We were trying to just stay focused on each question, one at a time."

Cherry Creek returns to nationals for the second time in three years, when the current team members, all seniors now, were freshmen. "We were just bystanders then," Atul Tiwary said. "But all of us on this current team have been together since we were freshmen taking physics, chemistry, and biology classes together. Seeing the team from three years ago, how they prepared, and being able to work together for such a long time really helped to motivate us and get us ready for this competition."

Members of the winning Cherry Creek team will start their journey for the national title in Washington, D.C., on April 26. DOE and NREL sponsor the Science Bowl program to provide an opportunity for students to embrace science, technology, engineering, and math studies as a primer for collegiate success and future careers.

More than 15,000 students across the United States compete for a trip to attend the National Science Bowl. Only about 500 make it. Students who participate agree that the competition enhances their understanding and appreciation of the sciences.

"This is a great way for students like us who are interested in science to get a chance to show what we know and to expand our own knowledge," Vishwamitra said. "It makes it more fun and keeps us focused. I'm fairly sure that everyone on this team will end up doing something science-related in the future, and participating in Science Bowl has helped to keep all of us engaged with that interest. It's also great to have a chance to meet and compete with students at other schools who have similar skills and interests."

Thomas Wu, center, celebrates a correct answer with his twin brother Kevin Wu, right, while teammate Evan Qi looks on. *Photo by Dennis Schroeder, NREL 20081*

> “Our hope is that a lot of these students, based on the positive experience and positive feedback from participating in these events [Science Bowls] will make the decision to pursue a course of study in science or engineering. That is good for all of us.”
>
> —**DAVID GINLEY,** *NREL Research Fellow*

Seeing Double on More than Just the Scoreboard

In addition to the exciting finish, the Colorado competition this year also was notable for an unusually high number of twins. Five sets of twins competed on the 27 teams.

For the team from Highlands Ranch High School, Science Bowl is a family affair. The team is anchored by twin brothers Thomas and Kevin Wu. Their coach is older sister Mengjie Wu, who was an intern at NREL in 2008. After-school practice sessions for the team were in the Wu family room.

“It was the first time for all of us and we really didn’t know what to expect,” team captain Thomas Wu said. “But we enjoy science and we enjoy competition so we expected that this would be good for us.”

The Wu’s Highlands Ranch team was impressive for being first time participants, finishing third and just missing an opportunity to compete in the finals. The Wu Brothers are juniors and their teammates are a sophomore and a freshman. Both teams that made the finals consisted entirely of seniors.

“We hope to be able to take what we have learned and come back even better next year. Hopefully, we will be in a position to be able to win next year,” Thomas Wu said.

No school participating had people seeing double more than Pueblo’s Centennial High School. Two sets of twins filled out the rosters of Centennial’s two teams. Gina Rossi and Kalie Saathoff are teammates on Team 1, while their twin sisters Rachel Rossi and Karyn Saathoff are on Team 2. Practice primarily involved competing against one another. “Competing and practicing against each other has been no problem,” Rachel Rossi said. “We’re all best friends as well as sisters and we’re all in this as a team trying to help each other.”

Kalie and Karyn Saathoff were participating in Science Bowl for the third time this year. “We love it because it’s a chance to do something different. Not many people do this, which makes it seem really special,” Kalie Saathoff said. “It’s a great opportunity to test yourself and find out how well you are retaining what you learn in class. And it’s a lot of fun too when you on a team with your sister and your friends.”

NREL and DOE Support of Science Bowl Over Two Decades Strong

For more than 20 years NREL and DOE have been actively encouraging high school students to expand their knowledge of math and science through the Colorado Science Bowl.

NREL Research Fellow David Ginley has been involved for almost as long. “At least 15 years now, maybe closer to 20,” he said.

“The questions have gotten a lot harder and the kids have gotten a lot faster,” Ginley said. “This is truly impressive. It’s amazing to me to observe how bright these kids are and how well they are able to answer really difficult questions.”

It takes nearly 70 NREL and DOE staff and volunteers to organize the competition and run it on the day of the event. The staff involved hopes the Science Bowl nurtures the next generation of scientists and engineers. “There is a potential future crisis in getting young people interested in science and technology,” Ginley said. “It is events such as these that act as the catalyst to help students make their decisions on what they want to study in the future. Our hope is that a lot of these students, based on the positive experience and positive feedback from participating in these events will make the decision to pursue a course of study in science or engineering. That is good for all of us.”

— David Glickson (February 7, 2012)

Fast Cars and Science Thrill Colorado Students

The buzz inside Dakota Ridge High School's gym on Saturday was palpable, the conversations ranging from whispers to shrieks.

Indy-500-style checkered flags, high-tech neoprene rubber tracks, and, of course, sponsor decals graced the site of the Junior Solar Sprint, Hydrogen Fuel Cell, and Lithium Ion Battery car competitions for Colorado middle schoolers.

Forty-five seconds before start time, seventh-grade boys raced to the repair table to solder metal parts together. Minutes after a time trial, eighth-grade girls had tweaked their designs and were ready for another heat, determined to shave a few seconds off their best time.

Parents smiled on the outside, butterflies churning on the inside. Coaches rounded up their teams; team members scattered to plot strategy or climb the wooden bleachers.

This wasn't your grandfather's mini-car race.

This was the 22nd annual electric car competition, sponsored by the U.S. Department of Energy's (DOE) National Renewable Energy Laboratory (NREL), the DOE Office of Science, Rocky Mountain Bottled Water, the Alliance for Sustainable Energy, Jefferson County Schools, Dakota Ridge High School, and the DOE Golden Field Office.

And to win, place, or just see solid improvement meant the world to participants in 104 teams from 23 Colorado schools.

Long Hours, Tangible Rewards

Cradling her hydrogen-powered model car like it was a baby chick, Naia Tenerowicz, 13, beamed in delight Saturday afternoon.

Her team's car, "Tommy the Tesla," had just finished first in a time trial, and its shape, engineering, and overall cuteness made it a favorite for the design award.

"It's made out of floral foam, the stuff you stick fake flowers into," Naia, a student at Woodlands Academy in Castle Rock, said. "It's really powdery, and you can squish it into shape easily. We spray it with sealant and then with white and green spray paint. And by then it's elastic and rubbery and a lot tougher."

The hydrogen fuel cell cars must use the standard cell sold by Numeridian, as well as a provided motor, electrolyzer, and battery pack. The rest of the design—chassis, wheels, shape, etc.—is up to the teammates, but the finished car can't be more than 20 centimeters wide or 40 centimeters in length. And to win a speed trophy, it had better get down the 10-meter track in about five seconds.

Yasmine Lamé, Naia Tenerowicz, and Grace Simpson of Woodlands Academy in Castle Rock celebrate winning first place in design for hydrogen fuel cell cars at NREL's Junior Solar Sprint, Hydrogen Fuel Cell, and Lithium-ion Battery car competitions, held at Dakota Ridge High School in Littleton, Colorado, on May 12, 2012. *Photo by Dennis Schroeder, NREL 20714*

The solar-powered cars must use one of two designated solar panels, must be less than a foot wide and two feet long, and must be ready to switch to AA batteries on a cloudy day—like Saturday. The cars race 20 meters down the neoprene track, hooked via eyelet to a taut guide wire to stay in a straight line.

Lithium-Ion Makes its Debut

This was the first year for a third design—the lithium-ion battery. Competitors used batteries, motors, connectors, and chargers provided by Horizon Hobby. Their races were won or lost by how well a team designed the rest of the car and how ingeniously they designed the compartment to carry extra payload—a 20-ounce water bottle placed on the chassis to provide stabilizing weight.

The winners of the inaugural lithium-ion race were from Fitzsimmons Middle School in Bailey, with a car named "Rage," which blazed to the finish line in just a beat over five seconds.

"We don't really have a captain, but Todd is the bossiest," Fitzsimmons team member Jeffrey Brown said.

Todd Bramblett cheerfully agreed. "Last year we went for a straight triangle, but this year we had a contest for the design that was the fastest, and we went with this one," which looks like a Gothic knife handle, Todd said. "I guess it worked fine."

The team credits a decision to put wide rubber bands on the rear wheels for the extra traction that gave them the victory by a few hundredths of a second.

Todd ranks the win as his second-greatest life thrill, right behind the motocross time trials he won when he was younger.

Todd, Jeffrey, Brian Wismar, and Justin Boline said they're interested in football, baseball, and other sports, but that in the long run they can see future careers in engineering or physics. They worked three hours a week for several weeks on the car, which will soon find a permanent place in their school's trophy case.

Woodlands Academy had a day to remember. It finished one-two in the race for the fastest solar-powered car with "Speedy Mercury" and "Perry the Platypus."

Its "Bobby the Bottle Rocket" won a first-place trophy for design in the lithium ion category, based on technology, craftsmanship, and innovation. And "Tommy the Tesla," the car Naia Tenerowicz cradled like a baby chick, came in first in design for the hydrogen fuel cell cars.

Students Have Stars and Science in Their Eyes

Naia, Grace Simpson, and Yasmine Lamé said they probably put in 100 hours on "Tommy."

Asked if this was their only interest, the trio laughed and said in unison, "We do everything."

"Legos, robotics, and all three of us were in theater," Yasmine said.

If they had to choose between an Academy Award for Best Actress and a Nobel Prize in Physics?

"Nobel Prize in Physics," Yasmine and Grace said without hesitation.

"Best Actress, I'm not going to lie," Naia said, laughing.

Wait 'Til Next Year

After the races and the awards, teams gathered their cars and their parts. Parents put arms on shoulders and said, "You'll do better next year," and "Are you kidding? You did great."

With the tracks rolled up and stored for the 2013 competitions, race starter David Ginley, a world-renowned scientist from NREL, took time to reflect.

"It was great. I think we're changing lives," Ginley, who has won five R&D 100 Awards for scientific innovation, said. "High school is sometimes too late; elementary school is too early. But right now, when they're in sixth, seventh, and eighth grades, something like this can really provide a spark.

"I've been doing this long enough that I've seen kids who've participated in these races, gone on to get internships at NREL during college, then come back as post-docs, making a career of it," he said. "It's very gratifying."

— Bill Scanlon (May 15, 2012)

NREL Summer Interns Lap Up Lab Experience

They come from the Ivy League, land-grant universities, and community colleges, with interests from the theoretical to the practical, to research solar cells, wind turbines, biofuels, computer modeling, analysis, and chemistry.

They're the 59 summer interns at the U.S. Department of Energy's National Renewable Energy Laboratory (NREL) and they're doing real research that generates real results to be published in real scientific journals.

Some were spurred by a caring high school teacher or an inspiring professor; others have had their eyes on NREL since they assembled a car for the solar races in middle school or participated in the Science Bowl in high school.

For 10 weeks every summer, college students from across the county migrate to Golden, Colorado, to work side-by-side with top researchers at the only national laboratory solely focused on renewable energy and energy efficiency research and development. This summer, there were 59 interns in four different programs. The largest program is the Science Undergraduate Laboratory Internship.

The summer internships are NREL's premiere workforce development program "to ensure that DOE, NREL and the nation have a sustained pipeline of highly skilled workers in science, technology, engineering, and mathematics," NREL Education Program Coordinator Linda Lung said. It's not uncommon for interns to eventually be hired as NREL researchers. This summer, for the first time, community college students were included in the roster of interns.

Community College Intern Designs, Tests Instrument

Dennis Paul, who attends Washtenaw Community College in Michigan, used his practical and theoretical skills to build a tool that controls the flow of biomass into a fluidized reactor that converts sawdust and pellets of New England hardwood into fuel.

He designed a three-eighth-inch diameter, two-foot-long auger together with housing, transfer tubes, and bearings. The precise flow of nitrogen gas keeps the bed warm and at a stable temperature.

"It was great," Paul said. "Our results were more significant than we expected. We found that keeping the temperature at 470 degrees Celsius (°C) instead of 560°C produced a lot more high-quality hydrocarbons such as toluene and xylene, and less benzene that you don't want.

"We found that cracking happens at a very specific temperature, and we were able to hold it a very steady temperature to make sure the catalyst works."

NREL intern Dennis Paul works on a new feed auger he designed and built for use in catalytic pyrolysis of wood at the Fuel Synthesis Catalysis Laboratory at NREL.
Photo by Dennis Schroeder, NREL 21957

Paul, who plans to transfer to the University of Michigan next spring, said he saved about $20,000 by going the community college route, "and in my physics and chemistry intro courses, I had classes of 30 instead of classes of 800 at the U."

Paul said his original goal was a mechanical engineering degree, but the work that seems most fun and challenging to him at NREL is being done by chemical engineers, so now he'll pursue that. "We'll see where it takes me."

"My dad was a skilled tradesman, and when something broke in the Paul residence, we fixed it," Paul said. He recalls the time on a family road trip when the van broke down. He and his father cut fuel lines, drilled a hole on one side of the dual gas tank, siphoned gas, switched lines, slathered some mastic, and went along their merry way.

NREL Senior Engineer Kristiina Iisa was Paul's mentor this summer.

"We were extremely pleased with Dennis," Iisa said. "I've only heard praise about him from everybody who has worked for him. He was really an outstanding intern, with a very good work ethic."

Iisa said the NREL internships often lead to career jobs at NREL. "But it also gets more people interested in renewable energy, even if they never go to work at NREL."

Paul's project "was something that was really valuable to our program, but which we would never have had the time and resources to do if it wasn't for the extra help during the summer," Iisa said. "The community college interns are very motivated, and for the most part interested in continuing their studies. At least in Dennis's case, we also got more practical skills than we often get with university interns."

Testing Trucks and Electric Vehicles for Thermal Load

Esther Chan is from the two-year Canada College in Redwood City, Calif., with plans to transfer to the University of California at San Diego.

She tested two semi-truck cabs and two electric vehicles for a long-term project that tries to use different paints and reflective materials to keep the interiors from getting too hot or too cold.

> "I said to myself, 'I have to do this.' So I just went for it and I haven't looked back."
>
> —**ESTER CHAN,** *NREL Summer Intern*

"Annually, 838 million gallons of diesel fuel are used in the United States just for the rest periods when trucks idle," she said. "And another 7 million gallons of fuel are used for idling passenger cars.

"We're trying to figure out new ways to reduce the amount of gallons used."

This summer, Chan set up a data acquisition system to gauge interior temperatures in the trucks and cars. She installed thermocouples in several different places in the vehicles; the trunks of the cars look like a full spaghetti dinner worth of red wires.

She tested on July 20, the mid-summer day when the solar load is most likely to be at its maximum. The instrument panel on one of the vehicles shot up to about 66°C—more than 150°F.

"Next year, we'll look at what different paints and other solar reflective material can do to reduce thermal load," she said.

Out of high school, Chan wasn't sure what she wanted to pursue. Watching a Discovery Channel show on future car concepts and in particular hydrogen fuel cells "blew my mind," Chan said. "I said to myself, 'I have to do this.' So I just went for it and I haven't looked back."

She calls the NREL internship "my greatest experience ever. I learned so much."

Analyzing Wave Energy in the Lab

Chris McComb, who just graduated from California State University at Fresno and will be attending Carnegie-Mellon University in Pittsburgh in the fall, is spending the summer at NREL modeling waves to advance knowledge about the potential of wave-generated energy off the European and American coasts.

"My mentors have been great," McComb said. "They're both post-docs and very easy to relate to. They know a ton and are willing to share it.

"Every Friday, we get together with our mentors for a research update. It's really cool to see what everyone else is doing," McComb said. "You want to keep up with the Joneses."

Hours in the lab are long, but there's still time for fun. "We get together," McComb said. "We've gone to a few breweries, several pot lucks."

His interest in environmental sciences sprang from his boyhood in California's Central Valley. "In the mornings, we'd drive into the valley and see this blanket of smog. Seeing that disparity between the clear skies higher up and the smog in the valley is what inspired me to get into science."

Three Summers, Three Different Projects

Natalie Bodington in her third summer as an NREL intern, just graduated from Brown University in Providence, Rhode Island.

This summer, she worked on a model that finds the best places in Colorado to site wind and solar farms in order to meet the state's mandate of 30% renewables by 2020.

"We have a huge database looking at hourly profiles of the wind and solar resource," she said.

"I started out very much hands-on with experimental materials," Bodington-Rosen said. "This summer I transitioned to something more market-oriented, focusing on modeling; which is in line with my thesis. It was great to make that transition."

After graduation from Brown, she plans to do a little traveling and then "test the job market" before going on to graduate school.

Loving the Experience

Tabitha Evans, from the University of North Dakota, spent 10 weeks helping design an instrument, then analyzing alkaline metals in three types of biomass to see how eucalyptus fared compared to pine or switchgrass.

"We used a process that allowed us to get rid of all the organic materials, so we would just see the metal," she said. Using a sample boat, a furnace and a skimmer, she heated and ionized the samples to get a precise read on the amount and kind of metals mixed in with the biological material.

"We found that eucalyptus had more metals than pine, but less than switchgrass," which keeps eucalyptus in the running as a possible biofuel heavyweight, she said.

Evans said "I loved this internship. My idea of government lab work had been what you see in the media, people in fancy white coats in a perfectly clean lab."

"That wasn't my experience at all. I worked in a real interesting space and I had to build the instrument. I didn't realize you got to do things like that. I loved being a part of that."

Her NREL mentor was Calvin Mukarakate who praised Evans for "her hard work and her ability to do things by herself. She was in on the design of the whole instrument and she tested it and it worked well. She's a self-starter."

— Bill Scanlon (September 4, 2012)

Schools Raise the Roof on Solar Energy

In one 50-minute period last month, the Intro to Engineering students at Chatfield High School in Jefferson County, Colorado, charted the strength of solar panels at their desks, then climbed through a trap door to examine the 100-kilowatt solar array on their school's flat roof.

"You see a couple of panels that have been shattered by last year's wind storm," teacher Joel Bertelsen told the 32 students, who were peering intently at the panels when not testing the springiness of the roof. "It hasn't affected the efficiency of the system much so far."

As more and more schools install solar panels on roofs, more and more students inside are getting a wide spectrum of knowledge about solar energy—thanks in part to the U.S. Department of Energy's National Renewable Energy Laboratory (NREL).

Jeffco Public Schools is Colorado's largest school district, with (nearly) 86,000 students and 154 schools—and it sprawls from the plains to high mountain peaks.

Thirty of its schools have rooftop solar panels. Golden Power Partners collaborated with Renewable Social Benefit Funds (RSB Funds) for financing, using combined federal and state incentives as well as Xcel Energy renewable energy rebates, and Tecta America for construction.

Jeffco Public Schools paid no upfront costs, and the "Solar on Schools" project is expected to save Jefferson County taxpayers $2.88 million in energy costs over the next 20 years. RSB Funds will own and maintain the solar panels, and it will sell the electricity the panels produce to the district at a price below its current utility rate.

To further amplify its green credentials, the school district two years ago called for proposals to bring solar into the classroom.

"We worked with Golden Power Partners to incorporate a user-friendly data acquisition system that the teachers and students could use in the classroom to get live data about their solar systems," Linda Lung, manager of education programs at NREL, said.

Golden Power Partners and NREL chose DECK Monitoring to set up a system that allows the students to see how their solar panels are working at the very moment, that day, that week, that month, or that year. And the students can compare how fast their school is turning photons into electrons compared to a school 30 miles away.

"And in Jefferson County, that can mean vastly different weather," Lung said. "There could be a blizzard in Evergreen in the mountains, while the sun is shining in Arvada—or vice versa, for that matter."

Chatfield High School seniors Jack Long, Zach Kugler, and Nichole Hagen get help from teacher Joel Bertelsen as they learn how a light source affects volts and amps on a solar panel. *Photo by Dennis Schroeder, NREL 22272*

> "I'm trying to get students excited to be a part of the solution to one of the most important problems we will face as a society: diminishing resources in an energy-hungry world."
>
> —**JOEL BERTELSEN,** *Chatfield High School Teacher*

Students are having great fun finding out how weather can affect the panels' performance.

Live Data Bolsters Intensive Solar Curriculum

To ensure that the students get first-rate knowledge about solar energy, NREL used the $30,000 awarded to the winning proposal to organize spring and summer Energy Institute for Teachers workshops attended by the most interested math and science teacher from each of the 30 solar-powered school—which include elementary, middle, and high schools.

"NREL worked with Jeffco staff to integrate standards-based renewable energy lessons with the data monitoring system so teachers could incorporate the actual real-time data into science and math classes. The photovoltaic system becomes a learning laboratory and an exciting learning tool—plus the school benefits from all the clean, renewable electricity it produces," Lung said. So a sixth-grade math teacher might have students graph differences in peak performances or changes brought on by cloudy days.

Bertelsen attended NREL's spring workshop and wasted little time incorporating solar into his Intro to Engineering class, which is comprised of seniors with their eyes on two-year or four-year colleges.

Experimentation Leads to Deductive Reasoning

On a recent day, Bertelsen's students were using meters to gauge the changes in volts and amps as artificial light moved farther away from the CD-case-sized solar wafers at their desks.

"So at 3 inches, we're at 5 volts," Chatfield senior Sebastian Goff said. "Let's check it at 6 inches."

After a few more measurements, a few hot fingers, and a few false starts, the pattern was clear:

"There's a direct relationship with the amps," Hoff said. "Twice the distance means half the amps."

"But the voltage doesn't change much no matter what the distance," said Brian Hoover.

"I'd say that as the light is spread over a larger area, the light is more dissipated, so it is producing less current," Marcello Nicoletti said. "I know from last year's class that voltage is potential flow and current is actual flow. So it makes sense that voltage wouldn't really change much."

That's the kind of deductive reasoning the Solar on Schools program is meant to inspire.

Bertelsen noted that his enrollment numbers have increased by about 60% since incorporating renewable energy into his curriculum.

"During registration last year, I emphasized to prospective students the renewable energy piece that I had added to the class. I'm trying to get students excited to be a part of the solution to one of the most important problems we will face as a society: diminishing resources in an energy-hungry world."

Workshops Prepped Teachers to Spread the Word

Bertelsen took away valuable lessons from NREL's workshop.

"Once we've learned some basics using the three-panel test boards, we can expand to calculate how many of our little panels we would need to match our 100-kilowatt system," Bertelsen said. "This will allow us to tie what we're doing in the classroom to the system on the roof."

He was wowed by the DECK Monitoring software, which he says will give him more options. "We'll use the software to study daily output, weekly output, monthly, and beyond. In addition, we can study the effects of weather on output by using the irradiance, cloud cover, and temperature readings that are displayed on the DECK Monitoring website."

After learning about photovoltaic electricity generation, his students will study ways to store the energy when it's not being used. They will consider many different methods of energy storage, including hydrogen production through the electrolysis of water, battery storage, and potential energy storage, which pumps water into a high reservoir for later use in a hydroelectric plant.

The students like the hands-on learning—but except for grumbling about the price of gasoline, they don't have a good grasp on the pros and cons of fossil fuels versus renewable energy. Bertelsen hopes to change that.

The trip to the roof was a good start, as students probed him with questions about angles, wavelengths, and hail damage.

As the students headed down the trap door from the roof, Nichole Hagen, the only girl in the engineering class, said she won't be dissuaded by the gender imbalance. She knows that at NREL, just a few miles away from the school, women make up a sizable minority of engineers and scientists. "I want to be an architect, and energy efficiency is getting so important in new houses," she said. "When we run out of natural gas and coal and stuff, we're going to have to find new energy sources."

— Bill Scanlon (October 16, 2012)

"I want to be an architect, and energy efficiency is getting so important in new houses. When we run out of natural gas and coal and stuff, we're going to have to find new energy sources"

—NICHOLE HAGEN, *Chatfield High School Student*


AURORA
AURORA
DC Disconnect & Wiring Box
ON
OFF

ENERGY ANALYSIS

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

Photo by Dennis Schroeder, NREL 20304

Solar Leases Attracting New Demographic

The sun is shining on homeowners in less affluent neighborhoods who are discovering they can afford solar energy after all—by leasing rather than buying the panels on their roofs.

The new business model lets homeowners save money the very first month, rather than breaking even a decade after an initial investment of $5,000 to $10,000.

Analysts with the U.S. Department of Energy's (DOE) National Renewable Energy Laboratory (NREL) found that the solar lease business is surging in southern California. And the model is being adopted in less affluent neighborhoods that had avoided customer-owned systems.

The NREL study found a positive correlation between customers outright buying solar energy systems and customers living in neighborhoods where the average household income was $150,000 or more.

But for third-party-leased solar panels, that positive correlation appeared in neighborhoods where the average household income was just $100,000 or more.

The study did not look at individual adopters, who can have many different reasons for installing solar. Still, the study strongly indicates an attraction for third-party leasing in neighborhoods with less affluence than those most likely to go for the customer-owned option.

If what's true in southern California proves true for the nation, it means that rooftop solar power could attract an additional 13 million Americans—and that could push solar energy into the mainstream.

Leasing Opens Solar to New Markets

NREL's Easan Drury is the lead author of the Energy Policy report "The Transformation of Southern California's Residential Photovoltaics Market through Third-Party Ownership."

"What is so interesting about the southern California data is that the strong decrease in PV prices—from lower retail costs and stronger federal incentives—didn't pick up a new demographic," Drury said. "But a new business model—leasing—did pick up a new customer demographic."

Repackaging the value of PV as a simple savings on the monthly electric bill is an attractive alternative to the pitch that it will pay for itself in a decade, he said. "If someone comes up to you and

Kyle Travis (left) and Jon Jackson (right) of Lighthouse Solar install microcrystalline PV modules on top of Kevin Donovan's townhome in Arvada, Colorado. *Photo by Dennis Schroeder, NREL 20286*

says you can make money next month and forever, that totally changes how people see the value of solar."

Immediate Savings is a Lure

The differences in upfront costs are stark between buying and leasing. Heather and Kit Lammers put $3,000 down for a 5.64-kilowatt system that is providing 62% of the electricity for their two-story home in Erie, Colorado. If they had bought the system outright, they would have had to pay more than $9,000 with incentives, or as much as $20,000 without incentives.

The Lammers had been averaging $107 per month for electricity. Now, they're paying $64 per month to lease the solar panels, plus $41 per month to utility Xcel Energy, which represents the 38% of their electricity use that won't be offset by solar energy.

That gives them only $2 per month in savings the first year. But the real benefits come over the next two decades, when that $64 lease payment stays constant while, presumably, the price of fossil-fuel-powered electricity rises with inflation. When their two-year-old graduates from college, the Lammers will still be paying the equivalent of 12 cents per kilowatt-hour through their solar lease arrangement.

Estimated total savings for the Lammers, after recouping their original $3,000 down payment, is more than $9,000, according to their solar provider, Solar City.

NREL Employees Bring Their Work Home

At NREL, where scientists and researchers are on the cutting edge of renewable energy and energy efficiency, an unofficial motto is "walk the talk."

Heather Lammers is one of several NREL employees who are embracing the solar lease model, in which the company keeps the state and federal incentives, but the customer enjoys the lower total electricity cost.

"Solar on our home was something we've wanted but thought we'd never be able to afford because of the upfront costs—even with the incentives," Lammers said. "When we first heard about solar leasing, we jumped at the opportunity. It has made something we thought to be unreachable a reality."

NREL analyst Michael Mendelsohn signed on with Solar City and selected the company's "$0 Down Plan" with no upfront cost. He pays just $22 per month to lease a 3-kilowatt system, which covers most of his electric bill and already gives him a net savings each month. Mendelsohn is something of an energy miser: he never runs air conditioning, has installed efficient lights, has all ENERGY STAR® appliances, and hangs the laundry to dry.

On the other hand, "I have a giant TV and kids who never turn off the lights," he said. "It's a great feeling to get free electricity on a sunny day."

NREL market analyst Lori Bird bought her system outright two years ago before third-party leasing was much of an option. Namasté Solar installed a 5-kilowatt system on her family's two-story house in Boulder. "It covers most of our electricity use," she said. "We refinanced our house and rolled it into the new mortgage. We save more from the PV system than we pay extra in mortgage."

> "When we first heard about solar leasing, we jumped at the opportunity. It has made something we thought to be unreachable a reality."
>
> —**HEATHER LAMMERS,** *NREL Employee*

Sun Can Power Electric Cars

My wife and I put $5,000 down for a system that will provide 120% of our current electric needs. The panels, designed by SunPower and provided by Independent Power Systems, fit on our steeply pitched detached garage, facing south.

Our monthly lease payment is $13.

There is room for two more panels on the garage, but 120% of current electricity usage is the limit set by most utilities, including ours. We will get a small check back from our utility once a year because we'll send more power onto the grid than we use.

Our long-term plan is to buy an electric vehicle that has a range of about 80 miles and can be recharged in the garage each

night. Once that extra draw of electricity starts to appear on our electric bill, we'll be eligible to install a couple more panels. With the help of light-emitting diode (LED) light bulbs, we hope to get all our household electricity needs and about two-thirds of the electric car's fuel needs via the sun.

Solar Prices Dropping Sharply

The steep drop in the prices of solar panels also has played a significant role in the growth of the solar market. Solar cells are being made for fewer dollars, and the costs of putting together the rest of the system and installing it are dropping, too.

The average installed cost in 2008 was about $9 per watt. That dropped to about $7 per watt by early 2011—and now there are indications that the latest residential installs are costing less than $6 per watt.

In 2008, there was a shortage of polysilicon, a main ingredient in many solar cells—so demand outpaced supply, driving up costs. Since then, silicon prices have dropped.

Among Drury's other findings:

- Third-party leasing usually eliminates the need for home-equity-style financing and thus the need for significant equity in the home. Without the hurdle of financing, more people can adopt solar, Drury said. "Not just the people who buy Priuses or who are the first to buy the latest electronics." The benefits provided by third-party ownership—lower upfront costs, secured financing, less complexity and risk, immediate savings on the monthly electric bill—can entice a broader base of customers to adopt PV, he said.
- Along with the lower income threshold, Drury found a surge in solar leasing in neighborhoods with younger families.
- In the Los Angeles and Orange County markets, customer-owned PV was five times more prevalent than third-party-owned PV in 2009. In 2010, the ratio had dropped to 2:1. And for the first quarter of 2011, the ratio was almost even.

Prices Vary, So Shop Around

Drury notes that lease terms vary significantly between different companies, so it is best to shop around.

What makes most sense to you? A low down payment with higher monthly lease payments? A down payment just high enough to start saving month to month?

Find out whether the lease terms will stay the same for 20 years or, say, rise 3% a year to counter inflation.

Prices have dropped so much in the past three years that some traditional price comparison websites might be out of date.

Homeowners contemplating leasing solar panels should read what they can and then make sure they compare prices offered by several solar lease companies, Drury said. "You do see a wide range of prices, so you want to be sure you're getting a good deal.

"Definitely do as broad a search as you can to see what the different offerings are," Drury added. "And make sure you understand the terms of your lease."

— Bill Scanlon (April 3, 2012)

NREL Narrows Energy Tech Emissions Estimates

The question of which energy technologies generate the most greenhouse-gas emissions—cradle to grave—now has a more precise answer, thanks to a meta-analysis of life cycle assessment (LCA) studies done by the U.S. Department of Energy's (DOE) National Renewable Energy Laboratory (NREL).

The new, robust analysis weighed the emissions estimates per kilowatt-hour from raw materials, manufacturing, transportation, operation, and decommissioning to get the best apples-to-apples comparisons. Sure, during operation solar panels release virtually no emissions, versus the tons of greenhouse gas produced by a large coal plant. But what about the emissions generated from the manufacture of solar panels versus, say, the turbines required for coal- and wind-based energy?

NREL's LCA Harmonization Project gives decision-makers and investors more exact estimates of greenhouse-gas emissions for renewable and conventional generation, clarifying inconsistent and conflicting estimates in the published literature and reducing uncertainty.

The analysis found that from cradle to grave, coal-fired energy releases about 20 times as much greenhouse gas into the atmosphere per kilowatt-hour as solar energy. Wind and nuclear energy are on relative par with solar energy. Natural gas generation wasn't included in the final analysis but is generally assumed to emit about half as much greenhouse gas per kilowatt-hour as coal.

What's more, the "study of studies" narrowed the huge ranges of estimates sometimes as much as 90%, presenting a more reliable look at the likely greenhouse-gas emissions from different technologies.

Decision-Makers Need Environmental Costs Before Giving Go-Ahead

Lifetime greenhouse-gas emissions are an increasing concern for lawmakers and investors who must weigh the merits of a new coal-fired plant versus, say, a wind farm, and need to know not just the relative dollar costs but also the potential harm or benefits to the environment.

Until recently, emissions estimates ranged wildly, sometimes because vested interests had a stake in demonstrating that a certain technology's emissions were high or low. For instance, if decommissioning costs aren't included in a total-emissions estimate for nuclear energy or natural gas, those studies give artificially low figures.

NREL was seeing surprisingly high emissions numbers for concentrating solar power (CSP) plants, but deeper digging

NREL Senior Scientist Garvin Heath works on data from the life cycle greenhouse-gas emissions study conducted by NREL's Strategic Energy Analysis Center. *Photo by Dennis Schroeder, NREL 20688*

found that many studies combined the numbers from both CSP and natural gas when a utility used combustion of natural gas to supplement solar-energy generation. When the harmonization process allowed CSP emissions to stand on their own, the numbers plunged.

NREL looked at more than 2,000 studies across many generation technologies, applied quality controls, and greatly narrowed the range of estimates to reach reliable medians for greenhouse-gas emissions.

"This methodology allows you to arrive at a better precision, so you can say with more certainty that this is the benefit you get from using this technology rather than that technology," said NREL Senior Scientist Garvin Heath, who led the project. "Anyone who wants a true comparison of the greenhouse-gas costs should benefit from this."

Heath noted that today's decisions on new plants will still have ramifications decades from now. Owners and investors will need to know about greenhouse-gas emissions and their possible effect on the bottom line, while policy-makers need to know the long-term implications of greenhouse gas on climate.

Investors "need to be very forward looking," Heath said. A power plant is long lived, and its attributes and shortcomings are locked in for decades. That's why investors push for estimates of greenhouse-gas emissions before they invest.

President Obama's clean-energy standards require these estimates for each technology as a way to assign credits or discounts for building new plants. Credits, discounts, and the possible future price of carbon all figure heavily into decisions on which technology to choose.

"Analysts and decision-makers want a more robust sense or a narrower range of uncertainty to make the best decisions," Heath said. Until now, no one has tried to differentiate between low- and high-quality estimates in a comprehensive way.

Narrowing Estimates to a More Reliable Median

Heath, Technology Systems and Sustainability Analysis Group Manager Margaret Mann, and their colleagues at NREL's Strategic Energy Analysis Center discovered that there is no shortage of reports and studies estimating the greenhouse-gas emissions of various energy technologies—in fact, there are hundreds for each—but they vary greatly in quality, consistency, and validity.

> "As a society, we need to better understand what the effects of our energy choices are. Greenhouse gases and climate change are a part of the discussion. As we try to envision what our future energy system will look like, we need an accurate picture of what that transition will mean."
>
> —**GARVIN HEATH,** *NREL Senior Scientist*

Narrowing these ranges of estimates is like hooking together a 1,000-piece jigsaw puzzle, or solving a devilish crossword.

Heath and his colleagues narrowed down the various studies to those meeting minimum thresholds for quality, relevance, and transparency. They looked upstream, making sure to include the materials that go into building a solar, wind, or coal plant. They examined in detail the emissions that occur when the plant is in operation. And they looked downstream: when a plant ceases to operate, what are the environmental costs of decommissioning it?

After harmonizing 397 LCA studies of greenhouse-gas emissions from photovoltaic (PV) projects, the study found a median of 45 grams of carbon dioxide emitted per kilowatt-hour of electricity generated. Just as important, the middle 50% of the range (75th minus 25th percentile) of differences narrowed—from 44–73 grams before the harmonization to 39–49 grams after the harmonization.

The 45-gram median for PV contrasts with a 1,001-gram median for coal.

Nuclear energy was found to have a large range even after harmonization reduced the published range by 50%, to 4–110 grams. The median harmonized estimate for nuclear is 12 grams, very similar to that of many renewable technologies.

Concentrated solar power's (CSP) medians were 26 grams for parabolic trough plants and 38 grams for power towers. Thanks to harmonization, the variability in estimates for CSP was reduced by 91%.

Thin-film solar cell technology demonstrated very low greenhouse-gas emissions: a median of 20 grams for amorphous silicon; 14 for cadmium-telluride; and 26 for copper indium gallium diselenide, with overall ranges reduced from 19–95 grams to 18–52 grams equivalent carbon dioxide per kilowatt-hour.

For wind, the harmonization study was able to narrow down the wide range of published estimates—1.7–81 grams—to a harmonized range of 3–45 grams (a 47% reduction) and a more reliable median of 11 grams of carbon dioxide per kilowatt hour.

The Fine Art of Comparing Apples to Apples

"We did a systematic review of the literature—not just peer-reviewed journals, but government reports, theses, reports from non-government organizations, and private companies," Heath said. "We had to verify them all."

The team brought in experts from different disciplines, including technology experts, literature search experts, and experts in LCA.

"We screened for quality and for transparency, and we screened out the studies that were of older technologies that probably won't be going forward."

If a study didn't use sound methods, it was out. But if a good study lacked a particular variable—such as not considering decommissioning—the team used formulas to add in greenhouse-gas emissions from those activities so the otherwise-satisfactory study could be included.

"After our quantitative adjustments, each study included in the final analysis was consistent in the broad sense, if not in every detail," Heath said.

Harmonization studies help guide policy locally, statewide, and nationally. Lobbyists, lawmakers, and the cost-analysis community can all use the harmonization estimates as building blocks to make their own estimates for specific projects or to guide policy.

"They can get numbers to plug into their own models; they can use our literature to assess the climate impacts of transitioning to new forms of energy," Heath said.

Findings Appear in Special Edition of *Journal of Industrial Ecology*

The NREL method is being heralded as an important step forward in LCA studies that paints a clearer picture of the environmental penalties and benefits of different technologies.

NREL's findings appear in six articles and an editorial in the April 2012 special supplemental issue of the Journal of Industrial Ecology on Meta-Analysis of Life Cycle Assessments.

Also contributing to the findings were subcontractors and researchers from DOE's Brookhaven National Laboratory.

"This is great work," said Reid Lifset, editor of the Journal of Industrial Ecology. "Garvin and his crew have done something very important."

A Crucial Tool for Future Decision Making

"As a society, we need to better understand what the effects of our energy choices are," Heath said. "Greenhouse gases and climate change are a part of the discussion. As we try to envision what our future energy system will look like, we need an accurate picture of what that transition will mean."

"The scope of these syntheses is staggering and provides real insight into what can be done with the burgeoning research literature in industrial ecology," Lifset said.

Peter Crane, Yale University's dean of Forestry and Environmental Studies, agreed: "The application of meta-analysis to life cycle assessment is an important advance. Decision-makers seeking to make greener choices need a way to make sense of the information that is coming at them so quickly now. This can help."

Heath added: "If we care about stabilizing our climate, we need to look at greenhouse gases. This study assembled the best available and most robust evidence. It helps us see the state of our planet, and it can help us make better decisions going forward."

— Bill Scanlon (May 10, 2012)

New Tool Makes Saving Electricity Easier

Thirty-one million American homes will be getting computer-friendly data about their electricity use from their utility companies, thanks to the work of the U.S. Department of Energy's (DOE) National Renewable Energy Laboratory (NREL) and a nudge from the White House.

The new consumer tool is called Green Button, and customers can link to it from their utility companies' portals. Green Button, based on exacting standards, helps consumers make informed purchase decisions and adjust electricity use to save both energy and money.

The Green Button initiative's main goal is to simplify energy data access for consumers. The federal government is encouraging utility companies to give consumers the ability to easily access and share their own energy use information for insight into how best to manage their consumption.

Green Button is an example of the government encouraging industry to accelerate the adoption of a standard, rather than issuing a federal mandate. The goal is better-educated energy consumers—which can be good news for both the planet and consumers' bank accounts.

Green Button is based on a standard developed by a working group of the North American Energy Standards Board (NAESB) at the request of the Smart Grid Interoperability Panel, a public-private partnership. The Energy Service Provider Interface (ESPI) standard brings together work done by ASHRAE, the EIS Alliance, IEC, and NAESB into a single specification for exchanging energy use information between utilities, customers, and third-party application developers. Having a common data format opens a broad market for entrepreneurs to develop innovative products that help customers understand and manage their energy use and utility bills.

Green Button is a White House initiative. Former U.S. Chief Technology Officer Aneesh Chopra announced the start of the initiative on January 18, 2012. It was initially adopted by three of California's largest utility companies.

NREL Helped Develop Standards

NREL was integral to the development of the standards for Green Button, as well as a consistent way to report the data. NREL's Scott Crowder noted that NREL-developed OpenEI.org provides a place for application developers to make their Green Button apps available.

Once logged into the utility's website, customers see a Green Button icon. Customers click the button to download their personal energy use data in the common format defined by

The Green Button program makes it easier for consumers to track their energy use and find ways to save on utility bills. Joe Lucas stands next to his photovoltaic meters outside his Denver home. He is participating in the Solar Benefits Colorado employee solar discount program. *Photo by Dennis Schroeder, NREL 22187*

> “That is a great embodiment of the challenge as a whole. They’re boiling down a complex concept to a simple one.”
>
> —**MONISHA SHAH,** *Promoter of The White House’s Green Button program*

the ESPI standard, which was developed jointly by industry and government. To learn more about the data, they upload it to any of several Green Button apps. Future versions of the standard will allow customers to set up a secure subscription so they will no longer have to manually transfer the data from the utility to their favorite apps.

Many of the apps on OpenEI came by way of DOE’s recent “Apps for Energy” challenge, intended to spur app developers to come up with tools to help define energy-saving strategies.

For example, customers can upload their data to one app for a “no-touch” energy audit that will show them how to save energy. The audit can show them that, say, running their dishwasher at times when there is little other demand for electricity will help avoid paying peak-demand rates, said Monisha Shah, who is on assignment with the White House to help promote Green Button.

One Apps for Energy award winner quantifies energy savings in terms of the number of trees saved. “That is a great embodiment of the challenge as a whole,” Shah said. “They’re boiling down a complex concept to a simple one.”

Thanks to the initiative, the number of Green Button applications housed on OpenEI skyrocketed from six to more than 60, Shah said. Innovation spurs innovation, and the number of apps is expected to continue to grow.

— Bill Scanlon (October 8, 2012)

ENERGY SYSTEMS INTEGRATION

NREL's electric infrastructure research and development efforts involve developing technologies, systems, and methods to interconnect variable renewable energy with the power grid.

Photo by Dennis Schroeder, NREL 23684

NREL's REDB Connects Smart Grid Research

Plug-n-play has become so integrated into daily life that most computer users don't give a second thought to hooking up a camera or smart phone to a laptop or tablet. Now, take the same concept and apply it to the nation's complex electrical systems when it comes to "plugging in" renewables or smart grid technologies.

To make that a reality, the U.S. Department of Energy's (DOE) National Renewable Energy Laboratory (NREL) is building electrically interconnected laboratories as part of its Energy Systems Integration Facility (ESIF) where research partners can literally plug in and test new energy technologies on real and simulated power systems before hooking them up to the grid.

This plug-n-play adaptability is possible because of the Research Electrical Distribution Bus (REDB) at ESIF, which will function as a power integration circuit capable of connecting multiple sources of energy, interconnecting laboratories and experiments. All of this will allow NREL and its partners to test and simulate what happens when components, such as solar inverters, are connected to the grid.

"Each lab in ESIF has its own niche with different kinds of equipment and functionality fostering research on all aspects of energy integration," NREL Electrical Engineer Greg Martin said. "There is nowhere else where you can bring in a piece of equipment, connect it up, and be testing in a matter of days—along with the type of data acquisition we can provide."

Made up of four ring buses—two for AC current and two for DC current—the REDB will be the backbone for all of NREL's energy systems integration testing.

"You can think of the ESIF equipped with the REDB as a place where you can bring your equipment and with our real time simulation tools, we can make your equipment think that it is connected electrically to another piece of equipment, a utility distribution feeder, or even the grid," Acting Group Manager for Distributed Energy Systems Integration Bill Kramer said.

The scale of the laboratories in the ESIF and the size of the equipment to be tested are hard to visualize, but according to Kramer, a real test scenario for the REDB could include the following.

A research partner delivers an experimental device to ESIF on a flatbed truck. The truck enters the ESIF through large overhead doors that lead into the high bay area of the Power Systems Integration Laboratory where a bridge crane lifts the experiment, which contains a battery in a 40 foot container, off the truck and places it in the lab. The battery is connected to DC power with a programmable switch that is connected to the REDB. Running parallel with the REDB is a Supervisory Control and Data Acquisition (SCADA) system. SCADA enables the researchers safely to turn power on and off, and track the data flowing during the experiment. At this point, using the SCADA and REBD systems,

An electrical contractor walks between two racetrack switchboards, which are being installed in the REDB room of the Energy Systems Integration Facility (ESIF) at NREL. These switchboards are capable of 1,600 amps and are part of the 1 megawatt testing capabilities at ESIF. *Photo by Dennis Schroeder, NREL 20050*

researchers can interconnect that large battery with another laboratory, or to a transformer connected to a solar array in the Outdoor Testing Facility. The battery can be charged and discharged thanks to the ESIF's power hardware in the loop.

SCADA Brings Testing into View

A key element to the testing power systems and components at ESIF is the SCADA, which will serve as the computer control system for the REDB. In addition to controlling the REDB safely, the SCADA also provides high resolution data output. The SCADA will support a large visualization screen in the control room allowing researchers and partners to watch the experiment in real-time.

In a control room, researchers can see the electrical bus, close switches, and check out grid simulators. Research partners will be able to control the systems on portions of the REBD checked out specifically to them. The data from the experiment is streamed to secure servers, so if a utility is working with the lab that information can remain with the researcher and their partner. It's easily compartmentalized so that an experiment has its own power system and data.

Safety is key at NREL and the SCADA will constantly run safety checks to make sure that no equipment is damaged or pushed beyond its safety limits.

ESIF is Not Just for Renewables, or NREL

"The ESIF labs are reconfigurable so that as technologies advance, we can change with them," Kramer said. "The design of ESIF in and of itself is an integrated system. ESIF bridges the gap between electrical, thermal, and fuels disciplines."

The nation's utility infrastructure currently is driven by fossil fuels. An objective for ESIF is to make it so industry can use and modify existing pieces of equipment to work with new technologies such as solar and wind.

"We are here to help utilities and companies that want to design new equipment that will increase the penetration of renewables into the energy grid," Kramer said. "However, we won't work just with renewables at the ESIF. We could also test natural gas field generators. This type of testing will also help us move forward because if you don't take into consideration the overall system and only work on a component at a time, you will never come up with the optimal solution."

> "Each lab in ESIF has its own niche with different kinds of equipment and functionality fostering research on all aspects of energy integration. There is nowhere else where you can bring in a piece of equipment, connect it up, and be testing in a matter of days—along with the type of data acquisition we can provide."
>
> — **GREG MARTIN,** *NREL Electrical Engineer*

"At the end of the day, we want to provide a platform to allow other laboratories, government, industry, utilities, to all develop technologies for the future energy marketplace," Martin added. "It is important for everyone to be able to do testing before putting something out in the field and discovering that it didn't work the way they thought. Instead they can bring their equipment to the ESIF, hook it up, and it is going to think it is part of the power system."

ESIF also is working to make virtual connections to other laboratories across the country in an effort to share expertise. "If you have a lab, and want to have a virtual connection into the ESIF with your equipment being tested in your lab, you will still be able to make use of ESIF and all of the equipment that is in it," Kramer said.

"We have this amazing capability that no one has ever had before," Martin said. "If you have an idea for a novel system, bring it in and we'll test it, or we'll partner with you on some other types of research."

This state-of-the-art facility is scheduled for completion by the end of 2012. It will enable NREL and industry to work together to develop and evaluate their individual technologies on a controlled integrated energy system platform. Testing at the ESIF is intended to facilitate widespread adoption of renewable energy and smart grid technologies and help reduce risks associated with early market penetration.

— Heather Lammers (January 27, 2012)

Sci-Fi No Longer, NREL Engineers Smart Homes

Thanks to TV shows such as The Jetsons and Star Trek, many Americans grew up dreaming that homes of the future would be equipped with fantastic high-tech features. From automatic food dispensers to sliding doors, to Rosie the Robot doing the household chores, the imagined homes of the future seemed to be driven by an unlimited supply of energy.

Research engineers at the U.S. Department of Energy's (DOE) National Renewable Energy Laboratory (NREL) have a different vision for the home of the future. The team is working on a "smart" home that will communicate with the electricity grid to know when power is cheap, tell appliances when to turn on or off, and even know when renewable energy resources are available to offset peak demand.

NREL is leveraging two laboratories to make its dream home a reality—the soon-to-be-built Smart Power Laboratory, which is part of the new Energy Systems Integration Facility (ESIF), and the Automated Home Energy Management Laboratory.

Smart Power for the Next Generation

NREL's 5,300-square-foot Smart Power Laboratory will focus on two key areas: the development and testing of power electronics systems and controls, and the implementation of newer control approaches for smart energy management devices and systems. The lab will feature three power electronics test bays with sound abatement walls and a 96-square-foot walk-in fume hood for testing early prototype systems that have a higher risk of failure. There will also be four smart grid test bays capable of testing a variety of household appliances and systems.

"A part of our research in the Smart Power Laboratory will focus on the integration of distributed energy resources using power electronics; we want to develop a new generation of power electronics systems that will provide advanced functionalities to consumers and utilities, and lead to more efficient integration of renewable energy into the smarter electric grid," NREL Senior Research Engineer Sudipta Chakraborty said. "The present work being done at NREL is on a smaller scale because we are constrained by the size and infrastructure of our current lab. The lab in ESIF will greatly enhance our ability to develop and test bigger power electronics systems."

The Smart Power Laboratory will allow NREL to perform equipment testing for industry. For example, if a manufacturer builds a new inverter, it can be tested and validated at NREL before the manufacturer takes the system for certification. This will greatly reduce the risk of failure for the manufacturer during the certification testing.

NREL engineers Dane Christensen and Bethany Sparn test advanced power strips at NREL's Automated Home Energy Management Laboratory. The lab enables researchers to study the complex interactions of appliances and other devices in connection to the energy grid. *Photo by Dennis Schroeder, NREL 20167*

"We've found that a large number of manufacturers don't have all of the necessary equipment to do the required testing—like having a grid simulator to see how their inverter behaves if there is a disturbance in the grid frequency," Chakraborty said. "ESIF will have equipment that can test this type of power electronics system, and thanks to our large grid simulators, load banks, and DC sources, connected through the Research Electrical Distribution Bus (REDB), we can be a test bed for even bigger inverters—which is the current trend in the market."

In addition to the power electronics research, the Smart Power Laboratory's smart grid test bays will be used to develop newer grid-monitoring equipment and to test smart appliances and home automation, energy management, and heating, ventilating, and air conditioning (HVAC) systems. The hardware-in-the-loop system and the capability of real-time control of the megawatt-scale power equipment will enable NREL to simulate integrated system responses such as household loads and generation as seen by the utility, and will ultimately lead to the development of better energy management algorithms.

"People are really looking at the whole integration of these energy systems," Chakraborty said. "At the residential level, you'll have your house with a photovoltaic system on the roof, with smart appliances inside, and we'll look at the data to see how those systems work together. The utility companies are interested in seeing how they can control those appliances to offset loads and make the peak power demands more stable. To do that, all of these pieces have to work together, which they don't do today."

The Home of the Future

To help figure out how those pieces must work together inside a home, NREL has built the Automated Home Energy Management (AHEM) Laboratory as part of NREL's advanced residential buildings research.

We are very cognizant of the fact that every home is part of a larger energy system," NREL Senior Engineer Dane Christensen said. "We've modeled the AHEM Lab around a real home, with the same plugs, panels, and appliances. The idea is that eventually our appliances and homes are going to be able to 'talk' to the grid. We are trying to figure out how demands from the grid and the dynamics of residential energy can be coordinated."

NREL researchers have found that power is viewed differently from either side of the grid. The homeowner sees that power is always available, at a uniform cost, so there is little motivation to save power during high-demand times and then use power later when it is less constrained. Currently, it doesn't matter to homeowners if they use a clothes dryer while they bake a cake, watch TV, and have all the lights turned on in their house. But, for the grid, that kind of behavior has a huge impact, especially during summer months when air-conditioning is added to the demand mix. Today, utilities have no way to mitigate that power consumption; they simply have to generate and deliver more power.

> "The lab in ESIF will greatly enhance our ability to develop and test bigger power electronics systems."
>
> —**SUDIPTA CHAKRABORTY,** *NREL Senior Research Engineer*

"There has to be something in the home to receive communications about energy availability and use built-in intelligence to act on it—especially when people aren't home to do it," Christensen said. "Just like in cars, you have systems that will automatically brake for you, or protect you. In the home, the only thing automated right now is probably your thermostat."

According to Christensen, the goal is to have communications coming into the home from the utility that include pricing, requests to conserve energy, and rebates to homeowners who can act quickly to reduce power when needed. Conversely, the power company could also send a signal letting homes know that it is OK to go ahead and do laundry while cooking dinner, because there is more power available.

"We're working on building systems for homes that can take the information from the utility, along with input from the homeowner, and manage the home's energy to satisfy both the homeowner and the utility," Christensen added. "The homeowner will still be in control, with built-in overrides and the ability to change settings. But we also want to help the utility meet its needs and keep costs down, while maintaining comfort."

Making it Work for the Long Term

Home energy management is a critical area for the DOE Building America program to reach its long-term goals of at least 50% energy savings for new construction and 40% savings over the minimum code for building retrofits.

Building America is the flagship program for residential research within the Building Technologies Program at DOE. The goal is to make energy efficiency cost effective for residential buildings; NREL is the technology lead and manager for the program.

"Work we did seven years ago is now being adopted into the current energy codes," Christensen said. "We are ahead of industry because it takes time for results of our research to make their way to the consumer. From where we sit right now, it looks like there is a big challenge in getting beyond the 50% energy savings for new home construction and 40 to 50% savings in retrofits, without home energy management technology in place.

"The technology created and tested at NREL's Smart Power Lab or Automated Home Energy Management Lab will enable those home-energy puzzle pieces to fall into place—helping people turn the lights off when nobody is at home, helping people adjust their thermostat when they are not at home, helping people understand that energy is expensive at a particular time of day so they can avoid running an energy-intensive appliance until power is less expensive—all of that helps save energy and costs across the board."

— Heather Lammers (May 24, 2012)

> "Work we did seven years ago is now being adopted into the current energy codes. We are ahead of industry because it takes time for results of our research to make their way to the consumer."
>
> **—DANE CHRISTENSEN,** *NREL Senior Engineer*

Microgrids: So Much More than Backup Energy

Most Americans don't have to think much about energy reliability. We plug in a computer and it powers up; we flip a switch and the lights come on.

While very reliable today, the U.S. electricity grid is old and has gone at least five decades without a significant technological upgrade. The U.S. Department of Energy's (DOE) National Renewable Energy Laboratory (NREL) is working with industry on one solution to help maintain a secure, reliable flow of energy: microgrids.

A microgrid is a smaller power grid that can operate either by itself or connected to a larger utility grid. Microgrids can serve areas as small as a few houses, all the way up to large military installations.

"If your home was part of a microgrid, you could continue to receive power even when the utility power goes out," NREL Electrical Engineer Mariko Shirazi said. "It gives you the ability to ride through any disturbances or outages by seamlessly switching over to locally generated power."

It's important to note that a backup power system—like a diesel generator—is not the same as a microgrid. Backup generators supply power to local loads in the event of an outage, but there is usually a delay or blip when you lose power and disconnect from the utility grid before the backup kicks in. In addition, a backup system is never meant to run continuously, nor to put power into the grid. However, the reverse is true—a microgrid can serve as a backup power supply.

A microgrid senses the quality of the power flowing through the grid. In the event of an outage, it can disconnect from the grid at a moment's notice. It can also leverage solar, wind, or stored energy to supplement a dip in the current power supply. If things are running smoothly with the regional grid, a microgrid generating electricity from renewable sources can export that clean energy to the grid for everyone's use.

Just Connect and Go?

The major components of a microgrid include a source of power generation, local loads, and electrical switching gear. It might also include inverters and energy storage—all of which sounds easy enough to just connect up to get started, right?

"These technologies are in different stages of maturity; the challenge is to get them all to operate together in a stable, concerted way to accomplish the goals of efficiency, security, and energy reliability—all of which are required from a microgrid," NREL Electrical Engineer Greg Martin said.

There are two prongs to the microgrid work at NREL: innovative research and partnering with industry.

While very reliable today, the U.S. electricity grid is old and has gone at least five decades without a significant technological upgrade. There are two prongs to the microgrid work at NREL: innovative research and partnering with industry. *Photo by Dennis Schroeder, NREL 21935*

NREL works with industry to test microgrid systems by providing the experts as well as the infrastructure to support microgrid testing. The U.S. Department of Defense is also working with NREL researchers to examine using microgrids to improve base reliability. Testing includes using grid simulators, load banks, and generators, all currently at the Distributed Energy Resources Test Facility at the National Wind Technology Center near Boulder, Colorado.

"We use equipment such as a grid simulator to create a virtual electric grid to test equipment that is planned to be connected to a utility," Martin said. "We create outages, or some other kind of electrical phenomenon, to make sure the equipment operates as expected. We basically try to make stuff work while making sure it works the way it's supposed to."

> "If your home was part of a microgrid, you could continue to receive power even when the utility power goes out. It gives you the ability to ride through any disturbances or outages by seamlessly switching over to locally generated power."
>
> — **MARIKO SHIRAZI,** *NREL Electrical Engineer*

"Utilities need to be shown that this technology is safe to integrate into the system and won't affect the normal operations," NREL Energy Systems Integration Director Ben Kroposki said. "One of the goals at NREL is to provide that test bed for a variety of scenarios to be run so that utilities can see that the risk is being reduced."

An example: take a 200-kilowatt microgrid in a residential area with 100 kilowatts of photovoltaics (PV) installed on homes. When all the homes are grid-connected through a local utility, those 100 kilowatts of PV are no big deal. But once the homes are disconnected from the grid, that's a high ratio of PV.

Researchers work with industry to figure out which resources have to be maintained to keep the power reliability needed for critical loads. Key questions include, should the homes start shedding loads if a cloud crosses the sun and the PV power drops? Or is energy storage needed, so when a cloud comes, the power supply stays consistent?

NREL is leading the way in understanding issues in energy systems integration and helping industry work through them. The lab's research tools will get a boost when the Energy Systems Integration Facility (ESIF) is completed later this year.

Taking Research to the Next Level

"ESIF is going to be like our current lab on steroids, and will expand our testing scale to 1 megawatt," Martin said. "We'll be able to test large single components like large utility-scale inverters. We'll also be able to scale up the complexity of our testing. Using the Research Electrical Distribution Bus [REDB], and hardware-in-the loop, we'll be able to connect dozens of sources and loads and be able to test their interactions with each other. Now, we collect single data points. At ESIF, we'll be able to collect high-speed, time-synchronized data at numerous points throughout the REDB."

Using a high-performance computing data center, NREL will be able to simulate entire distribution systems. When testing a microgrid system, engineers can monitor its voltages and frequencies at the point where it joins the distribution system, enabling them to simulate the effect of a microgrid on the larger utility. This is important, because being physically connected to the grid is often not practical—plus, the utility doesn't have to worry about putting an unproven technology on their system.

"Utilities see this as a growth area, and they would like to understand it," Shirazi said. "Even if they aren't implementing a microgrid themselves, they may want to understand how it works for those customers who do want to install one on a section of their distribution system. Working with NREL helps them implement this type of system without impacting their customers."

NREL's grid simulators make this testing possible without hooking up the equipment to the regional utility grid—which would be prohibitively tricky. First, researchers would need the foresight to know when voltage anomalies were going to happen,

> “ESIF is really going to move us forward to the next generation of power systems in this country. There is consensus that our utility grid is aging and that we can get benefit out of making it more intelligent, efficient, and capable of accepting more sources of energy.”
>
> —**BEN KROPOSKI,** *NREL Energy Systems Integration Director*

and assuming they could catch them, there would be only one chance to test equipment. With grid simulators, researchers can create voltage and frequency anomalies and see how the system behaves.

“ESIF is going to give us more research power, both in the actual electrical power but also in the ability to collect data across all points in the system,” Martin said. “It will also offer really awesome visualization that will enable us to look at data coming in from different places, to look at simulations and video feeds, in a really nice, easy, big way. We’re sure this visualization capability will help ignite collaborations among NREL, industry, utilities, academia, and government agencies.”

“ESIF is really going to move us forward to the next generation of power systems in this country,” Kroposki said. “There is consensus that our utility grid is aging and that we can get benefit out of making it more intelligent, efficient, and capable of accepting more sources of energy.”

— Heather Lammers (August 24, 2012)

FUEL CELLS AND HYDROGEN

NREL's Hydrogen and Fuel Cell research works in partnership with industry, academia, and other research organizations to address the nation's energy challenges by encouraging the widespread commercialization of renewable hydrogen and fuel cell technologies.

Photo by Dennis Schroeder, NREL 21373

Sun Shines on Old Idea to Make Hydrogen

Back in 1998, when gasoline prices were $1.03 per gallon, John Turner of the U.S. Department of Energy's (DOE) National Renewable Energy Laboratory (NREL) dropped jaws all over the energy world by demonstrating that he could use sunlight to extract hydrogen from water at a remarkable 12.4% efficiency.

Three hundred articles and news reports followed, there were predictions of the next big thing, and then … almost nothing happened.

Energy companies went back to their gasoline and their diesel, or their attempts to extract fuel from biofuels, or to extract hydrogen via algae or coal-powered electricity.

Now, with gasoline at $3.89 per gallon, and still the dominant transportation fuel, there is renewed interest in Turner's work.

Last month, the Japan Society of Coordination Chemistry awarded Turner with its first Lectureship Award for his pioneering work in the fields of solar hydrogen and fuel cells and for being an international spokesman for hydrogen production via photoelectrochemical water splitting. "It was quite an honor to be recognized that way," he said.

"It's what I've been doing for 30 years, pushing this technology into new areas that are more fruitful," Turner added. "People are looking at climate change, looking at solar fuels. The tsunami has people in Japan rethinking nuclear, plus they import 90% of their oil. Countries are looking at technologies that give them greater energy independence."

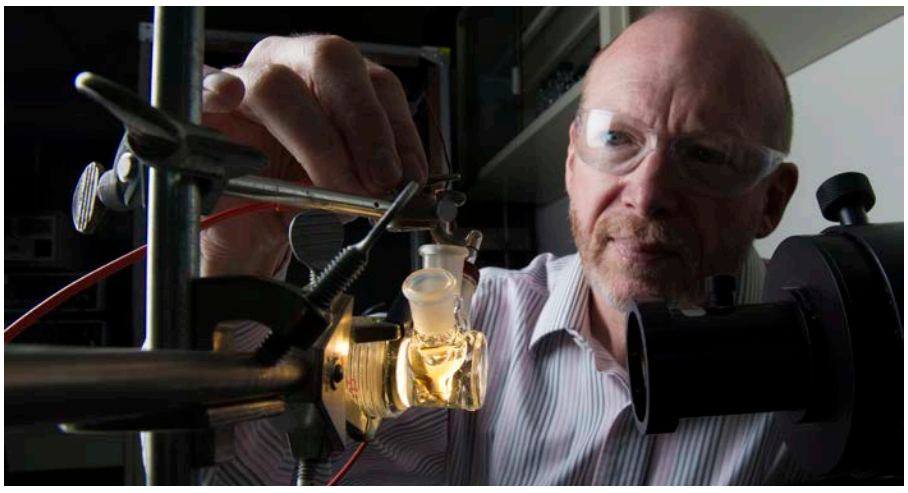
Momentum Grows for Solar-Fueled Water Splitting

As often happens in science, researchers are turning back to a breakthrough that had lost momentum.

Japan, South Korea, and Singapore are starting advanced artificial photosynthesis centers. In October 2012, DOE announced the availability of $1 million in grants to evaluate technology pathways for cost-competitive hydrogen fuel.

In 2010, DOE established the Joint Center for Artificial Photosynthesis at the California Institute of Technology as one of its Energy Innovation Hubs, with the aim to find a cost-effective method to produce fuels using only sunlight, water, and carbon dioxide as inputs.

It's photosynthesis without the green stuff. Turner uses multijunction solar cells made mostly from elements in the third and fifth columns of the periodic table, such as gallium, arsenic, and indium. These so-called III-V solar cells still work the best.



NREL Research Fellow John Turner tests a photoelectrochemical water-splitting system in NREL's hydrogen lab. Turner set a world record for efficiency for the process in 1998, and the record still stands today. *Photo by Dennis Schroeder, NREL 22651*

NREL also funds research through its Laboratory Directed Research and Development Program aimed at trying to make alloys that combine the benefits of the III-V elements with the strengths of elements such as cobalt, manganese, phosphorous, or titanium. The trick is to combine the materials in such a way that they are not only stable and robust but also have the right band gaps to generate enough voltage to split water.

Turner, who has been with NREL since 1979, says the cleanest way to produce hydrogen is by using sunlight to directly split water into hydrogen and oxygen.

The amount of greenhouse gases such a method can save is almost unfathomable. Consider that in the United States alone, 9 million tons of hydrogen are made each year, much of it in petroleum refineries and primarily via a process called steam reforming of natural gas.

> "Countries are looking at technologies that give them greater energy independence."
>
> —**JOHN TURNER,** *NREL Research Fellow*

For each kilogram of hydrogen produced that way, about 12 kilograms of carbon dioxide are produced. A process that could replace all that natural gas reforming with the sun and water can save 100,000 trillion kilograms of carbon dioxide from reaching the atmosphere each year. Hydrogen produced from water and sunlight can replace natural gas reforming if it is made near the refinery and used in place of the hydrogen typically made from reforming.

It won't be easy. In fact, Turner says that the reason his initial breakthrough lost momentum is that improving the technique "was hard work, and people don't like to do hard work."

Better technology, the cost of gasoline, and worries about nuclear power in the post-tsunami era have combined to make researchers believe water splitting may be worth the hard work. Turner's pioneering work—and the renewed enthusiasm for it—is leading researchers in several directions.

New, More Robust Materials Show Promise

Turner's NREL colleagues Dan Ruddy and Nate Neale are researching new materials that can duplicate the elegance and efficiency of the 1998 breakthrough, but are robust enough to remain stable hour after hour, month after month.

They're getting help from the Center for Inverse Design, a DOE Energy Frontier Research Center that uses theory and supercomputing to first come up with the ideal properties of a new material, then find the mix of chemicals that holds those properties.

The aim is materials that can regenerate even as they disintegrate. It's something the human body can already do, from replacing plasma every 48 hours to regenerating a new stomach lining every five days.

Some metal oxides look particularly promising, Ruddy and Neale said. They're plenty stable, but typically have large band gaps—meaning the gap between the band that can conduct energy and the band that cannot is too wide to allow for efficient conversion of photons into electrons.

Ruddy and Neale are taking hints from some previous work at NREL that combines several layers of semiconducting material into a solar cell that has multiple junctions and thus has ideal band gaps to capture the sun's energy morning, midday, and afternoon.

Instead of a junction where two layers meet, as in the case of a conventional solar cell, the water-splitting cell has a junction where a layer hits an electrolyte.

"We're seeing a lot of promise in some of these new materials," Neale said.

Researchers at MIT are bonding a solar cell to a newly developed catalyst to try to efficiently use the sun to split water into hydrogen and oxygen. The catalyst of the so-called artificial leaf is made of earth-abundant, inexpensive materials, mostly silicon, cobalt, zinc, nickel, and molybdenum. Like the NREL approach, MIT's needs no external wires or control circuits to operate.

"John Turner's work was seminal," said MIT and Harvard chemist Daniel Nocera. "He set a new path for photoelectrochemical cells. Before Turner, the path of photoelectrochemistry was to have materials that absorbed light and did the catalysis of water

splitting. Turner separated the function of light collection and charge separation from catalysis in his now-called 'Turner cell.'

"The field was slow to pick up on this," Nocera added. "But we followed Turner's lead, and with the development of new catalysts—and by following Turner's approach—we were able to develop a buried junction comprising earth-abundant materials."

The Longer and Shorter Visions for Hydrogen

Turner envisions a day when the United States and other nations depend by and large on domestically produced hydrogen as an energy carrier for transportation, heat, and electricity. No pollution, no dependency on foreign oil, no national security worries.

"In my view, a hydrogen economy is inevitable," Turner said. "Simply because we can't run on fossil fuels forever, and hydrogen makes the most sense when it comes to building a sustainable infrastructure." Turner says the two big visions for the hydrogen economy are its use in fuel cell vehicles and in producing ammonia, which is essential for food production.

"I'm talking about a system that will last for millennia."

Neale and Ruddy take a shorter-term view. They can envision solar-powered water splitting replacing reforming natural gas as the way refineries produce the hydrogen that is used to remove sulfur from petroleum or to convert heavy crude into lighter, easier-to-refine products.

If all the hydrogen were pulled out of a gallon of water, that amount of hydrogen would have 40% of the energy equivalence of one gallon of gasoline.

One challenge is the amount of solar cells needed to generate as much hydrogen fuel each day as a typical large oil refinery does. "You might need a few square miles of solar arrays around the refinery," Neale said.

Another hurdle is to show that the process will work as well when it is boosted to manufacturing scale. Recent NREL analysis indicates a path to getting a gallium-arsenide-based solar cell down to about $2 per watt. Using that as the base for the Turner water-splitting device would produce hydrogen at about $3 per kilogram. That would make it fairly competitive with gasoline.

A kilogram of hydrogen can propel a car almost three times farther than a gallon of gasoline, but because hydrogen is so light, a vehicle's gasoline tank would provide a greater range than a vehicle's hydrogen tank.

> "In my view, a hydrogen economy is inevitable."
>
> —**JOHN TURNER,** *NREL Research Fellow*

Solar Power for the Long Run

Millions of middle-school students have done the basic experiment: Use an electric source and clamps to electrolyze water and watch the bubbles of hydrogen climb to the surface.

Using the sun and a solar cell eliminates the need for electrolyzers, or anything else that needs a fossil-fuel source.

"This has been languishing in the weeds, and now all of a sudden it's in the forefront," Turner said. "Our funding has been zeroed out twice, but in the past few years we've seen more interest." In fact, Turner already has given 23 invited talks on hydrogen in 2012, a personal record for talks in a year.

"I'm optimistic—if people will focus on the right concepts," Turner said. "That's what's necessary to make this field viable. It's going to take a new material, and people haven't been interested in looking at new materials. Now they are."

Of course, there are other pathways to produce hydrogen, including using biomass or algae, or extracting hydrogen using extreme heat. "The one that has the lowest cost for the hydrogen is the one that will prevail," Turner said.

NREL has a hydrogen filling station at its National Wind Technology Center (NWTC), the stored hydrogen coming from solar- and wind-powered water splitting. And NREL houses the data repository for DOE's technology validation project on the performance of fuel cell vehicles.

On Track to Being a Scientist Early

Turner was sure of his future career when he was 12 and first saw the word "scientist" written on a blackboard in his Idaho elementary school.

"I saw the word, and I knew that was me," he said. "I came home and told my mom I was going to be a scientist. She said, 'That's cute, Johnny. Tomorrow you'll want to be a fireman.'

"But it never changed. In high school I took calculus, chemistry, physics, and biology, and decided on chemistry."

And he was fast enough in the 100- and 200-yard sprints and adept enough in the hurdles and triple jump to make sure his passion saw fruit.

He won a track scholarship to Idaho State University, got his Ph.D. in chemistry from Colorado State University, and did post-graduate work at Caltech—now the site of the big DOE Energy Innovation Hub on hydrogen.

Water and the Sun: For the Long Haul

Turner was a celebrity for a short while in 1998. His paper on using the sun for water splitting even inspired a film starring Keanu Reeves titled "Chain Reaction" about a hydrogen-fueled economy being the Earth's last best hope.

"We need a chemical energy carrier like gasoline, petroleum, methane, that carries energy in chemical bonds," Turner said. "It's all stored sunlight. That's what hydrogen represents."

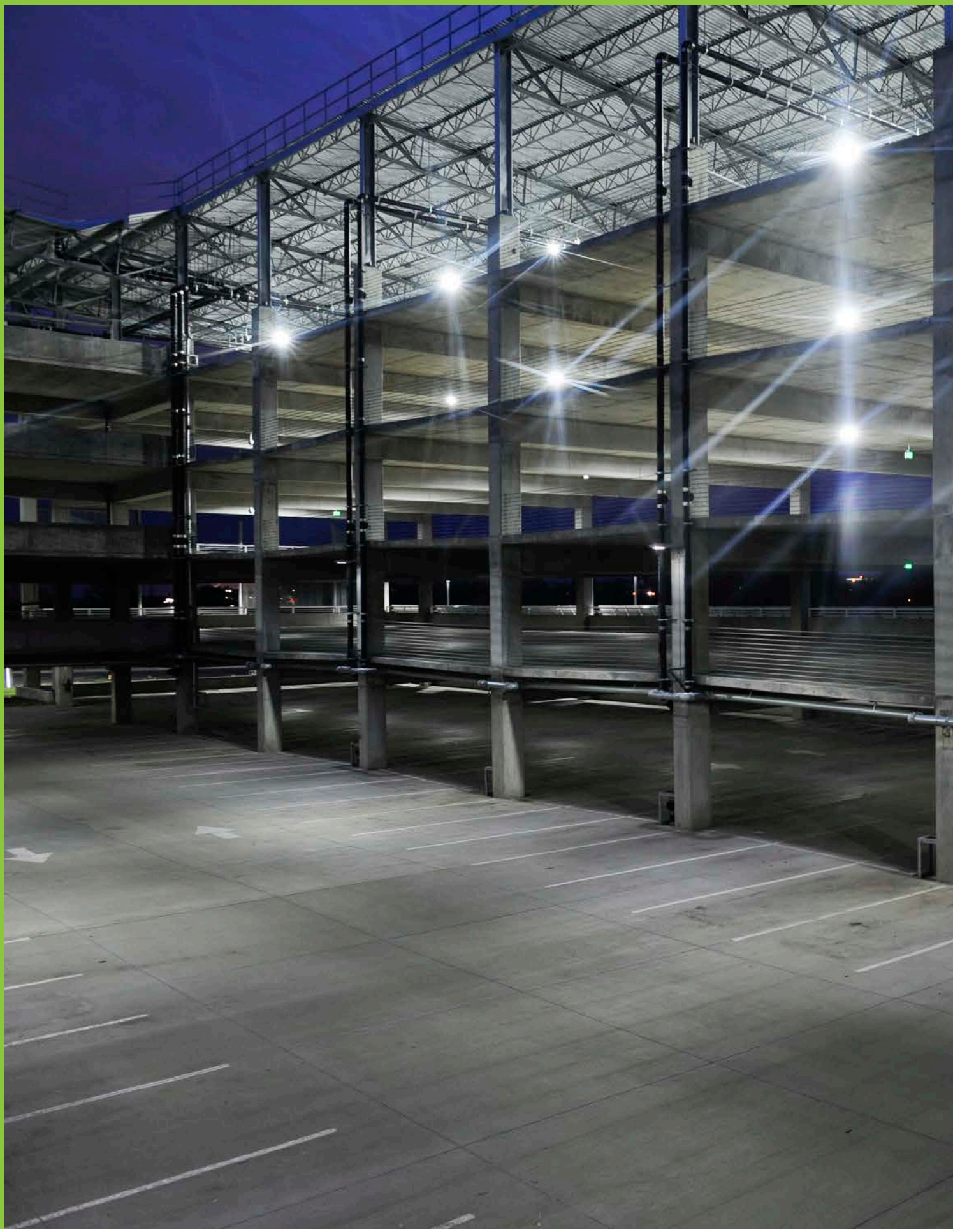
Turner has some greats in science and literature on his side.

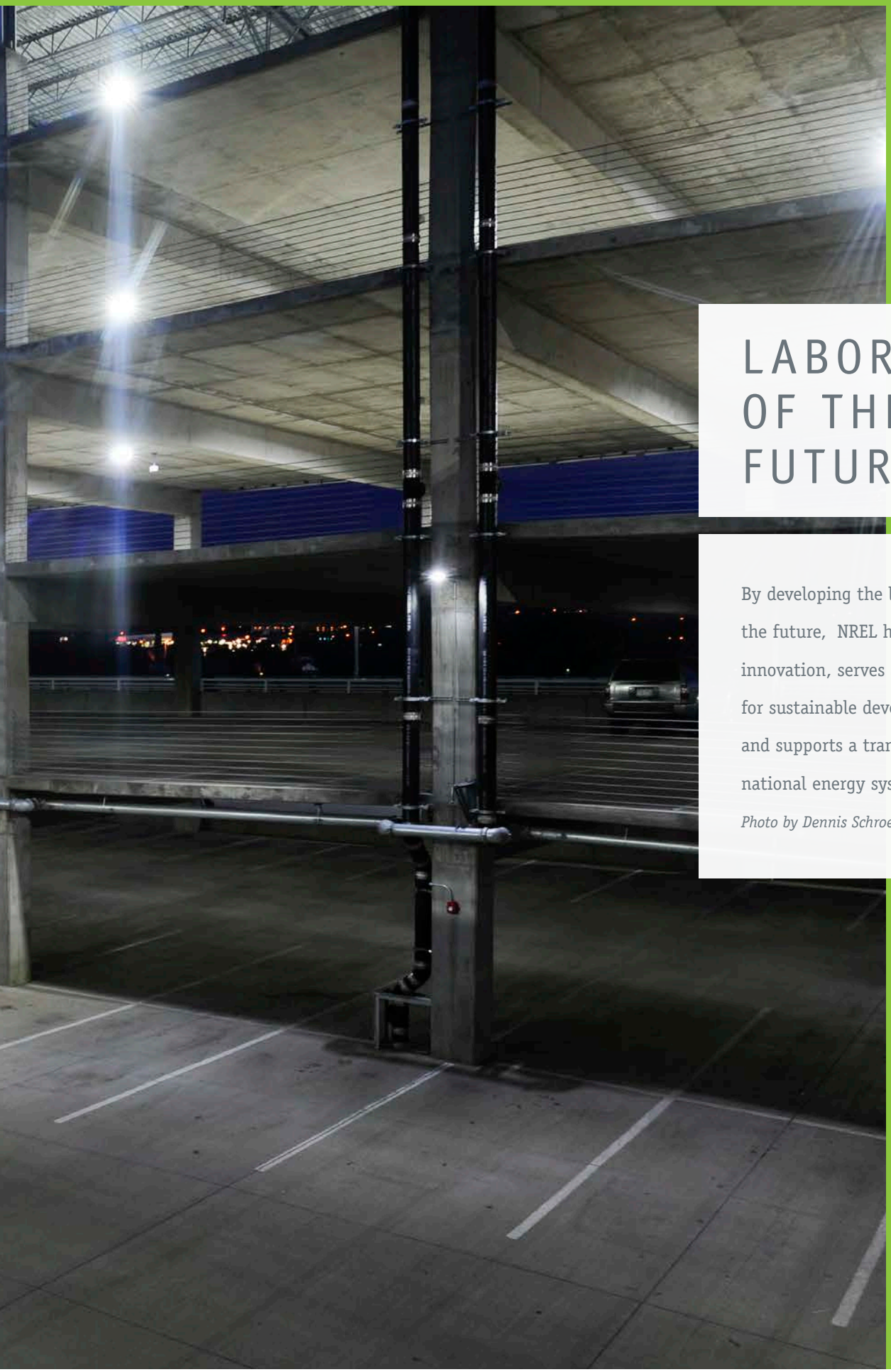
In Jules Verne's 1874 novel "Mysterious Island," a protagonist says: "Yes, my friends, I believe that water will someday be employed as fuel, that hydrogen and oxygen which constitute it … will furnish an inexhaustible source of heat and light … Someday water will be the coal of the future."

And in 1931, shortly before he died, Thomas Edison told his friends Henry Ford and Harvey Firestone: "I'd put my money on the sun and solar energy. What a source of power! I hope we don't have to wait until oil and coal run out before we tackle that."

Turner puts it this way: "How much coal will we have in 75 years or 200 years? We have enough coal for ourselves and our kids, but what about our grandkids and great-grandkids? The sun and the wind are intermittent resources. We'll run out of fossil fuels. But the sun and water will be around for a long, long time."

— Bill Scanlon (October 29, 2012)





LABORATORY OF THE FUTURE

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

Photo by Dennis Schroeder, NREL 22507

Sustainability Efforts Earn Accolades for NREL

The U.S. Department of Energy's (DOE) National Renewable Energy Laboratory (NREL) is known nationally for its leading edge work in renewable energy and energy efficiency research and development. But, NREL also has been a quiet leader in sustainability efforts.

Now this aspect of the lab is getting noticed. This past year, NREL received three national awards—one from the White House and two from DOE—for its decade long efforts to "walk the talk."

"The mission of NREL lends itself to running the laboratory in the most sustainable manner possible," NREL Director of Sustainability Frank Rukavina said. "It means minimizing the amount of resources we use and the waste we generate all while maximizing the output of the laboratory. At NREL, we're managing today's needs for the benefit of future generations."

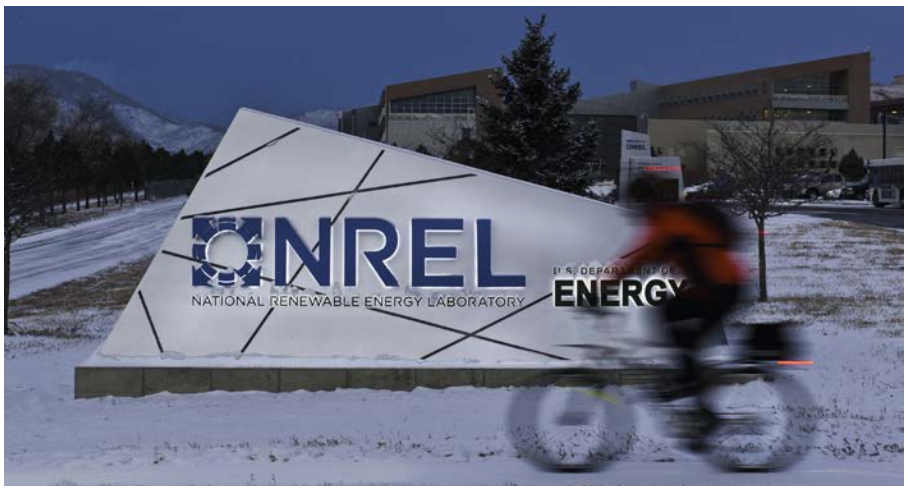
According to Rukavina, although NREL has been a leader in federal sustainability efforts for more than a decade, applying for awards has not been a staff priority. The focus has been on "getting things done."

NREL recently developed a comprehensive campus master plan with extensive efforts to increase building densities, preserve and enhance open space, and establish a walkable campus.

"Master planning and creating a walkable campus are imperative because NREL expects to see over a 300% increase in our main campus' footprint between now and 2020," Rukavina said. "While it presents our team with a challenge, this growth is needed to maintain NREL's position as the national leader for renewable energy and energy efficiency research."

NREL's energy efficient buildings, renewable power supplies, transportation, and campus operations have evolved to become an integrated system balancing environmental, social, and economic goals. NREL has been able to steadily reduce energy consumption despite a 22% increase in staff from 2010 to 2011, by enhancing building efficiencies and adding renewable energy throughout the campus including:

- Approximately 2.7 megawatts (MW) of on-site photovoltaic (PV) panels from Power Purchase Agreements, which displace roughly 19.5% of NREL's electric use
- NREL also is adding 1.7 MW of purchased PV panels, which will displace an additional 12% of electricity use
- The waste-wood-fired Renewable Fuel Heating Plant currently provides 50% of the heat in the district heating system offsetting the lab's natural gas use
- Solar hot water systems, ventilation air preheating systems, and Trombe walls add an annual thermal output of nearly 10.2 million Btu



As part its efforts to reduce greenhouse gas emissions, NREL supports alternate ways for its employees to get to work including bicycling, Eco Passes for public transportation and vanpool vouchers. *Photo by Dennis Schroeder, NREL 18298*

- NREL has leveraged extensive use of building design best practices, which incorporate passive solar and daylighting.

The Four Rs

By making the four Rs (reducing, reusing, recycling, and re-buying) an integral part of its operations, NREL also is working to establish a campus with near-zero waste.

One way the lab works to achieve this is by procuring products that can be recycled or composted at the end of their life. In fiscal year 2010, NREL's purchase of recycled products grew roughly 350% over the last couple of years as a result of green procurement practices.

The near-zero waste initiative relies heavily on employees' active participation. NREL staff has diverted 77% of its waste from local landfills through recycling, including roughly 126 metric tons of compost, in the last year. The lab also has experienced a surge in construction over the past few years; in 2010, contractors diverted 72% of construction waste as well.

NREL also is a government leader in electronics recycling. In September, the lab earned a 2011 platinum-level award from the Federal Electronics Challenge (FEC) recognizing NREL's efforts to help the federal government improve its sustainable practices. This is the first time a platinum-level FEC award has been available and NREL is the only DOE facility to achieve the newly-implemented platinum level partnership. In past years, NREL's efforts have garnered two gold awards and one silver award.

NREL achieved the award for tracking lifecycle data for electronic equipment, replacing old cathode ray tube monitors with liquid crystal display units, ensuring the environmentally friendly disposal of electronics, and reviewing and revising NREL's policies to make the lab's information technology environment more energy efficient.

In addition, NREL drafted a case study on the new Research Support Facility's (RSF) desktop computing and data center policies. The study documented a 75% decline in NREL's overall power consumption at the user's desktop, and a drop to an average 1.16 PUE (power usage effectiveness), or less, in the RSF data center.

Greenhouse Gases in the Bull's-eye

Since 2009, NREL has achieved carbon neutrality for Scope 2, or indirect greenhouse gas (GHG) emissions through the deployment of on-site energy efficiency, renewable energy, and the purchase of Renewable Energy Certificates (REC). Scope 2 GHGs result from the generation of electricity or heating. As the campus continues to grow, NREL will rely on energy efficiency retrofits and new high performance buildings to mitigate increases in electricity consumption.

The lab also decreased its overall Scope 1 (direct) emissions by providing heat using wood waste, reducing natural gas purchases by 19% in 2011. NREL's use of advanced fuel fleet vehicles also helps minimize direct emissions.

> "The mission of NREL lends itself to running the laboratory in the most sustainable manner possible."
>
> —**FRANK RUKAVINA,** *NREL Director of Sustainability*

NREL strongly promotes telecommuting and compressed work weeks along with campus-wide recycling and composting to help reduce its Scope 3 emissions, which are in part tied to employee commuting and waste disposal. However, NREL continues to look for ways to tackle the more elusive Scope 3 emissions. "We do very well on Scope 1 and Scope 2 emissions," Rukavina said. "Scope 3 is really challenging. We have grown our population by 87% since 2008 and doubled our infrastructure. So, after taking an overall view of our total footprint, we are focused on employee behavior moving forward."

To support the reduction of Scope 3 GHG, NREL provides EcoPasses for public transportation and vanpool vouchers. The combination of those two programs offers every employee an alternate ride to work.

All of this combined has resulted in prestigious recognition for the lab.

Three National Awards Highlight NREL's Efforts

NREL was a winner of this year's White House GreenGov Presidential Award for an innovation, or idea, with the potential to transform the federal government's overall energy and environmental performance.

NREL won for the design and sustainable nature of its green data center, which is located in the new ultra-energy efficient RSF. The lab designed a net-zero energy data center that creates as much energy as it consumes. The data center also leverages the climate as a natural coolant, captures waste heat that is piped to employee workstations in the cooler months, and uses advanced equipment to minimize energy use.

> "I applaud the NREL team for leading by example on their commitment to innovation, which is helping to improve energy efficiency, reduce pollution, and save taxpayers money."
>
> —STEVEN CHU, *DOE Energy Secretary*

"NREL's pioneering data center recognized with the GreenGov Presidential Award for Green Innovation is a testament to the Energy Department's leadership in realizing the nation's clean energy future," said Energy Secretary Chu. "I applaud the NREL team for leading by example on their commitment to innovation, which is helping to improve energy efficiency, reduce pollution, and save taxpayers money."

NREL was one of eight winners, in six award categories, representing federal agency teams and employees from across the country. A panel of judges that included federal and local decision-makers reviewed nearly 250 nominations and recommended the award recipients to the President.

NREL also recently received Environmental Sustainability (EStar) awards from DOE for its "Sustainable Campus of the Future" and "Cradle to Cradle—Near-Zero Materials Waste and Beyond." EStar awards highlight environmental sustainability projects and programs that reduce environmental impacts, enhance site operations, reduce costs, and demonstrate excellence in pollution prevention and sustainable environmental stewardship. "These are DOE's leading awards for sustainability and environmental stewardship," Rukavina said. "It's the highest recognition NREL can get from DOE for our sustainability efforts."

NREL is not keeping its sustainability strategies under wraps. NREL staff shares information with other DOE labs, other federal agencies, local agencies, and the community through NREL-hosted training sessions, building tours, and interagency partnerships.

"All of these awards are really a culmination of many years of hard work by NREL staff," Rukavina said. "With our campus expanding, our work becomes increasingly important. We will continue to share our lessons learned and hope to have a ripple affect across the federal system."

— Heather Lammers (January 20, 2012)

NREL: 35 Years of Clean Energy Leadership

Thirty-five years ago this month, when President Jimmy Carter opened the Solar Energy Research Institute (SERI) in Golden, Colorado, gasoline cost 62 cents a gallon, and solar power about $100 a watt.

Now, in the summer of 2012, the price of gasoline at the pump is $3.89 per gallon, the installed cost of solar power about $4 a watt.

That's a six-fold increase in the cost of gasoline, and a 95% reduction in the cost of solar. And with solar and wind energy growing by about 35% a year, and biofuels burgeoning, the laboratory in Golden is more vital than ever.

After 14 years as a solar institute, SERI achieved national lab status in 1991 under President George H. W. Bush. SERI became NREL, the U.S. Department of Energy's (DOE) National Renewable Energy Laboratory (NREL).

35 Years of Innovations, Breakthroughs, Discoveries

What a 35 years it's been.

From its start on July 5, 1977, to today, NREL has pushed the boundaries of what's possible, leading the way to a clean energy future.

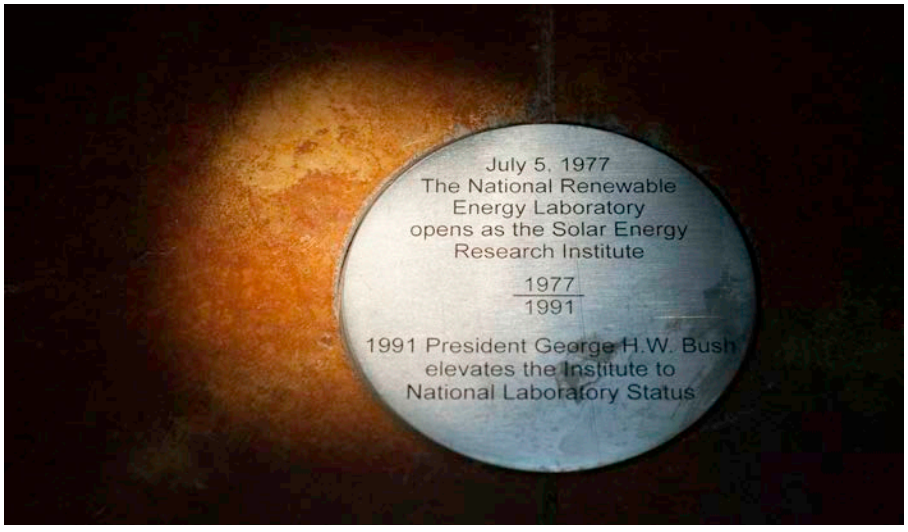
Wind turbines have grown from farmhouse curiosities to multi-megawatt behemoths.

NREL scientists inaugurated the era of the super-efficient multi-junction solar cell and combined those cells with lenses that concentrate the sun's rays by 500 times to multiply the power of photovoltaics (PV).

The laboratory worked with industrial partners to lower the price of enzymes used to refine alternative biofuels by 97%.

And NREL scientists found ways to get two electrons from a photon of light; discovered a cost-effective way to virtually eliminate wasteful reflection off a solar cell; helped engineer an economic way to place transparent solar cells in window glass; engineered ways to get biofuels and hydrogen from algae; mapped renewable energy resources in dozens of countries; came up with new standards for aerodynamic wind turbines and concentrating solar power; and set the bar higher for sustainable buildings.

NREL researchers have won 52 R&D 100 awards—the "Oscars of Invention." That places NREL among the top national labs in R&D 100 awards per employee. Just this year, NREL won two: one for the highest-efficiency solar cell, and another for a revolutionary new type of air conditioning that uses 75% less energy than typical systems and can work in any climate.



The sun hits the commemorative medallion on the floor of NREL's Science and Technology Facility (S&TF) at solar noon on July 5, 2012. The medallion was placed in the S&TF in 2006 to commemorate the anniversary of the lab in 1977, and the day in 1991 when President George H.W. Bush elevated the Solar Energy Research Institute to National Lab Status. *Photo by Dennis Schroeder, NREL 21318*

From Rented Space to the Laboratory of the Future

From its origins in rented office space, NREL has expanded to a 327-acre campus that is a model for what a sustainable, green office park can look like.

"When I bring visitors on the site, I often tell them that when I came to SERI, this site was 300 acres of nothing but sage brush and rattlesnakes," said Stan Bull, NREL's former associate director for Science and Technology. "But look at it now."

Today, the NREL campus is a living model of sustainability, hosting hundreds of architects, planners, and lawmakers each year, along with a multitude of scientists from around the world.

It wasn't always so.

"The people who joined SERI early, who suffered through the great swings of support and inattention in the 1980s, were like monks in a monastery keeping the candle of hope and dedication burning while nobody else cared," said Art Nozik, an NREL senior research fellow emeritus whose breakthroughs on singlet fission opened the door to greater solar cell efficiency. "Today, when the awareness and importance of our mission is understood and appreciated by a large fraction of the world's population, we can be confident that we can move forward at an accelerated rate to help our society and planet to survive and flourish."

Ron Judkoff arrived in 1978, as the organization's first building energy efficiency scientist. "Back then, we were all in rented space, and when NREL built its first major building on campus, the Field Test Laboratory Building, no one thought to invite our small group of building energy efficiency scientists and engineers into the process," recalled Judkoff, who is now NREL's principal program manager for building energy research. "In fact, most of the staff and management probably thought the term 'building science' was an oxymoron."

Last month, Construction Digital, a monthly online magazine, named NREL's RSF—a 326,000-square-foot building housing 1,300 employees—the top net-zero energy building in the world. "Net zero" means the building uses no more fossil-fuel-based energy in a year than it makes up for in on-site renewable energy. In all, the RSF has received more than 30 awards for sustainable design and construction.

Now, with several buildings that have achieved lofty Leadership in Energy and Environmental Design (LEED) status, the technologies developed by NREL and its industrial partners are found on the campus and in the world market. The "SolarWall" transpired collector, light louvers, electrochromic and thermochromic windows, thermal storage walls, and NREL's Open Studio software tools that simplify optimal energy design, are getting friendly receptions in the marketplace.

"I expect the awards to keep coming, and our campus to serve as a shining example of energy efficiency throughout the world for many years to come," Judkoff said.

> "When I bring visitors on the site, I often tell them that when I came to SERI, this site was 300 acres of nothing but sage brush and rattlesnakes. But look at it now."
>
> —STAN BULL, *former NREL Associate Director for Science & Technology*

Origins Traced to 1970s Oil Embargo

SERI was approved by Congress and championed by President Carter in large part because of the oil embargo that pushed the price of gasoline from about 36 cents a gallon in 1972 to 62 cents in 1977.

From a focus on solar energy, NREL has grown to also include cutting-edge breakthrough research in wind, biofuels, energy efficiency, transportation, and geothermal energy.

Walt Musial was hired in 1988 as a testing engineer at a time when many of the U.S. wind power companies were going bankrupt because of canceled tax credits.

"The industry was moving to Europe, and NREL's National Wind Technology Center [NWTC] was one of the last safe havens where good-quality research was being done to explore big problems still facing the technology," Musial recalled.

NREL's wind center became the go-to site for companies, both foreign and domestic, to test their turbines and blades in the wind blowing down from the foothills of the Rocky Mountains and in the NWTC's dynamometer.

Not Just a Research Lab, but a Factor in the Marketplace

In its early years, SERI/NREL was a research lab that didn't involve itself in the realities of the marketplace. That changed in the early 1990s as NREL reached out to industry to help turn science into technology, working with the private sector to ramp up and bring renewable energy and energy efficiency to market.

Many of today's top solar companies percolated their ideas in the DOE Incubator program run at NREL.

NREL has been issued 262 patents and has agreements with 305 industry partners, 64 universities, and 33 not-for-profit organizations. It currently has 116 Cooperative Research and Development Agreements (CRADA) with industry.

An International Reach; a Helping Hand in Disasters

NREL's reach spreads across five continents—from wind and solar studies in Indonesia to biofuel-powered vehicles in Antarctica.

NREL's Roger Taylor and Dick DeBlasio recall that in the wake of the Earth Summit in Rio de Janeiro in 1992, they implemented the first stage of what later became a Brazilian national program to deploy solar and small wind power systems in communities without electricity in rural Brazil. "Luz para Todus" (Light for All) became a multi-year rural electrification program after the installation of more than 100 lighting, water pumping, and health clinic systems. "Our work in Brazil was very rewarding and fun," said DeBlasio, a chief engineer. "I started here in May of 1978, but it seems like yesterday."

NREL scientists and engineers have helped rebuild communities devastated by hurricanes, floods and tornadoes—showing how to bring sustainable energy and architecture to cities and towns, from tornado-ravaged Greensburg, Kansas, to New Orleans, flooded in the wake of Hurricane Katrina.

Renewable Energy's Growth Has Exploded

In the 35 years that NREL has led the way to a clean energy future, renewable energy has exploded:

- Installed renewable energy tripled between 2000 and 2009 in the United States and globally.
- While renewable energy comprised 2% of all new electrical capacity installations in the United States in 2002, by 2009 renewable energy comprised 55% of all new installations.
- Installed wind energy capacity increased by a factor of 14 between 2000 and 2009 in the United States.
- The weighted average price of wind power in the United States fell to 4.4 cents per kilowatt hour, making it cost competitive with fossil fuels.
- The United States leads the world in wind energy capacity at more than 35 gigawatts.

Just in the past decade, solar energy generation quadrupled in the United States. The annual growth rate of installed solar photovoltaic electricity capacity was 39%, while wind energy capacity grew by 34% a year.

Bull recalls the early days as "a mixture of wild-eyed hopes and utter disappointment," as the lab at first grew rapidly, then "declined precipitously overnight" when half the staff was laid off. Now, more than 2,000 people are employed at NREL.

"SERI/NREL has been and I think always will be a special place because the staffers have such a deep-seated dedication and commitment to the vision and mission," Bull said. "Just the name NREL is an incredible 'door opener' both nationally and internationally. It's almost frightening at times the impact the name alone has on acceptance in the world of energy."

— Bill Scanlon (July 5, 2012)

NREL Parking Garage Leads in Efficiency

It's no secret that researchers at the U.S. Department of Energy's (DOE) National Renewable Energy Laboratory (NREL) do cool things—including finding new ways to capture energy from the sun and wind. But there's nothing cooler than working on a parking garage, right?

"It doesn't sound glamorous, but it is a place for building energy savings," NREL Energy Efficiency Research Engineer Jennifer Scheib said. "A garage typically uses 15% of the energy that the building that it is designed to support uses. Many would say it's only 15% of the energy, but we'd say it's still 15% that can be improved on. For every watt you save in the building, that's $33 worth of photovoltaics you don't have to buy when you are targeting net-zero energy." A net-zero energy building produces as much energy as it uses over the course of a year.

NREL bid the parking garage and accompanying site entrance building for the lab's expanded campus using the same streamlined design-build process that was leveraged in the construction of the Research Support Facility (RSF). The team of RNL and Haselden Construction partnered with NREL to build these new energy-efficient facilities.

"It's an interesting thing to look at a parking garage as not just something that's subservient to the campus, but as a building that has its own energy-saving contributions to make," RNL Senior Project Manager Tony Thornton said. "There's usually a lot of sacrifice when it comes to designing a garage. So often, people don't care about the energy, they don't care as much about the aesthetics, and they don't think as much about the lifespan because it feels like a secondary structure."

Making NREL's garage an attractive structure that's both affordable and high performing presented a unique combination of challenges. In the end, the design-build team came up with a structure that is expected to perform 90% better than a standard garage built just to code.

Turning Off the Lights

A key focus from the beginning was how to light the parking structure. Fundamental building features such as structure type and bay sizing were carefully considered, in part to reduce the need for electric lighting. This upfront, integrated design allowed the lighting to be reduced by 90% versus code.

"We started by doing a survey of other garages to see how low the lighting density could go, because we knew lighting is one of the biggest energy uses," Scheib said.

NREL required daylighting to be one footcandle at minimum, even on a cloudy winter day. This means that the garage's

Installers attach photovoltaics to the south face of the NREL parking garage. The solar panels help make the Research Support Facility (RSF) and garage net-zero for energy use. The panels also help offset the energy used by the garage's 36 electric vehicle charging stations. *Photo by Dennis Schroeder, NREL 20947*

lighting system should be off except at night. To ensure proper illumination, a daylight model was created for the garage. "That's unique because most people wouldn't pay to model a garage," Scheib said. "But to get it right, it had to be done."

The skin of the garage is made of perforated aluminum panels that let in sunlight (while keeping out weather). There are also light wells that draw sun into the middle of the structure. Stairs are central to the design; they are well lit and so convenient that most people don't even realize there are elevators.

But nighttime is when NREL's garage looks really different—it's dark. "At night, when lights are needed, there are occupancy sensors in zones; as you move through the space, the lights turn on for you," Scheib said. "That's great for energy, and it's also great for the neighbors."

To handle the dark, the garage has a lighting control system normally used in office buildings, which leverages daylight and occupancy sensors. "By taking these systems and combining them with quick-response LED lighting, we could do it in a way that made the parking garage safe while maximizing the way that it saves on power use," Thornton said.

Most parking garages are open to the outside, so there is the opportunity to turn off some of the lights. In garages for retail buildings, this presents challenges because people perceive fewer lights as a security concern, and companies want to appear open for business. But according to Scheib, when it comes to lighting, safety is largely based on uniformity, rather than having very brightly lit spaces with stark light boundaries.

"While some might be worried about approaching a dark garage, we've heard that some people at the lab now see it as a safety feature," Scheib added. "If you approach and see the lights on, you know someone is in the garage, because otherwise the lights would be off."

Other energy-saving features include natural ventilation, which saves energy because there are no mechanical systems. The perforated panels are made from recycled aluminum, which can be recycled again. The paneling is used sparingly to maximize daylighting, but it also keeps snow and rain out.

Where the south side of the building didn't need as much protection from the weather, NREL staff and designers had the opportunity to get creative.

> "The big picture is that no matter what, there is room for innovation in the design process to see savings as big as 90% over code. It doesn't matter if it's a parking garage, lab, or office building."
>
> —JENNIFER SCHEIB, *NREL Energy Efficiency Research Engineer*

"We were investigating using the same aluminum panels, even though they don't have the same job as the north and west sides," Thornton said. "But NREL staff recommended during a project meeting that the south side be covered in solar. It turned out great. It's hard to see the panels on the roof of the garage or the RSF. On the south where panels will be most visible to the world, we have the ability to extend the message of what NREL is about."

The south-side solar panels are a striking sight that when added to those on the roof brings an additional 1.13 megawatts (MW) of solar to the NREL campus and helps make the RSF and garage net-zero for energy use. The panels also help offset the energy used by the garage's 36 electric vehicle charging stations.

Keeping Traffic Under Control

The size of a structure that can accommodate 1,800 parking spaces is impressive. But it also brings to mind something else—traffic. Getting people on and off the campus smoothly was another crucial part of the planning.

"Before the construction of the RSF, we did an environmental assessment, and a traffic study is part of that," NREL Transportation Project Manager Lissa Myers said. "We did determine that moving large numbers of staff on site could have potential significant impact to the nearby traffic intersections." Traffic impact scenarios included morning backups onto nearby I-70 and afternoon backups from a nearby intersection back to the NREL east gate. These traffic tie-ups would impact all the neighboring office buildings and the residential community.

"We looked at what could be done to mitigate those traffic impacts, and one of the long-term solutions was creating a third entrance to the campus," Myers added. As a result, DOE worked with Jefferson County to build a south entrance to the campus.

In the short term, after the RSF was built and while the parking garage and south entrance were still under construction, NREL put a traffic mitigation plan in place. Staff parked at a nearby shopping mall, and shuttles bussed employees back and forth between the campus and offsite parking. NREL also continues to offer bus passes and van pool vouchers, and encourages staff to carpool, bike to work, and take advantage of alternative work schedules and telecommuting.

With the parking garage now open, NREL no longer has offsite parking that requires shuttle buses. NREL also worked with the local transportation district to shift a popular bus route to drop off NREL employees right at the south entrance, so they can easily walk to their offices.

> "As designers, we can talk about designs and concepts all day long, but built structures speak to all clients. If you can show them rather than tell them, it makes all the difference."
>
> —TONY THORNTON, *Senior Project Manager, RNL Design*

Ongoing traffic assessments indicate the system is working. The morning and afternoon delays at the east and south entrances are minimal. "With all of these efforts, we have worked to spread the traffic out, so there isn't one high-impact area for the surrounding community," Myers said. A follow-up traffic study is planned in 2013.

Small Building, Giant Energy Savings

Some employees who can't take advantage of alternative transportation are now entering NREL's campus via a new road and site entrance building.

"The south entrance building is pretty wild. It is a hyper-efficient building," Thornton said. "It's a little security station—again, those are not given much respect and are usually very utilitarian. This building is brighter and more welcoming to visitors. The point is to make it feel like it does when you visit the RSF."

The new site entrance building has a wind catch tower for natural ventilation and features geothermal heating and cooling. It's a net-zero energy building and has the same types of daylighting and occupancy sensors as the garage and the RSF.

Both the garage and the new site entrance building are metered like the RSF, so NREL can monitor energy use to ensure that the buildings meet design goals. When people ask how NREL's buildings are performing, researchers know they will able to answer confidently.

"We believe the site entrance building will fall into the upper range of LEED [Leadership in Energy and Environmental Design] points," Thornton said. "If 80 out of 100 is needed for platinum designation, we're trying to achieve a score in the 94–95 range, because we are maximizing the sustainability of the structure."

The metering and the ability to prove that buildings can be built to be energy efficient, high performing, and still affordable is important to NREL's mission to help shape the commercial buildings of the future.

"The big picture is that no matter what, there is room for innovation in the design process to see savings as big as 90% over code," Scheib said. "It doesn't matter if it's a parking garage, lab, or office building."

"There's no demonstration piece better than a living, active building," Thornton said. "As designers, we can talk about designs and concepts all day long, but built structures speak to all clients. If you can show them rather than tell them, it makes all the difference."

— Heather Lammers (August 2, 2012)

Sustainability is a core part of NREL's mission. The laboratory commits itself to "walking the talk" by minimizing the use of resources (energy, materials, and water) while receiving the maximum value from resources used—along with balancing environmental, economic, and human impacts. *Photo by Michelle Slovensky, NREL 23114*

NATIONAL AND INTERNATIONAL IMPACTS

NREL facilitates comprehensive energy solutions by helping put renewable and energy efficiency technologies to work around the world through a range of capabilities. *Photo by Dennis Schroeder, NREL 21764*

NREL Helping Virgin Islands Cut Fuel Use

The U.S. Virgin Islands (USVI) are a great place to visit, but you wouldn't want to pay energy bills there.

The tiny U.S. territory in the Caribbean has just 110,000 residents, all the beach, surf, wind, and sun you'd ever want, but energy prices that are four to five times higher than are paid in the continental United States.

Like many islands on earth, the USVI are almost 100% dependent on imported oil for electricity and water generation. Residents pay about 47 cents per kilowatt hour to light their homes and run their appliances. Imported oil is even used to desalinate the water because there is so little fresh water available other than what residences catch on their roofs in the form of rain water.

But USVI Governor John P. de Jongh Jr., working with the U.S. Department of Energy's (DOE) National Renewable Energy Laboratory (NREL) and the U.S. Department of the Interior, has vowed to transform energy use dramatically. In January, at his State of the Territory address, he announced the goal of reducing use of fossil fuels by 60% in the next 15 years.

That's huge, and a great challenge, and just possibly a blueprint for how to achieve those similar reductions on the mainland.

"What we're attempting to do is integrate every large portion of renewable energy into our system," said Karl Knight, the director of USVI's energy office, who also is a board member of the Virgin Islands Water and Power Authority. "Think of it as a pilot for how to integrate renewables as a large proportion of the grid."

To get there, a half dozen different technologies need to be implemented, and energy efficiency will have to become a rallying cry.

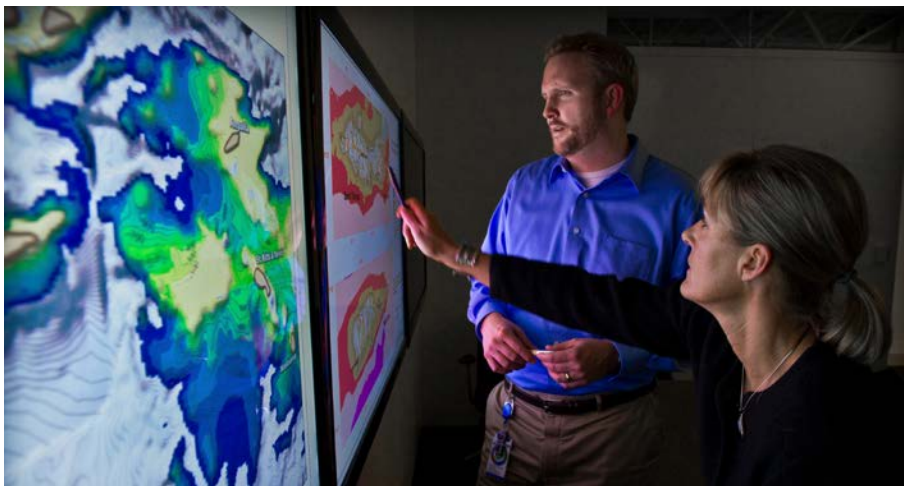
A Recipe for Energy Savings

That's where NREL's scientists and engineers are helping.

The United States, New Zealand, and Iceland are partners in the international partnership Energy Development in Island Nations (EDIN), and for the United States, its Virgin Islands territory was a natural fit.

"We wanted to help USVI particularly because the governor was very committed to transforming the energy infrastructure, as was the CEO of their utility," NREL's Adam Warren, who heads NREL's EDIN program, said.

NREL has helped USVI—its government, utilities, and public and private groups—to map the renewable energy potential, and to determine how to get to a 60% reduction by 2025. Early on, NREL produced a major technological report on grid integration, transmission, and distribution.



NREL's Adam Warren, left, and Karen Petersen examine a map that shows the wind and sun resources of the U.S. Virgin Islands. *Photo by Dennis Schroeder, NREL 19962*

> "We're working to create a whole cultural shift."
>
> —KAREN PETERSEN, *NREL Communication Specialist*

"We think 60% is very realistic," Knight said. "The government established that goal in collaboration with NREL and the Island Nations global partnership. They challenged Governor deJongh to be aggressive in his goal-setting and he took them up on it. We established the aggressive goal because we spend so much on energy. The only thing that people in the Virgin Islands talk about is the size of their electric bills."

The high rates have hurt low-income residents and have been a deterrent to economic investment, Knight said. "If the rate is going to be 40 cents a kilowatt hour or more, it shapes the type of business that's willing to locate in the Virgin Islands," he said. "Our total dependence on oil for power generation in an era of expensive crude oil is having a huge impact."

USVI burns 2.6 million barrels of oil each year to generate electricity and desalinate water.

The recipe to achieve a 60% reduction:

- 2% biomass
- 3% landfill gas
- 3% solar
- 6% wind
- 8% waste-to-energy
- 38% energy efficiency.

NREL's Karen Petersen said the most cost-effective way to reduce fossil-fuel use—the low-hanging fruit, so to speak—is "to help the utility become more efficient in its operations." Simple measures such as turning off lights in buildings and lowering the air conditioning use in tourist hotels also will help immensely.

"We're working to create a whole cultural shift," Petersen said. "They're very conservative in their use of energy because of need, but it doesn't necessarily revolve around an environmental ethic."

Island residents "had a healthy dose of skepticism" when the plan for more solar, wind, and biomass was proposed because past proposals haven't kept their promises, Knight said. "But we have tried to convince the community that we're not promising lightning in a bottle. This is a 15-year strategy, We're using tried and commercially proven technologies, gathering up the best practices and working in close consultation with energy experts such as the folks at NREL.

"This is not a developer selling some Star Trek technology that is going to save the day," Knight added. "It is going to be a gradual build-up to what we believe is a successful achievement of our goals."

Energy Transformation Isn't Easy

Dramatically changing how an island, a state, or a nation gets its energy presents enormous challenges, not the least being a shaking of cultural norms.

"That's why we work with the entire community," said Warren. "In the past, they've seen systems go in by these fly-by-night developers that don't work the way they're supposed to."

"You need everyone on board—government, the private and public sectors, to get something that big," Warren said. "We set up working groups to attack different areas—efficiency, renewables, transportation."

"That's been key," Knight said. "We've been able to secure some good partnerships that have really put some effort into helping us achieve the goal. Through the assistance of NREL, we've established local working groups, both public sector and private sector and the participation of non-government organizations."

Some 80% of the USVI's economy is dependent on tourism. Tourist hotels use much more electricity, especially in the form of A/C, than does the average full-time resident. "If you're not using A/C, most of the load is going toward heating water or keeping the refrigerator cold," Warren said. In all, the household usage is about half of what it is in the United States—450 kWh per month compared to 900 kWh.

Moving Renewables onto the Grid

One of the thorniest challenges is how to get so much renewable energy on the grid and still have it operate smoothly all hours of the day.

Solar and wind energy are variable—they surge onto the grid when the sun is shining and the wind is blowing, but trickle or stop when the winds calm and the sun sets, or even when a thick cloud passes by.

Happily for the USVI, the highest electrical use is when the sun is shining—and all those tourists want the air conditioning cranked up.

Still, the variability means that distributed systems make more sense. So, USVI likely will have small solar arrays on dozens of rooftops, and just a few of the larger solar projects; likewise, wind energy is likely to be distributed widely, with a mix of small turbines and some larger turbine farms.

Combining wind and solar energy with electricity generated from closed landfills and waste gives a nice balance of variable sources and so-called dispatchable sources—the kind that utilities can ramp up and down to match demand.

Tackling how to load a high rate of renewables onto the grid will help the mainland United States, too. "We as a nation want to figure out the problems associated with a high-penetration of renewables," Warren said. "We hope we can show that first in the islands like USVI and Hawaii."

Islanders Face Tough Choices

Virgin Islanders have heard horror stories about installed renewables that couldn't handle the load because the variability was too much, so part of NREL's job is to show how the proper steps with the right technology can make it a success.

Island residents are leery of overloading the grid with too much renewable energy, but they're faced with the reality of 47 cents per kilowatt hour. They're facing serious tradeoffs, Warren said. "'Do I pay my electricity bill or do I buy my medication?' is a real question that is forced on many."

"They're motivated to bring renewables on board and to conserve as much as possible because they need to," Petersen said. Businesses are closing daily because of the cost of electricity.

Optimism Grows from NREL/USVI Partnership

Knight is confident, and says NREL's participation has been crucial. "First, it has given the policy-makers the confidence that they're making the right decisions," Knight said. "To have a neutral party to discuss decisions with, to make sure that we are doing what is in the best interest of the population and the governor's goal, gives us and the policymakers credibility. We're able to say to the public, 'this isn't pie-in-the-sky.'"

> "We as a nation want to figure out the problems associated with a high-penetration of renewables. We hope we can show that first in the islands like USVI and Hawaii."
>
> —ADAM WARREN, *Project Lead, NREL's Energy Development in Island Nations (EDIN) initiative*

"We've sat down with the greatest experts in the nation out in Golden, Colorado, and discussed our plans—and they've endorsed them fully. We can tell the most passionate members of our community that we've had conversations with NREL and, yes, they've endorsed the proposed projects."

"Our first and foremost goal is to assist other small island nations to curb their appetites for fossil-fuel-derived energy and to provide a model on the cost and investment return on the latest technologies."

"We're hoping there's a lesson to be learned here to benefit larger systems. Hopefully, we can be the test bed for the rest of the nation and the globe."

— Bill Scanlon (January 11, 2012)

Embrace of Renewables in Heartland Wows Execs

Seventeen executives traveled through middle America last month and came away amazed by the can-do spirit alive in the heartland, in awe of how those connected to the land overcame disaster and economic crisis to embrace renewable energy.

The 17 were members of the 2012 class of the Executive Energy Leadership Program (Energy Execs) run by the U.S. Department of Energy's (DOE) National Renewable Energy Laboratory (NREL). Each of them—representing private business, local, state, and federal government, and nonprofits—will use the program to bring back to their workplaces an idea to enhance sustainability or build renewable energy projects. The field trip complemented classwork done at the NREL campus on the practical outgrowth of research in renewable energy and energy efficiency.

The Energy Execs traveled by bus from Denver to Lamar, in the southeast corner of Colorado, to meet with economic-development and community leaders and see one of the largest wind farms in the nation. They then rode on to Greensburg, Kansas, site of a devastating 2007 tornado—and now site of the most LEED (Leadership in Energy and Environmental Design) Platinum energy-efficient buildings per capita of any town or city in the world.

"To see them embrace these technologies, to bring their care for the land and their conservation values to the newest technologies … that's pretty impressive," said Charles Allison, Jr., an associate professor in finance, energy policy, and sustainability management at the New School in New York City. "Understanding who they are goes a long way toward knowing how to integrate energy efficiency into their towns."

Old Windmills and New Wind Turbines

In Lamar, the Energy Execs visited the Emick family ranch, where 98 1.5-MW wind turbines rotate at speeds of up to 24 rotations a minute, bringing electricity to tens of thousands of homes—and where in the blazing sun, cows find shade in the turbines' shadows. It's part of a 150-turbine wind farm that spreads from Prowers County to Bent County to the east.

"NREL approached my dad and said they wanted to put up some meteorological towers to study the wind," rancher Greg Emick earlier told a gathering of the Energy Execs, the Prowers County Economic Development organization and other policymakers from Prowers and surrounding counties. "They spent five years studying the wind, and they found that we had a really good wind resource here."

Xcel Energy got interested, and in 2003, during a six-month span of busy construction, the Colorado Green Wind Power Project

Executive Energy Leadership Program (Energy Execs) participant Mark Dow checks out the wind turbines at the John Deere dealership in Greensburg, Kansas.
Photo by Dennis Schroeder, NREL 21765

built 98 turbines on Emick's land, with another 10 on nearby property. In addition to the Colorado Green Project, Lamar Light & Power generates electricity from their own two turbines.

The wind farm gives the Emick family a steady income and adds $400,000 a year to Prowers County's coffers. That "may seem insignificant, but down here that is very significant," said County Commissioner Gene Millbrand. During construction, there were 250 jobs; now there are about 20 well-paying jobs. "I don't know how our county could have survived this recession had it not been for the stimulus and the revenue we get from this wind farm."

Emick and Millbrand said there was near-universal agreement among residents that wind energy would be a good thing. Why? Well, there are the jobs and the tax revenue, and besides, said Emick, "It beats ranching."

The tour of the Emick farm provided an unexpected historic perspective when family patriarch Bob Emick presented his barn containing dozens of antique but freshly painted windmills, each a work of art in itself, adorned with the finest in 19th-century script. Another 40 of Bob Emick's windmills are on display at the American Wind Power Center in Lubbock, Texas.

"I just can't get over the irony of Mr. Emick being into those windmills, collecting them for 30 years, and the serendipity of having 98 wind turbines put on his land," said David Warner of NREL. "His own hobby and interest played out for him and his family in a very big way."

Town Embraces Its Values to Rebuild

Then it was on to Kansas.

Greensburg, Kansas, is about 100 miles west of Wichita, in Tornado Alley—no more so than the evening of May 4, 2007, when an EF-5 twister smashed into town, destroying 95% of the structures.

It was just one more slowly dying rural Kansas town until then, its chief attraction the Big Well, the largest hand-dug well in the nation, said Superintendent of Schools Darin Headrick.

The destruction was too much for some, who relocated, dropping Greensburg's population from about 1,400 to fewer than 1,000. But those who remained were steadfast.

> "To see them embrace these technologies, to bring their care for the land and their conservation values to the newest technologies … that's pretty impressive."
>
> —CHARLES ALLISON, JR., *Associate Professor, The New School*

At the first post-tornado town meeting a week later—attended by 500 people—a proposal to turn the town into a sustainable, tornado-safe paragon of clean energy caught fire.

As part of a DOE rebuilding team, NREL scientists, including Shanti Pless, came to town to advise on energy efficiency and the prospects for wind energy. Residents said yes to the grand vision, even though it meant months-long delays in getting back into permanent housing in the town.

At a meeting with town leaders and Energy Execs, Daniel Wallach, executive director of the nonprofit Greensburg GreenTown, said: "After this disaster, it would have been easy to say 'let's fold this whole town up.' But if we were going to survive and be a player and bring business here, we had to do this."

"Our ancestors were the original recyclers," Greensburg Mayor Bob Dixson said. "They farmed, they ranched, they didn't waste. It was so much in their nature, and it's so much common sense. Why import energy when we have abundant solar and wind resources?"

Today, Greensburg has nine LEED Platinum buildings, including the K-12 school, the city hall, the county hospital, and the biggest employer in town, the John Deere dealership. Each uses half or less of the energy of a standard building of its type. The Deere building employs skylights and natural daylight, captures and recycles water, uses geothermal heating, and draws power from its own wind turbine.

"It takes a lot of courage, when you've lost everything you had, to not just want to get back to a sense of normalcy, but to wait and do it right," Greensburg City Administrator Ed Truelove said.

Energy Execs Inspired to Take Action, Collaborate, Innovate

On the ride back to Denver, the Energy Execs reflected on what they had learned and how they can bring clean energy to their workplaces.

Raimone Roberts, an executive with a large construction company, wants to help rebuild inner-city Detroit, one energy-efficient block at a time. "I learned that simple systems can work very well, and that you need to be very clear about the vision, about showing how the project reflects community values," Roberts said. "They inspired me to not be afraid to ask questions, no matter how ludicrous, because if you ask enough questions you come up with innovations that can lead to great change."

Manisha Patel, deputy assistant director for regulatory policy at the White House Council on Environmental Quality, said: "We no longer have to change the way people think about renewable energy. The mental change has happened. What isn't there is an infrastructure that will allow renewables to truly penetrate into our delivery system around the country."

"I was awestruck by the human ingenuity and the perseverance of the human spirit, how driven people can be," Patel said. "The things I've seen make me personally want to be a better person. I'm going back and sharing these stories. I'm energized, and I want to do things."

"When you hear about American spirit and innovation, it is often just rhetoric. This trip showed me that it isn't just rhetoric. It can be real."

Keith Hay of the Colorado Public Utilities Commission said visiting Greensburg convinced him to be more ambitious with his clean energy project. "How do we take energy efficiency from the status quo to deepening it, taking it to the next level? I want to help the commission figure out how we move to more integrated solutions."

Finding Sustainability Fans Everywhere

Patrick Hamel of the Colorado Department of Public Health and Environment will redouble his efforts to win approval for a rooftop solar project for the Argo Mine in Idaho Springs, which would cut energy use by 40%. "I saw a sign in the new school that stuck with me" when touring Greensburg's new K-12 school, Hamel said. "Your beliefs don't make you a better person, but your actions do.'"

Carol Dollard, an energy engineer at Colorado State University (CSU) who wants to build a small wind farm at a CSU cattle research center on the Eastern Plains, was impressed by "the whole green building thing in Greensburg.

"Did I see anything I hadn't seen before? No. But they just got it. They weren't content with one LEED building that could be financed with government help. They have the mentality that you should do it right every time.

"The most remarkable thing for me was the human ingenuity," said Dollard, who lives in a neighborhood recently devastated by the High Park wildfire. "It started with individuals and spread. They wanted to do what was right for them, but also what was right for their community and for the future."

Karen Hancock joined the field trip after the theater shootings in her city, Aurora, Colorado. "I had to ask, 'Aren't you just traumatized by what happened to you?'"

Greensburg residents said they did experience trauma, and some are still feeling it, Hancock said. "But they said the rebuilding of the town was a kind of green therapy that took them away from their problems. They were able to make their community better and their personal lives better out of a tragic event."

Dick Hemmingsen, director of renewable energy initiatives at the University of Minnesota, said the can-do spirit of the people in Lamar and Greensburg—and their embrace of conservation—reminded him of his own great-grandparents, who built sod huts with green roofs, using the warmth of the earth to survive.

"It's just another way to get back to the future," Hemmingsen said. "It's an inspiration to see people rolling up their sleeves to get things done that have to be done."

— Bill Scanlon (August 13, 2012)

SOLAR

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

Photo by Dennis Schroeder, NREL 21615

Thermal Storage Gets More Solar on the Grid

It's 4:45 p.m. on a sweltering August afternoon, and the rooftop solar panels are starting to lose juice. The sun's lower angles and that huge cottonwood tree are interfering with the efficient photon-to-electricity transfer.

What is an environmentally conscious—but air-conditioning-loving—homeowner to do?

Peak demand for electricity in the United States typically hits between 4 p.m. and 8 p.m., which doesn't quite line up with the sun's schedule. It's fortunate that the sun is high in the sky during many of the hours when the air conditioning is in demand. But in summer, people tend to need air conditioning during the dinner hour and beyond, when kitchen appliances are whirring, lights are on, and TVs are blaring.

To the rescue comes concentrating solar power (CSP), a technology being tested and deployed by utilities in America's deserts and southern Spain.

New analysis at the U.S. Department of Energy's (DOE) National Renewable Energy Laboratory (NREL) has found that CSP, with its greater grid flexibility and ability to store energy for as long as 15 hours, can enhance total solar power generation and actually give photovoltaic (PV) systems a greater presence on the grid.

PV panels convert photons from the sun directly into electrons for electricity—and are grabbing real estate on rooftops across the Americas, Europe, and Asia.

CSP technologies use mirrors to reflect and concentrate sunlight onto receivers that collect the sun's heat. This thermal energy can then be used to drive a steam turbine that produces electricity for utilities.

Thermal Storage Can Even Out the Bumps

Like Edison and Tesla or Dempsey and Tunney, the two major solar energy technologies never meant to play nice. Each had its niche—and its dreams of market share.

But that's changing, said NREL analyst Paul Denholm, co-author with Mark Mehos of the study "Enabling Greater Penetration of Solar Power via Use of CSP with Thermal Energy Storage."

Think of power from PV as a roller coaster of highs and lows, and power from CSP, via thermal energy storage, as a gently rolling train.

PV panels and wind turbines contribute electricity to the grid, but without the ability to store that power, they cannot supply the grid after the sun sets, or after the wind dies. Even passing clouds can cause drops in the amount of solar energy that gets on the grid.

Abengoa is erecting more than 3,200 mirrored parabolic troughs at its Solana plant near Gila Bend, Arizona. When at full operation, the concentrating solar power plant will serve more than 70,000 homes.
Photo by Dennis Schroeder, NREL 20100

> "It all gets down to grid flexibility. What sets of grid technologies do you deploy to make the grid respond faster and over a greater range to the input of variable energy such as solar and wind? If you can't respond quickly, you end up potentially throwing away wind and solar energy."
>
> —PAUL DENHOLM, *NREL Analyst*

Large fossil-fueled and nuclear power plants can't be quickly stopped or started to accommodate variable energy sources such as solar and wind energy.

CSP can even out these ebbs and flows because it can store power and ramp up output when the amount of direct wind or solar power drops.

Grid Flexibility is the Key

"It all gets down to grid flexibility," Denholm said. "What sets of grid technologies do you deploy to make the grid respond faster and over a greater range to the input of variable energy such as solar and wind?

"If you can't respond quickly, you end up potentially throwing away wind and solar energy."

"We know that the more wind and solar you add to the grid, the harder it is to balance the grid and maintain reliability."

A CSP plant works by heating a heat transfer fluid that is used to boil water to make steam. But because of thermal inertia, by the time that fluid gets through the system's pipes to the power plant, perhaps 10 or 15 minutes have passed.

When a cloud passes over a PV panel, the drop in energy production is immediate. But because of the 10 or 15 minutes of thermal inertia, a cloud passing over a CSP tower doesn't cause this immediate drop. Nor is there the immediate surge when sunlight returns.

"The change is more gradual," Denholm said. "That's one reason CSP can bring a greater quality to the grid."

Still, the greater potential for CSP—and for CSP helping PV to expand its role on the grid—is its capacity to store the energy it captures from the sun for several hours, making it a source of reliable energy after the sun sets.

"CSP can fill in that gap in the evening when there's peak demand for electricity," Denholm said. "Together, the solar resource can provide all that peak demand. And together they can reduce or eliminate the need to build new power plants for those peak periods."

Molten Salts a Low-Cost Solution

Thermal energy storage at CSP plants "is low-cost because it's not exotic," Denholm said. "It's some large tanks with some media to store energy before you use it to boil the water." The best medium for storage available today is molten salt, NREL's Greg Glatzmaier said.

Molten salts are abundant and not very costly. They behave themselves, neither decomposing nor volatizing at the high temperature needed in a CSP plant—about 565 degrees Celsius (°C).

At a typical molten-salt CSP plant, the salts are stored in two tanks, one much hotter than the other.

In the case of a power tower CSP plant, in which the mirrors focus the sun's rays on one receiver atop a tower, the lower-temperature tank is at about 293°C, while the higher-temperature tank is at 565°C, Glatzmaier said.

The salt is pumped from the "cold" tank to the power tower, where it collects the solar energy that's focused on the receiver, raising its average temperature. The salts then descend into the "hot" tank, where they can maintain this very hot temperature for several days, though typically they are used within hours.

The salt in the hot tank is then sent to a heat exchanger that generates the steam needed to turn the turbines at a power plant. The turbines generate electricity that goes to homes and businesses.

As they exit the steam generator, the salts cool, and by the time they return to the cold tank, they measure at about 293°C.

When the sun is shining, the CSP plant can take the salts out of the cold tank, heat them up at the tower's receiver, and then dump them into the hot tank for storage, Glatzmaier said. "If you come to the end of the day and the hot tank is pretty full, you can keep generating electricity by withdrawing the salts from the hot tank to generate steam."

It's a continual balancing act. If all the salt is in the cold tank, no stored energy is available. If it's all in the hot tank, there's plenty of energy stored for later use, but nothing to replenish the system.

Molten salts tend to freeze at about 200°C, so as long as the two tanks range between 293°C and 565°C, the salts are in no danger of reverting to a solid state. At room temperature, the salts look like powdery white table salt. At the higher temperatures in a CSP plant, the salts look like water.

The molten salts used for storage are a mix of sodium nitrate and potassium nitrate. Sodium nitrate is mined from dry lake beds in Chile, in surroundings similar to the Utah salt flats. Potassium nitrate also occurs in nature and is mined in Chile, Ethiopia, and elsewhere.

Plants with Storage in Spain, Nevada, Arizona, California

Abengoa Solar is building a 250-megawatt CSP plant near Gila Bend, Arizona,that will cover 1,900 acres and use 900,000 mirrors to direct sunlight to heat a working fluid inside its tubes. The plant's six hours of thermal storage mean it can deliver electricity after the sun sets to approximately 70,000 homes.

The 19.9-MW power tower run by Gemasolar near Granada in southern Spain is configured to store enough energy during the summer to provide solar-generated electricity 24 hours a day, Glatzmaier said. In the winter, when there's less sunshine, electricity comes from more conventional sources a few hours each day. The system aims to power 25,000 homes and reduce carbon dioxide emissions by more than 30,000 tons a year.

SolarReserve is building the 110-MW Crescent Dunes Solar Energy Project near Tonopah, Nevada, which will use molten salt to store the sun's energy as heat for several hours. It will include more than 17,000 mirrors to focus the sun's light on a tower 640 feet high.

BrightSource is building an even larger CSP project in the Mojave Desert near Needles, California, that will have storage for just a couple of hours a day—but this will be enough to serve more than 140,000 homes during peak hours. Company executives say the plant will reduce carbon dioxide emissions by more than 400,000 tons per year.

PV/CSP Symbiosis Makes Economic Sense

The cost of PV has been plummeting, and it has a cost advantage over CSP. But CSP has the advantage of storage, and so teamed with PV can improve the benefits and bottom lines of both technologies. Storage does raise the price of a CSP plant, but "if you're running your turbine more hours in a day, you're amortizing your turbine cost over more generation time, and there's a real cost benefit there," Glatzmaier said. The bottom line: when storage is added to a CSP plant, it increases the value of its electricity—both its energy value and its capacity value.

Solar plants also can store energy in batteries, but at least for now, that approach is quite expensive. Other thermal storage technologies being investigated by researchers include phase-change or thermal-chemical storage.

Denholm and Mehos caution that the preliminary analysis in their study will require more advanced grid simulations to verify the actual ability of CSP to help wind and PV gain a larger presence on the grid. An important next step, they say, would be more complete simulations using utility-grade software. That will answer questions on the realistic performance of the generation fleet, transmission constraints, and actual CSP operations.

— Bill Scanlon (February 14, 2012)

NREL Helps PV Industry Make Panels Last

During 30 years on a rooftop, a solar panel gets bombarded by UV rays, soaked by rain, buffeted by wind, pounded by hail.

How well it stands up to that beating is a crucial factor in setting the warranties of solar modules—and in convincing the public that solar energy can be counted on like the sun rising in the east.

The U.S. Department of Energy's (DOE) National Renewable Energy Laboratory (NREL) plays a crucial role in improving the reliability of the photovoltaic (PV) panels that are being installed on rooftops in record numbers.

NREL helps set standards for reliability and serves as a neutral third party in tests of manufacturers' new solders, edge seals, and glues. At its Golden, Colorado, campus, NREL subjects solar panels to heat, humidity, and mechanical stress to simulate conditions in Denver, Phoenix, the Philippines, and elsewhere.

In March, leading scientists and engineers in the industry gathered at NREL for the PV Module Reliability Workshop.

The workshop encouraged a frank discussion of reliability problems that can plague solar power companies.

What standards are needed for the glue in the edges that seal a panel's top and bottom? How does weather affect cracking? What can be done to prevent one glass panel from creeping away from the other?

NREL Stresses Edge Seals to Predict Failure

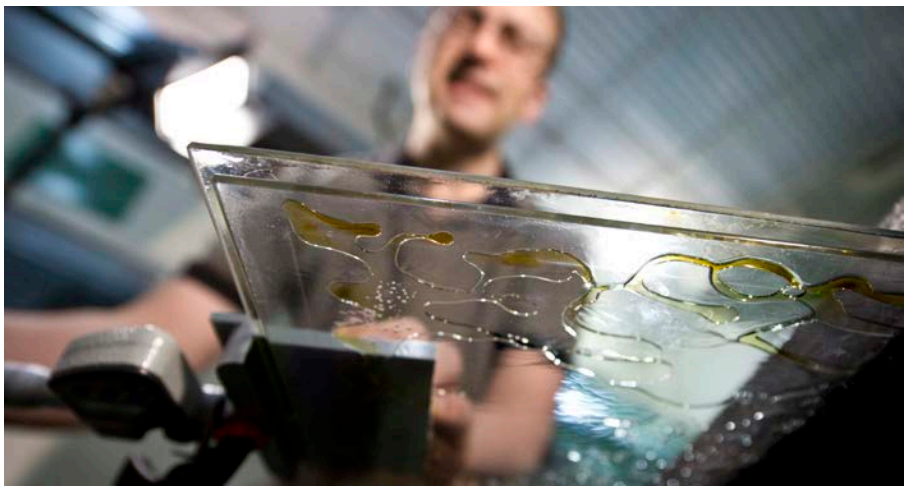
Solar modules must be sealed to keep out moisture—and that's why edge seals are so crucial.

NREL scientist Michael Kempe exposes edge seals to different configurations and environments using Atlas Weather-Ometers.

On what looks like a whirling see-through geodesic dome—albeit just two feet in diameter—NREL scientists attach matchbook-sized samples that simulate the construction of PV modules to determine at what combination of UV radiation, high temperature, high humidity, and mechanical stress those samples can fail.

It's important that manufacturers not just check for single stresses. By demonstrating that a combination of two or three factors can cause a failure, NREL is helping manufacturers prepare for the worst.

"We help manufacturers to know what kind of stress to put on their samples to determine if Sample A is better than Sample B," Kempe said. "Every tiny detail, every aspect of these things has to be examined."



Working in his lab at the NREL Outdoor Test Facility, NREL scientist Michael Kempe measures the "creep" of the top and bottom glass of a solar module, testing the encapsulant and demonstrating how enough stress can produce a spectacular failure. *Photo by Dennis Schroeder, NREL 20427*

A typical 12-millimeter-wide edge seal should keep out moisture anywhere in the world—from Salt Lake City to Bangkok—if it maintains a good adhesion, Kempe said. And the cost is between $1 and $2 a module, whether it is a tape-style edge seal or a hot-melt extrusion.

For humidity tests, NREL uses a vacuum oven to expose samples to controlled relative humidity using saturated salt solutions: lithium chloride for low humidity; magnesium chloride for 25% to 31% humidity; sodium nitrates for higher humidity.

Testing Leads to Good News on Panel Creep

NREL has been able to share good news with the industry.

In the case of "creep," NREL's sophisticated tests showed that the problem isn't as big as was feared.

In a solar module, two pieces of glass are adhered together with a plastic encapsulant that may be solid at one temperature but flow—or "creep"—at another temperature. If it flows during the expected lifetime of a solar module, solar panel components can be displaced, and that can cause a short, break electrical connections, or even cause fires.

The stakes are high: a one-centimeter creep can expose live wires to the elements, and that can cause arcing or other serious safety problems.

NREL's tests found that most encapsulants used today or proposed for future use do a very good job of preventing creep. But showing that failure is possible keeps manufacturers from becoming complacent.

Last summer, Kempe and his colleagues used eight different encapsulants from six manufacturers to assemble several mock and actual solar modules. The scientists then evaluated them side by side in an objective manner, and in a way that uncovered strengths and weaknesses of the various encapsulants without pointing fingers at individual companies. The industry's trust in NREL made the tests possible. "They were able to participate without the fear of being singled out," Kempe said.

The researchers put insulating materials on the test modules and deployed them in Arizona so they would reach the highest temperatures (104°C) that are likely in the field.

The only material that crept significantly in the outdoor experiments was one that was intentionally formulated improperly so that it would still melt at moderate temperatures.

"All the other plastic materials that people in the industry were considering for encapsulation were essentially OK outdoors," Kempe said. "It would only be under very extreme circumstances that you might have a problem. The standards community realized that this stumbling block was not nearly as big an issue as was suspected."

> "We help manufacturers to know what kind of stress to put on their samples to determine if Sample A is better than Sample B. Every tiny detail, every aspect of these things has to be examined."
>
> —MICHAEL KEMPE, *NREL Scientist*

Stress, Temperature Tests Help Prevent Cell Overheating

NREL also works on the problem of concentrating PV cells overheating in a module. Concentrating PV uses lenses to focus more sunlight on a solar cell. The solder or epoxy that adheres the panel's glass and edges will fatigue with time because of temperature changes that happen with the weather, NREL scientist Nick Bosco said. When the attachment goes bad, heat can't escape, and the cell overheats.

NREL uses high-frequency weather data to model the changes in cell temperature for Houston, Los Angeles, Albuquerque … wherever a company wants a climate test. The data are publicly available.

The most damaging locales are those with high temperatures and partly cloudy skies. The frequent temperature changes when clouds pass by can cause extra stress. "In Golden, Colorado [site of NREL's main campus], where we get hot mornings and then clouds roll in every afternoon, that can be more damaging than in Phoenix where you don't have many clouds," Bosco said. "We're early in the process, but we're seeing easily a 20% to 40% difference between certain locations."

To test the effect of temperature cycles on the modules, NREL uses various solders and epoxies to attach pieces of the panels, and then exposes them to different temperatures at varying intervals. Researchers test thermal cycling in indoor chambers and expose modules to outside conditions, comparing the results.

"We're interested in how cracks grow in the solder as the module goes through cycles," Bosco said. "Our instruments can image the cracks on a computer, analyze them, and measure their size. We'll do that periodically, then put the module back in the chamber, do more cycles, then measure the growth rate of the cracks as a function of the number of cycles."

Bosco is working on models and experiments to determine the amount of damage the attachment will accumulate. The goal is for the indoor test chamber to accurately reflect outdoor conditions.

"The amount of damage the attachment accumulates is different for every city, and we're hoping to model that," Bosco said. "We're hoping to be able to make real-life predictions based on location." So many cycles in the chamber is equal to so many years outside. "So, a company might expect similar crack growth after so many years."

The challenge for industry is to design solar modules that are very durable and reliable, yet not overly expensive. NREL scientists and their industry counterparts agree they can meet that challenge.

"They're looking for a route to a less expensive design and architecture of a cell assembly," Bosco said. NREL is able to figure out why a solution works, not just that it does work. It can report that a change in design or materials has this or that consequence in reliability. And NREL shares that knowledge with the industry to help the technology move forward.

NREL scientists and their industry partners have learned that an accelerated test will mean different things in different locations—and that the material and architecture of the design can influence reliability dramatically. "You can certainly have an expensive bad design," Bosco said. And, of course, a good product that is incorrectly installed can fail.

As tempting as it is to accelerate the testing so that new, presumably better products can get to market sooner, testing experts know that validating a product for 20 or 30 years of useful life is complicated without comparisons to real-life durability.

So, NREL and the industry keep a poultry analogy in mind. "When you're trying to hatch an egg, you give it 25 days at about 40°C, and you get a chicken," Kempe said. "If you try to accelerate the time by accelerating the temperature, you get a boiled egg."

The results of NREL's testing will provide the technical basis for changes to reliability standards.

Today, the standards aren't robust enough to predict the overall longevity of solar panels. NREL, the PV industry, and the attendees of the PV Reliability Workshop are working toward the day when tests and standards can determine the lifetime reliability of a module.

"What can come out of this is a graded test sequence," Bosco said. "If you pass, say, Level A, it means the module is good for a lifetime in these certain locations. A stricter Level B certification will provide a similar lifetime warranty in more damaging locations."

— Bill Scanlon (June 6, 2012)

Thermal Scout Finds Trouble at Solar Plants

At a 20-MW concentrating solar power (CSP) plant, some 10,000 mirrors reflect sunlight onto 10,000 receiver tubes, each of which must operate efficiently to get the maximum impact from the sun.

Yet, operators don't have a good sense for which among the 10,000 tubes may have an air leak, or a hydrogen leak, or have been shattered by a flung rock. The best they can do is look at the entire output and roughly guess that if the plant seems to be operating, say, 4% under capacity, it may have about 400 bad tubes.

The only alternative is to laboriously check each tube by hand, an odyssey that can take months.

Now, the U.S. Department of Energy's (DOE) National Renewable Energy Laboratory (NREL) has available for license a device called Thermal Scout that can identify and analyze bad receiver tubes as fast as a car or truck can rumble down the rows of mirrors at a CSP plant.

Thermal Scout combines a global positioning system (GPS) on the roof of a car, an infrared camera in the back seat, and some sophisticated software that tracks and analyzes in real time. All the driver has to do is push a couple of buttons, then drive in a very straight line down the rows while Thermal Scout does all the rest of the work.

For the 40 multi-megawatt CSP plants in the world today—and the 28 new ones slated to be built by 2014—Thermal Scout could mean turning a months-long task into a two-day sprint.

Need for Rapid Detection Device Spurred Invention

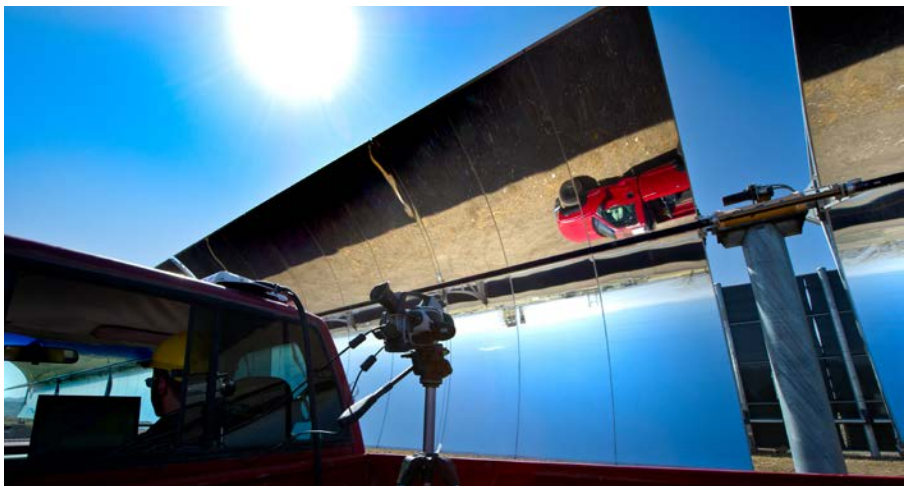
NREL Senior Engineer Tim Wendelin started working on the concept a decade ago when leaders in the parabolic trough industry explained to him the importance of being able to characterize the performance of their receivers in the field.

Wendelin combined an infrared camera with a precise GPS unit and software to produce a device that provided shortcuts to the old, labor-intensive method of checking each tube manually. But it was still cumbersome.

He credits his NREL colleagues Allison Gray and Benjamin Ihas with bringing real-time analytics and user-friendliness to the device, which they dubbed "Thermal Scout" in 2011.

"They brought it into the 21st century," Wendelin said. "Now, it is so smooth and easy to use."

At a CSP plant, the sun strikes mirrors that heat up a fluid that turns water into steam to turn turbines that generate electricity for homes and buildings. The heating fluid is enclosed in a



At SkyFuel, Inc.'s testing facility in Arvada, Colorado, NREL Engineer Allison Gray drives a pickup truck equipped with Thermal Scout, a device that teams a GPS unit on the roof with an infrared camera in the pickup bed. NREL colleague Benjamin Ihas checks the readings on a laptop to the right of the driver's seat. *Photo by Dennis Schroeder, NREL 20339*

black-coated stainless-steel tube—the receiver. The receiver is surrounded by a glass tube and a vacuum that minimizes thermal loss. The infrared camera in Thermal Scout focuses on that glass tube.

The GPS device ensures that even with slowdowns or potholes, the camera captures the image of that glass tube as the vehicle wheels down the row of receivers.

The tube-shaped receivers are typically about 4 meters—or 13 feet—long and about 70 millimeters—or 3 inches—wide. In a typical CSP plant, there might be 100 receivers in a row, and some 100 or 200 rows.

"The beauty of Thermal Scout is that it's used in a consistent geometry," Wendelin said. "The receivers are all in rows, and it can snap a shot of each one of them."

Receivers are designed to last for decades, but something as simple as a rock sent flying by a passing vehicle can compromise the tubes and let in outside air. Or, the thermal fluid that passes through the tube can degrade over time, causing a buildup of hydrogen between the steel tube and the glass. Earlier generations of receivers weren't built quite as well and may have shorter lifetimes compared to today's receivers.

Thermal Scout is User-Friendly

Thermal Scout users start with NREL-developed software that asks them to define the row geometry and specify the number of rows, something they only need to do once. Users also need to input the temperature of the fluid as it enters a row of receivers and its (higher) temperature when it reaches the end of the row.

Armed with that information, the infrared camera—with the help of the GPS—knows when to snap to capture thermal images of each receiver.

The GPS device is on top of the car, the infrared camera mounted on a tripod in the back seat.

The driver clicks "Start Test," the software fine-tunes the camera to get the right focus, and the driver starts moving.

Thermal Scout can operate well at 25 mph, but most plants have a 10-mph speed limit to keep road dust from landing on the mirrors or receivers.

If a passenger is interested, he or she can watch a video on the left side of the screen and still images on the right. At the bottom is a real-time plot of the average of the peak temperatures.

"The software will find the highest peak temperature, which in our case is always the receiver tube," Ihas said. "It can take 100 slices and run a statistical analysis to make sure there are no strange artifacts giving a false reading."

For example, if the camera captures a metal joint or the sun's reflection on the bottom of the tube, eliciting a temperature way above the norm, that anomaly is filtered out of the equation.

> "The beauty of Thermal Scout is that it's used in a consistent geometry. The receivers are all in rows, and it can snap a shot of each one of them."
>
> — TIM WENDELIN, *NREL Senior Engineer*

Later, when plant operators analyze the data, they can see, for example, that receiver 35 in row 12 showed some higher temperatures. They can retrieve the images from that specific receiver and verify—or not—that the tube is indeed malfunctioning or running a little warmer.

Device Helps Operators Determine When to Replace Receivers

The latest enhancement of Thermal Scout is built-in data analysis, which has been streamlined and made intuitive for users.

Click for a row report in Thermal Scout, and a Web page is generated that can be shared with anyone at the plant. Click to "acquire one image," and that image can be examined in detail, now or later.

Another click, and a complete data analysis for a row, a series of rows, or the entire plant appears on the screen.

> "Thermal Scout can very quickly identify a hot receiver, including the row, the number, the glass temperature, and where to find it."
>
> —BENJAMIN IHAS, *NREL Optical Engineer*

"Thermal Scout can very quickly identify a hot receiver, including the row, the number, the glass temperature, and where to find it," Ihas said.

Every line of pixels is a line of data, Gray, an NREL engineer, noted. And NREL can help troubleshoot problems remotely.

Of course, it's up to plant operators to decide when to replace the problematic receivers—when a few are bad, or when dozens or hundreds are bad. A row of receivers can be shut down overnight, and a few replaced by the time the sun rises the next morning. Still, it's a laborious job, so the plant uses its own discretion on what failure rate warrants replacement of receivers.

A recent test of a five-year-old plant found that about 5% of the receivers were performing poorly or starting to waver, Ihas said.

"Thermal Scout would likely be used every two years or so at a large CSP plant, unless something happened to the output that warranted more frequent checks," Gray said.

"There's probably a threshold where they would say, 'We need to address this; we need to replace some receivers,'" Wendelin added.

Florida Power and Light, which installed early-generation CSP receivers, used an early version of Thermal Scout several years ago to quickly assess their tubes and determined that it made the most fiscal sense to replace them all. "They never would have been able to make that determination without Thermal Scout," Wendelin said.

—Bill Scanlon (June 27, 2012)

PV Reliability Workshop at NREL Sets Ambitious Goals

More than 160 people attended the February 28–March 1, 2012, National Renewable Energy Laboratory (NREL) Photovoltaic (PV) Module Reliability Workshop in Golden, Colorado, and discussed, among other topics, keeping moisture out of PV modules, reliability issues specific to thin-film and PV concentrator modules, new test methods, performance failures, and modeling of reliability.

The workshop was a regional meeting of the International PV Module Quality Assurance Task Force, which is developing international standards for comparative testing of PV modules.

"Every company is required to share a presentation in order to attend the workshop. If everyone brings a little to share, everyone takes home a lot of information, and that leads to faster progress toward understanding how PV modules will fare as they are deployed worldwide," Sarah Kurtz, the NREL senior scientist who organized the workshop, said.

Task Groups reported ambitious goals, including:

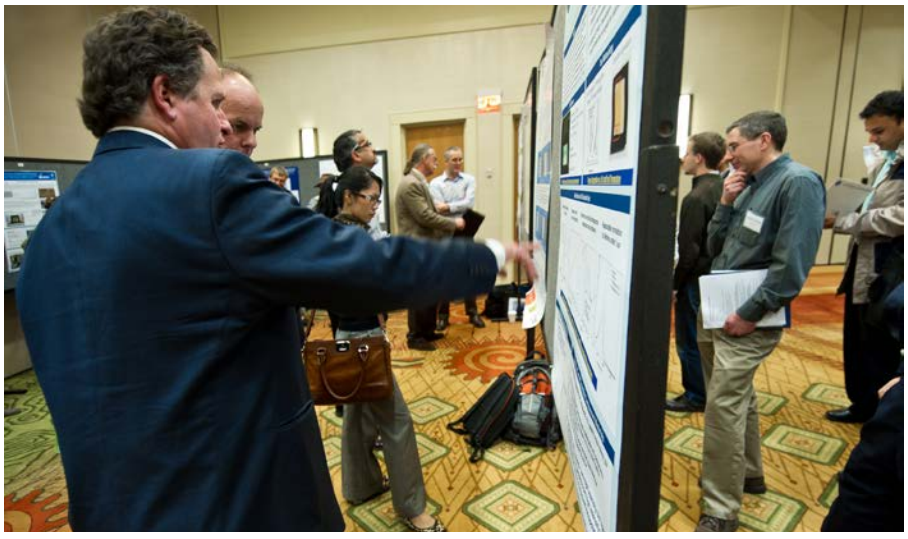
- Rewriting standards by December 2012 with regard to solder-bond quality control
- Proposing new standards for tests on thermal and mechanical fatigue
- Adding a test to better measure how humidity, temperature, and voltage can affect reliability
- Further study to better ensure reliability of diodes
- Discussing how UV exposure affects PV reliability in a range of environments, and how both UV and humidity interplay in a module's performance.

New Focus on Climate Effects

NREL's workshop this year included a new discussion about how to quantify and communicate the durability of PV modules for different climate zones and applications.

Will a module that lasts long in one location hold up equally well in other locations? Should a 30-year warranty for a solar panel be adjusted when the panel is sold in a very hot climate, or in tundra conditions, where sometimes the panels don't last as long?

First Solar recently announced plans to retain a 1% higher warranty reserve in recognition that more of its modules are being installed in hot climates.



The PV Reliability Workshop brought scientists and engineers together to discuss how to improve the reliability of solar panels. *Photo by Dennis Schroeder, NREL 20437*

> “It was nice to have this semi-private platform where companies feel more comfortable to share their trials and tribulations. It’s helpful for everybody to know the stumbling blocks and what we’re doing to get over them.”
>
> —NICK BOSCO, *NREL Scientist*

Kurtz wasn’t surprised by First Solar’s move.

“It’s not just how well modules do in Germany,” Kurtz said. “The PV industry is selling to markets around the world, and manufacturers are recognizing that modules might last different amounts of time in different locations.”

Trust Essential to Workshop’s Success

“Durability is a continuing quest, and the scientists know there’s always room for improvement, even when it’s going in the right direction,” NREL scientist Michael Kempe said. “There are always stumbling blocks, barriers, and plateaus to get past, and those at the workshop believe they can overcome them all.”

Durability “is a very difficult topic for companies to talk about,” Kempe said. “That’s why we restrict attendance at the workshop to people who are more scientifically based—so you don’t get lawyers, marketers, prospective buyers, or those looking for a competitive edge. Having this tighter group is good for opening up the discussion about durability issues.”

“The PV Workshop was great,” NREL scientist Nick Bosco said. “It was nice to have this semi-private platform where companies feel more comfortable to share their trials and tribulations. It’s helpful for everybody to know the stumbling blocks and what we’re doing to get over them.”

— Bill Scanlon (June 6, 2012)

Solar Cells Light Up Prison Cells on 'The Rock'

"Machine Gun Kelly," Al Capone, the "Birdman"—Alcatraz prison has had some infamous residents on the craggy island known as "The Rock" in the middle of San Francisco Bay.

Now, the prison is host to 1,300 solar panels, powering lights and appliances that for three-quarters of a century were powered by diesel fuel ferried across the bay.

The panels are part of an effort by the National Park Service (NPS) and the U.S. Department of Energy's (DOE) National Renewable Energy Laboratory (NREL) to bring clean energy to national parks and landmarks.

Blackberries and honeysuckles still grace Alcatraz Island, and black-crowned night herons and slender salamanders still circle above and below. But diesel fuel use has been slashed, and that means far less corrosion of pipes and smokestacks, and less pollution in the bay.

Instead, a 307-kilowatt photovoltaic (PV) array sits on the roof of the main Cellhouse building, attached to two 2,000-amp-hour battery strings and an inverter plant. The new 1,300-panel system produces close to 400,000 kilowatt-hours of electricity a year, reducing carbon dioxide (CO_2) emissions by about 337,000 kilograms a year and reducing the time the generator runs from 100% to 40%. The NPS also made some energy efficiency changes, such as better light bulbs and changes in operation to reduce energy consumption.

A massive solar battery system helps power the island when the sun doesn't shine — and it, too, is hidden from the view of the 1.4 million visitors the island and prison get each year.

The $3.6 million project was funded by the American Reinvestment and Recovery Act—and, importantly, it is saving money. The cost of transporting diesel fuel to the island (maintenance costs and the price of the fuel itself) boosted the cost of electricity for the island to about 76 cents a kilowatt-hour, said Andy Walker, a senior engineer and task leader for design assistance in the DOE Federal Energy Management Program (FEMP) at NREL. The PV project brings that cost to 71 cents a kilowatt-hour, and that includes the capital costs of buying the solar panels and erecting them on roofs.

Meeting Historic Landmark Guidelines

The project was a long time coming.

NREL's involvement began in 1995, when FEMP enlisted NREL's Applying Technologies team to monitor the strength of the sun at the island, do a feasibility study, and mock up what a solar installation would look like from up close and from across the bay.

Alcatraz Island in San Francisco Bay is referred to as "The Rock" and was home to a notorious prison for 75 years. NREL recently helped the National Park Service and the DOE Federal Energy Management Program transform the island's electricity source from diesel fuel to photovoltaic panels on the rooftop of the Cellhouse building. *Photo courtesy of the National Park Service, NREL 21416*

> "Right now, we're helping to commission PV, solar hot water, and hydro-turbines at Mesa Verde National Park's museum."
>
> —ANDY WALKER, *NREL Senior Engineer*

FEMP and the NPS contracted with the Sacramento Municipal Utility District (SMUD) to install PV on Alcatraz's New Industries Building and sell power to NPS for a penny less per kilowatt-hour than what it was costing for diesel electricity.

SMUD got as far as putting a new roof on Alcatraz's New Industries Building and installing roof stanchions to hold the solar panels.

But a historic landmark group protested that the solar panels would be too visible. They could be seen by tourists from an exit door in the exercise yard—and that would mar the historic nature of the New Industries Building, where Al Capone once worked a sewing machine, and Machine Gun Kelly did the laundry.

The Cellhouse became a possible alternative because its roof was less visible from the ground or from the bay.

The NPS asked SMUD to put the panels on the Cellhouse roof, but SMUD wanted a guarantee that this time the panels would be up for good. The best the NPS's Advisory Council for Historic Preservation could say was that it had "no objections at this time" to the solar panels being on the Cellhouse roof. That wasn't enough assurance for the utility, and it dropped out of the project.

When Recovery Act funds became available, the Alcatraz project got new life.

"It's ironic," Walker said, "because when the National Park Service was contemplating doing it on its own, they assumed that the Cellhouse would be considered more iconic than the New Industries building." It turned out that there were fewer objections to panels being on the Cellhouse.

The NPS envisioned solar panels on both the New Industries Building and the Cellhouse, but problems with nesting birds and the visibility of the panels delayed installation, said NREL's Byron Stafford. Happily, the progress made by the PV industry over the years—primarily higher-efficiency PV panels—made it possible to put the entire PV system on the roof of the Cellhouse, where it is less visible.

Kent Brogger, the former project manager on the Alcatraz project for the NPS, said "the expertise of NREL has been of great value" in coming up with a green solution for an island so isolated that electricity needs had been provided by diesel generators.

NREL Supports National Park, Landmarks

The design assistance NREL provides for FEMP includes modeling, monitoring, analysis, and alternative financing assistance to support energy conservation and renewable energy projects in federal buildings.

NREL has helped the NPS with several projects, either through interagency agreements or NREL's Work for Others program: "Right now, we're helping to commission PV, solar hot water, and hydro-turbines at Mesa Verde National Park's museum," Walker said.

"We've had great support from NREL," Paul Cloyd of the NPS said.

NREL is also integral to the effort by several military bases to achieve net-zero energy. And the lab has helped cities and towns recover from natural disasters to become leaders in clean technology.

— Bill Scanlon (July 23, 2012)

Award-Winning PV Cell Pushes Efficiency Higher

It takes outside-the-box thinking to outsmart the solar spectrum and set a world record for solar cell efficiency. The solar spectrum has boundaries and immutable rules. No matter how much solar cell manufacturers want to bend those rules, they can't.

So how can we make a solar cell that has a higher efficiency than the rules allow?

That's the question scientists in the III-V Multijunction Photovoltaics Group at the U.S. Department of Energy's (DOE) National Renewable Energy Laboratory (NREL) faced 15 years ago as they searched for materials they could grow easily that also have the ideal combinations of band gaps for converting photons from the sun into electricity with unprecedented efficiency.

A band gap is an energy that characterizes how a semiconductor material absorbs photons, and how efficiently a solar cell made from that material can extract the useful energy from those photons.

"The ideal band gaps for a solar cell are determined by the solar spectrum," said Daniel Friedman, manager of the NREL III-V Multijunction Photovoltaics Group. "There's no way around that."

But this year, Friedman's team succeeded so spectacularly in bending the rules of the solar spectrum that NREL and its industry partner, Solar Junction, won a coveted R&D 100 award from R&D Magazine for a world-record multijunction solar cell. The three-layered cell, SJ3, converted 43.5% of the energy in sunlight into electrical energy—a rate that has stimulated demand for the cell to be used in concentrator photovoltaic (CPV) arrays for utility-scale energy production.

Last month, that record of 43.5% efficiency at 415 suns was eclipsed with a 44% efficiency at 947 suns. Both records were verified by NREL. This is NREL's third R&D 100 award for advances in ultra-high-efficiency multijunction cells. CPV technology gains efficiency by using low-cost lenses to multiply the sun's intensity, which scientists refer to as numbers of suns.

Friedman says earlier success with multijunction cells—layered semiconductors each optimized to capture different wavelengths of light at their junctions—gave NREL a head start.

The SJ3 cells fit into the market for utility-scale CPV projects. They're designed for application under sunlight concentrated to 1,000 times its normal intensity by low-cost lenses that gather the light and direct it at each cell. In regions of clear atmosphere and intense sunlight, such as the U.S. desert Southwest, CPV has outstanding potential for lowest-cost solar electricity. There is enough available sunlight in these areas to supply the electrical energy needs of the entire United States many times over.

Bending Material to the Band Gaps on the Solar Spectrum

Sunlight is made up of photons of a wide range of energies from roughly zero to four electron volts (eV). This broad range of

An operator inspects a photolithography tool used to manufacture high-efficiency Solar Junction concentrator solar cells. NREL's pioneering multijunction work led to the Solar Junction SJ3 solar cell with tunable bandgaps, lattice-matched architecture, and ultra-concentrated tunnel junctions. *Photo by Daniel Derkacs/ Solar Junction, NREL 21386*

energies presents a fundamental challenge to conventional solar cells, which have a single photovoltaic junction with a single characteristic band gap energy.

Conventional cells most efficiently convert those photons that very nearly match the band gap of the semiconductors in the cell. Higher-energy photons give up their excess energy to the solar cell as waste heat, while lower-energy photons are not collected by the solar cell, and their energy is completely lost.

This behavior sets a fundamental limit on the efficiency of a conventional solar cell. Scientists overcome this limitation by using multijunction solar cells. Using multiple layers of materials in the cells, they create multiple junctions, each with different band gap energies. Each converts a different energy range of the solar spectrum. An invention in the mid-1980s by NREL's Jerry Olson and Sarah Kurtz led to the first practical, commercial multijunction solar cell, a GaInP/GaAs two-junction cell with 1.85-eV and 1.4-eV bandgaps that was recognized with an R&D 100 award in 1990, and later to the three-junction commercial cell based on GaInP/GaAs/Ge that won an R&D 100 award in 2001.

The researchers at NREL knew that if they could replace the 0.67-eV third junction with one better tuned to the solar spectrum, the resulting cell would capture more of the sun's light throughout the day. But they needed a material that had an atomic structure that matched the lattice of the layer above it—and that also had the ideal band gap.

"We knew from the shape of the solar spectrum and modeling solar cells that what we wanted was a third junction that has a band gap of about 1.0 electron volt, lattice-matched to gallium arsenide," Friedman said. "The lattice match makes materials easier to grow."

They concentrated on materials from the third and fifth columns of the periodic table because these so-called III-V semiconductors have similar crystal structures and ideal diffusion, absorption, and mobility properties for solar cells.

But there was seemingly no way to capture the benefits of the gallium arsenide material while matching the lattice of the layer below, because no known III-V material compatible with gallium arsenide growth had both the desired 1-eV band gap and the lattice-constant match to gallium arsenide.

That changed in the early 1990s, when a research group at NTT Laboratories in Tokyo working on an unrelated problem made an unexpected discovery. Even though gallium nitride has a higher band gap than gallium arsenide, when you add a bit of nitrogen to gallium arsenide, the band gap shrinks—exactly the opposite of what was expected to happen.

"That was very surprising, and it stimulated a great deal of work all over the world, including here at NREL," Friedman said. "It helped push us to start making solar cells with this new dilute nitride material."

Good Band Gaps, but Not So Good Solar Material

The new solar cells NREL developed had two things going for them—and one big issue.

"The good things were that we could make the material very easily, and we did get the band gap and the lattice match that we wanted," Friedman said. "The bad thing was that it wasn't a good solar cell material. It wasn't very good at converting absorbed photons into electrical energy. Materials quality is critical for high-performance solar cells, so this was a big problem."

Still, NREL continued to search for a solution.

"We worked on it for quite a while, and we got to a point where we realized we had to choose between two ways of collecting current from a solar cell," Friedman said. "One way is to let the electrical carriers just diffuse along without the aid of an electric field. That's what you do if you have good material."

If the material isn't good, though, "you have to introduce an electric field to sweep the carriers out before they recombine and are lost," Friedman said.

But to do that, virtually all impurities would have to be removed. And the only way to remove the impurities would be to use a different growth technique.

Using Molecular Beam Epitaxy to Virtually Eliminate Impurities

Solar cells are typically grown using metalorganic vapor-phase epitaxy, or MOVPE.

"It works great, except you always get a certain level of impurities in the material. That's usually not a problem, but it would be an issue for this novel material, with the gallium arsenide diluted with nitrogen," Friedman said.

A different growth technique, molecular beam epitaxy (MBE), is done in such an ultra-high vacuum—10 to the minus 13 atmospheres—that it can lower the impurities to the point where

an electric field can be created in the resulting photovoltaic junction. And that would make the otherwise promising gallium-arsenide-dilute-nitride material work as a solar cell.

"The only problem was that there was no one in the entire world manufacturing solar cells by MBE," Friedman said.

But that was soon to change.

Partnering with a Startup out of Stanford University: Solar Junction

A Stanford University research group with expertise in the use of MBE for other electronic devices saw an opportunity, and around 2007, they spun out a startup company they named Solar Junction.

Because Solar Junction was a mix of enthusiastic recent Ph.D.s and experienced hands from outside the established solar cell field, "they weren't tied to the constraints of thinking this couldn't be done, that the only economically viable way to make solar cells was with MOVPE," Friedman said.

The federal lab and the startup got together. Solar Junction won a $3 million DOE/NREL Photovoltaic Technology Incubator contract to develop a commercial multijunction cell using dilute nitrides, and also received more than $30 million of venture-capital funding for this commercialization effort.

"So Solar Junction had this good idea. But now they had to prove that you could actually make a high-efficiency solar cell with this," Friedman said. "Otherwise, who cares? People can make a lot of claims, but it's very simple to know whether you have a good solar cell or not—you just measure it."

It didn't take that long, Friedman said. By 2011, NREL had certified a new efficiency record for Solar Junction's SJ3 cell. The cell achieved an efficiency of 43.5% under concentrated sunlight, a significant step beyond the previous multijunction efficiency record of 41.6%, and far beyond the maximum theoretical efficiency of 34% for traditional one-sun single-junction cells.

Dilute-Nitride Junction Eliminates Need for Heavy Germanium Layer

With the new dilute-nitride junction, the germanium layer, which constitutes about 90% of the weight of the cell, is no longer needed. That may not be a big deal when it's part of a huge fixed utility-scale array. But when solar cells are used to power satellites, reduction in weight means a smaller rocket is needed to launch into space, potentially reducing costs significantly. The lighter weight is also essential for the military, which is increasingly asking soldiers to carry backpacks that include solar devices to power electronics.

Serendipitously, if the germanium substrate is retained, it has essentially the ideal band gap of 0.7 eV for a fourth junction, perfect for capturing longer wavelengths of the solar spectrum. That paves the way for a 50%-efficient solar cell in the not-distant future.

The cost to manufacture the SJ3 cell is competitive with that of the industry-standard GaInP/GaAs/Ge cell, according to Solar Junction. Its greater efficiency translates to significant cost-of-energy savings.

According to a report released this fall from IMS Research, the CPV market is forecast to double in 2012 and reach almost 90 megawatts. The World Market for CPV—2012 predicts installations of CPV will grow rapidly over the next five years to reach 1.2 gigawatts by 2016.

Because of its design and size, SJ3 is an instant plug-in replacement for the standard cell now used by the space and CPV industries. So, for example, if a 40%-efficient cell were replaced with a 44%-efficient cell, this would instantly increase the entire system power output by close to 10%.

"This is really a classic example of NREL developing something and then industry picking it up and running with it and making it a great commercial success," Friedman said. "We started with some very basic materials research. We took it to the point where it made sense for industry to take over and take it to the marketplace."

"We conceived the cell, demonstrated the individual parts, and let the world know about it," Friedman said. "But Solar Junction put all the parts together with record-breaking results, made it work with MBE, and commercialized it at a time when no one else seemed to be interested in or able to do it."

And now, utilities are ordering the SJ3 cells so fast that Solar Junction has depleted its pilot-scale stock and gone into partnership with manufacturer IQE to ramp up to full manufacturing scale.

— Bill Scanlon (December 28, 2012)

TECHNOLOGY TRANSFER

Through a variety of commercialization programs, NREL works to stimulate the market for clean energy technologies and foster the growth of clean energy start-ups. *Photo by Dennis Schroeder, NREL 20211*

Growth Forum Offers Networking Nirvana

A greener detergent, a better solar-cell coating, an off-the-grid freezer—cleantech entrepreneurs pitched their ideas to money-men and -women in 10-minute bursts at the 2012 Industry Growth Forum last month in Denver.

The U.S. Department of Energy's National Renewable Energy Laboratory (NREL) held the 25th Industry Growth Forum, an annual event that features presentations from emerging clean energy companies, provocative panels led by thought leaders, one-on-one meetings, and organized networking opportunities.

While the Forum allows growing companies to prepare, refine, and present their businesses to a wide range of investors, it also provides entrepreneurs with many opportunities to connect directly with investors and other clean energy professionals during its one-on-one networking session.

This one-on-one networking is the industry's version of speed dating. It was the featured event that launched the two-day Forum, which NREL has sponsored for the past 17 years.

During this session, which featured 56 separate meeting tables set up throughout the ballroom of a downtown Denver hotel, investors, professionals, and government officials cycled through a series of meetings with different entrepreneurs. While the concepts discussed varied wildly, all parties hoped for success, whether it be in the form of a research contract, a business opportunity, or generous funds-in support for the next great cleantech innovation.

NREL Acts as Broker, Then Lets the Market Work

Bill Farris, NREL's associate laboratory director for Innovation Partnering and Outreach, noted that the Forum attracted nearly 400 investors, entrepreneurs, clean energy professionals, and policymakers.

"'Speed dating' actually describes this particular event pretty well," he said. "This is where a lot of the action happens. We use our convening power to get exciting companies together with investors. We get the conversations started, then get out of the way so the conversations and networking can happen."

$4.5 Billion Raised by Forum Attendees Since 2005

"Our favorite statistic is that in the past seven years, companies that have presented at the Forum have cumulatively raised $4.5 billion," Farris added.

That's a lot of geld.

In all, this event generated more than 600 meetings between the seated professionals and the hundreds of small companies vying for their attention.

The key to making a pitch is to be engaging, says Douglas Hitching, left, CEO of Silicon Solar Solutions, as he makes a point to potential investor Henry Chung, representing LG Innovation Ventures, during a 10-minute one-on-one networking session at the 25th Industry Growth Forum in Denver. *Photo by Dennis Schroeder, NREL 22887*

Richard Adams, manager of NREL's Innovation and Entrepreneurship Center, noted this was the third year the Forum has had the one-on-one 10-minute meetings.

"The beauty of this is that you can very quickly get a lot of meetings, and you can very quickly get a sense of whether the partner is interested in what they have from a technology perspective," Adams said. "It's no harm, no foul. They can follow up, and if they're not interested, it's a way to narrow down the time they spend looking for investors."

Chris Raczkowski of China-based investment company Azure International said: "We find it a good way to separate the wheat from the chaff. With the 10 minutes, you have a forced conclusion. You get to talk to companies you'd otherwise never talk to, but you can figure out pretty quickly if you might want to do business."

Despite Market Conditions, a Lot of Demand

Kate Cheesbrough, a project manager in NREL's Commercialization Assistance Program, said that despite the pendulum swinging toward unfavorable conditions in the past year or two, "We still had a lot of demand from investors wishing to participate in the one-on-one networking and meet with startups.

"Startups weren't the only ones requesting meetings. We had a number of investors reach out in advance of the Forum to connect them with attending startups," she added. "It's a great way to make an introduction. This year, we're doing it at the onset of the Forum, as it creates a platform for investors and entrepreneurs to begin and expand discussions.

"They get a flavor for what your technology is. If you can't provide a compelling pitch and clearly articulate the company's key value proposition in this short timeframe, that immediately raises a red flag. It's a good first date. If you pass it, there will be further dialogue."

Eight Canadian companies attended, four of them representing geothermal energy, noted Stephen Davis, who is with the Canadian Consulate in Colorado.

"My charge is to maximize the global reach of the Canadian companies," he said. "When I looked at that sea of 56 tables of investors doing this dating dance, I was so impressed. Our companies told us that was worth the price of admission right there."

Thirty Companies Give Longer Pitches to Judges

The first morning's networking session was followed by the Forum's premier event that day: formal company presentations. This component of the Forum features 30 companies that have been selected from hundreds of applications to present before panels of judges representing the investor community.

Organized into tracks of similar technologies, such as transportation systems or power components, each company sends a single representative to present an innovation for exactly 10 minutes and then face the judges' panel for an intensive question-and-answer session. The judges provide feedback on the presentation, and then each presenting company receives scores that are tabulated for the Forum's overall competition.

During the chemicals track, a representative of NuMat Technologies, Inc., touted a way of using metal-organic frameworks (MOF) to increase the storage capacity of natural gas. MOFs have the highest surface area per gram of any absorbing material. That asset means a car's fuel tank can store as much natural gas as before, but under lower pressure, which enhances safety and prevents leakage. Or, it can store much more natural gas under the same pressure, increasing range.

Another company, Lotus Leaf Coatings, presented its hydrophobic and hydrophilic coatings that can either repel water or attract it as a way of keeping lenses, solar panels, or a variety of other products clean. CEO Lawrence Chavez mentioned a $19.5 billion market, noting that the coatings' customers can range from ophthalmology to heating and cooling.

The coatings may have to last 20 years in the United States—but in some parts of the Middle East, if they last just a few months, they'll be a great improvement over the current reality, in which once a week someone has to wipe clean the mix of desert dirt and high humidity that gunks up solar panels.

— Bill Scanlon (November 13, 2012)


U.S. DEPARTMENT OF
ENERGY

WIND

NREL's experienced staff, unique research capabilities, and specialized state-of-the-art equipment provide industry partners and stakeholders with technical support from the design table to the marketplace for wind technologies. *Photo by Dennis Schroeder, NREL 19067*

NREL Thinks Big at Wind Technology Center

The Front Range environment at the National Wind Technology Center (NWTC) is harsh. The winds—the very reason the NWTC is there—have little mercy. The frigid cold of winter gives way to the baking sun of summer. Yet in the midst of this difficult landscape, the future of wind energy grows bigger and stronger thanks to the work being done by the U.S. Department of Energy's (DOE) National Renewable Energy Laboratory's (NREL) NWTC and its industry partners.

Findings from a recent report by analysts from NREL and Lawrence Berkeley National Laboratory indicate that further technology improvements will be critical to increasing wind turbine efficiency and lowering the cost of wind power development in the future. Research at NREL's NWTC is leading the way.

Giant Turbines Tower Over the Landscape

The most noticeable change at the NWTC in recent years is the addition of four multi-megawatt wind turbines to be used for a wide variety of research and development (R&D) activities in collaboration with industry partners. The most recent of the four new turbines, a Gamesa 2.0-megawatt machine, was installed at the site in late 2011.

"The addition of these four modern megawatt-scale machines has been truly transformational for our center," said Fort Felker, director of the NWTC. "Not just in the physical landscape, but in the depth and relevance of the research that is going on here. It's changed the way industry thinks about us in the sense that now the work we are doing is directly relevant, clearly impactful, and immediately beneficial to them."

Each of the four turbines is a test apparatus with unique attributes. For example, the Siemens 2.3-megawatt turbine at the site has extensive instrumentation and structural load measurement capabilities in the blades, nacelle, and down the tower all the way into the underground foundation beneath the turbine. This allows researchers to connect the entire path of unsteady loads caused by turbulence in the wind to better identify where improvements will directly lead to more efficient turbines and lower-cost wind energy.

The next sizable step into the future of wind energy is an expansion of the dynamometer testing capabilities at the NWTC. The new dynamometer facility scheduled for completion in summer 2012 will dramatically expand the capability of NREL and its industry partners to verify the performance and reliability of wind turbine drivetrain prototypes and commercial machines.

The new facility is capable of testing drivetrains up to 5.8 megawatts—large enough to test virtually any land-based turbine for the foreseeable future—and will employ a non-torque loading

The most noticeable change at the NWTC in recent years is the addition of multi-megawatt wind turbines used for a wide variety of R&D activities in collaboration with industry partners. *Photo by Dennis Schroeder, NREL 18937*

capability that is dynamically variable. This means researchers will be better able to simulate conditions a turbine might experience in the field.

"These new capabilities will make this a special facility, the finest of its kind in the world," Felker said. "Instead of just putting a steady load on a test article, we'll be able to better simulate dynamically variable loads that it would see in the real world."

It Takes Big Blades to Energize Big Turbines

As turbines have grown, so have the blades required to capture the wind for them. Turbine blades have grown so much, in fact, that the NWTC, with its landlocked location, cannot effectively work with the largest blades because they are difficult to ship over land.

To solve this, NREL has partnered with the Massachusetts Clean Energy Center to develop a world-class large wind turbine blade testing center in Boston, Massachusetts.

The Wind Technology Testing Center (WTTC) offers a full suite of certification tests for turbine blades as long as 90 meters and is designed to help the wind industry deploy the next generation of onshore and offshore wind turbine technologies. NREL staff on site provides technical expertise and testing hardware at the facility.

The WTTC is located on an existing deep water port so that large blades can be shipped by boat to the site, allowing it to test the largest wind blades in development for both onshore and offshore use.

Huge Brains, Huge Computers, Huge Ideas

Another significant development for NWTC researchers has been access to high-performance computer resources now available for wind science and technology development.

A challenge in the wind industry has been how to tackle the interactional aerodynamics that occurs within wind farms, where large numbers of multi-megawatt wind turbines are placed together. The wind turbulence in the wake of upstream turbines interferes with the downstream turbines, which leads to higher structural loads and fatigue damage on the downstream turbines—resulting in increased maintenance costs and adding to the overall cost of wind energy.

NREL is taking on this problem using next-generation modeling capabilities that will allow researchers to use computer simulations to assess individual turbine performance as well as turbine-to-turbine interactions. The simulations will use RedMesa, NREL's 180-teraflop supercomputer.

"To date, there has never been a scientific analysis and simulation tool that allows us to tackle this problem. We've broken that barrier," Felker said. "It's a transformational capability, and we're really excited about it."

This work will create a better understanding of wind farm performance and will allow future wind developments to be designed in ways that will minimize this impact, from altering the layout of the turbines to more advanced engineering concepts such as using differently designed turbines in downstream locations as compared to those upstream. The result will be wind farms that are more efficient and less costly to operate, leading to less expensive wind energy.

A Big Future Ahead for Wind Energy

NWTC researchers are keeping their eyes on the future and how the center's increased capabilities will advance wind energy deployment at the lowest possible cost. Effectively working with industry partners is an important piece of this puzzle.

"We're very proud of the dramatic increase we have had in the depth of our partnerships with industry. That has been a tremendous success for us over the last few years," Felker said. "It has made us much better connected with the wind industry in terms of knowing what is important to them and how we can help them and be a key partner in their success."

The next logical step is to look offshore. Offshore wind resources allow for the deployment of even larger turbines that could not be considered for use on land.

"In the future, we're going offshore," Felker said. "Our biggest challenge and opportunity in the future is that as the U.S. begins to develop an offshore wind industry, all of the R&D skills and testing capabilities that we have developed can be brought to bear in the offshore world."

— David Glickson (March 22, 2012)

Gamesa Turbine to Serve as Research Platform

The latest addition to the collection of multi-megawatt wind turbines towering over the U.S. Department of Energy's (DOE) National Renewable Energy Laboratory's (NREL) National Wind Technology Center (NWTC) is a Gamesa G97 Class IIIA 2.0-megawatt turbine. The turbine was installed in late 2011.

NREL and Gamesa Technology Inc. will collaborate in a public-private partnership to study and test a variety of components and systems on the turbine, which will guide development of the next generation of wind turbines designed specifically for the U.S. market.

NREL and Gamesa will collaborate on work in three key areas: developing new wind turbine components and rotors; researching and testing the performance of new control strategies; and devising models that will help develop turbines for U.S. coastal waters.

Using Gamesa's turbine platform as a laboratory, researchers will study the behavior of systems and how new designs, products, or equipment can affect performance.

"We are pleased to have Gamesa working with NREL as a research and development [R&D] partner," said Dana Christensen, NREL's deputy laboratory director for Science and Technology. "These types of collaborations demonstrate a commitment to crucial technology development and the public-private partnerships necessary to ensure the continued momentum of the wind power industry. Our role with the Department of Energy is to help reduce technical risks and thereby help accelerate next-generation technology into the marketplace. NREL is proud to be at the forefront of this important work."

Since its introduction last year, Gamesa's G9X-2.0-megawatt turbine platform has gained recognition for its advanced blade design, updated nacelle, enhanced control systems, and other features that substantially increase energy output. The model installed at NREL is designed specifically for low-wind sites, a segment from which Gamesa expects more than half of all future onshore demand.

"Wind energy is going to continue to play a key role in creating a stronger and more sustainable American economy," said Miguel Angel Gonzalez-Posada, vice president of technology for Gamesa North America. "This partnership is an exciting venture that showcases Gamesa's commitment to enhanced clean energy development, as well as our drive to deliver reliable, efficient, and cost-effective wind turbine technologies to the U.S. marketplace."

Full project testing on the entire slate of programs is set to begin this month. The core provisions of the public-private partnership run through 2013, with options for two additional years of collaboration.

— David Glickson (March 22, 2012)

Crews lift a blade assembly onto the nacelle of Gamesa's G9X-2.0-megawatt turbine at the NWTC. The Gamesa G9X-2.0 turbine is the latest addition to the collection of multi-megawatt wind turbines at the NWTC. *Photo by Dennis Schroeder, NREL 20242*

High-Tech Tools Tackle Wind Farm Performance

From a distance, a wind farm can seem almost placid, turbines turning slowly, steadily, churning out electricity. But there's more to it than meets the eye.

The wind, though it can seem consistent, often has varying degrees of turbulence that impact wind turbine performance. Heating and cooling change the wind over the course of the day. A wind farm's turbines interact in ways that reduce performance and add to structural loads on the turbines, increasing maintenance costs and the overall cost of wind energy.

Researchers at the U.S. Department of Energy's (DOE) National Renewable Energy Laboratory (NREL) are learning how to better understand these issues and are working toward effective solutions for the wind industry. Their goal is to maximize turbine performance and minimize structural loads, which will ultimately result in lower-cost wind energy. Toward that goal, NREL researchers are leveraging the lab's supercomputing resources and have developed high-tech modeling and simulation capabilities.

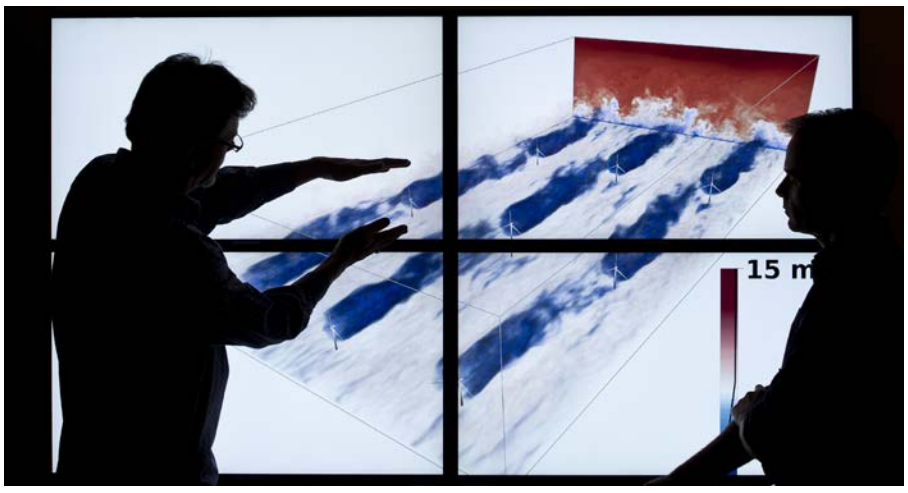
An Industry-Wide Concern

The market for wind energy continues to grow—and so do the wind turbines and farms themselves. Unfortunately, the power production of these energy plants has, in many cases, been lower than initially predicted. Wind plant underperformance has become a concern throughout the wind industry and could potentially cost developers millions of dollars over the life of a wind plant because of reduced power generation and increased maintenance costs.

"The wind industry is increasingly concerned with these underperformance issues," said Pat Moriarty, senior engineer at NREL's National Wind Technology Center. "The average underperformance is about 10%, with some seeing underperformance as high as 30% to 40%. This adds up to a lot of lost energy and high cost for the industry over the life of a wind plant and presents us with a big opportunity to improve wind plant efficiencies."

Models Enhance Understanding of Performance Issues

Wake turbulence is a type of instability in the wind flow and is the result of wind flowing through the rotor of a wind turbine. Its effects and how they impact wind turbine and plant performance have not been well understood. To better understand these issues and move toward effective solutions, NREL researchers have developed sophisticated simulation tools to perform large-eddy simulation models that are designed to predict the performance of large wind plants with greater accuracy than any previous models.



NREL's Steve Hammond, director of the Computational Science Center, and Kenny Gruchalla, senior scientist, discuss a 3D model of wind plant aerodynamics that shows low-velocity wakes and the resulting impact on downstream turbines. *Photo by Dennis Schroeder, NREL 19886*

Wind plant developers have used design tools going back to the 1980s, which are generally effective for basic optimization of the layout of a wind farm. However, none have been able to simulate with consistent accuracy how wakes propagate and how wind turbines interact with one another.

"Previous models were very simple and don't capture a lot of the physics—how the atmosphere behaves and how wind turbines respond to changing conditions in the field," Moriarty said. "It was clear that we needed better models, specifically understanding issues around wake-turbine and atmosphere-turbine interactions."

Good models need good data. Data from operating wind farms provides validation for the models. So the project has been collecting data from offshore and onshore wind farms in both Europe and the United States to compare to the simulations. "We're comparing the data from actual wind turbine performance in the field to the predictions from our models," Moriarty said. "The models have been very accurate and very close to what is actually happening in the field."

Big Computers Facilitating Big Ideas

The backbone of this new modeling capability is the high-performance computing resources that run the simulations.

Researchers are currently using RedMesa, NREL's most powerful high-performance computing system, located at DOE's Sandia National Laboratories and managed in collaboration with Sandia. Peak computational capability of RedMesa is about 180 teraflops, which means it can process 180 trillion floating point operations (flops) per second. For comparison, a basic calculator requires only 10 flops.

NREL will be adding additional high-performance computing capability in the next year with a new supercomputer on the lab's Golden, Colorado, campus. The supercomputer in NREL's new Energy Systems Integration Facility (ESIF) will be nearly a petaflop in scale (a petaflop is 1,000 teraflops) and will be the fastest computer system in the world dedicated to renewable energy and energy efficiency technologies.

> "We are trying to get a better handle on the physics of what is actually going on within the wind farm. All these issues affect performance, and that is the industry's greatest concern."
>
> —PAT MORIARTY, *NREL Senior Engineer*

Building a Better Wind Farm

One anticipated outcome of this enhanced simulation and modeling capability is improved understanding by wind plant developers of how to lay out their projects to achieve maximum performance from individual turbines. Issues to consider include placement of turbines in a wind farm, spacing between turbines, and how terrain and other location-specific conditions might impact turbine performance. Improved tools for wind plant design will enable improved physical understanding of turbine interactions and ultimately lead to plant designs with higher energy production and lower maintenance costs.

"We are trying to get a better handle on the physics of what is actually going on within the wind farm. All these issues affect performance, and that is the industry's greatest concern," Moriarty said. "This makes sense because it impacts their costs.

A wind turbine getting beat up by wakes may have higher maintenance costs. This increases costs for the wind plant operator as well as the cost of wind energy in general."

The Wind Farm as a System, Not the Sum of its Parts

Another benefit to using these tools is in the area of 'wind farm controls.' This concept—a hot topic of discussion in the industry today—involves looking at a wind farm as a total system rather than just a collection of wind turbines. It explores how to best operate that system in a manner that leads to maximum efficiency for the wind farm as a whole.

"Wind turbines are greedy," Moriarty said. "They will try to extract as much energy from the wind as possible without consideration for anything around them, such as other turbines in a wind farm. This is not necessarily the optimal way to operate a wind farm as a whole."

Studies have shown that if the front row of wind turbines extracts less energy from the wind in an array than the turbines would by themselves, more potential energy would be available for all turbines downstream. In this scenario, the total energy capture of the entire wind plant would be increased. Another consideration is the slight turning of upstream turbines to steer wakes away from downstream turbines, maximizing the efficiency of the other turbines around them.

> "This capability is of significant importance for various segments of the wind industry—manufacturers, developers, and operators. It provides science behind wind energy that is beneficial to all in their roles toward expanding the deployment of wind energy and reducing costs."
>
> —PAT MORIARTY, *NREL Senior Engineer*

The concept is to view wind farms from a global controls perspective and to seek ways to operate the wind farm as a total system. These types of controls improvements hold great potential for making wind farms more efficient and more productive. Modeling capabilities can be used to study how to operate a wind farm to optimize the energy capture of the entire plant instead of just looking at individual turbines. This capability could be applied to both onshore and offshore wind plants already in operation, as well as new developments.

Leading the Way to Lower-Cost Wind Energy

This work will create a better understanding of wind farm performance and will allow wind developments to be designed to maximize performance through increased energy capture and reduced maintenance costs—all of which leads to lower-cost wind energy.

"This capability is of significant importance for various segments of the wind industry—manufacturers, developers, and operators," Moriarty said. "It provides science behind wind energy that is beneficial to all in their roles toward expanding the deployment of wind energy and reducing costs."

—David Glickson (September 20, 2012)

°C – Celsius

°F – Fahrenheit

A/C – Air conditioning

AEDG – Advanced Energy Design Guidelines

ASHRAE – American Society of Heating, Refrigerating, and Air Conditioning Engineers

CO_2 – Carbon dioxide

CPV – Concentrator photovoltaic

CRADA – Cooperative Research and Development Agreement

CSP – Concentrating solar power

CSU – Colorado State University

DEVAP – Desiccant-Enhanced Evaporative

DOE – U.S. Department of Energy

Energy Execs – Executive Energy Leadership Program

EDIN – Energy Development in Island Nations

ESIF – Energy Systems Integration Facility

ESPI – Energy Service Provider Interface

EStar – Environmental Sustainability award

eV – Electron volt

FEC – Federal Electronics Challenge

FEMP – Federal Energy Management Program

GHG – Greenhouse gas

GPS – Global positioning system

HVAC – Heating, Ventilation, and Air Conditioning

IBRF – Integrated Biorefinery Research Facility

LCA – Life cycle assessment

LED – Light-emitting diode

LEED – Leadership in Energy and Environmental Design

MBE – Molecular beam epitaxy

MOF – Metal-organic framework

MW – Megawatt

NAESB – North American Energy Standards Board

NPS – National Park Service

NREL – National Renewable Energy Laboratory

NWTC – National Wind Technology Center

PUE – Power usage effectiveness

PV – Photovoltaics

R&D – Research and development

REC – Renewable Energy Certificate

REDB – Research Electrical Distribution Bus

RSB Funds – Renewable Social Benefit Funds

RSF – Research Support Facility

S&TF – Science and Technology Facility

SCADA – Supervisory Control and Data Acquisition

SERF – Solar Energy Research Facility

SERI – Solar Energy Research Institute

SMUD – Sacramento Municipal Utility District

USVI – U.S. Virgin Islands

WTTC – Wind Technology Testing Center

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