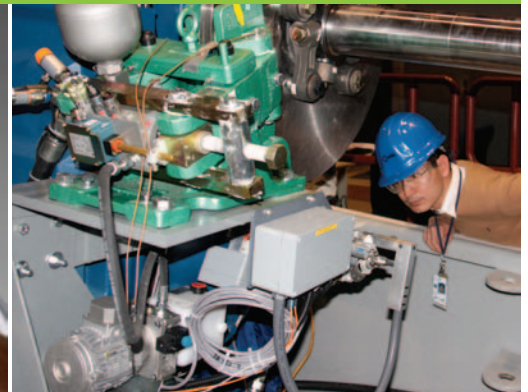
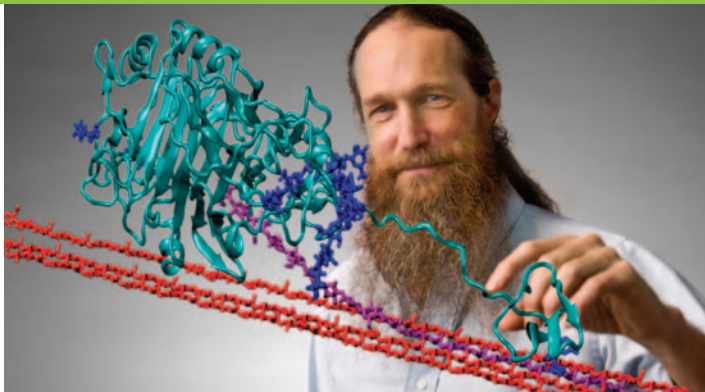


# NREL: A Year in Clean Energy Innovations

A Review of NREL's Feature Stories



**Cover photos:** Left: NREL has dispatched clean energy experts to Hawaii and Alaska to work as advisors to local policymakers and utilities. See story on page 34. Courtesy of Hawaiian Electric Light Company. Center: NREL Senior Scientist Michael Crowley created an animated model of Cel7A, nature's primary enzyme for decaying plants. Computer-aided modeling similar to this is helping NREL researchers look for faster ways to make cellulosic ethanol. See story on page 18. Credit: Pat Corkery. Right: Senior engineers at NREL are expanding a research partnership with operators, utilities, and turbine manufacturers to increase long-term wind gearbox reliability. See story on page 62. Credit: Joseph B. Verrengia

# CONTENTS

INTRODUCTION	1	ENVIRONMENT	40
ADVANCED VEHICLES & FUELS	3	Governor Honors Alternative Energy Advocate	40
Controlling Heat Key to Hybrid Performance	3	Lab Preserves Nature, History	42
NREL and Ford Team Up to Develop 'Cool' Cars	4	FUEL CELLS & HYDROGEN	43
NREL Team Tests Higher Ethanol Fuel Mix	6	NREL Scientist Finds Time to Do it All	43
NREL Works with Truckers to Reduce Fuel Use	8	Eco-Friendly SUV Gets a Hydrogen Mileage Boost	45
BASIC SCIENCES	9	LABORATORY OF THE FUTURE	47
NREL Center Turns Materials Design Upside Down	9	NREL Tests Energy-Saving Office of the Future	47
Award-Winning Battery's Secret is 'Buried'	11	Recovery Act Money Invested at NREL	48
BIOMASS	13	Labyrinth to Store Energy in Basement for Later Use	49
NREL Helps Set Stringent Biodiesel Standards	13	Recycled Natural Gas Pipes Shore Up Green Building	51
Partnerships Boost Research, Improve Technology	14	Building Panels Protect, Provide Comfort	52
Algae-to-Fuel Research Enjoys Resurgence at NREL	15	NREL Sets the Bar for Office Building Energy Use	53
Biofuels Studies to Benefit from Better Lab Test	16	PHOTOVOLTAICS	56
NREL Breaks Down Walls for Biofuels	18	Unique Research Tool Aims to Reduce PV Cost	56
BUILDINGS	19	RENEWABLE RESOURCE MAPS & DATA	58
NREL Helps New Orleans Go Green	19	NREL Helps Sort Green Transportation Options	58
Two Years Later, Greensburg is Officially Green—with NREL's Help	21	On the Road with Alternative Fuels	60
NREL, Industry Work to Halve Building Energy Use	22	WIND	61
Software Helps Design Energy Stingy Buildings	24	Bigger and Better: Lab Aims to Improve Giant Wind Turbines	61
CONCENTRATING SOLAR POWER	25	NREL Gearbox Study Aims to Grease Wind Power's Future	62
New Solar Technology Concentrates on Cost, Efficiency	25	Wind Technology Center Installing a Dynamic Duo	63
Weathering System Cuts Product Testing Time	26	Largest Wind R&D Study Underway at NREL	65
Award-Winning Reflector to Cut Solar Cost	28	COMMUNITY OUTREACH	67
New Labs to Concentrate on Solar Thermal Energy	30	Science Bowl is Fun with a Future	67
ELECTRIC INFRASTRUCTURE SYSTEMS	32	Solar, Hydrogen Model Cars Race Toward New Energy Future	68
Conference Tackles Interstate Transmission	32	Vets and 'Gray Fields' Go Green with NREL	69
ENERGY ANALYSIS	34	Lawmakers Visit NREL for Clean Energy Solutions	70
NREL Assigns Renewables Experts to Hawaii, Alaska	34	NREL Summer Labs Season Science Students	71
NREL Energy Analysts Dig into Feed-In Tariffs	36	NREL Energy Execs Make an Impact Nationally	73
NREL Uncovers Clean Energy Leaders State by State	38	It Takes a Solar Village	75
		Generation-Y Start-up Stuns NREL Growth Forum	77



# INTRODUCTION

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

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

What follows is a compilation of articles featuring NREL research and development, deployment, commercialization, and outreach activities in 2009. The feature stories can be found online at <http://www.nrel.gov/features/>.

Questions about these articles should be directed to NREL's Public Affairs Office by calling 303-275-4090 or sending an e-mail to [public.affairs@nrel.gov](mailto:public.affairs@nrel.gov).



NREL facilities on South Table Mountain in Golden, Colorado. Credit: Pat Corkery/PIX 16911



## CONTROLLING HEAT KEY TO HYBRID PERFORMANCE



NREL senior engineer Ken Kelly monitors testing of a Toyota hybrid system drive. Kelly's group is developing ways to transfer heat from the system's electronics in order to improve efficiency and extend the component's life. Credit: Pat Corkery/PIX 16586

From Tokyo to Detroit, the buzz on the 2009 auto show circuit is all about *really* new cars—plug-in hybrids, gas-electric hybrids, electric cars, and more.

Chrysler has two new concepts. Honda has four. Mercedes Benz has four, including one that would be powered by a fuel cell. Chevy will begin production of its plug-in electric Volt in 2010, and is working with cities now to prepare charging stations.

Together they suggest a very different transportation lineup in the next decade.

At NREL, engineers are exploring several ways to improve hybrid performance to such a convincing level that millions of commuters will make the switch.

To the lab, that means increasing the vehicles' range to 100 mpg or more, improving reliability, and reducing costs—all while operating with drastically reduced tailpipe emissions.

"The real answer isn't Detroit making the right car but the consumer deciding they want the right car," said Rob Farrington, manager of NREL's advanced vehicles program.

In the Advanced Electronics Laboratory, research engineers are exploring key components of the electric drive systems.

Their ground-floor windowless research unit is about the size of a large suburban garage. There isn't an intact car in sight, however.

Instead, researchers are testing key power components at bench stations, including motor controllers, AC to DC converters, and inverters that condition the electrical signal between

the power generation unit (a fuel cell or battery) and the electric motor to provide power to various components.

### Greater than the Sum

No single improvement will make the difference. But combined, the results can help automakers overcome technical barriers can delay the successful commercialization of advanced vehicles.

"About one-third of the incremental cost of hybrids is in its power electronics," said senior engineer Ken Kelly, task leader for the advanced electronics lab. "We need to process that electricity in ways that are reliable and extend the range of the vehicle. That's what this lab is all about."

On one bench, engineers are testing the performance of a Toyota hybrid system drive. It already works at 90% efficiency. But heat is an enemy; the vehicle's efficiency dips as the coolant temperature increases.

If it could run cooler, it would run longer. And it could be manufactured using less expensive materials.

Kelly's group is experimenting with heat exchangers made of different layers, including graphite and indium.

"One-third of your radiator's capacity is used to cool the vehicle's electronics," Kelly said. "People want to package things smaller and powerfully. That means there is more heat in a small space. So the challenge is growing to get heat from the device to the coolant."

### All in the Grease

In a separate heat-related experiment, senior engineer Sreekant Narumanchi is exploring advanced materials for the interface between power electronics components.

Silicon chips in power electronics typically rest on a metal base plate that conducts heat away from the chip. Coolant flows underneath the plate to carry away the heat. The heat transfer is aided by a very thin layer of "grease" spread between the parts.

"Even though the layers fit together, there are little gaps that cause resistance to the transfer of heat," Narumanchi explained. "The grease is used to close those gaps. It's a much better conductive pathway than air."

Automakers don't use conventional grease containing animal fats; typically it's a silicon gel containing aluminum particles and other inorganics. The gels' performance eventually suffers under the heat and pressure generated inside the engine in harsh conditions such as summertime rush hour traffic.

In extended tests, Narumanchi is precisely testing new gels that include different metals, graphite, and even advanced ingredients such as carbon nanotubes.

The bench-scale equipment simulates years of high-temperature conditions and temperature cycling over weeks.

"Our target is a material that will perform for 15 years," he said.

— Joseph B. Verrengia (Feb. 20, 2009)

## NREL AND FORD TEAM UP TO DEVELOP 'COOL' CARS



Solar lights in NREL's Vehicle Climate Control Laboratory help simulate heating of cars and assist researchers in finding more efficient ways to cool cars. Credit: Heather Lammers/PIX 16869

Summer in the city" means settling into a hot car, cranking the air conditioning and hoping the sun will duck behind a cloud while you wait to cool off. What you may not know is how much energy and gasoline it takes to cool a sun-soaked automobile on a hot summer day.

A 2002 NREL analysis discovered that the United States uses 7 billion gallons of fuel per year for light-duty vehicle air conditioning. It takes roughly 9.5% of U.S. imported crude to produce this much gasoline.

"When operating the air conditioning system to cool down your car, it is the largest auxiliary energy drain on cars today," says Senior Engineer John Rugh.

"If we can lessen the amount of fuel used to power A/C, we can realize significant reductions in our oil and fuel usage."

In December 2008, a project to study and develop high-efficiency thermoelectric heating and cooling systems for cars was announced by the U. S. Department of Energy (DOE). As partners in the project, NREL will team up with Ford to research efficient ways of cooling vehicles based on the science

**"If we can lessen the amount of fuel used to power A/C, we can realize significant reductions in our oil and fuel usage."** – John Rugh

of thermoelectrics. This public-private collaboration is possible thanks to a cooperative research and development agreement or CRADA.

NREL is a key partner in the Ford CRADA because NREL has been working for years to understand how cooling techniques affect fuel use as well as thermal comfort. NREL has key knowledge and tools that will be instrumental in the thermoelectric cooling system research.

### NREL's Vehicle Climate Control Laboratory is... Hot

Imagine sitting your car under a row of intense lights typically used to illuminate sports stadiums—just to see how hot your car can get. That's essentially what happens to a passenger car in NREL's Vehicle Climate Control Laboratory (VCCL).

The VCCL was developed to simulate the heating that takes place as the passenger cabin is exposed to sunlight, changing temperatures and humidity—all while the cabin interior is cooled using an air conditioning system monitored by sensors linked to a computer.

"The reason the VCCL is such a great lab is that we can consistently create the effects of the sun warming a car, study the climate that is created and repeat as needed," Rugh said.

But having a warm car is only half the equation, it doesn't matter how hot it gets as long as no one needs to be in the car.

Meet ADAM, the VCCL's most sophisticated test subject. ADAM is the ADvanced Automotive Manikin, which means he is basically a human sized sensor that measures heat at 120 independently controlled zones. As ADAM "sweats" or "shivers," corresponding data goes into a computer model that simulates human responses.

"ADAM is an ideal test subject because we don't have the safety issues of exposing a living person to the heat of a car and because he's very consistent. We can repeat tests all day long without him getting tired," Rugh said.

The physiological model that controls ADAM is linked to another NREL computer model that predicts human comfort in various temperature settings. Working with researchers at University of California, Berkeley, NREL developed a way to translate data into corresponding human comfort levels allowing researchers to surmise how cool a car will need to be in order for passengers to reach a base level of comfort.

### NREL Looks at How to Take a Load Off

NREL's Vehicle Ancillary Load Reduction team has previously evaluated technologies that reduce the amount of fuel used for automobile air-conditioning. NREL looks to improve vehicle efficiency and fuel economy by controlling the climate in a vehicle while keeping passengers comfortable.



The theory behind thermoelectric heating and cooling dates back to the 1800s but has only recently been eyed as a solution for cooling cars.

With no moving parts except for the air blower, thermoelectric heating or cooling is achieved by providing an electric current to a thermoelectric unit. Heat can be generated or removed from the passenger compartment depending on the direction of the current. The conditioned air is directed where needed. Researchers believe this type of system has the potential to augment the traditional air conditioning unit and reduce vehicle fuel use.

One critical benefit of reducing thermal loads is that occupants experience lower temperatures when entering a heated vehicle and feel more comfortable. NREL's research has shown that certain technologies, such as solar-reflective glass and parked-car ventilation, can significantly reduce thermal loads and fuel use. Cooling occupants through ventilated, cooled, or low-mass seats also shows potential for energy savings.

This is why Rugh says that, "all of these pieces—from our past research in load reduction, to the VCCL and ADAM—make NREL a strong partner in this CRADA and we are excited to helping move this research forward and hopefully someday change the way we cool our cars."

**"ADAM is an ideal test subject because we don't have the safety issues of exposing a living person to the heat of a car and because he's very consistent. We can repeat tests all day long without him getting tired."** — John Rugh

## What Will Be Explored

The FORD-NREL CRADA won't kick into high gear until the summer of 2009, but according to Rugh, some of the areas the research teams will be looking at are:

- Analyzing and reducing overall thermal loads when it comes to vehicle cooling
- How the number of thermal electric devices in a car can be reduced and to help reduce costs
- How to cool the people in the car rather than the car itself possibly through strategic vent placement.

The research agreement is set up so that work is done in phases and key milestones will have to be met before the project can continue to the next level, which means ADAM may have a little waiting to do.

"At first we'll be working with Visteon and Ford to determine the best thermal comfort tools each partner has and then we'll select the best ones for the project," Rugh said. "We won't get to use ADAM to test those ideas until the later phases of the project."

— Heather Lammers (April 24, 2009)



NREL Engineer Charlie King works with ADAM, the ADvanced Auto-motive Manikin. If the research proceeds as planned, ADAM will be used to help determine how to cool the people in the car rather than cooling the car itself. Heather Lammers/aPIX 16272

## NREL TEAM TESTS HIGHER ETHANOL FUEL MIX



Storage canisters lined up in NREL's lab hold gas emission from cars that got a taste of higher levels of ethanol in the gasoline. Study results so far have shown that as ethanol increased, tailpipe emissions stayed largely the same. Credit: Heather Lammers/PIX 16890

Going on a diet can be good for you. And maybe a gasoline “diet” of traditional fuel blended with increased levels of ethanol will be good for the environment and economy without hurting conventional cars and small engines. NREL researchers are trying to find out, because these new ethanol blends could play a significant role as America tries to wean itself off petroleum based fuels.

The Energy Independence and Security Act of 2007 (EISA) is one force behind the quest for higher ethanol blends. The 2007 law requires that the United States use 36 billion gallons of renewable fuels by 2022. But, a leaner benchmark is just around the corner, with 15 billion gallons required by 2012. “We’re pushed right now to find ways to get more ethanol into the fuel stream,” said Keith Knoll, senior project leader for NREL’s Fuels Performance Group.

Currently, ethanol is the most widely used and readily available renewable fuel. As a result, it is a likely candidate to make up a significant chunk of the 36 billion gallons required under EISA. Ethanol as a motor fuel is commonly found in E85, a fuel intended for use only in Flexible Fuel Vehicles (FFVs).

**“Picture a chainsaw calmly idling. But then it suddenly starts spinning on its own as if someone had goosed the throttle.”** –*Chicago Tribune*

Ethanol also is widely used as a 10% blend in standard gasoline (E10) to reduce carbon monoxide emissions and smog. But, increasing ethanol from the current 10% blend to a proposed blend of E15, or even E20, brings up a whole host of questions and issues.

For instance, E20 is currently not allowed for use in conventional automobiles under the Environmental Protection Agency’s (EPA) Clean Air Act. This is where research from NREL and Oak Ridge National Laboratory (ORNL) will play a pivotal role in understanding how blends like E15 and E20 affect vehicles currently in the market. The research is examining whether using higher ethanol blends will have an adverse impact on tailpipe emissions, exhaust temperatures, catalytic converters, and engine performance and durability.

### Cars Don’t Seem to Mind

While NREL and ORNL will be studying mid-level ethanol blends for some time, data from initial tests on small engines and cars was released in October 2008 and updated in February 2009. Follow-up reports addressing other vehicle effects will be issued over the coming year. Generally, the tests have shown no big surprises or short-term effects when using greater blends of ethanol in existing cars.

“So far nothing has jumped out at us and vehicles don’t show a significant impact with ethanol blends of 15% and 20%,” Knoll said.

The automobiles used in NREL’s test were meant to represent a cross section of cars currently in use. The 16 vehicles ranged from model years 1999 through 2007 with odometers reading from 10,000 to 100,000 miles.

All vehicles in the test experienced some loss in fuel economy, which is expected because ethanol has a lower energy density than gasoline. At the E20 blend level, the average reduction in miles per gallon was 7.7% when compared to gasoline only. “Another issue we looked at was whether there would be any unintended consequences on air quality when using the higher blends,” Knoll said.

Study results so far have shown that as ethanol increased, tailpipe emissions stayed largely the same. There was no significant change in nitrogen oxides or non-methane organic gas emissions. Carbon monoxide emissions declined for all of the ethanol blends. There were increases in ethanol and acetaldehyde emissions, but these were balanced with reductions in other hydrocarbon air-toxic emissions.

When it came to how catalytic converters reacted to increased ethanol, results depended on how the engine control system regulated the fuel-to-air ratio during high power operation such as heavy accelerations or long hill climbs. Cars that adapted to the increased ethanol during these activities showed no change in catalyst operation—in fact some even ran cooler at higher ethanol blend levels. Seven of the 16 vehicles tested were found to not adapt

to higher ethanol blends during high-power operation. For these vehicles, catalyst temperatures increased during power-enrichment, running about 29–35°C higher on E20 compared to gasoline only. The long-term effects of this temperature increase are being investigated in other, ongoing experiments also funded by DOE.

“While these initial results are interesting, the next step is going to be a larger study, with more vehicles, that will look at the long-term effect that ethanol has on catalytic converters and numerous other issues like drivability and engine durability,” Knoll said.



Keith Knoll, senior project leader for NREL's Fuels Performance Group, leads the NREL team testing cars and other engines running on fuels containing 15–20% percent ethanol. U.S. laws mandate an increase in renewable fuel use by 2012. Credit: Heather Lammers/PIX 16891

### A Small Engine Can Get Revved

While car engines seem to take the higher ethanol blends in stride, the same can't be said for small non-road engines (SNRE). An April 2009 *Chicago Tribune* article on this subject painted an eerie picture, “Picture a chainsaw calmly idling. But then it suddenly starts spinning on its own as if someone had goosed the throttle.”

The *Chicago Tribune* article was a creative, but exaggerated take on what was found in the lab. For instance, it was the hand-held trimmers that got a little excited in the lab, however, “small non-road engines may have trouble with higher blends of ethanol,” said Knoll. “This is an area where we need more research.”

For this phase of the testing NREL and ORNL used 28 SNREs. Small engines don't have the same feedback control system as cars, nor do they have exhaust oxygen sensors. This means the engines can't automatically compensate for the added ethanol. So, small engines using higher ethanol blends tended

to run leaner and hotter. The temperatures of the exhaust components, cylinder heads, and cylinders increased. Exhaust temperatures rose by 10–50°C when moving from gasoline only to E15 and 20–70°C from gasoline only to E20.

Back to those lawn trimmers. When running on a higher ethanol blend, three trimmers did show higher idle speeds and sometimes the clutch engaged on its own. However, Knoll thinks this is easily overcome. “Small engines can be designed to handle differences in fuel. While these engines may not handle a 20% change in ethanol, most currently run on E10. Future designs could be engineered to operate with whatever ethanol standard we move to.”

Don't read too much into the initial tests for both auto and small engines cautioned Knoll, “Although we've got good data, this was a very small sample that is part of a much larger program.”

### Future Tests and Decisions

The focus for all of this testing is to help policymakers like the EPA evaluate and understand the impact that new ethanol mixes will have on the existing cars that Americans drive every day.

The ethanol industry is currently seeking a waiver from EPA that would allow for widespread use of E15 in all automobile types. Right now, most gas stations across the country already sell blends using 10% ethanol.

“I think that for a long-term solution our focus for consumers is on E85,” Knoll said. “Right now E85 use is limited because of the few fueling stations that are available and the limited number of flex-fuel vehicles that are on the road. Our research will give policymakers sound technical advice to help them decide the potential that blends like E15 and E20 will have in the marketplace.”

Future mid-level ethanol blend studies will take a further look at issues like:

- Emission control
- Fuel system compatibility
- Engine durability
- Evaporative emissions
- Drivability.

This research is co-led and co-funded by the U.S. Department of Energy's Biomass Program and the Energy Efficiency and Renewable Energy Vehicle Technologies Program with technical support from NREL and ORNL. The team is working closely with representatives from the EPA, U.S. auto manufacturers, engine companies, oil companies, and Battelle Memorial Institute to develop and conduct a robust test program.

— Heather Lammers ( Sept. 18, 2009)

## NREL WORKS WITH TRUCKERS TO REDUCE FUEL USE



NREL Senior Project Leader Ken Proc examines sensors that measure the outside ambient temperature and compare it to the temperature in truck cabs. Credit: Pat Corkery PIX 16811

Being “green” can have positive impacts on your pocket book, and the National Renewable Energy Laboratory (NREL) is working with one industry to find ways to shave \$3 billion a year in fuel costs.

Like many, the trucking industry has been hit with increased costs from rising fuel prices and higher maintenance. Excessive idling of trucks has been identified as a source of wasted fuel, and an unnecessary expenditure. Surveys estimate that sleeper trucks idle an average of more than 1,400 hours annually consuming more than 800 million gallons of fuel at a cost to the industry of approximately \$3 billion per year for long-haul trucks.

However, truckers have good reasons for idling their trucks—driver comfort. “Truckers typically idle trucks while at mandated rest period to get either air conditioning or heat,” NREL Senior Project Leader Ken Proc said. “NREL is looking for ways to reduce the thermal load in trucks, possibly enabling a battery or other energy storage solution to be used for comfort control rather than running the truck engine the whole time. Reducing the amount of truck engine idling can significantly reduce fuel consumption, save money, and also reduce tailpipe emissions.”

This summer, NREL researchers began two new cooperative research and development agreements (CRADAs), with truck manufacturers Kenworth (a division of PACCAR) and Volvo Trucks North America. These teams will work with researchers in NREL’s Center for Transportation Technologies and Systems (CTTS) to find ways improve thermal efficiency in truck sleeper cabins as part of the “CoolCab task.”

For CoolCab, reducing the heating or cooling load is the first step in improving a long-haul truck cab’s efficiency to reduce overall fuel consumption. A secondary objective of the program is to decrease heating and cooling loads while a truck is on the road. This load reduction also might help improve fuel

economy. Long-term goals for the CRADA include working with industry to design a newer, more efficient truck cab with energy saving heating and cooling systems that keep the cab comfortable without the need for engine idling.

According to Proc, some thermal storage solutions store cooling energy while driving down the road, basically by making ice. When resting, the system discharges that frosted air into the cabin. But NREL researchers identified a need for more options.

“Since starting the initial evaluation into existing idle reduction technologies, we found some pretty good heating solutions,” Proc said. “But, on the cooling side, the solutions just weren’t getting it done. And, we launched CoolCab because we saw a need to improve this.”

### First, a Little “Soak”ing

“We began our CoolCab testing with solar soaks to quantify the amount of heat the truck cabs absorb during the day from the sun,” Proc said. The bulk of data being collected by NREL is temperature measurements. Numerous sensors measure the outside ambient temperature compared to the temperature in the truck cab. The cabs are also heated while temperatures are monitored to determine an “R” value of thermal resistance for the cab. NREL infrared testing also is used to identify potential areas to reduce heating and cooling loads with improved insulation. The infrared cameras showed the greatest heat loss around windows, seams, and other areas within the cab where insulation is lacking.

### CoolCalc Creates a New Model

All of the data collected from the trucks will be used to validate CoolCalc, a new computer modeling program in development at NREL. CoolCalc works with the user-friendly SketchUp program, a 3D modeling program available from Google. Recently, NREL developed a program called Open Studio to help building designers create energy efficient buildings. Working off the same EnergyPlus data files, CoolCalc will help researchers simulate energy use in long-haul truck cabs.

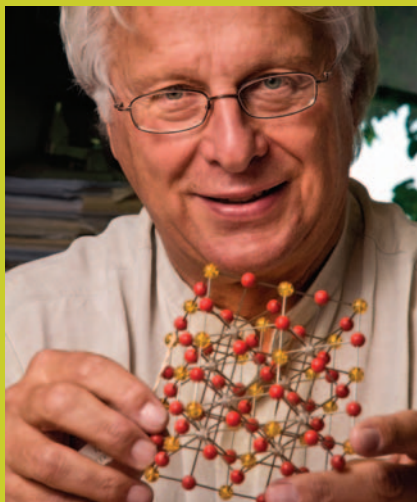
“NREL researchers will be using our new CoolCalc tool to model, test, and analyze truck cabin heating and cooling loads,” Proc said. Team members will be able to input key information like the size and shape of the truck and climate conditions. The program will estimate the existing thermal loads as well as provide estimates for reducing the thermal loads. NREL will then work with its industry partners to test the CoolCalc results on vehicles in production.

Although seeing changes in commercial long-haul truck cabs will take years, there will be initial results such as insulation and the use of window screening that truckers will be able to implement immediately and help take a load off their costs.

“Independent owner/operators can be early adopters of some of our findings because it can directly affect their bottom line as well as their comfort level,” Proc said. “And, many fleet owners have a corporate desire to be green and reduce their carbon footprint.”

— Heather Lammers (Dec. 11, 2009)

## NREL CENTER TURNS MATERIALS DESIGN UPSIDE DOWN



The same set of atoms can have starkly different properties depending on their arrangement in space, says Center for Inverse Design Director Alex Zunger.

Credit: Pat Corkery/PIX 16760

Like most everything else we take for granted in the macroscopic world, the logic of design breaks down in the quantum realm.

Most designers, be they architects, hair stylists, or aerospace engineers, start with a concept of the end product (buildings, coiffures, fighter jets) and work backward toward the building blocks and actions required to realize the images crystallized in their minds.

Materials scientists seeking new semiconductors, superconductors, lasers, sensors, magnets, and alloys have worked in opposite fashion. Generally they stumble across a new material in nature or via laboratory happenstance and then try to figure out its physical properties and potential uses. Such reliance on accidental discovery is “actually very pathetic,” concludes Dr. Alex Zunger, a materials theorist and Research Fellow at the U.S. Department of Energy’s (DOE) National Renewable Energy Laboratory (NREL).

“The development of a technology based on accidentally discovered materials normally takes about 20 years because it takes a long time to figure out what is it exactly that we discovered by accident,” Zunger said.

“The development of a technology based on accidentally discovered materials normally takes about 20 years because it takes a long time to figure out what is it exactly that we discovered by accident.” —Alex Zunger

### Starting with a ‘Dream’

He directs the NREL-led Center for Inverse Design, a \$4 million-a-year for 5 years research endeavor aiming to turn materials design on its head. The center’s success could accelerate the pace of materials discovery and trigger leaps in performance and efficiency in everything from sensors to lasers to solar panels.

The center is a collaboration among NREL, Northwestern University, Oregon State University, and the SLAC National Accelerator Laboratory, which Stanford University operates for DOE. It is just beginning operations.

The starting point will be articulating what would the properties of a “dream material,” as Zunger puts it. For transistor applications, a dream material will allow extreme electron mobility; for photovoltaics it would resist deterioration while allowing greater absorption of incoming light.

“Everybody has a dream material in mind that doesn’t exist,” Zunger said. “Most of us have resigned ourselves to the fact that life is tough and we’re not going to get our dream.”

But, Zunger hopes to make the dreams of material scientists come true.

### Atoms’ Arrangement Matters

The fundamental insight behind the Center for Inverse Design is that the same set of atoms can have starkly different properties depending on their arrangement in space. Diamonds and graphite are both elemental carbon. But graphite is soft and black—the stuff of pencil leads—while diamonds are hard and transparent and star in engagement rings. The difference is how the carbon atoms arrange themselves, which in turn dictates electron behavior. Electrons, the quantum drama’s lead actors, dictate a material’s hardness, chemical reactivity, and how it reflects or absorbs light, transports electrons, and so forth.

The Center for Inverse Design will work in three main steps.

First, Zunger and colleagues in NREL’s Solid State Theory Group will envision a realistic “dream material” for which there is a clear need. They then will use supercomputers running NREL-developed genetic algorithms—mathematical routines capable of learning as they go—to come up with a manageable number of variations on a recipe of atoms. An example might be a semiconductor with specific optical properties consisting of 25% aluminum arsenide molecules and 75% gallium arsenide molecules stacked in whatever arrangement that would pro-

duce the targeted optical behavior. With just 64 atoms capable of producing roughly 500 trillion possible atomic layouts,

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genetic algorithms capable of focusing quickly on the most promising combinations are indispensable.

Next, Zunger's team of NREL theorists will pass some of the semifinalists to NREL Research Fellow David Ginley's group, which specializes in combinatorial chemistry. "Combi," as Ginley calls it, is an automated, high-throughput approach to material synthesis, allowing scientists to create hundreds of variations on a chemical theme at once. Such synthesis involves the creation of crystal superlattices, in which single layers of atoms are applied using lasers or molecular beams. "We do libraries of materials and see whether the area theory highlights look interesting," Ginley said.

Third, Ginley's team will pass promising samples on to the specialists at Oregon State, Northwestern and Stanford, who are, as Zunger put it "the best growers in the world" of phase-pure crystal superlattices.

### **A Lot of Back-and-Forth**

"Many of the materials that we plan to examine have not previously been synthesized," said Douglas Keszler, distinguished professor at Oregon State and one of the center's principal investigators. "In some cases, we will need to develop new growth methods and techniques to strictly control compositions and structures."

Zunger expects a lot of back-and-forth. The combi team may find a theorists' top choice impossible to make, for example, or find that, in the physical world, materials on the lower rungs of the theorists' draft board show greater promise than the assumed top prospects.

**"My role is to take an astronomical number of possibilities, and, without visiting all of them, find where the answer might reside in that space."** – Alex Zunger

"My role is to take an astronomical number of possibilities, and, without visiting all of them, find where the answer might reside in that space," Zunger said. "Then I'll throw it to the experimentalists, and they'll throw something back."

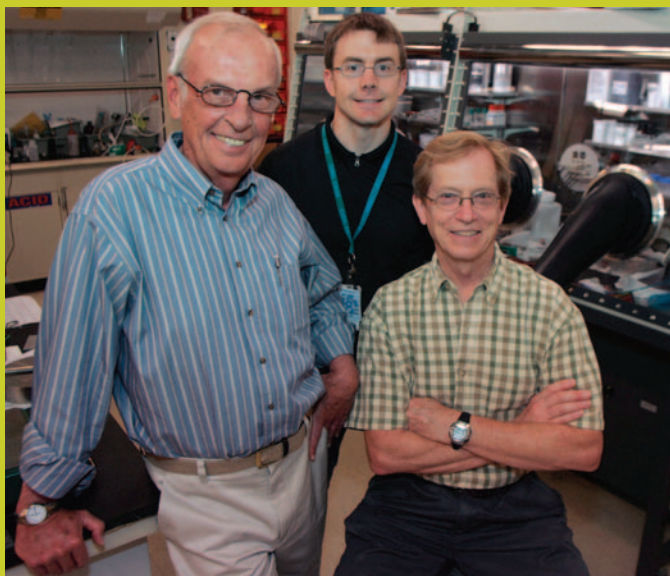
Without advances in combinatorial chemistry and computing power over the past decade, the Center for Inverse Design would never have been possible, Zunger said. But the real

enabler was in the realm of theoretical physics—in particular, advances in density functional theory, he said.

"It permitted us to cast the good old equations of quantum mechanics in ways that are useable and give us numerical results."

— Todd Neff (Aug. 14, 2009)

## AWARD-WINNING BATTERY'S SECRET IS 'BURIED'



NREL scientists Ed Tracy, left, Roland Pitts, right, and Dane Gillaspie, rear, pose in the lab where they continue to work on improving the award-winning buried-anode battery.

Credit: Joe Poellot/PIX 16888

An innovative microbattery based on a National Renewable Energy Laboratory (NREL) team's inspired digression is already bringing home major awards. But those involved with the buried anode thin-film rechargeable battery's ongoing development say the technology holds greatest promise as a building block for big batteries powering automobiles and storing power generated by wind, solar, and other renewable energy systems.

The PowerPlane UX, a coin-cell-sized battery produced by Planar Energy Devices based on NREL's patented design, recently won the World Technology Network's 2009 energy award. The battery was also counted among *R&D Magazine's* 2009 R&D 100, viewed in industry as the "Oscars of Innovation." It was one of three 2009 R&D 100 awards for NREL scientists and one of 45 such awards the national lab's scientists have earned since NREL opened in 1977.

To understand why NREL and Orlando, Florida-based Planar are attracting such attention, it helps to understand a bit about batteries.

Batteries work through chemistry. The simplest battery contains two electrodes—a negatively-charged anode and a

positively charged cathode—plus an electrolyte. Since their invention in the 19th century, the vast majority of batteries have contained liquid electrolytes, as everything from lead-acid car batteries to lithium-ion laptop computer batteries still do today. When the battery's circuit closes, the metal electrodes launch into chemical reactions in the electrolyte that spawn electrons. The electrons flee the anode in search of the cathode, only to find themselves devoured by various lights, motors, and electronics along the way. Primary batteries—single-use throwaways—expire when the chemical fuel runs out. Rechargeables allow a reverse current to rewind the chemical cycle.

### Two Innovations Key to New Battery

The NREL-developed buried-anode lithium-ion battery hinges on two key innovations. The first was a materials science breakthrough by U.S. Department of Energy scientist John Bates's Oak Ridge National Laboratory team in 1991. They developed the first thin film solid electrolyte using a glass called lithium phosphate oxynitride, or LiPON. A solid-state lithium-ion battery was now possible, which promised increased safety (lithium-ion batteries with liquid electrolytes have been known to cook themselves in a process called thermal runaway, which yields flaming gases) while enabling production using processes familiar to the microelectronics industry. Solid-state lithium-ion batteries also can tolerate extreme temperatures and can be recharged thousands of times, subsequent testing has shown.

The other innovation, a process-engineering breakthrough, involved three NREL scientists in a group specializing in electrochromic technologies that dynamically control transmitted light in high-performance windows. Although the connection with batteries may seem tenuous, "thin-film electrochromics are nothing more than poor batteries that change color," as Ed Tracy, an NREL senior scientist, explained it.

In late 1999, Tracy and colleagues Se-Hee Lee and Ping Liu had recently wrapped up a battery project when they came up with the idea that eventually became the buried-anode thin-film battery.

Oak Ridge had made a solid-state battery comprised of three thin layers. On the top was the anode, in the middle was the electrolyte, and below that was the cathode. The anode, rich in lithium, had to be shielded from the outside world or it would corrode quickly from moisture in the air.

**"The ultimate aim is to be able to use the same process technologies to inexpensively make a wide range of batteries for a wide range of vertical markets."** — Roland Pitts

### Process Cut by a Third

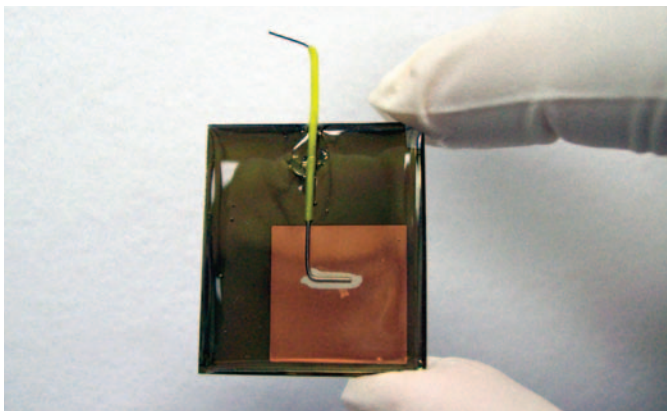
At NREL, Lee, Liu, and Tracy decided to try applying the LiPON electrolyte first, then layering the cathode over it. There was no anode at all. But the cathode contained a lithium compound. When a charge was applied, the lithium in the cathode migrated through the glass electrolyte and formed a metal layer on the other side—that is, the battery

“manufactured” its own lithium anode. Not only that, the anode was buried under the glass electrolyte such that the atmosphere couldn’t touch it.

They came in on a Saturday and made a battery. The following week, they tested it, then broke the news to their group leader, NREL Senior Scientist Roland Pitts, who liked it despite its lack of application in high-end office windows. In addition to avoiding corrosion, the approach would make solid-state battery manufacturing easier.

“The battery itself is three layers, but we form it by making just two layers,” Pitts said. “So we get rid of a third of the process and that’s pretty cool.”

But without an industrial partner—and being somewhat far afield from their day-to-day electrochromics work—the new battery was shelved for five years. The patent on the technology issued in 2004. Soon thereafter, the buried-anode lithium-ion battery attracted the interest of Battelle Ventures, which brought in serial entrepreneur M. Scott Faris to help with assessment of the business potential. In 2007, Faris launched Planar Energy Devices as a NREL spin-off to commercialize the technology. Pitts returned to NREL in 2009 from a two-year sabbatical to serve as the company’s chief science officer, and NREL continues to work with Planar on technology development.



The small PowerPlane battery holds huge potential as a building block for bigger batteries for power tools, renewable-energy storage and electric and hybrid vehicles. Analysts predict the battery market will grow by billions of dollars in the next five years.

Courtesy of Planar Energy Devices/PIX 16889

## Big Plans for Tiny Battery

Despite the microbattery’s promise in such applications as wireless remote sensors, Planar is thinking big—to markets for power tools, renewable-energy storage, and electric and hybrid vehicle batteries, which analysts predict will grow by billions of dollars in the next five years. Planar expects to have large-scale buried-anode batteries on the market in two years, says Andrea Wesser, the Planar product manager for the new battery technology.

Further process innovations will be crucial to entering such markets, she said. One of the key changes will be replacing LiPON with a new solid-state electrolyte—one that needn’t be applied in a vacuum chamber. Vacuum chambers sharply increase production costs while limiting battery size, she said.

“Once you remove it from the vacuum chamber, you can introduce solid-state batteries into all applications,” she said.

To that end, NREL is working on ways to deposit the buried-anode battery’s cathode material outside a vacuum. Planar is doing the same with the electrolyte, Pitts said.

“The ultimate aim is to be able to use the same process technologies to inexpensively make a wide range of batteries for a wide range of vertical markets,” Pitts said.

— Todd Neff (Sept. 11, 2009)

“The battery itself is three layers, but we form it by making just two layers. So we get rid of a third of the process and that’s pretty cool.” — Roland Pitts



## NREL HELPS SET STRINGENT BIODIESEL STANDARDS



Robert McCormick examines a biodiesel sample in the Fuel Chemistry Laboratory. NREL researchers helped revise standards for the fuel. Credit: Pat Corkery/PIX 16165

Most drivers don't have a clue about the percentage of free glycerin or Group I and II metals in the biodiesel they are pumping into their tanks. But if their vehicles sputter in the breakdown lane, questions about the quality and reliability of renewable fuel blends could idle a new industry before it gets started.

NREL Principal Engineer on Fuel Performance Robert McCormick says biodiesel quality is improving rapidly in the United States, with large producers consistently meeting specifications. However, some small producers still have trouble meeting national standards.

McCormick and Senior Engineer Teresa Alleman served as significant contributors to revised biofuels specifications recently published by ASTM International (formerly the American Society for Testing and Materials). Research conducted by NREL provided the technical basis for setting the new standards. McCormick and other collaborators also have co-authored the 2008 edition of the *Biodiesel Handling and Use Guide*.

The rigorous ASTM process yielded stringent specifications to help ensure the availability of high quality biodiesel blends in the marketplace and bolster automaker support and consumer demand for biodiesel.

### All Blends, All Feedstocks

The new standards are the result of years of research at NREL on how the properties of biodiesel blends affect engine performance, and apply to all finished biodiesel blends, regardless of the type of feedstock used to make the fuel.

The new standards will quickly play a crucial economic role. Diesel-powered trucking delivers 70% of the freight in the United States and represents 5% of the U.S. gross domestic product, so new fuel blends must prove reliable.

Several automakers are beginning to sell low-emission, high-mileage diesel cars and light trucks in the United States, too.

"These standards will lead to an expansion of markets for biodiesel while at the same time ensuring that users have trouble-free performance," McCormick said.

Biodiesel is manufactured by the transesterification of domestic plant oils, animal fats, and recycled cooking oils. It's renewable and energy-efficient, and its expanded use displaces petroleum-based fuels. It's cleaner than conventional diesel, and can reduce levels of both air toxics and tailpipe emissions related to global warming.

The total U.S. production capacity for biodiesel reached million 2.24 million gallons in 2007.

"Today biodiesel could displace 5% on on-highway diesel use," McCormick said. "With aggressive feedstock development, displacing as much as 25% could be possible over the long-term."

### ASTM Standards Protect Engines

Pure biodiesel is known as B100, but many engine parts are not compatible with the pure fuel. Burning B100 in an engine with incompatible parts can cause fuel system leaks, ruin a fuel pump, or clog a filter as the hose material gradually erodes.

At concentrations up to 20%, biodiesel blends can be used with minor or no modifications to the equipment. With the new specification in place, automakers and engine manufacturers can test B20 and know that consumers will be fueling their vehicles with a fuel of the same quality.

And those tougher specs are leading to improvements. Two years ago, half of the 32 biodiesel samples tested in McCormick's lab failed—what McCormick described as an "unacceptably large fraction" even for a new industry that still is experimenting with several different production and refinement methods.

In the most recent NREL tests with 56 producers, reported in 2008, samples representing nearly 90% of production volume met specifications and the major producers hardly ever failed the tests.

While a few small and medium producers consistently produced a high quality product, generally the smaller producers continued to have significant failure rates. However, their combined production accounts for about 11% of biodiesel production.

The research was jointly supported by the U.S. Department of Energy and the National Biodiesel Board under a cooperative research and development agreement.

— Joseph B. Verrengia (Jan. 5, 2009)

## PARTNERSHIPS BOOST RESEARCH, IMPROVE TECHNOLOGY



NREL's John Ashworth, left, and Dan Schell inspect a fermentation tank in the lab's Alternative Fuels User Facility pilot plant. DuPont and NREL researchers worked side-by-side in the facility to move biomass conversion technology from the laboratory to pilot scale. Credit: Nick Nagle/PIX 13486

Steve Jobs and Steve Wozniak. Marie and Pierre Curie. NREL and DuPont. Sometimes the most efficient path to success is to find a partner to work with along the way. That's the basic premise for how NREL collaborates with businesses to help boost the lab's research and transfer technology into the marketplace. NREL and businesses form CRADAs (cooperative research and development agreements) to help the best minds in business and government team up to find solutions for alternative energy and fuels.

More than five years ago, NREL and the DuPont Corporation entered into this type of scientific partnership. The goal was to find ways to convert the non-food parts of corn plants (also known as stover) into biofuels. Corn stover is abundant and accessible in the United States, so it made sense for researchers to see if the non-grain parts of the entire plant could be used to make biofuels such as ethanol. But making fuel from a corn kernel easily converted to sugar is one thing. Making fuel from sugars Mother Nature has locked away to protect the plant is another. That's where NREL and DuPont decided to put their heads together.

**"DuPont had a wealth of scientific and engineering knowledge they brought to the table, which brought about competition and some healthy tension."** — Richard Elander

"What made this CRADA attractive for everyone was that NREL already has the intellectual property in several areas relating to biomass and DuPont is very good at science," said National Bioenergy Center Team Leader for Partnership Development John Ashworth. "So, we knew we could do great research together."

### NREL Leverages Turnkey Research

In addition to NREL's extensive intellectual property, another reason companies such as DuPont choose to partner with NREL is our in-house expertise in taking ideas from bench scale tests all the way to full-blown pilot programs. "Companies don't have to piece out the research to company X, Y, or Z throughout the process," said Biochemical Process R&D Supervisor Richard Elander. "We can also look at one idea and eliminate right off the bat the stuff that doesn't work, and that's another of our strengths as a partner."

For the first few years, teams for NREL and DuPont worked closely coming up with new biomass-to-ethanol processes and equipment designs. About a year and a half ago, the NREL-DuPont project scaled up from the lab and was successfully tested at NREL's Alternative Fuels User Facility (AFUF) pilot plant. Bringing the project to this size and scale often required 24/7 collaboration with both teams working side-by-side.

There were a number of factors at play in the NREL-DuPont partnership that made things work so well, Ashworth said. "CRADAs like this work best when they are true collaborations that push and explore the boundaries of science. When companies enter into a CRADA they need to first know where they want to end up and, the work needs to be central to their business plan."

### Competition Sparks Creativity and Drives Success

As with most partnerships, a little friendly rivalry between researchers doesn't hurt either. "DuPont had a wealth of scientific and engineering knowledge they brought to the table, which brought about competition and some healthy tension," Elander noted. "It doesn't hurt the creative process, it helped moved the project forward, and was much better for things overall."

Now that the CRADA has ended, the shining success for both NREL and DuPont is that the research is making its way from the lab to the commercial world. DuPont is taking what was learned during the CRADA and is looking to commercialize the technology. Through a recently formed joint venture (Dupont Danisco Cellulosic Ethanol, LLC) with enzyme technology provider Genencor, DuPont and its industrial partner are building a dedicated pilot-scale biorefinery in Tennessee that is utilizing technology and processes initially developed within the NREL-DuPont CRADA.

— Heather Lammers (March 6, 2009)

## ALGAE-TO-FUEL RESEARCH ENJOYS RESURGENCE AT NREL



NREL maintains a repository of hundreds of strains of algae that could be used to make biofuels. The strains must be grown and maintained under strict temperature and light conditions. Credit: Pat Corkery/PIX 15583

Passenger jets cruise at 35,000 feet without a hiccup. Catfish farmers lease ponds to biofuels entrepreneurs. Venture capitalists sink \$1 billion into green crude.

Judging by the headlines, can it be long before we're filling our tanks with clean fuel from algae?

At NREL, researchers are accelerating efforts to identify and characterize the most promising strains of algae for fuel production. The work has resumed more than a decade after its original algae fuels program was curtailed because the fuels were considered too costly to compete with petroleum.

Today, algae fuels still are not close to being economically competitive with petroleum, according to NREL scientists. So what's changed?

Record high crude oil prices, instability in the Middle East and other oil exporting regions and global warming concerns connected to increasing levels of carbon dioxide have made algae an appealing potential fuel source—again.

### Interest at an All-Time High

And public interest is soaring after recent well-publicized algae fuel demonstrations, including airliner test flights using blends with conventional jet fuel—most recently in Houston by Continental Airlines. Some airlines and engine manufacturers hope to be using algae blends within a few years.

"I'm getting calls every day from people who want to get into algae fuels," said Al Darzins, a group manager and principal researcher in NREL's National Bioenergy Center. "There are hundreds of companies looking into it now here, in Europe, and the Middle East."

So is pond scum ready to replace nearly 100 million gallons of petroleum diesel and jet fuel burned every year?

Not remotely, Darzins says. Biological questions about the organisms and engineering questions related to fuel production, distribution and quality standards must be answered for algae fuels to be competitive with oil currently priced at less than \$50 per barrel.

"All we've really seen are tests involving one engine of a jet running on a blend using a small percentage of algal fuel—and there were no passengers, of course," Darzins said. "In my book, that's a long way from commercialization."

### Potential is Enormous

That doesn't mean the prospect isn't tantalizing. Algae are like microscopic factories using photosynthesis to transform carbon dioxide and sunlight into lipids, or oil. Some strains can double their weight in a few hours under the right conditions.

Algae can grow in fresh, salty, or even contaminated water, can generate 30 times more oil per acre than plants used for biodiesel and other biofuels, and algae don't compete with food crops.

Scientists think algae might grow fatter and faster if they were force-fed extra carbon dioxide, which could help alleviate the buildup of greenhouse gases. Smokestack emissions from power plants and other sources could be diverted directly into the ponds, feeding the algae while keeping greenhouse gases out of the atmosphere.

From 1978 to 1996, the laboratory was a pioneer in the field with the Aquatic Species Program. Researchers screened and characterized more than 3,000 potential strains, shed light on the growth conditions that stimulate lipid production, demonstrated open ponds for mass production of biomass, and made significant breakthroughs in genetic engineering.

### Back to the Basics

Today, NREL has resumed that work, while putting a greater emphasis on understanding their basic biology. When these microalgae are starved of the nutrients they need, their lipid content can increase as much as 60%.

NREL and Chevron Corporation are working under a Cooperative Research and Development Agreement (CRADA) in which NREL is boosting microalgae's productivity. Chevron anticipates using the resulting oil as a feedstock for renewable transportation fuels.

But not every strain contains all the qualities required to produce algae fuel—growing fast, growing fat, and tolerating a wide variety of conditions.

And, different strains have evolved under different conditions in different locales. It's unlikely, Darzins says, that one strain would be used nationwide because of regional differences in climate and water.

"We've only begun to scratch the surface," Darzins said. "We need to understand the lipid pathways and what regulates their lipid production and growth."

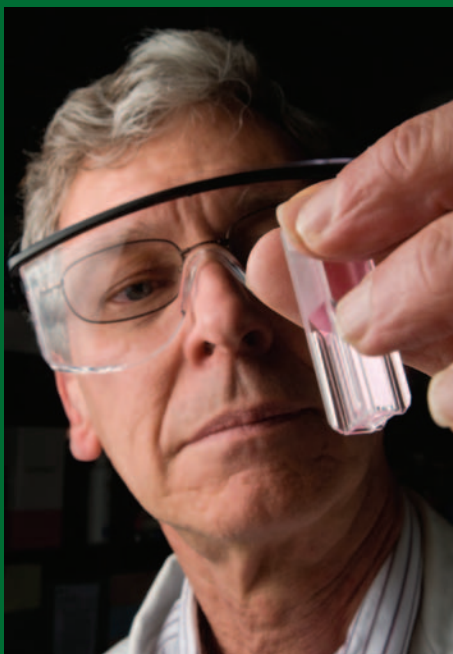
Currently NREL's algae experiments are limited to 1-liter flasks under fluorescent light. When renovations to the greenhouse at the Field Test Laboratory Building are completed, algae strains can be tested in 75 gallon batches under natural light conditions, which can be 10 times more intensive than artificial lighting.

"Some strains that look good now may not maximize photosynthesis when we scale up or expose them to natural light," Darzins said.

Within a few years, Darzins hopes to complete construction of new outdoor ponds behind the FTLB that will test algae strains, production systems and harvesting methods at scales up to 100 acres.

— Joseph B. Verrengia (April 3, 2009)

## BIOFUELS STUDIES TO BENEFIT FROM BETTER LAB TEST



NREL Research Fellow Michael Seibert holds a manganese sample. Knowing the exact manganese content in photosynthetic membranes could help scientist better understand how plants split water.

Credit: Pat Corkery/PIX 16414

Thank sunlight, algae, and green plants for the air we breathe, the food we eat and, in the not-too-distant future, the fuels that power our trips by plane, rail and automobile.

In a process that is as complex as it is elegant, as breathtaking as it is breath-making, sunlight excites electrons in plant cells setting off a chain reaction that rips apart water to release oxygen and then changes carbon dioxide to sugars to produce fuel.

Now, a couple of scientists at the National Renewable Energy Laboratory (NREL) have found a simpler, faster, and far less costly way to measure manganese—the metal that helps plants split water. It's a breakthrough that could support the development of photosynthetic systems for producing biofuels.

The finding is likely to make a loud noise in alternative energy because the efficiency of biofuels production depends on the efficiency of photosynthesis.

**“It could help our lab and others make a lot more progress in understanding photosynthesis ... and ultimately developing artificial photosynthetic systems.”** – Michael Seibert

### New Tool Makes Lab Work Easier

“This is going to make a difficult analysis much more routine,” NREL Research Fellow Dr. Michael Seibert said of the new process that quantifies the manganese content in plants that split water to get electrons for biofuels.

Up to now it has taken a half day and equipment worth as much as \$200,000 to measure manganese in the water-splitting process of photosynthesis.

The NREL process takes a half hour and uses equipment that costs less than \$10,000. And that opens up the process to any professional or undergraduate lab in the world.

“It’s a new tool that makes life in the lab easier,” Seibert said. “It could help our lab and others make a lot more progress in understanding photosynthesis ... and ultimately developing artificial photosynthetic systems.”

### Striving to Understand Nature Better

A paper on the study, co-authored by Seibert and his Russian colleague Boris Semin was just published in the journal *Photosynthesis Research*.

Seibert has a doctorate in molecular biology and biophysics from the University of Pennsylvania. He worked at General Telephone Laboratories for six years before joining the Solar Energy Research Institute, the precursor to NREL, in 1977. Semin, a professor at Moscow State University in Russia, has spent four months each fall for the past decade at NREL working with Seibert.

Plants and algae convert the energy of sunlight into fuel, a process that has served them well for eons, and, by the way, has kept animals and humans alive by converting water to oxygen. But humans must better understand and improve on that natural process to gain the maximum benefit of biofuels.

Seibert and Semin used spinach when they quantified the manganese ions in the water-splitting process, but the assay could be used for algae or any other organism that does plant-type photosynthesis. The procedure counts the number of manganese ions per photosynthetic electron transport chain, the natural process that starts with sunlight and fixes carbon, or releases hydrogen, and oxygen.

### Making the Complex Simple

The counting of manganese has been done before, but only via complex assays using Atomic Absorption spectroscopy or Electron Paramagnetic Resonance spectroscopy, processes that take several hours and require extremely expensive equipment.

Manganese ions can be depleted when plants are exposed to heat, excess salt, heavy metals, radiation, light, pH extremes, and other stresses. That’s why it’s often

crucial to know the exact manganese content in photosynthetic membranes.

Seibert and Semin used a laboratory-grade, visible light spectrometer and very small amounts of spinach membranes. Their workspace was a countertop.

First, they purified the samples. All green plants contain small amounts of manganese that bind on the surface of the membranes but that don't have a specific function in photosynthesis. If those manganese were included in the count, the information would be useless. So, they used calcium chloride to purify the samples.

Next, they used hydrochloric acid to extract the functional manganese from the membranes.

Now they had the manganese, but they also had contaminating membrane particles that could absorb or scatter light and affect the accuracy of the assay. To spin away the impurities, they used a small counter-top centrifuge, spinning for several minutes at 12,000 revolutions per minute.

So, they had purified manganese but no easy way to quantify it.

### A Day in the Library

The final "Aha!" came when Semin and Seibert realized that they could use a dye to determine the precise number of manganese ions used when plants split water and make oxygen.

"The Eureka moment was learning that the dye was specific for only manganese," Seibert said.

### How Did He and Semin Find That Out?

They went to the library, and found that someone a decade ago had used the dye 3,3,5,5-tetramethylbenzidine to determine the manganese content of salt water. "Sometimes a day in the library can save months in the laboratory," Seibert said. "From there it was a development process to clean up the sample material so that we could use the dye" to fingerprint the manganese. The dye binds to the manganese in the solution and changes color in proportion to the amount of manganese present.

When they applied the dye, sure enough, it revealed that there were four manganese ions per electron transport chain, just as had the far more expensive spectroscopy processes. "If we can easily characterize how much manganese there is in the natural system, we can start replacing the natural manganese with other metals such as iron to learn how the system works biochemically," Seibert said.

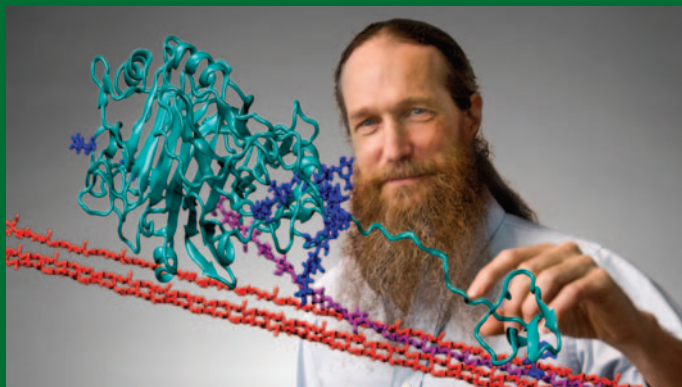
That in turn could lead to information useful for artificial systems to split water and make, say, hydrogen fuel without having to use an electrolysis system.

That's in the future. But perfecting the understanding of the water-splitting process of photosynthesis—in a structure called Photosystem II—is a key step in providing renewable, non-polluting fuels that can power the future of transportation without contributing to global warming.

— Bill Scanlon (July 2, 2009)

"Sometimes a day in the library can save months in the laboratory. From there it was a development process to clean up the sample material so that we could use the dye." — Michael Seibert

## NREL BREAKS DOWN WALLS FOR BIOFUELS



NREL Senior Scientist Michael Crowley created an animated model of Cel7A, nature's primary enzyme for decaying plants. It's computer aided modeling similar to this that is helping NREL researchers look for faster ways to make cellulosic ethanol. Credit: Pat Corkery/PIX 15957

Researchers at the National Renewable Energy Laboratory (NREL) and ethanol producers are racing to come up with ways to make ethanol from cellulosic biomass that are cheaper and easier to produce than current methods. But they are hitting a wall. Cell walls in plants are making the production of cellulosic ethanol a challenge. So researchers are creating their own computer program to help model and break down the tiny fibers of cellulose—or fibrils—found in plant cells.

Although ethanol is becoming more available to consumers, NREL is working closely with the U.S. Department of Energy (DOE) to meet a quickly approaching goal to produce competitively priced ethanol for \$1.50 per gallon by 2012. Why the rush? DOE believes this is the price at which ethanol will be able to go head-to-head with gasoline while the United States strives to reduce our dependence on oil. In addition, the Energy Independence and Security Act of 2007 requires that the United States use 15 billion gallons of renewable fuels by 2012. All of this means the United States needs to find ways to make more ethanol and fast. To help accomplish this goal, NREL researchers are looking at how to make cellulosic ethanol a cheaper, quicker reality.

"To reduce the cost of cellulosic ethanol we must understand how to break down the plant cells into the sugars needed to make ethanol," NREL researcher Antti-Pekka Hynninen said. "The cellulose fibrils of these plants are very long so we use computer modeling to see how we can break them apart."

### Plants are Naturally Tough

Currently, there are no ethanol plants in the United States that distill ethanol using the non-edible parts of plants such as corn stalks, grasses, or wood chips. All commercially available ethanol is made the "easy" way using starchy products such as corn kernels because starches are much easier to break down and convert into the sugars needed to make ethanol. Cellulosic biomass contains sugars that are much harder to get because the plants combine the sugars into cellulose fibers and use these tougher fibers as structure to hold up the plant and protect the cells from

outside attack—and in the case of woody biomass, it's the very cell structure that leads to the slow deterioration of wood.

"Cellulose is grouped in bundles and gives the plant cell walls their strength," Principle Scientist Mark Nimlos said. "We need to learn more about how they are grouped and attached to the plant cell walls so we can take it apart to make more ethanol that's cheaper and requires less energy to produce."

NREL researchers typically study cellulose fibrils that are 500 to 1,000 glucose units long and figure out with easiest way to bust them apart. However, these fibrils are too large to study using current computer models.

"Right now the technique is to consider each atom in each fiber, which is not practical using existing computers," Nimlos said. "We need to group atoms into beads, or larger grains."

### New Approach for Computer Modeling

NREL hired Hynninen in early 2009. He has a Ph.D. in physics from Utrecht University in the Netherlands. Hynninen hopes to overcome the problem presented by such large molecules by building a simpler "coarse-grained" computer model of cellulose fibrils. In the new approach, multiple atoms (typically 3 to 7) are grouped into a single spherical bead. The coarse-grained model is then built up from these beads. The new model is expected to allow computer simulations that are 10 to 100 times faster.

"The big question that we will need to answer is how to define the forces between the beads," Hynninen said. "Those forces must be equal to the forces acting in the atomistic model. At the moment, our work is centered on building the software tools that map those atomistic forces onto the coarse-grained model."

"The key here is how to get rid of the details and keep the overall picture," Senior Scientist Mike Crowley said. "We can't model every detail of every atom. Think of modeling the collision of two cars. When studying the force of the collision, you don't examine the pistons in the engine, you look at just the vehicle even though it's made of many parts. We need to look at larger segments to model the cell overall. Sounds simple, but it's very tricky."

The idea of something being "tricky" is motivation for Hynninen and makes him a valued member of the NREL team. "Antti-Pekka's programming expertise means he sits down and writes a program needed without being restricted by existing software," Crowley said. "He's a maestro who can make a computer do what he needs it to do."

Hynninen's view of his work is more mathematical. "My goal is simply solving a problem that has some impact on our lives and makes a difference," he said. "This is a nice example of applied science working on real problems and goals we need to meet."

Next steps for the program officially titled "Meso-Scale Computational Modeling of Polysaccharides in Plant Cell Walls" are to validate the model and publish the work done at NREL so this type of modeling can be used in other areas.

"I believe this same method could be used for other systems and they don't have to be cellulosic or proteins—there's a potential for many uses." Hynninen said.

— Heather Lammers (November 30, 2009)

## NREL HELPS NEW ORLEANS GO GREEN



Small, energy-efficient two-story homes such as this one under construction in New Orleans are the result of a partnership among DOE's Building America program and local foundations. NREL is providing energy efficiency advice for the homes' design.

Credit: Phil Voss/PIX 16863

New Orleans is going green as it continues rebuilding after Hurricane Katrina—with a big assist from the U.S. Department of Energy's (DOE) National Renewable Energy Laboratory (NREL).

Sprouting in once-flooded neighborhoods are some new energy-efficient homes featuring rooftop solar panels, extensive insulation, and more efficient climate systems. These standards will be applied citywide in schools and hospitals, too.

Many of the improvements are based on renewable energy programs and strategies provided by DOE and the laboratory.

Nor are the energy-saving improvements limited to hurricane reconstruction. Even before Katrina, many of the city's commercial buildings and dwellings were blighted. Entire neighborhoods were built decades ago without insulation and are subject to termite infestations.

The lab's commitment to demonstration projects and community partnerships has encouraged city officials to embrace renewable energy.

Now the motto "Cleaner...Smarter" is stenciled on the city's new buses that run on a 5% biodiesel blend, and New Orleans has been selected as one of DOE's Solar America Cities.

"New Orleans has an amazingly vibrant local culture," says senior project leader Phil Voss, who returned to Golden in January after 18 months in New Orleans. He is the lab's first energy expert to be embedded in a field project.

"And until now, that same culture has not been open to many outside ideas, like energy efficiency."

### A Huge Challenge

Hurricane Katrina was the single largest natural catastrophe in U.S. history.

The storm hit on Aug. 29, 2005. More than 1 million people were evacuated from the Gulf Coast; 2,541 were killed or remain missing.

Katrina flooded 80% of New Orleans, causing \$89.6 billion in damages. Half of the city's homes were under at least four feet of water. Three weeks later, the storm surge from Hurricane Rita flooded the city again.

During the city's extended recovery, Steve Chalk, DOE Principal Deputy Assistant Secretary for the Office of Energy Efficiency and Renewable Energy, and Mary Werner, NREL's Integrated Deployment Manager, established an office in New Orleans to promote energy conservation in the city's rebuilding plans and introduce the use of renewable energy technology.

In addition to assigning Voss, NREL added local staff that included rehiring one of its former employees, Joe Ryan, a New Orleans resident. The NREL/DOE team has advised two dozen organizations focused on recovery and rebuilding.

### Housing for Hundreds of Thousands

DOE has challenged the homebuilding industry to build thousands of new high-performance homes in New Orleans by 2012 under the department's Building America program.

The first homes to be certified as meeting the DOE Builder's Challenge criteria are being built in the Gentilly neighborhood by a philanthropic effort named "Project Home Again"

with Green Coast Enterprises and the Leonard and Louise Riggio Foundation.

Four high-performance homes have been completed, and 16 more will be ready by spring. Eventually the project could expand to 100 homes or more. They are reserved for qualifying lower-income Gentilly homeowners whose previous homes were destroyed.

"If that doesn't sound like progress," Voss said, "you don't know the challenges in New Orleans. When it comes to rebuilding, the Big Easy is anything but."

**"New Orleans has an amazingly vibrant local culture. And until now, that same culture has not been open to many outside ideas, like energy efficiency." – Phil Voss**

The two to four bedroom houses are designed to reduce energy use by 30–40% and lower utility bills by as much as \$1,000 per year. Key features include:

- Passive heating and cooling features such as cross-ventilation and screened-in porches
- Daylighting with highly efficient “low-E” double-hung, double-glazed windows
- Whole-house insulation using high-density spray foam
- Properly sized, efficient heat pumps paired with dehumidifiers
- Air-handlers and ductwork within conditioned space
- Energy Star® appliances and lighting
- Foundation piers to elevate the houses above the flood plain.

By eliminating drafts and removing moisture from the indoor air, residents won’t have to overchill their homes to be comfortable, even when summer weather hits 95°F with an equal dose of humidity.

NREL and Building America partner Florida Solar Energy Center are improving affordable home designs with the most active homebuilder in the New Orleans Area: Habitat for Humanity. Habitat has built two demonstration houses side-by-side in the Musicians Village district. The organization is expanding its building program in New Orleans by a factor of 10 over pre-Katrina levels.

Catholic Charities is working with Building America and its partner Building Science Corp. on another affordable energy-efficient design. NREL is performing long-term monitoring and analysis of the home’s heat pump with enhanced dehumidification capability.



New Orleans is one of the DOE’s 25 Solar America Cities.

Credit: Phil Voss/PIX 16862

## Energy-Efficient Schools

NREL and DOE also formed a partnership with the Orleans Parish school district to use the Integrated Design approach to building high performance schools.

Of the district’s 128 schools open before Katrina, only 84 are expected to be open over the next 10 years. Many of these facilities must be replaced or substantially renovated. Taking into account the decades of deferred maintenance as well as storm damage, the reconstruction price tag for schools alone will approach \$2 billion.

So far, four new schools are under construction. With help from NREL’s Buildings Group, they will be 25–35% more energy efficient than code by including new construction methods, energy efficient systems, and energy management tools.

That energy efficiency standard has been incorporated in the school district’s 10-year master plan. The lab and DOE are completing energy audits of existing schools, too.

In a separate project, NREL’s Paul Torcellini and Shanti Pless are consulting on the design of a shared \$2 billion hospital complex with Louisiana State University and the U.S. Department of Veterans Affairs.

## Energy Policy Development

The NREL team also helped the city council develop a comprehensive energy policy and a plan to generate community support.

The “Energy Smart New Orleans Plan” includes financing for energy efficiency improvements in homes and small businesses, low-income weatherization, a pilot solar thermal and PV component, and a contractor training and certification program.

The state government also offering a 50% residential tax credit on the first \$25,000 of the cost of an installed rooftop photovoltaic system.

NREL is engaging local utilities, public officials, and central business district leaders on integrating power generated by distributed PV systems into the local electricity grid.

— Joseph B. Verrengia (Feb. 27, 2009)



## TWO YEARS LATER, GREENSBURG IS OFFICIALLY GREEN—WITH NREL'S HELP



A tornado on May 4, 2007 destroyed 90% of Greensburg, Kansas. With NREL's help, the city is rebuilding to stringent energy efficiency standards and adding renewable energy sources in an effort to be the nation's greenest community. PIX 16290

The same natural force that annihilated Greensburg, Kansas, in 2007 soon will be illuminating the town that has been rebuilt into America's most energy-conscious community.

With technical assistance from NREL, the city of Greensburg, John Deere Renewable Energy and other partners will open a wind farm generating 12.5 MW of electricity, enough to power 4,000 homes. Replacing fossil-fired electricity with a renewable source is a significant step in the town's well-documented recovery—not only for the environmental benefits, but as an economic development strategy, too.

Traumatized residents could be forgiven for doubting any promise delivered on the wind. But now, says NREL project Leader Lynn Billman, townspeople proudly wear T-shirts that quip "Greensburg, KS—It's a Wind-Wind Situation."

### When Catastrophe Brings Opportunity

On May 4, 2007, an evening tornado cranking at 205 mph leveled the town, killing 11 people and uprooting its 1,400 residents. The giant twister destroyed 90% of the buildings in its unusually wide path, including Main Street, schools, government offices, the fire station, the bank, and the hospital.

Within a few days, advisers from NREL, the U.S. Department of Energy, and other agencies were huddling with local officials and residents under the big white emergency services tent to help answer the Big Question—what will become of Greensburg? Since then, Billman has coordinated NREL experts and subcontractors who have served as technical advisors on every aspect of renewable energy and sustainable reconstruction.

Already, Greensburg's decision to set a new green standard is paying off. Tests on 100 new homes built since the disaster show energy efficiency has improved by an average of 40% over homes built to conventional building codes. Some residents saw their winter heating bills reduced by as much as two-thirds.

On May 2, 2009, Greensburg recognized the NREL with the city's first annual Outstanding Support Award for playing an "instrumental" role in the town's recovery. NREL advisers will work in Greensburg for another year to complete on-the-ground projects and develop a sustainability blueprint that other cities and towns might follow.

"NREL has made our lives easier and better," said City Administrator Steve Hewitt. "Our experience will benefit many other communities that NREL will be working with."

### Community-Sized Wind Power

The Greensburg wind farm will include 10 turbines, each rated at 1.25 MW. John Deere Renewable Energy will build and maintain the wind farm, and it will sell power to the Kansas Power Pool, a cooperative of several Kansas cities. Greensburg expects to consume about a quarter of the electricity the wind farm generates.

When the wind isn't blowing and the turbines cannot generate electricity, the Kansas Power Pool will provide the town with clean power from other sources, including hydropower, to meet the community's goal of being powered entirely by renewable sources.

Groundbreaking for the Greensburg wind farm is planned for this summer at a site three miles outside of town. Commercial operation is expected to begin in 2010.

Laboratory advisers recommended wind power to Greensburg early in the rebuilding effort; Kansas has the third highest potential among the U.S. states to generate electricity from wind, according to a NREL analysis.

And, they realized that Greensburg could be a showcase for distributed community-scale wind power.

NREL developed extensive wind farm technical studies and business models as part of its broader green recovery plan but, the city decided to contract the wind farm's development with John Deere Renewable Energy.

Billman said the laboratory wants Greensburg to have a wind system generating clean electricity economically and at a location visible from town, and the John Deere Renewable Energy plan achieves those goals.

"We fully support the city's decision," Billman said. "It will help Greensburg achieve its vision without raising the cost of electricity for its residents."

### Part of a Broader Clean Energy Plan

Other areas that NREL advisers have been working on to keep Greensburg operating sustainably on its own for decades include:

- Municipal building design and construction to LEED-platinum standards, making it the first city in the nation to do so
- LED streetlights
- Energy-efficient framing, insulation, ductwork and other improvements to new residential and commercial construction
- Helping establish a local wind turbine distributorship at the John Deere farm equipment dealership
- Assessing biomass-fueled heating opportunities.

— Joseph B. Verrengia (May 8, 2009)

## NREL, INDUSTRY WORK TO HALVE BUILDING ENERGY USE



The BigHorn Home Improvement Center, a retail complex in Silverthorne, Colorado, is an example of a retailer using natural daylighting to reduce energy use. Credit: Jim Yost/PIX 09218

Walk into your favorite retail or office building, and something's at work all around you that you probably take for granted—energy. Energy to run lights for displays, energy to cool the building on a hot summer day, energy to keep your favorite ice cream nice and cold.

Partners from the private sector, the U.S. Department of Energy (DOE), and two national labs, NREL and Pacific Northwest National Laboratory (PNNL), are working together to reduce energy consumption in commercial buildings in the United States. NREL launched a Web site dedicated to the collaborative research project dubbed "National Accounts."

NREL and PNNL are currently working with 23 National Accounts Companies (NACs), including nine retailers, 13 real estate management companies, and one distribution facility. Through the program, the team will create, test, and validate design concepts that will move the industry towards net-zero energy commercial buildings.

**"Another area we are evaluating is outside air. How much ventilation do you really need for retail space? If we are over-ventilating, then we have extra air to heat and cool." – Paul Torcellini**

### Aiming Toward Zero-Energy Buildings

National Accounts is part of DOE's Net-Zero Energy Commercial Building Initiative (CBI), which was mandated by the 2007 Energy Independence and Security Act (EISA). EISA enabled DOE to bring together parties from the private sector, DOE national labs, other federal agencies, and nongovernmental organizations to advance research into low- and zero-net-energy buildings. CBI's goal is to develop market-ready, net zero-energy commercial buildings by 2025. A net zero-energy building makes as much energy as it uses over a year.

The CBI program is currently funded as a public/private cost share. DOE is contributing \$15 million through the technical expertise of NREL and PNNL. Companies kick in 20% of the project value. Construction costs and capital improvement fees to retrofit older buildings are not included in the program.

Currently, retail and office buildings consume 18% of the nation's total energy and half of nation's overall building energy (including homes, schools, and other structures). The program partners will work to build new facilities that use 50% less energy and retrofit older buildings to use 30% less energy.

"This program is unique because it involves the energy end-users," explained NREL Senior Engineer Paul Torcellini. "Using a flipped model, we are engaging energy consumers from a business point of view."

The business motivation for industry participants is often related to their bottom lines. "Some retailers' margins are so small, they can actually make money by saving money with energy efficiency," Torcellini said.

### Your Very Own Technical Adviser

As partners in the program, NREL provides technical and research support to the NACs. "When they come up with questions," said Torcellini, "We do the analysis and say, 'this is what you should do to get the maximum value.'"

Issues like daylighting, refrigeration, and replacing conventional parking lot lights with LEDs are some of the energy design measures the teams are beginning to tackle.

"Another area we are evaluating is outside air," added Torcellini. "How much ventilation do you really need for retail space? If we are over-ventilating, then we have extra air to heat and cool."

Having NREL staffers serve as technical advisers is a great perk for the companies participating in program. In addition, each NAC receives state-of-the-art assistance from NREL that may include:

- State-of-the-art energy modeling
- Integrated design processes that incorporate energy efficiency and renewable energy technologies
- Guidance to help procure materials and equipment

- Low-energy building designs that can be replicated across company portfolios
- Detailed documentation, including business case studies with information about both process and results
- Research quality results
- Recognition as leaders in their industry.

The state-of-the-art energy modeling saves building owners time and effort as they develop low-energy buildings. “The modeling allows everyone involved in the project to run through ‘what-if’ scenarios relatively inexpensively and it’s one of the services the teams get from NREL as part of the cost-share,” Torcellini said.

NREL also wants to provide data and tools for anyone interested in using these strategies to build or renovate low-energy buildings.

“We are also helping make the business case for incorporating these technologies,” Torcellini said. “We’ll be preparing case studies and research reports, and we’ll be measuring actual performance against energy goals. And, we’ll work with NAC members to share non-proprietary research with members of their industry.”

### Web Site to Share Progress Reports

NREL’s National Accounts Web site helps “make the case” for more energy efficient buildings. Some NACs will be posting information about their work with National Accounts, including lessons learned, what’s working, and the challenges they’ve encountered as their new construction and/or renovation project progress. They will also share non-proprietary details about how they achieved energy efficiency targets.

“What’s exciting about the fruits of this program is that the participating companies will continue to benefit from reduced energy costs long after the construction or retrofitting is complete,” Torcellini said. “They’ll also have been involved in a program that will help the commercial building industry develop new best practices for low-energy design.”



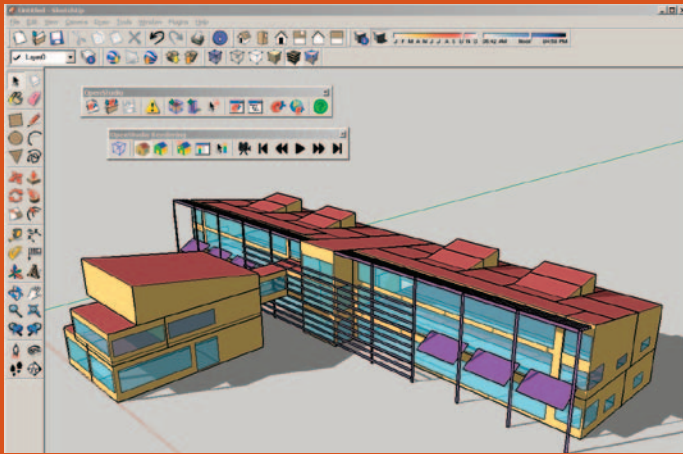
NREL Senior Engineer Paul Torcellini examines an energy management system, which helps optimize the operation of the mechanical and lighting systems in a retail store. The system controls the heating systems, ceiling fans, and lighting levels. Credit: Jim Yost/PIX 09214

### National Account Companies

- Bank of America
- Best Buy
- CB Richard Ellis
- Forest City Enterprises
- Hilton Hotels Corporation
- Hines
- InterContinental Hotels Group
- JCPenney
- John Deere
- Kohl’s
- Macy’s
- The Opus Group
- PNC Financial Services
- ProLogis
- Regency Centers
- Ryan Companies U.S.
- Simon Property Group
- SUPERVALU
- Target
- Tishman Speyer
- Toyota
- The Westfield Group
- Whole Foods Market

— Heather Lammers (June 19, 2009)

## SOFTWARE HELPS DESIGN ENERGY STINGY BUILDINGS



OpenStudio, a new quick, easy to use and free software tool created by NREL developers seamlessly combines the building energy simulation of EnergyPlus with the popular drawing interface of Google's SketchUp.

One is the tedious and time-consuming task of manually entering building geometry data. Now users can quickly sketch a computerized 3-D drawing of a building and run a fast simulation during the early design phase to determine if their design is energy efficient. Taking a virtual X-ray of a building's energy use in the conceptual phase helps architects design a structure with fewer carbon emissions, lower utility bills and a healthier environment.

### OpenStudio Simulates Energy Usage in Early Design Phase

The OpenStudio plug-in is bridging the gap between energy modeling and the building design process. Nick Long, a NREL engineer who helped develop OpenStudio, says the software is a critical piece to getting energy simulation into the early design phase of building construction.

"Integrating energy analysis into that phase is very important because you can start to reduce energy use well before a building is even in conceptual design," he said.

Because of the simplicity of OpenStudio and the quickness of the SketchUp models, architects can easily use this tool during the launch of a building project. "Our hope is that by using OpenStudio in design charrettes, users can start throwing away designs at the very beginning of a project, saying: 'This is not a good design because we're going to use too much energy,'" Long said.

### Users Download OpenStudio for Free

Around the globe, architects and engineers are embracing OpenStudio, which was launched in April 2008. Users can download the software for free and see how easy it is to improve a building's energy consumption in a fraction of the time of more-expensive computer-aided design (CAD) packages.

Approximately 700 copies of OpenStudio are downloaded each month. "It's been great," Long said. "Thousands of users of EnergyPlus are learning about OpenStudio and adopting it as the defacto geometry editor."

Developed by the Department of Energy in 2001, EnergyPlus is a stand-alone simulation program that models whole-building energy consumption from heating, cooling, ventilation, lighting, water systems, and other energy flows. Long explains that the primary value of OpenStudio is to provide a graphical user interface to develop geometry that can be used directly with EnergyPlus. If a user already has an EnergyPlus input file, he can use OpenStudio to render and change the geometry without losing any of the other information already contained in the EnergyPlus file.

"Architects won't go into a text file to edit geometry, changing vertex by vertex," he said. "They want something graphical, and SketchUp is a quick method to render a building." In little time, a designer can create a building's geometry from scratch in SketchUp: add zones, draw heat transfer surfaces, draw windows and doors, etc., and then run an energy simulation in EnergyPlus.

OpenStudio offers many practical applications that give users the freedom to explore different design options, such as performing overhang analyses. When a building design has a lot of windows on the south side, the designer needs to know how big and how deep to make the overhangs.

"With OpenStudio you use the capabilities of SketchUp that will show the sun's path and cast shadows on the windows—at any time of the day for an entire year," Long says. "Then you can play a video and watch the sun move over the building for a year to figure out if you have effectively shaded your windows and also validate it using EnergyPlus."

### Plug-in Designed as an Open Source Program

Peter Ellis, principal developer of OpenStudio, took 18 months to write the complex program. He used open-source coding principles so that any developer has the flexibility to modify or enhance the software.

Christopher Cronin, Google's Strategist for SketchUp, says, "OpenStudio is lauded around our office as one of the most complicated plug-ins ever written for SketchUp." And Sang Ahn from Google adds that OpenStudio is the most impressive extension he has seen.

NREL developers are working to make OpenStudio faster and add functionality. "We're hoping to provide OpenStudio as a full graphical interface to EnergyPlus that allows users to edit HVAC, plug loads, and lighting loads, and the remaining building inputs at the same time," Long said.

Future enhancements for OpenStudio might include:

- Integrating with a daylighting program
- Linking to a construction-cost database
- Connecting to the U.S. Green Building Council's Leadership in Energy and Environmental Design.

Reducing energy use is an important factor in improving the sustainability of residential and commercial buildings. OpenStudio makes energy modeling software easier to use and more accessible and affordable in the early design phase. This enables architects to evaluate energy-saving strategies when design changes are least costly.

The OpenStudio plug-in is bridging the gap between energy modeling and the building design process, says Nick Long, a NREL engineer who helps develop the software.

— Mary Darr (Oct. 9, 2009)

## NEW SOLAR TECHNOLOGY CONCENTRATES ON COST, EFFICIENCY



NREL senior engineer Keith Gawlik and University of Colorado graduate student Kathleen Stynes are conducting tests on the new SkyTrough parabolic trough design atop South Table Mountain for the next several months. Gawlik is holding a sample of the trough's highly reflective metal skin. The sheet metal replaces heavy glass mirrors. Credit: Pat Corkery/PIX 16139

It looks like a giant funhouse mirror. But the big new dish atop South Table Mountain could be a renewable energy breakthrough that helps make concentrated solar power more affordable and appealing to utilities and their customers.

For the next several months, NREL engineers will be testing the performance of SkyTrough, an innovative parabolic trough that is coated with a gleaming reflective skin instead of mirrored glass.

NREL offers leading-edge testing and performance analysis for advanced solar technologies and other renewable energy designs.

The SkyTrough was developed by SkyFuel, an Albuquerque-based manufacturer with a research facility near NREL in Arvada, Colorado.

The unit's lightweight glass-free mirrors are made of sheet metal beneath ReflecTech® mirror film.

This highly-reflective, silver-metalized film is lighter and less expensive than the breakable glass mirrors that are traditionally used. The film is a joint invention of NREL and ReflecTech™ and exclusively licensed from NREL. The glossy laminate is comprised of multiple layers of polymer films with an inner layer of pure silver to provide for a highly reflective surface that also protects the silver layer from oxidation.

In commercial use, a SkyTrough could measure as large as 375 feet long and 20 feet high. One SkyTrough would supply enough electricity for 125 homes. The test model is smaller, but uses the same technologies.

"It's unlike any parabolic trough design used so far," said NREL senior engineer Keith Gawlik. "Our new facility is designed to test the optical efficiency of the unit, which they can't do on their own at SkyFuel."

### How Parabolic-Trough Systems Work

Parabolic-trough systems concentrate the sun's energy through long U-shaped mirrors. The mirrors are tilted toward the sun, focusing sunlight on a vacuum pipe that runs down the center of the trough.

The tube contains heat-transfer oil that absorbs the focused sunlight and reaches temperatures of 400°C. The hot oil then is used to boil water in a conventional steam generator to produce electricity.

As the sun moves across the horizon, the troughs follow its trajectory by rotating along their axes with the help of tracking motors. This keeps the collectors oriented towards the sun to maximize the system's performance throughout the day.

### SkyTrough Testing at NREL

The SkyTrough itself is mounted on NREL's Large Payload Solar Tracker. It supports solar components that require 2-axis tracking. The tracker is capable of carrying a maximum vertical load of 9,000 pounds with a tracking accuracy of 1 milliradian.

The NREL tests will center on validating the SkyTrough's optical performance. A key step in concentrating solar power (CSP) is making sure the light collected in the parabolic trough is accurately converted and focused on the receiver tube so it can heat the transfer oil efficiently.

"Lots of things come into play when focusing light," Gawlik said. "We have to consider the reflectivity of the surface, the accuracy of the surface and then aiming all of the light into the narrow focal line of the receiver tube."

Typically, a parabolic trough operates at nearly 80% optical efficiency, and SkyFuel expects its design to function at least as well, while being less expensive to manufacture, transport, and maintain.

The NREL test will span portions of at least three seasons to explore the unit's performance under a variety of weather conditions and sun angles.

"There is a cascade of opportunities to lose some light at every step in the process," Gawlik said. "That's why we field test the whole unit and get solid data over a number of months. It removes the uncertainty in the final efficiency result."

### Future Concentrating Solar Power Plants

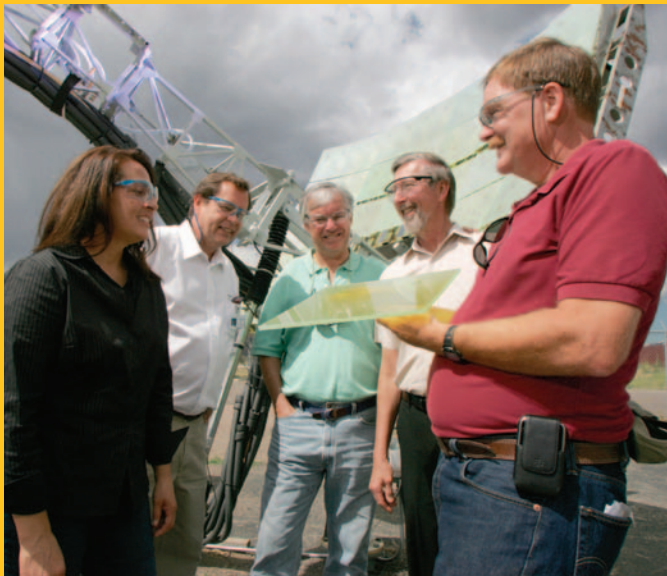
The NREL tests will not include actual electricity generation because that step in the process uses conventional steam turbine technology. But it is that hybrid combination of the renewable and the conventional that makes CSP appealing to utilities as a source of cleaner bulk power during peak and intermediate load periods.

Parabolic trough power plants also require relatively large tracts of nearly level open land with strong solar characteristics, as well as transmission lines and other infrastructure. These factors make Southwestern states the leading candidates for additional CSP installations; in California, the Solar Energy Generating Systems plants have been operating for two decades.

By 2015, the Western Governors' Association estimates that 4 gigawatts of new concentrating solar power plants could be built in the United States.

— Joseph B. Verrengia (Jan. 9, 2009)

## WEATHERING SYSTEM CUTS PRODUCT TESTING TIME



NREL's Ultra-Accelerated Weathering System tests products for outdoor durability. Researchers who worked on the project include (left to right), Judy Netter, NREL; Henry Hardcastle, Atlas Material Testing Technology; and Al Lewandowski, Gary Jorgensen and Carl Bingham of NREL. Credit: Joe Poellot/PIX 16793

Engineers design a new auto paint, a better solar device, or a sturdier vinyl siding. But how can they know if the new products deserve a five-year, 10-year or 30-year warranty, with the sun beating down on it day after day?

### Better a leap in technology than a leap of faith.

A senior scientist at the National Renewable Energy Laboratory (NREL), working with researchers in Russia and Arizona, has come up with a way to shine the equivalent of 50 suns on new products that need to be tested for outdoor durability.

### Beyond the 'Rip Van Winkle' Approach

Product manufacturers can find out in 10 weeks how their new paints or new anti-corrosive materials will look in 10 years.

"What's been done in the past is the Rip Van Winkle approach to testing," NREL senior scientist Gary Jorgensen said. "You put a product on exposure outdoors and go to sleep for 20 years. You wake up and see how long it lasted."

How to accelerate the effects of weather has long been a conundrum for the products testing industry.

The challenge has been how to simulate the effects of decades of the sun's rays, without getting things so hot that the product gets destroyed because it heats up more than it ever would in the real world. If the product gets too hot, it will blister, peel, melt, or otherwise fail to function.

Sun damage on outdoor products comes almost exclusively from the ultraviolet rays in the spectrum, the same light that causes skin cancer in humans. The thermal load itself does little damage. However, the thermal load of five or 10 or 50 suns certainly would damage the sample.

The nub: How to let the ultraviolet light in, but block the visible and near-infrared parts of the solar spectrums.

### Fruit of a 15-Year-Old Idea

NREL's new Ultra-Accelerated Weathering System (UAWS) is able to reflect virtually all of the sun's ultraviolet rays onto the samples, but attenuate the visible and near-infrared rays. The result is a system that quickly gives an accurate portrait of what the sun will do to a product in 10, 20, or 30 years.

The seeds of the idea go back almost 15 years. In the mid-1990s, NREL was involved with a national consortium trying to address a critical industry need: highly accelerated testing to allow companies to predict with confidence what the service-life guarantee should be on their products.

The automobile industry alone spends about \$18 billion a year fulfilling service guarantees associated with their paint systems. It is crucial to know how long the warranties should be—and they can't wait 15 years to find out.

"It occurred to me that at NREL we already had a high-flux solar furnace that could provide exposures of 2,000 suns," Jorgensen recalled.

The furnace wasn't suitable for product testing, though, because it couldn't shine rays evenly over samples.

"We wanted to scale back from 2,000 suns to 50 or 100, and at the same time have the solar flux become much more uniform," Jorgensen said.

### From Russia, with Mirrors

Serendipitously, an NREL scientist working on the furnace also was embarking on a separate project to homogenize the solar flux. "We had all the components there that we needed," Jorgensen said. "It was just a matter of putting existing pieces together and initiating our new project."

NREL researchers got going, but found they needed help. The scientists looked back to the end of the Cold War to find it.

**"What's been done in the past is the Rip Van Winkle approach to testing. You put a product on exposure outdoors and go to sleep for 20 years. You wake up and see how long it lasted."** – Gary Jorgensen

The U.S. government had freed up some money to put former Soviet nuclear weapons scientists back to work. The aim of the Initiative for Proliferation Prevention was to re-employ the laid off Soviet scientists so they wouldn't be tempted to sell weapons technology to unstable regimes in order to feed their families.

"The Russian group designed the coated mirrors and the faceted mirror array," he said. "They were able to work on a socially redeeming project."

The UAWS has an array of 29 square mirrors with spherical curves. Just as a light house uses numerous pieces of bent glass to magnify light, the UAWS uses the curves of the many mirrors to concentrate the UV portion of natural sunlight.

Each of the mirrors has 96 layers of vacuum deposited coatings on them, Jorgensen said. Each layer of film uses alternating high- and low-refractive materials. The thickness of each layer helps produce mismatched refractions which, in turn, transmit some wavelengths and reflect other wavelengths back toward the sample chamber.

The array reflects the UV portion of the solar spectrum back to a chamber that holds the samples, which is on an arm about 10 feet away from the array.

### Turning Down the Heat

By attenuating most of the thermal and infra-red spectra—that is, not letting them reflect back to the samples—the system keeps the heat down to about 35°C (95°F) for some tests, about 65°C (149°F) for others. "It's called spectral splitting," Jorgensen said.

The samples still can get awfully hot just with the small sliver of thermal energy allowed in. So, to more precisely simulate the damage the actual sun will do over time, samples being tested are attached by vacuum to chilled copper blocks during exposure. Also, cool air blows across the surface of the samples to keep the temperature down.

NREL scientists have been able to successfully correlate exposure at the UAWS with real-time outdoor exposures and exposures in controlled laboratory chambers that use artificial lights sources. Using the UAWS they have demonstrated product lifetimes of 20 years based on two summer's worth of exposure. NREL also involved Atlas Materials Testing Technology, a global leader in product testing, with headquarters in Phoenix.

"The best acceleration technology was at the level of five or six suns," Jorgensen said. "We told them we could do better than that by a factor of 10. They got really excited and interested. They're now commercializing the technology."

### Award-Winning Technology

UAWS is expected to be a hit with manufacturers of car paints, as well as the aerospace and electronics industries, the Department of Defense and designers of anti-corrosion materials for bridges and buildings. "Anything that is expected to last in an outdoor environment could benefit from the accelerated testing," Jorgensen said.

Pharmaceutical and biomedicine companies also could become customers because they need to know the effect of UV on human tissue, as well as "the efficacy of UV blocking agents" such as sunscreen, Jorgensen said.

NREL scientists Jorgensen, Al Lewandowski, Carl Bingham, and Judy Netter, together with collaborators at the Institute of Laser Optic Technology in Moscow and Atlas Material Testing Technology, earned a prestigious R&D 100 award in 2009 for the new technology. Called the "Oscars of Invention," the awards are presented by *R&D Magazine*.

NREL has a UAWS on South Table Mountain near its headquarters in Golden, Colorado. Half-inch square samples of new products are attached to the device, complete with the chillers and the coolers. The mirrors let ultra-violet do its damage but block most of the heat and the rest of the solar spectrum from the samples.

"This answers the question: 'Will it last for 20 years?' in a 20-week time frame," Jorgensen said. "It gives a tremendous competitive advantage to companies that will test this way."

— Bill Scanlon (Sept. 25, 2009)

**"The best acceleration technology was at the level of five or six suns. We told them we could do better than that by a factor of 10. They got really excited and interested. They're now commercializing the technology." — Gary Jorgensen**

## AWARD-WINNING REFLECTOR TO CUT SOLAR COST



SkyFuels Chief Tech Technology Officer Randy Gee, left, and NREL Senior Scientist Gary Jorgensen developed a thin silver polymer film to substitute for bulkier glass mirrors on solar-collecting troughs. Credit: Pat Corkery/ PIX 16464

**H**uge parabolic mirrors catching the sun's rays could crisscross America's deserts soon, thanks to a breakthrough that may greatly lower the cost of solar power.

A small solar company has teamed with scientists at the National Renewable Energy Laboratory (NREL) to develop massive curved sheets of metal that have the potential to be 30% less expensive than today's best collectors of concentrated solar power.

The SkyTrough Parabolic Trough Solar Concentrating Collectors will be longer than football fields and look like fun-house mirrors, but could be the game-changers in solar energy's bid to out-muscle gas and coal in providing electricity for America's homes.

The breakthrough recently was honored by *R&D Magazine* as one of the top 100 technical innovations of the year, and by the Federal Laboratory Consortium with a 2009 Excellence in Technology Transfer Award.

**"Glass is highly durable, but is heavy and hard to shape without added cost. Once industry sees the advantages of the silver polymer and is convinced the product is durable in an outdoor environment, the sky is the limit." – Gary Jorgensen**

Solar power has been nipping at the heels of fossil fuels for decades, but hasn't yet found a way to be cost-competitive on a large scale.

### 'The Sky is the Limit'

That could change, says NREL senior scientist Gary Jorgensen, who with SkyFuel Chief Technology Officer Randy Gee developed a thin silver polymer film to substitute for bulkier glass mirrors on solar-collecting troughs.

"Glass is highly durable, but is heavy and hard to shape without added cost," Jorgensen said. "Once industry sees the advantages of the silver polymer and is convinced the product is durable in an outdoor environment, the sky is the limit."

Gee said the film, trademarked ReflecTech® Mirror Film, "has the same performance as the heavy glass mirrors, but at a much lower cost and much lower weight. It also is much easier to deploy and install." The glossy film uses several layers of polymers, with an inner layer of pure silver.

The government scientist and the chief technology officer say the cost advantage is about 30%, a huge dividend in an industry that has scratched together savings one percent at a time for decades.

Solar scientists for years have understood the advantage of the parabolic shape, which distorts the rays, concentrating the sun's heat onto a tube filled with heat-transfer fluid, which carries the heat to the boilers in a power station.

The heat-transfer fluid can get as hot as 400°C (more than 750°F).

### More than 10 Years in the Making

The thorny problem has been how to find an alternative to glass, something that is cheaper and lighter, easier to install, yet durable in the hot sun.

The story goes back to the late 1990s, when Gee and Jorgensen worked with a small \$25,000 federal grant to see if they could come up with an alternative reflector.

They used NREL's testing facilities to sample dozens, indeed hundreds, of possible materials that potentially provided the low-weight low-cost highly flexible properties needed to drive down the cost of solar power collection.

"Within two years, we had enough data to believe we had a substantial improvement relative to predecessors," Jorgensen recalled.

They found that silver had great potential, but that by itself the metal would delaminate and corrode too easily. It's the combination of metals and polymer film layers that protect the silver that makes the film commercially viable.



“We reduced the concept to practice and filed for the patent,” Jorgensen said. SkyFuel now holds the exclusive license for using the patented technology developed by both Gee and Jorgensen.

NREL’s technology transfer office aims to make it easier for private industry to invest in renewable energy by developing mutually beneficial partnerships, including teaming on research and patents.

A prototype SkyTrough is capturing the sun’s rays right now atop South Table Mountain overlooking NREL’s Golden, Colorado, campus; a larger pilot system also has been installed at SkyFuel’s location in Arvada, Colorado, a few miles north of NREL. The parabolas could spring up by the end of the year in the highest desert regions of California, and soon in Arizona, Nevada, New Mexico, Texas and Colorado, states blessed with lots of sunshine and vast open areas.

Parabolic collectors have been around since the 1970s. Back then they were about seven feet wide and 20 feet long, a half dozen or so lined up to collect the sun’s rays, a motorized system turning the mirrors as the sun moved across the sky.

“The natural evolution was to get larger and reduce costs,” said Gee, who worked with Jorgensen in the 1980s at the Solar Energy Resource Institute, NREL’s predecessor. “Each generation got larger,” pointing to the day when utility companies would want to purchase the troughs for 50- to 100-megawatt plants.

In commercial use, a SkyTrough would measure 375 feet long and 20 feet high. One SkyTrough would supply enough electricity for at least 50 homes.

Gee describes the technology transfer as a natural outgrowth of NREL’s presence in a large metro area. “Just the fact that you have that level of expertise in a national lab, you’re going to have naturally occurring spinoffs. This didn’t occur through any particular program, other than the contact between different people in the research community in this particular area of solar.”

Gee recalls the methodical testing of samples at NREL’s optical materials lab. “Bit by bit, we improved the performance of these samples,” he said.

“The real important moment came when we filed the patent. It took many years of working through the patent process, but we were rewarded with it in 2007.”

### ‘Perfect Storm’ for Renewable Energy

SkyFuel’s R&D Center in Arvada has 16 employees, mainly scientists and engineers that have been improving the design of the SkyTrough.

“Just two-and-a-half years into the development cycle, it looks like our great technical team is going to be able to take a big chunk out of the costs of installing CSP systems,” Gee said. “We’re not doing this in tiny steps but in big chunks.”

NREL’s contribution to the breakthrough film “was absolutely critical,” Gee said. “Over the past two years, we’ve had the ability to ask the scientists there, where they have the optical test equipment, to come over and bring their specialized equipment to measure the accuracy our parabolic trough collector.”

“It was absolutely important for us to verify the optics of our technology before we put it in the field.”

Several utilities that have installed expensive fossil-fired plants in the past decade “are very excited about solar in general, and many of them see our technology as a very important part of that,” Gee said.

Gee maintains that it all could have come together years ago, if not for wavering. “It requires political will to make this happen,” Gee said. “There’s no reason why we couldn’t be 20 years ahead of the game, compared to where we are now.

“A lot of work in materials has evolved,” Gee added. “It remains to be seen whether this time we break through. It depends on how seriously climate change is taken, what sort of actions are taken to move us away from fossil fuels.”

Jorgensen has been working on renewable energy for 30 years. He calls today’s climate “a perfect storm ... with the realization by the public of the importance of alternative energy, with politicians listening to the public, with energy demands, and with security issues of not wanting to rely on foreign oil.”

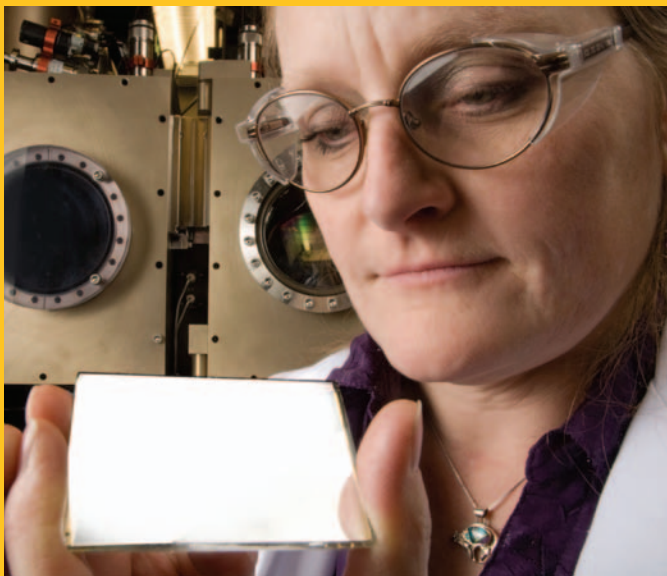
“With the whole impact of global environmental change, we’re truly at the pinnacle of a golden age,” Jorgensen said.

— Bill Scanlon (Aug. 3, 2009)



Kathleen Stynes removes the cover from the heat transfer tube on the prototype SkyTrough on South Table Mountain overlooking NREL’s Golden, Colorado, campus. Credit: Pat Corkery/Pix 16465

## NEW LABS TO CONCENTRATE ON SOLAR THERMAL ENERGY



NREL Senior Scientist Cheryl Kennedy holds a sample of an experimental mirror coating to increase the efficiency of concentrating solar power. NREL is receiving \$5.4 million in ARRA funding for new laboratories to accelerate CSP research and development. Credit: Pat Corkery PIX 16815

As the market for clean solar power rapidly expands, researchers at the National Renewable Energy Laboratory (NREL) are investigating advanced concepts in concentrating solar power (CSP) with \$5.4 million in American Recovery and Reinvestment Act (ARRA) funding awarded from the U.S. Department of Energy (DOE).

The new work includes establishing two new facilities and extensive improvements to an existing third facility on the NREL's research campus. It also will include field testing of new CSP technologies at the Solar Technology Acceleration Center (SolarTAC), a new 76-acre solar test site.

CSP uses mirrors to reflect sunlight onto receivers. Unlike photovoltaic cells that directly convert sunlight into electricity, this method uses the sun's heat to drive a generator to produce electricity.

Key to CSP's commercial success is developing an economical, effective energy storage capability that will hold the sun's heat for use to generate clean electricity at periods of peak power demand, or during cloudy weather or at night.

NREL is studying new thermal storage materials and technologies that will allow CSP plants to work at higher temperatures and greater efficiencies, while lowering the cost of energy produced by these systems.

DOE's goal is to make CSP cost-competitive by 2015 and provide a sizeable amount of clean energy to the grid by 2020.

### Rapid growth expected

CSP plants are generating about 600 megawatts of electricity today, mostly in the United States and Spain. An additional 1,000 megawatts are under construction by utilities in sunny regions such as the desert Southwest.

In the United States, an additional 8 gigawatts of CSP are being planned. Internationally, a similar level of CSP development is underway.

NREL maintains an online database of CSP projects and technologies with SolarPACES, an international cooperative organization, to track CSP development worldwide.

NREL and Sandia National Laboratories are funded by DOE to develop CSP technologies.

"The CSP industry is growing rapidly and needs DOE's help to evaluate technologies that will make projects more financeable," said CSP program manager Mark Mehos.

"The industry needs performance and durability data in everything from materials to systems," he said. "And on the R&D side, these new facilities will help us develop the next generation of materials and systems."

Two of the NREL facilities—the Advanced Thermal Storage Process and Components Integration Laboratory and the Optical Components Characterization Laboratory—will be located in NREL's new Energy Systems Integration Facility (ESIF), which is scheduled to be completed in late 2011.

Department of Energy funding will be used in four important areas:

#### 1. Advanced Thermal Storage Process and Components Integration Laboratory, \$660,000.

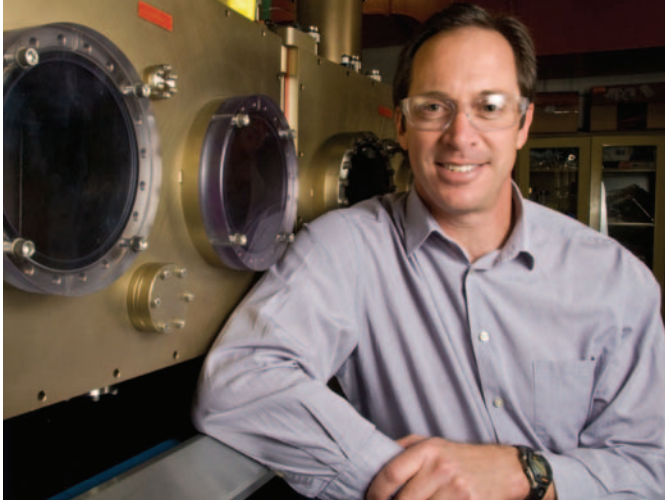
Economically storing thermal energy for generating electricity during peak utility load periods is vital if CSP is going to help meet clean energy demand. Mehos said this new facility would include two test units—one 15 kilowatt and the other 100 kilowatt—to evaluate advanced CSP heat transfer fluids and thermal energy storage methods. The lab will test concepts being developed through grants awarded to industry and universities for developing advanced fluids and storage concepts.

#### 2. Advanced Optical Materials and Optical Components Characterization and Integration Laboratories, \$1.36 million.

NREL's existing advanced optical materials laboratories develop and test new lower-cost, durable optics and coatings

**"We can't wait 30 years to find out if the new mirrors for CSP systems will actually last for 30 years. We do acceleration tests in these chambers that will be working 24 hours a day, seven days a week." – Cheryl Kennedy**

for mirrors and receivers. Weatherization chambers currently expose a large number of advanced reflector materials under accelerated conditions of ultraviolet light, temperature, and humidity. An advanced deposition chamber is being used to develop advanced reflector and absorber coatings. A diverse set of optical characterization equipment is used to evaluate the optical properties of advanced materials. Currently NREL has three laboratories located in the Field Test Laboratory Building doing versions of this work. A portion of the funding will be used to expand the capabilities within each of these laboratories.



Mark Mehos, manager of the concentrating solar power program, says much of the ARRA funding for the CPS program will be spent on new facilities to improve thermal storage and other CSP technologies. Credit: Pat Corkery/PIX 16816

NREL researchers already have worked with one CSP company, Sky Fuel of Albuquerque, New Mexico, to develop a film-based optical coating on an aluminum parabolic shaped substrate to replace heavier, breakable glass mirrors. That development won a 2009 R&D 100 award. “Sky Fuel’s material is the furthest along,” Mehos said. “But other companies—3M, Alcoa, Abengoa—also are looking at new materials.”

Some equipment for the ARRA-funded improvements is being installed now at NREL’s Advanced Optical Materials Laboratory, including four new WeatherOmeters to test mirrors and other CSP components. At \$120,000 to \$160,000 apiece, these advanced chambers use xenon arc lamps and other systems to concentrate sunlight at about seven times typical outdoor exposure. They also simulate the freeze-thaw cycle and other conditions.

“We can’t wait 30 years to find out if the new mirrors for CSP systems will actually last for 30 years,” said NREL senior scientist Cheryl Kennedy who leads the advanced materials team developing and testing reflector and absorber materials. “We do acceleration tests in these chambers that will be working 24 hours a day, seven days a week.”

NREL also supports optical characterization of industry-furnished collectors and mirror facets at an indoor laboratory located at NREL’s Joyce Street facility. Currently, the only practical orientation for indoor and field testing of complete parabolic trough modules has been an arrangement in which the collector axis points to the horizon.

However, rarely—if ever—does the CSP collector point toward the horizon during normal operation. Mehos said it is important to test these collectors under standard operating conditions where effects like gravity can impact optical performance. With this in mind, the funding will allow researchers to develop an overhead test configuration that will accommodate full parabolic trough module testing in the vertical position to more closely simulate real-world operations.

### 3. Nanomaterials for Thermal Energy Storage in CSP Plants, \$1 million.

This project will develop new nanomaterials and encapsulation strategies that could lead to significant improvements in the thermal energy storage density for CSP systems. The nanostructure research leverages NREL’s existing fundamental materials research program.

### 4. Advanced Thermal Energy Storage Test and Evaluation Facility, \$2.4 million.

This pilot-scale facility will be built 30 miles east of the laboratory in Aurora, Colorado, at the new SolarTAC. The SolarTAC site near Denver International Airport is being privately developed as a test site for industry with NREL’s participation, both for large-scale photovoltaic and CSP trials. Being able to test advanced thermal energy storage systems for CSP at scale is essential to developing and deploying these new concepts commercially. The proposed pilot-scale storage facility will provide a general-purpose test bed available specifically to support DOE laboratory, industry, and university test and evaluation activities.

NREL’s plans were endorsed in letters to DOE by more than two dozen corporate and university leaders in solar research.

“One of the key advantages is that it will be possible to get direct comparisons of competing thermal energy storage concepts,” said Henry Price, vice president of technology development at Abengoa Solar Inc. “More cost-effective forms of thermal energy storage need to be developed.”

— Joseph B. Verrengia (Dec. 18, 2009)

## CONFERENCE TACKLES INTERSTATE TRANSMISSION



Moving clean electricity to cities from distant wind and solar farms will require complex interstate agreements. Some western states may try to model their agreements after interstate compacts like those that have regulated water diversion for nearly 100 years. Credit: Warren Gretz/PIX 10927

It sounds like a dreaded word problem on a final exam:

*More than 50% of the best class 5-7 winds in the Western U.S. occur in southern Wyoming. Southern California's population is expected to grow by 74% by 2030 to 23 million residents, and will need all the low-cost renewable power it can get. How do you build a transmission line to carry that clean electricity across mountain ranges, sensitive wildlife habitat and 1,000 miles of public and private property in as many as five states?*

There is no certain answer, says NREL senior energy analyst David Hurlbut, because building new transmission for renewable energy is less of a technical question and more of a policy issue.

Hurlbut and the laboratory's Strategic Energy Analysis Center recently convened NREL's first conference to address the issue of interstate collaboration on transmission policy. They started with regulators, policymakers, and legal analysts from four states likely to be affected—Colorado, Wyoming, Utah, and New Mexico.

**"A congressionally approved compact generally shields the states from certain kinds of federal preemption, which is a major concern in renewable energy projects right now." –Robin Craig**

Proceedings of the Conference on Multistate Decision-making for Renewable Energy and Transmission will be published in the *University of Colorado Law Journal*. Additional meetings that would focus other groups of neighboring states are being discussed.

"To achieve the large scale potential of renewable energy in the most cost-effective way, we have to solve the transmission issue and aside from the federal government there is no institution with multi-state jurisdiction over transmission," Hurlbut said. "Federal preemption makes states nervous especially in the West, so it's fair to ask what states themselves can do in collaboration with one another."

"There has been a lot of attention paid to the technical aspects of renewable energy. But this is political—deciding where to build a line and how to pay for it."

### Transmission's Critical Crossroads

At the NREL conference, participants examined how each of the four states regulates electricity transmission now and how they might cooperatively approach building new lines to carry power from clean, renewable sources.

The nation's transmission system is at a critical crossroads. Rising power demands and transmission bottlenecks make it difficult to keep the power grid operating smoothly.

Renewable energy adds an additional challenge. The nation's windiest and sunniest locations often are located far from major cities. Under some scenarios, this new transmission capacity could include 19,000 miles of new lines at a cost of \$60 billion.

The U.S. Department of Energy (DOE) recently identified transmission limitations as a chief roadblock to obtaining 20% of our electricity from the wind as detailed in its report, "20% Wind Energy by 2030."

In the United States, each state determines how transmission lines will be sited within its borders. New projects generally must demonstrate they are serving a public need, but how that need is defined varies, as well as how local impacts are evaluated. Issues such as clean energy and climate change are pressing state authorities to broaden how they approach the question of need.

### Interstate Compact Offers Historic Model

The NREL conference was an early opportunity for the participating states to explore policy approaches towards new renewable energy transmission.

The most likely framework is an interstate compact, conference speakers said.

Interstate compacts are binding agreements between two or more states in which they accept the jurisdiction of other

states over a shared resource, service, or facility. Compacts must be approved by the legislatures of the participating states as well as Congress—a process that can take years. Once approved, the states hold the power over the project.

“A congressionally approved compact generally shields the states from certain kinds of federal preemption, which is a major concern in renewable energy projects right now,” said Robin Craig, associate dean for environmental programs at the Florida State University College of Law and a featured speaker at the NREL conference.

Prominent examples of interstate facilities run under compacts include the New York-New Jersey Port Authority and the transportation authority serving the District of Columbia and suburbs in northern Virginia and Maryland.

Interstate compacts that manage natural resources across state lines offer specific guidance because they deal with both infrastructure and seasonally variable resources.

For example, the Colorado River Compact has been allocating water since 1922 in seven Western states—many of the same states that have vast potential to produce wind and solar power and where power demand also is dramatically increasing.

Craig said renewable energy states can draw on decades of lessons if the energy resource changes or renewable energy prices shift dramatically.

“The beauty of interstate compacts is that they have no set substantive requirements—states are free to negotiate the contents of the compact as they think will work best,” Craig said.

### If It Walks Like a Duck

If states don’t want to form an interstate compact, others said they must be careful not to create a transmission agreement that tries to act like a compact, but sidesteps the approval process. It’s that additional legislative scrutiny that reinforces the compact’s binding nature and reduces risk.

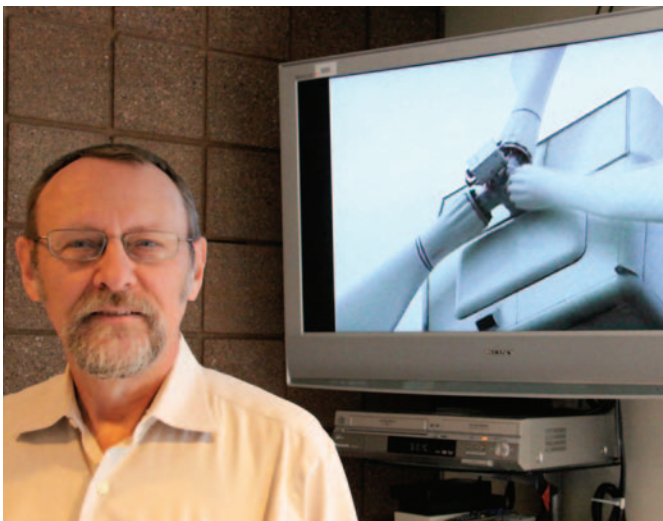
“When one state agrees it will be bound by the decisions of another state, then they start going down the compact road,” said Commissioner James Tarpey, who attended the conference for the Colorado Public Utilities Commission.

The voluntary nature of alternative agreements may generate uneasiness as well, especially considering that transmission lines are expensive and expected to remain in place for decades.

“There needs to be sufficient certainty regarding cost allocation among the states, resulting in recovery of the capital invested and a reasonable profit, over the long term.” Tarpey said. “Otherwise, Wall Street may not be willing to invest or will only be willing to do so at a cost commensurate with the perceived risk.”

“If you are going to go forward with renewable energy,” Tarpey said, “this is an example of the issues you need to start grappling with.”

— *Joseph B. Verrengia (Oct. 2, 2009)*



NREL senior energy analyst David Hurlbut organized the conference to highlight the policy challenges facing both energy-exporting states and major demand centers.

Credit: Joe Verrengia/PIX 16892

## NREL ASSIGNS RENEWABLES EXPERTS TO HAWAII, ALASKA



A 10.5 MW wind farm near the northern tip of Hawaii's Big Island has been generating electricity since 2006. Courtesy of Hawaiian Electric Light Company (HELCO)/PIX 14697

**N**REL has dispatched clean energy experts to Hawaii and Alaska to work as advisors to local policymakers and utilities.

At a glance, the two states couldn't appear to be more different—tropical and small versus Arctic and huge.

However, Hawaii and Alaska both have considerable renewable energy resources, including solar, wind, geothermal, biomass, and wave energy.

And because of their remote locations, they have the nation's highest energy costs and rely almost exclusively on fossil fuels.

Department of Energy (DOE) and NREL officials recognize that both states could serve as renewable energy models for the Lower 48. But integrating renewables into the states' economies and infrastructures is a complex job that won't get done simply by offering advice from the lab's Golden, Colorado, campus.

The programs are modeled on successful recent DOE and lab clean energy efforts in Greensburg, Kansas, and New Orleans.

"To accomplish something on the ground, you have to have experts on the ground," said Mary Werner, the lab's executive manager of integrated deployment. "Being there in real time is a critical piece in getting a community—or an entire state—to move in the same direction towards renewable energy goals."

### Clean Energy in a Generation

In Hawaii, two NREL senior project leaders have started working directly with state officials, utilities, and the private sector to help implement the Hawaii Clean Energy Initiative (HCEI).

The HCEI is a partnership between DOE and the state that was formed in January 2008 to help Hawaii generate 70% of its energy from clean sources by 2030. It's an aggressive plan; according to the lab's 2008 State of the States report, Hawaii ranks 46th in the amount of renewable energy flowing to its electricity grid. More than 90% of its electricity and fuel comes from fossil fuels shipped to the islands.

As part of the HCEI, Gov. Linda Lingle and state lawmakers met with DOE officials and researchers in July at the lab.

On March 16, 2009, Paul Norton started as the lab's senior project leader in Hawaii to work with the Energy Efficiency Branch in the Department of Business, Economic Development and Tourism's (DBEDT) State Energy Office. Norton brings 14 years of residential buildings research and analysis experience, but his portfolio will expand to include all renewable technologies in the HCEI.

NREL's second advisor, Debra Lew, is a senior project leader for transmission and integration with the National Wind Technology Center. Lew is helping Hawaii's utilities learn how to integrate wind and solar power on the electricity grid, and manage the effects of these variable resources on utility operations and costs.

"Hawaii doesn't have the benefit of 14 neighboring states to help keep a shared grid in balance when it adds wind and solar power," Werner said. "Each island has its own micro-grid, where putting in high levels of variable renewable energy sources will be extremely difficult to do."

Norton and Lew are married, making the complex field assignment a "fortuitous" pairing, Werner said.

### Dozens of Renewable Initiatives

In addition to new solar and wind farms and planned zero-energy communities, the state and the Hawaiian Electric Company are pursuing an undersea cable to connect several islands, and transmit an additional 400 MW of wind power to Honolulu and the island of Oahu, where most residents and tourists are concentrated.

**"Hawaii doesn't have the benefit of 14 neighboring states to help keep a shared grid in balance when it adds wind and solar power. Each island has its own micro-grid, where putting in high levels of variable renewable energy sources will be extremely difficult to do." – Mary Werner**

Hawaii also is establishing a “feed-in tariff” that would pay a standard rate for power fed into the grid from renewable energy systems, and eliminating caps on the amount of electricity homeowners can send to the grid from their own PV and wind systems.

The NREL team’s portfolio is likely to grow. Norton says state lawmakers are considering another three dozen renewable energy bills.

“Less than 24 hours after Debbie and I arrived, Gov. Lingle invited us to her office,” Norton said. “She is strongly committed to this program.”



This family’s home in a remote village in Alaska is powered by a solar/diesel hybrid system featuring 4 kW of solar panels and two diesel generators. Fuel is expensive in Alaska and makes renewable energy a competitive seasonal energy option.

Courtesy of Northern Power Systems/PIX 08963

## High Tech Villages

In Alaska, Brian Hirsch of Homer has been named as the lab’s representative in the nation’s largest state.

Hirsch, who holds a Ph.D. in natural resources, formerly was development director for the Yukon River Inter-Tribal Watershed Council, a coalition of 64 Tribes and First Nations in Alaska and Canada. His projects have included village wind turbines, a small in-river hydrokinetic turbine in the Yukon River and photovoltaic panels in Arctic Village, a community above the Arctic Circle.

Alaska is one of the nation’s leading oil and gas producing states. It ranks 39th in renewable energy on its grid, virtually all of which comes from hydroelectric dams.

Hirsch will focus on bringing renewable power to a state that has among the nation’s highest energy prices—as much as \$1 per kilowatt hour in remote villages.

“He knows renewable energy and he has well-established relationships,” Werner said.

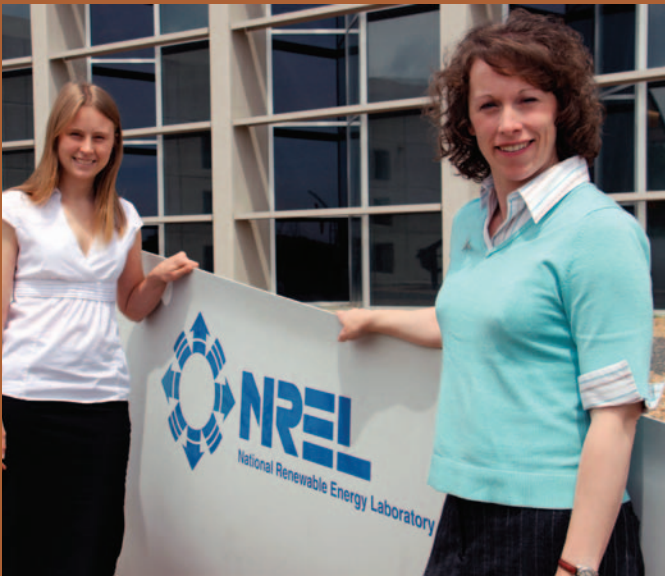
— Joseph B. Verrengia (March 27, 2009)



A volcanic vent on Hawaii’s Big Island glows with heat from lava that exceeds 2,000 degrees Fahrenheit. Hawaii has one geothermal power plant that generates 30% of the Big Island’s electricity.

Courtesy of John Lund, Geo-Heat Center/PIX 13101

## NREL ENERGY ANALYSTS DIG INTO FEED-IN TARIFFS



NREL energy analysts Claire Kreycik, left, and Karlynn Cory have examined feed-in tariffs in North America and Europe.

Credit: Joe Verrengia/PIX 16878

Feed-in tariffs (FiTs) are the world's most widely used policy to drive renewable energy development. They have helped transform cloudy Germany into the world leader of installed solar power and photovoltaic manufacturing.

Now FiTs are stimulating green energy investment in North America, too.

Locations as disparate as the city of Gainesville, Florida, the province of Ontario, Canada, and the state of Washington recently have adopted measures establishing guaranteed long-term prices for clean electricity. A dozen more states and many more communities are considering similar energy policy proposals.

NREL energy analysts are digging into these complex policies in a series of technical reports designed to inform government policy makers, clean energy investors, utilities, and other stakeholders.

### Stability, Reduced Risk Attracts Investors

Feed-in tariffs guarantee long-term payments at pre-established rates for the electricity generated from renewable sources. The production-based payments are often higher than

market rates, but are on the verge of becoming competitive in specific locations for certain technologies such as wind power.

While utilities are obligated to buy the power, the long-term payments help encourage renewable energy development by reducing risks for investors. Any added costs are typically passed along to ratepayers and, for technologies like wind and landfill gas, may provide a hedge against electricity price volatility and large price spikes over the long-term.

According to the NREL studies, experience around the world suggests that FiTs can effectively expand renewable energy deployment and remove barriers to renewable energy development, while creating jobs and helping meet renewable energy standards.

### Best Programs Tailored to Local Conditions

States—or even local communities—may be tempted to copy the successful German model word for word. But, NREL analysts say that FiTs are most effective when the policy design is adapted to local context.

“Every jurisdiction has unique characteristics that will influence the details of the FiT design and affect its success—these local differences are critical to consider,” said Karlynn Cory, co-author of “State Clean Energy Policies Analysis (SCEPA) Project: An Analysis of Renewable Energy Feed-in Tariffs in the United States”.

The NREL reports examine a wide range of FiT programs. For example, Gainesville's tariff is limited to photovoltaic projects with a total city-wide cap of 4 megawatts. Under Washington state's FiT policy, solar PV, solar thermal, wind, and anaerobic digesters are offered a payment that differs by technology and that increases if system components are manufactured in-state.

This spring, the Canadian province of Ontario revised its three-year old program to include a 20-year fixed price of as much as \$0.69 for every kilowatt-hour of solar power generated. In response, SunEdison, First Solar, Everbrite Solar, and

Nanosolar are developing both solar energy farms and manufacturing facilities near Ottawa, Kingston, and other cities.

### Timely Topic

With so many tariff options, Cory said it is timely for the laboratory's Strategic Energy Analysis Center to tackle the topic.

“Understanding the policy design options allows decision makers to formulate more effective policies for their specific circumstances,” Cory

said. “This was a real opportunity for NREL to evaluate the key lessons learned in Europe and translate them to the U.S. context.”

The second NREL study of FiTs suggests that the policy can work effectively with renewable portfolio standards (RPS).

“Every jurisdiction has unique characteristics that will influence the details of the FiT design and affect its success—these local differences are critical to consider.” – Karlynn Cory



States use RPS policies to set long-term requirements on how much renewable energy must be developed to meet consumer demand, boost clean energy development, and reduce their reliance on fossil fuels.

Cory co-authored that report, “Feed-in Tariff Policy: Design, Implementation, and RPS Policy Interactions,” with NREL analyst Claire Kreycik and Toby Couture, now of E3 Analytics.

Kreycik recently briefed New York state policymakers on how FiTs can drive renewable energy deployment and job creation as they prepare to vote on a FiT proposal.

RPS mandates have been adopted in 29 states and Congress is considering a national standard. However, not all of these policies are designed to address investors’ needs for revenue certainty. That’s where FiT programs can be complementary.

“RPS policies tend to set the requirement and let the market figure out how to get there,” Cory said. “FiT policies can help utilities meet their RPS target. It doesn’t have to be an either-or choice.”

A third NREL report will focus on best practices for FiT policies. It will be completed later this year.

### Key Factors to FiT Success

NREL analysts have identified several key factors in a successful FiT policy.

- **Stability.** Energy projects require several years to develop, so FiTs have to be in place five years or longer to encourage certainty with investors and manufacturers.

“RPS policies tend to set the requirement and let the market figure out how to get there. FiT policies can help utilities meet their RPS target. It doesn’t have to be an either-or choice.” – Karlynn Cory

- **Long-term contracts.** Contracts in the range of 15–20 years allow investors time to recover their costs.
- **Adequate energy prices.** FiTs must cover project costs, plus a reasonable return to create stability, attract investors, lower risk, and keep financing relatively simple.
- **Annually decreasing payments.** As innovation and growth reduce technology costs, tariffs should be lowered according to a transparent and incremental plan. This encourages rapid deployment and increases competition among manufacturers.
- **Differentiate payments** according to technology type, project size, and resource quality.
- **Incorporate FiT into the electricity rate base.** Tying FiT payments to ratepayers distributes costs and provides certainty that investors will get paid.
- **Reduce bureaucracy.** Streamlining approvals reduces barriers and costs. Streamlining procedures especially helps small projects and encourages broader participation.

— Joseph B. Verrengia (June 12, 2009)

## NREL UNCOVERS CLEAN ENERGY LEADERS STATE BY STATE



Clean energy projects in Maine such as the 42-megawatt Mars Hill wind farm help the New England state rank first in the nation in some renewable categories, according to NREL's 2009 State of the State report. Credit: Skip Babineau/PIX 15332

An exclusive state-by-state analysis by the U.S. Department of Energy's National Renewable Energy Laboratory (NREL) shows that clean energy development is spreading rapidly throughout the country, often in conjunction with public policies designed to spur such growth.

By 2007, 24 of the nation's 50 states were generating at least 1 gigawatt of renewable electricity from non-hydro sources, according to the 2009 NREL State of the States report. While states such as California and Texas with abundant resources continue to rank among the leading states in terms of total renewable electricity generation, the study shows that a range of other states are demonstrating strong growth in the clean energy sector, including those with historic fossil fuel legacies, such as Oklahoma and Illinois.

Wind energy accounted for the largest percentage of nationwide growth in renewable generation between 2001 and 2007, including a 30% increase in 2006 and 2007.

Biomass generation continued to expand across most regions, with states as disparate as Delaware, Utah, Minnesota, and Alaska showing the most recent growth in the sector. Biomass generation continued to be strong in southeastern states, including Georgia, Alabama, and Florida.

The State of the States project was developed by the U.S. Department of Energy, NREL, and the American Council for an Energy-Efficient Economy (ACEEE). It is funded by the Department of Energy's office of Energy Efficiency and Renewable Energy (EERE).

### Not a Scorecard

This is the second annual State of the States report. NREL energy analysts began compiling new data and making initial comparisons February 2008.

The 212-page report contains 101 charts dissecting major renewable energy technologies and policies, as well as an extensive appendix listing clean energy resources. While the report provides state-by-state comparisons, NREL authors said the report is not meant to be a renewable energy scorecard.

Its broader purpose is to document the interplay between renewable energy technology development, policy implementation and markets on the state level—and, as a result, to help make renewable energy development more effective.

"This is the only report that looks at data from every state and attempts to quantify the links between renewable energy development and policy implementation," said NREL Senior Energy Analyst Joyce McLaren, who led the report team.

"Of course, it's interesting to know where and how much wind energy is being produced, but knowing that alone isn't going to help move you forward," McLaren said. "This report tries to identify how states are moving forward and which mechanisms are the most effective and efficient."

### Making the Policy-Energy Connection

All but 14 U.S. states now have adopted renewable energy portfolio standards or goals. And, all but seven states have net-metering policies in place, which allow customers who generate their own electricity to send surplus power back to the grid and have it subtracted from their retail electricity use.

State policymakers who commented on the project in its draft stages said they were impressed by breadth and scope of the final report. Knowing what is taking place beyond your own state's borders can be influential, they said, even when one state's renewable energy resources are different from another's.

"In recent years, our energy committee has been dealing with questions that are hyper-local, such as whether we should consider including wood from construction and demolition as

a renewable resource for purposes of our renewable portfolio standard," said Kevin McCarthy, principal analyst for the Connecticut General Assembly's Office of Legislative Research.

"This report puts much more information at our fingertips and allows us to take a much broader view," he said.

**"This is the only report that looks at data from every state and attempts to quantify the links between renewable energy development and policy implementation." – Joyce McLaren**

The NREL report also provides observations about the effects of state-based renewable energy policies.

McLaren said certain policies appear to be working particularly well in combination. For example, more renewable energy has been developed in states that require utilities both to disclose their fuel mix and offer customers the option to purchase electricity produced with renewable fuels.

States that have a renewable portfolio standard appear to be generating more clean wind energy the longer the RPS has been in effect.

States that implemented net-metering legislation in 2005 had significantly more renewable energy generation by 2007 than states without such a policy. The analysts looked back in time in order to identify development trends and make the link between past policy implementation and current development. However, McLaren cautioned that the reliability of the conclusions will be strengthened if future analyses identify the same trends.

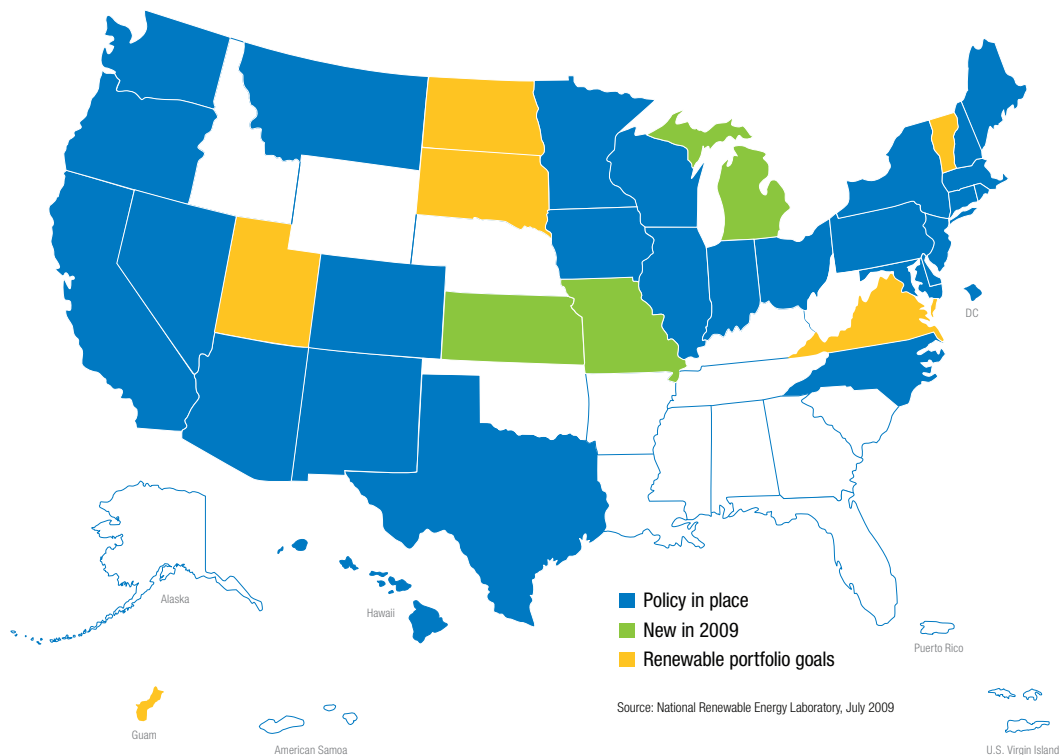
“It’s when we see the same thing every year for three or four years that we can be confident in the result,” she said. “As the renewable energy field continues to develop, connections between policy and the ensuing development will only become more evident.”

The report also contains an extensive list of resources with online links to renewable energy information, maps, research centers, industry associations and related information from NREL and other institutions.

### Key Findings

- Non-hydro renewable electricity generation as a percent of total electricity generation increased 33.7% between 2001 and 2007, reaching a national total of 105 million megawatt-hours.
- California led the nation in terms of total non-hydroelectric renewable generation in 2007; Maine is No. 1 when also considering state population and gross state product.
- Washington led in total renewable generation in 2007 if hydroelectric resources are included.
- South Dakota ranks first in overall growth in non-hydro renewable energy generation between 2001 and 2007.
- Geothermal electricity generation in the Lower 48 is concentrated in California, Nevada, and Utah.
- Solar capacity is concentrated in the southwestern and northeastern states.
- Leading wind energy states are Texas, California, Iowa, Minnesota, and Washington. However, sparsely populated Wyoming leads in per-capita wind generation.

— Joseph B. Verrengia (Nov. 20, 2009)



States that have a renewable energy portfolio standard appear to be generating more clean wind energy the longer the RPS has been in effect.

Credit: NREL

## GOVERNOR HONORS ALTERNATIVE ENERGY ADVOCATE



Chuck Kutscher leads concentrating solar power research using NREL's Large Payload Solar Tracker. Credit: Sam Potts/PIX 16861

When you have the opportunity to spend 30 years working in a field you love, some might be worried about losing their zeal, but NREL's Chuck Kutscher is a shining example of someone who continues to find new passions along the way.

His passion for identifying climate change solutions using renewable energy recently caught the attention of Colorado's Gov. Bill Ritter. He presented Kutscher with the 2nd Annual Governor's Excellence in Renewable Energy, Individual Award. "I was very surprised," Kutscher said. "I had no idea I had been nominated."

The governor's award honors outstanding contributions to protect Colorado's environment and provide clean power through renewable energy.

Kutscher has done all of this and more; from creating NREL's first solar cooling test lab to leading research on the basic theory of the solar wall, he

has researched concentrating solar power, solar heating and cooling and geothermal electricity. He is currently a principal engineer and group manager of the Thermal Systems Group in NREL's Center for Electricity, Resources and Systems Integration, where once again he is taking the lead on concentrating solar power research using NREL's Large Payload Solar Tracker.

### A Climate Change Advocate

It's what Kutscher has been doing outside of the office—educating people on the urgency of climate change and how it can be addressed—that's also earned the attention of the Governor as well as the University of Colorado at Boulder and the National Oceanic and Atmospheric Administration's (NOAA) Earth Systems Research Lab in Boulder, Colorado.

In fact, it was a colleague at NOAA's research lab who nominated Kutscher for the award. According to physical scientist and Intergovernmental Panel of Climate Change member Melinda Marquis of NOAA, "Chuck has tirelessly continued to educate experts and lay people about how renewable energy can support climate-change mitigation."

It was through his membership in the American Solar Energy Society (ASES) that Kutscher brought the issue of climate change to the forefront. "I developed a passion for the climate change issue while serving as ASES chair back in 2000 and 2001," said Kutscher. "The more I studied the science, the more I became convinced that it is a much more serious problem than most Americans realize." When he chaired the 2006 National Solar Energy Conference in Denver, he seized the opportunity to focus the event on how renewable energy can address climate change.

In preparation for that conference, he brought together a cross-section of energy experts—many of them NREL colleagues who volunteered their time. This resulted in the publication of a 200-page 2007 ASES report, "Tackling Climate Change in the U.S.—Potential Carbon Emissions Reductions from Energy Efficiency and Renewable Energy by 2030." The study shows that energy efficiency measures can halt the rise in U.S. carbon

emissions and renewable technologies can provide the large cuts that will be needed.

"Energy efficiency and renewable energy technologies have tremendous capacity to reduce the U.S. carbon footprint," Kutscher said. "Many of those technologies are ready now, including wind, concentrating solar power, photovoltaics, biomass power, and geothermal. While continued R&D will improve performance and lower costs, we can't afford to wait to deploy them."

The ASES report generated a great deal of interest and a number of invitations for Kutscher to speak on the potential for renewable energy at conferences around

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the country. The Governor's Energy Office is using a spreadsheet on how efficiency and renewable energy can be implemented in Colorado that he developed with a small volunteer task force. Kutscher delivered the keynote address at the first *Colorado's New Energy Economy Conference* in October 2007.

### Colorado and Kutscher Lead the Change

"In Colorado, we have all the ingredients we need to address climate change. We have the foremost renewable energy lab in the nation, collaboration between universities, and many of the nation's top climate change experts at NOAA and NCAR. We also have a very supportive state government, and we are the first state in the nation where the voters themselves initiated a renewable energy portfolio standard. Pull all of these people together and we can be national leaders in this effort," Kutscher said.

It is not just the renewable energy world that benefits from his passion for clean energy. Kutscher also is an adjunct professor at the University of Colorado at Boulder where he teaches a course titled "Climate Change Solutions." He also has supported Melinda Marquis's initiative at NOAA to look at the tie between climate science and the integration of renewable energy solutions. They have worked together on a monthly seminar series designed to enhance communication between scientists at NREL and NOAA, as well as with community members working to deploy renewable energy.

His travels around Colorado have given him a newfound appreciation for the breadth of activities taking place. "I'm always amazed to see all the things people are doing throughout the state at the grass roots level. They are really working hard to deploy all forms of renewable energy. They've been implementing Colorado's "New Energy Economy" since before we started using that term. Colorado is an exciting place to be right now."

"I will continue to work on applications for concentrating solar power and will continue to look for ways that energy efficiency and renewable energy can address the problem of climate change." – Chuck Kutscher

Energized by what the future holds, Kutscher has plenty of opportunities to be an advocate for tackling climate change. He has been invited to speak at the upcoming Aspen Environment Forum and the Santa Fe Institute's Global Sustainability Summer School as well as the State of World Forum in Washington, D.C. But, his work is foremost on his mind, "I will continue to work on applications for concentrating solar power and will continue to look for ways that energy efficiency and renewable energy can address the problem of climate change."

— Heather Lammers (Feb. 13, 2009)

## LAB PRESERVES NATURE, HISTORY



Native rabbit brush grows along a hill near NREL's Science & Technology Facility (S&TF). This LEED Platinum building was completed in 2006, and is an example of how NREL strives to blend its research and support facilities into the natural environment. Credit: Bill Timmerman/PIX 14963

**N**REL's South Table Mountain campus teems with wildlife. Its dry landscape is home to more than 200 plant species. The site includes cultural gems that speak to the region's past. And, NREL is growing. But growth for the future won't mean changing the nature of the place or ignoring its history. NREL staff is keeping a watchful eye to ensure that construction has minimal impact on the environment.

The U.S. Department of Energy (DOE) and NREL are constructing new 218,000 square foot Research Support Facilities (RSF) slated to open in the summer of 2010. Other new buildings are planned as NREL scientists and engineers work to develop and refine renewable energy and energy efficiency technologies. Staff always have kept a vigilant eye on the natural resources on and around NREL's campus, and now with the growth—even more so. NREL is putting into action its Environmental Management System along with the National Environmental Policy Act (NEPA) program to ensure that construction proceeds with the lowest possible impact on the environment.

"Protecting the environment is at the heart of NREL's mission and all of our employees' daily activities," Environmental Specialist Denise Rayborn said. "We diligently work to protect areas near facilities to help preserve Colorado's natural beauty and native ecosystems."

### Preservation for Generations

NREL's main campus sits on a small portion of land owned by DOE near Golden, Colorado. Because the site is largely undeveloped, NREL and DOE have seized the opportunity to safeguard numerous species of plants and animals, and even a few pieces of history.

"Our policy continues to be to protect the natural ecosystems in the undeveloped areas of our campus," Senior Environmental Scientist Maureen Jordan noted. "Employees here have a passion for environmental stewardship and sustainability—incorporating those concepts at NREL in everything we do."

In 1999, DOE ensured the preservation of its piece of South Table Mountain along with its inhabitants by placing 177 acres under a conservation easement. This means that the land will not be developed and that habitat and visual panoramas on the mesa top will be kept as natural open space. The easement also allows public access, with hiking trails managed by the Jefferson County Open Space program. The RSF and other future buildings will be integrated into the current campus at the base of South Table Mountain and will not encroach on the conservation easement.

"Since I started my hikes in the mid '90s, Jefferson County Open Space has made significant improvements to the mesa trails, adding greatly to the quality of the trail system," NREL Senior Engineer and photography enthusiast Steve Wilcox said. "It's rewarding to see more and more people enjoying the mesa."

### Plants and Animals

The wide-open space outside NREL's "back door" provides a visual feast for employees on their breaks and is home to a wide variety of animals and plants.

"It's a dry, dusty environment, in sharp contrast with the lush foothills just a couple miles to the west. But I love the desert-like landscape and never tire of my daily hikes across the mesa surrounded by brush, grasses, cactus, and wildlife," Wilcox said. "I always take my camera with me. It's always a challenge to find something new and interesting to photograph after so many years, but nature provides an infinite variation of light, colors, contrasts, and subjects."

One of those subjects might be a herd of mule deer, frequently seen grazing outside of NREL's research buildings. Employees also have the pleasure of seeing coyotes, foxes, raccoons, and rabbits. Mountain lions occasionally roam the open spaces and hikers are always on the look-out for native reptiles including rattlesnakes.

South Table Mountain also provides a temporary home to a variety of migratory birds throughout the year. Wildlife surveys since 1987 have identified more than 50 species including raptors such as American Kestrels and nesting pairs of red-tailed hawks. Preserving open space along South Table Mountain for migratory birds is important because many of the birds stopping by are just taking a breather during a trip than can cover thousands of miles each year.

The plants on the STM site provide habitat for winged visitors and homes for numerous smaller mammals like deer mice and prairie voles. The plant life is consistent with what you would expect to see in grassland areas. But don't think it's "only" grass—there are nearly 200 species of plants ranging from cactus to wild roses to a wide variety of wildflowers (and of course, grasses).

### Echoes from Another Tough Economic Time

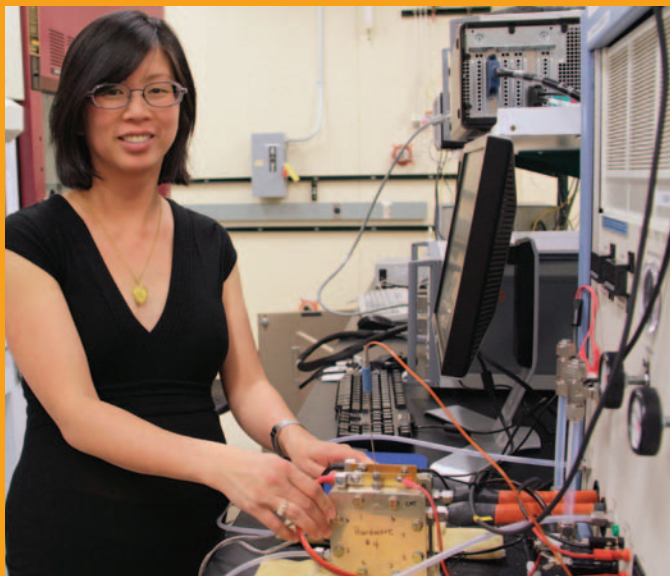
In the 1930s, when the economy was at an all-time low and the country was mired in the Great Depression, President Franklin Roosevelt launched the largest jobs initiative in U.S. history—the Works Progress Administration (WPA). The NREL campus is home to three relics of the WPA, including an amphitheatre nestled in the hillside. While no longer open to the public, the amphitheatre was once a meeting place for nearby residents.

"At one time people gathered at the amphitheatre on South Table Mountain to socialize and watch movies," Rayborn said. "Although our gatherings on the STM site are now business rather than social, it's really neat to see a piece of history and know the evolution of our site."

NREL is serious about caring for these significant cultural resources and submitted paperwork to add these sites to the National Register of Historic Places in the 1990s. The lab also is interested in protecting artifacts that could be discovered in the future.

— Heather Lammers (March 20, 2009)

## NREL SCIENTIST FINDS TIME TO DO IT ALL



In addition to bringing in new research funding, Dinh also leads and coordinates a team of researchers writing Standard Photoelectrochemistry (PEC) Characterization Protocols for evaluating materials that can extract hydrogen from water splitting. Credit: Heather Lammers/PIX 16870

Imagine that you walk in to your office on a “normal” work day and these are just a few of the items on your to-do list (side note: you are doing all of this while preparing for the arrival of a new baby boy).

- Spearhead a project across five different time zones to come up with industry testing standards for photoelectrochemistry (PEC) research
- Serve as a project lead for polymer electrolyte membrane fuel cell catalyst research
- Work as a co-project lead for fuel cell manufacturing research and development
- Write and send proposals to the U.S. Department of Energy to bring millions of dollars to NREL to expand its fuel cell research program
- Mentor college students working on fuel cell projects.

That’s a day in the life of Huyen Dinh, Ph.D., and a senior scientist in NREL’s Hydrogen Technologies & Systems Center.

As insiders at NREL know, the staff at the lab is changing. The saying goes, you’ve been here 20 years or two. Dinh is one of the fresh faces at NREL. She joined the staff in 2007 after working in private industry on fuel cell research and development. But, she found corporate life less than stable and began

thinking about a move to Colorado when she heard about NREL. “I thought, wow! This is the place I want to work,” Dinh said. So, she contacted NREL Research Fellow John Turner who was also looking to expand the hydrogen fuel cell program at NREL.

### Growing Fuel Cells

“I convinced management that Huyen would be a strategic hire and that she would be beneficial to my PEC research,” Turner said. “But more important, her background would enable her to bring in funding and help grow a program in fuel cells here at NREL—and that’s exactly what has occurred.”

To say that Dinh quickly began making an impact at NREL is an understatement. In the summer of 2008, Dinh and her colleagues submitted seven proposals to the U.S. Department of Energy (DOE) for fuel cell related funding.

On May 11, 2009, DOE announced that NREL has been awarded three fuel cell projects. Dinh is the principal investigator for two of the three. The \$2.4 million direct methanol fuel cell project will focus on improving catalysts performance and lower the cost of fuel cells, which will help accelerate micro fuel cell commercialization. In addition to the catalysts research, Dinh and NREL’s Bryan Pivovar also won another DOE project, which will focus on the effects that system contaminants have on fuel cell performance and durability. The DOE award for this project is \$6 million.

“We had really high expectations and hoped to win two or three new projects. We’re very excited because this means millions of dollars to fund fuel cell research at NREL,” Dinh said.

### Making Sense Out of Photoelectrochemistry

Dinh also is showcasing her talents as a project leader. One of the things she realized when she first started working on photoelectrochemistry water splitting at NREL was that standardized PEC protocols for hydrogen production did not currently exist for researchers. “Standardized testing protocols and efficiency reporting are necessary to screen materials and guide research towards the most promising PEC materials,” said Dinh. “I saw a need, so being new and naïve, I volunteered.”

PEC is the direct conversion of the sun’s energy into electrical energy, which is used to split water into hydrogen and oxygen. A PEC system combines the harvesting of solar energy and the electrolysis of water into a single device. For the process to work, the semiconductor must meet several key criteria simultaneously. “PEC water-splitting is a promising approach to solar-to-hydrogen production,” Dinh said. “But standardized testing and screening is essential to have successful research and development.”

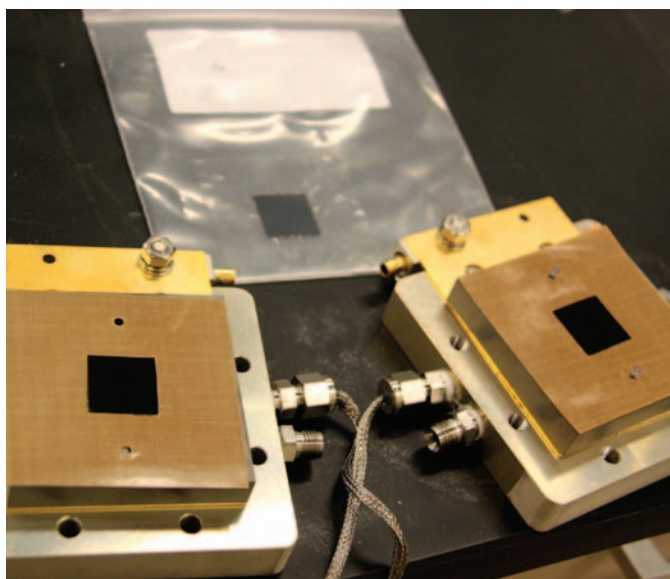
Dinh’s working group is taking collaborative leadership to a whole new level. In May 2008, she began working with colleagues from five different time zones scattered across the globe including: Stanford University, the Hawaii Natural Energy Institute, University of California Santa Barbara, University of Louisville, University of Tokyo, the Department of Energy and the Australian Nuclear Science & Technology

Organization. Since July 2008, the team has met weekly via Webcast and teleconference. Each member of the group agreed to write a series of documents for a final paper to be submitted to a peer reviewed journal for publication.

So far, the group has produced 18 different documents and has identified the top 10 experiments for characterizing and screening PEC materials relatively quickly to make informed decisions about a PEC material. They also have drafted the first PEC characterization flow chart to show the recommended sequence of experiments and decisions points.

With a deadline looming for submitting their final paper, Dinh said the group is taking it all in stride, “The team works very well together and everyone is eager and very committed to the project. We know we have an international audience waiting and wanting to know when it will be ready.”

Dinh already is being recognized for her efforts in the PEC standardization. She has received letters of appreciation from DOE and she has earned a President’s Award from the Alliance for Sustainable Energy, LLC.



The inside of a polymer electrolyte membrane fuel cell in NREL’s fuel cell lab; Dinh, a co-project lead for an NREL team working to improve the cost, performance and durability of these types of fuel cells. A fuel cell is electrochemical and continuously converts the chemical energy of an externally supplied fuel (like hydrogen or methanol) and oxygen from the air directly to electrical energy. Producing energy this way is two to three times more efficient than an internal combustion engine. PEC provides a renewable source of hydrogen for applications like fuel cells.

Credit: Heather Lammers/PIX 16871

## Past Challenges Keep Her Motivated

While the PEC project alone would keep many of us working late nights, for Dinh, it’s just one of a variety of projects she’s excited about. The obvious question is, how does she stay so inspired? “I’ve been very motivated to do well in school and in life because my mom had to work so hard to support us,”

Dinh said. Her mom, in fact, had to battle extraordinary circumstances to see that her children had the opportunities that many of us take for granted.

Dinh was born in Vietnam and her family fled the country in 1979 among the millions of Vietnamese boat people seeking refuge from the communist government. Dinh’s journey took her, along with her mother and sisters, onto a small boat crowded with several hundred people. Crossing the open ocean, their boat at one point was chased by pirates. Sick and

exhausted, they eventually made their way to Malaysia where authorities tried to keep them from landing, but their mother pulled Dinh and her siblings from the boat and made it to shore. They lived on the beach for a number of weeks before moving to a refugee camp. It was months later before they were able to secure passage to Canada and reunite with their father.

The events from her past motivated her to excel at school, work, and beyond. Dinh attended college and did her graduate work at the University of Calgary in Canada. She finished her post doctoral work at Los Alamos National Laboratory in 2000. But it’s Colorado where she now sees her future. “I love the people, it’s an active place, it’s a good place to raise a family—this is where I want to settle.”

NREL also has on the drawing board a new research building, the Energy Systems Integration Facility (ESIF). When completed, the ESIF will house a variety of research programs and plans call for three new fuel cell labs to be included. Part of the reason Dinh works so hard and is passionate about her chosen field is the future she believes it brings, “Hydrogen fuel cell technology is not only good for the environment, but it will help our country progress as well.”

And, Dinh hopes that all of these programs will bring an opportunity for her to work with students pursuing their graduate education or doing their post doctoral research, like she did at Los Alamos National Laboratory. “I love working with students, one of the reasons I came to NREL is because it’s a nice cross between academia and industry.”

“I think about our children, and their future, and that’s very motivating for me. At NREL, it’s great to be able to work with people who have the same motivation and want to do their part toward a great mission.”

— Heather Lammers (May 15, 2009)

“I think about our children, and their future, and that’s very motivating for me. At NREL, it’s great to be able to work with people who have the same motivation and want to do their part toward a great mission.” — Huyen Dinh



## ECO-FRIENDLY SUV GETS A HYDROGEN MILEAGE BOOST



The 11-hour trek to independently verify the Highlander's fuel economy began at 8 a.m. during the peak of southern California's morning rush hour. To mimic a typical commuter's drive, the route included high-speed highway driving, moderate highway driving, and stop-and-go traffic. Credit: Keith Wipke/PIX 16856

When researchers from the U.S. Department of Energy's (DOE) National Renewable Energy Laboratory (NREL) and Savannah River National Laboratory (SRNL) participated in a test drive for a hydrogen fuel cell SUV that reached the equivalent of a 431-mile driving range, it wasn't just California dream. The research team, along with Toyota, recently completed a 331-mile round trip drive between Torrance and San Diego, California, driving two Toyota Highlander Fuel Cell Hybrid Vehicles – Advanced (FCHV-adv). And, with the fuel remaining in the tanks, those SUVs easily could have crossed the 400 mile mark.

Toyota Motor Engineering & Manufacturing North America, Inc., along with NREL/SRNL entered into a cooperative research and development agreement (CRADA) with the sole objective to determine the real-world driving range of the FCHV-adv.

"The main thing was the driving range of the vehicles," said Keith Wipke, NREL senior engineer and group manager for Hydrogen Analysis. "We were basically showing that using today's technologies, you can achieve above 400 miles, or more, of real-world driving using a hydrogen fuel cell vehicle. It was exciting and surprising to see such high fuel economy for an SUV."

Although hybrids like the Toyota Prius currently get lots of press for helping Americans use less oil, hydrogen also holds great promise. NREL and SRNL researchers verified that the two FCHV-adv used during the driving test achieved an estimated range of 431 miles on a single fill-up of compressed

hydrogen gas. The average fuel economy came out to the equivalent of 68.3 miles/kilogram of hydrogen (equivalent to mpg for gasoline-powered cars). And, the only "exhaust" from these eco-friendly vehicles is H<sub>2</sub>O (water).

### A California Rush and then Coast

The day before the big ride, researchers visited Toyota's headquarters to watch the Highlanders being fueled up. The next morning saw the start of an 11-hour trek to verify the Highlander's driving range and efficiency. The evaluation began at 8 a.m., during the peak of California's morning rush hour.

Crews started the trip at Toyota's headquarters in Torrance, which is just south of Los Angeles. Each vehicle had one driver from the vehicle manufacturer, a scientist from NREL or SRNL, and equipment to log data along the way. Drivers headed north then west to Santa Monica, and down along the coast to Redondo Beach for the first rest stop. The next leg went from Redondo Beach to Dana Point, and the final leg went from Dana Point south all the way to San Diego. They took the same route back after lunch.

"Because of the California traffic, which was heavy for much of the time in the morning and evening, the trip took longer than originally planned," Wipke said. "But the situation definitely matched the real world evaluation we were after, with a mixture of driving conditions."

To mimic a typical commuter's drive, the route included highway driving and stop-and-go traffic. The maximum speed during the test route reached approximately 75 mph with an average speed for day that was approximately 30 mph. The actual range for the vehicles was calculated by using the 331.5 miles covered during 11 hours driving, plus 99.5 miles of additional range calculated from the average fuel economy from the day multiplied by the remaining usable hydrogen. Driving range results were independently calculated for each vehicle, and these results averaged together to achieve the final 431-mile range estimate.

Although the idea of using hydrogen as fuel for your SUV or car may conjure up worries of the Hindenburg, today's hydrogen fuel cell vehicles are safe. The tanks used to store the hydrogen are well constructed and the fueling stations are easy to use and similar in design to modern gas stations.

In fact, one characteristic of hydrogen actually makes it safer to use than gasoline. "Hydrogen can be safer than gasoline because it is significantly lighter than air," Wipke said. "In the rare event that you do have a leak in your tank, the hydrogen will disperse quickly and not pool on the ground around a vehicle as gasoline does."

### Data Collection Showed Early Promise

To verify how far these hydrogen fuel cell vehicles could go, data collection systems installed in the SUVs tracked vehicle speed, distance, hydrogen used, hydrogen tank pressure, temperature, and internal tank volume.

NREL and SRNL analyzed all data gathered during the evaluation and prepared a formal report for DOE verifying range

results and estimated miles per gallon. Wipke and the crew were able to see exciting initial results during the evaluation. “We were able to see the data displays in the vehicles as we drove. It was really neat to see the data play out in live action, and it gave us a strong indication that the range would be high right from the start,” Wipke said.

The teaming of Toyota and NREL for this type of evaluation is a natural match. “The analysis will help regulators and government research programs accurately assess the status of the fuel cell industry and viability of the current technology,” Toyota Technical Center Advanced Power Train Engineer Jared Farnsworth said.

NREL has six years experience working with automotive companies and their fuel providers to evaluate the on-road performance of hydrogen fuel cell vehicles as well as the needed refueling infrastructure through DOE’s Learning Demonstration. The Learning Demonstration encompasses 140 fuel cell vehicles and more than 20 refueling stations and has accumulated more than 2 million miles traveled.



NREL’s work evaluating fuel cell vehicles got a boost recently with an on-site hydrogen fueling station. Colorado blue skies and light winds (two key components in making fuel for the station) made an appearance at a recent ribbon cutting event along with NREL’s Deputy Lab Director for Science & Technology Robert McGrath, Technology Validation Task Leader Keith Wipke, Associate Lab Director, Renewable Fuels & Vehicle Systems Dale Gardner, and PI for Wind-to-Hydrogen Station Kevin Harrison.

Credit: Keith Wipke/PIX 16899

## NREL Makes its Own Fuel

Although NREL researchers didn’t get to bring the FCHV-adv back to the lab for further testing, they did come home to the commissioning of a new Hydrogen Fueling Station that can fill hydrogen fuel cell vehicles being tested at NREL.

“We were basically showing that using today’s technologies, you can achieve above 400 miles, or more, of real-world driving using a hydrogen fuel cell vehicle. It was exciting and surprising to see such high fuel economy for an SUV.” – Keith Wipke

The new station is part of NREL and Xcel Energy’s Wind-to-Hydrogen (Wind2H2) project. Wind2H2 uses wind and solar energy to generate electricity. That electricity is then used to split water into hydrogen and oxygen. The hydrogen is compressed, stored in large steel tanks and later converted back to electricity or dispensed into fuel cell cars or used to generate electricity using a 50 kilowatt internal combustion generator. A 5 kW fuel cell will be installed later in 2010 that will be

integrated with wind and solar sources for testing of hybrid power systems.

“Since our project uses wind and solar electricity directly from the sources—without sending it out to the utility grid first—our hydrogen is some of the ‘greenest’ in the world,” NREL Senior Engineer Kevin Harrison said.

Because the station is part of a larger Wind2H2 research project, the hydrogen created isn’t used solely to fuel hydrogen cell vehicles. However, NREL is interested in partnering with companies and agencies that may be placing hydrogen vehicles in their fleet in the future and need a place northwest of Denver to fill-up. With a large concrete pad and lots of wind and sun at the site, the station can even accommodate hydrogen buses up to 40 feet in length. To accommodate bus fueling, new high-pressure tanks will be installed at the Wind2H2 site during the spring of 2010.

— Heather Lammers (Nov. 13, 2009)

## NREL TESTS ENERGY-SAVING OFFICE OF THE FUTURE



Collaboration between NREL employees like Rick Horner and John Williams has been enhanced by the new workstations. Storage bins with rollers and padded tops become guest chairs for quick meetings and team conversations. Credit: Heather Lammers/PIX 16864

**M**aking sure that the new Research Support Facilities (RSF) will achieve Platinum level certification from the U.S. Green Buildings Council Leadership in Energy and Environmental Design (LEED®) takes not only planning, but practice.

NREL planners have set their sights on achieving a LEED Platinum rating for the RSF, which means the building will:

- Meet the needs of the workforce—both current and future
- Maximize the efficiency of the employee workspaces
- Make the best use of the space while using the lowest attainable amount of energy per square foot.

Reaching these goals will not be easy in a building as large as the RSF, which is planned to be a 218,000 square-foot facility supporting nearly 740 staff, along with an energy efficient information technology data center. As a result, tearing down walls is an important concept in the RSF, both literally and figuratively.

The most dramatic change from a traditional office to NREL's office of the future can be seen in employee work areas. Frontline staff and supervisors will work in open air cubicles. Workstation panels are only 42 inches high and bookshelves between workstations top out at 54 inches. Management level cubicles do have privacy walls that are 6-feet tall with doors; however, most of the ceilings at the RSF will be 13-feet high.

### Taking the Space for a Test Drive

Staff from NREL's Information Services (IS) office volunteered to prototype the new office designs, furniture, and technology, and moved in November 2008.

"People see these work stations and, initially, are concerned about the noise factor," said Client Services Group Manager Henri Hubenka. "But, what we've found is that the new workspaces are very conducive to collaboration between teammates."

The low cubicle walls are vital energy savers allowing for circulation of both air and light. Background office chatter is mitigated through white noise, which is incorporated into the building to help mute conversations. Employees who need privacy can use "huddle rooms," small conference rooms set aside for teams who want to have conversations in a quiet space. Other design and technology features the RSF will incorporate include:

- Daylighting along with overhead lights that automatically turn on or off
- Globally regulated temperatures throughout the building
- A reduction in stand-alone machines such as printers, faxes, copiers, and refrigerators; in the prototyped office being tested by IS, 68 staffers on one floor reduced their use of standalones from 50 machines to 10.

### Computers Go Back to the Future

NREL is also looking to phase out standalone CPUs at each workstation and utilize either laptops or "thin client" machines, which are basically a monitor, keyboard, and mouse. All software programs needed by thin client users are housed on a central mainframe—like the terminal days of the '80s. The energy savings of a laptop over a standard PC is 85% and using thin client machines brings the energy savings up to 92% per workstation.

While it's cool to move into a new office with sleek furnishings and the latest technology, one thing that will make or break the transition to an office of the future is communication.

"Start early," advises Hubenka. "Let employees know how things will work and what the differences are between a regular office and a super-efficient office."

Upon hearing about the drastic workstation changes, Hubenka estimates that up to 80% of the IS staff had some trepidation. But constant communication, a Web site dedicated to the new office, and constant requests for feedback have lowered that estimate to less than 10%.

IS Group Manager Mary Donahue agrees with Hubenka, "I like it, it's a great space and it is very comfortable to work in."

The RSF is slated to open the summer of 2010. When some of NREL's workforce moves into the new building, the employees at the prototyped "office of the future" will be able to acquaint their colleagues with the energy efficient workspaces and technologies that will be in place.

"All of these updates to how we work are going to get NREL where we need to be now and in the future," said Hubenka.

— Heather Lammers (March 13, 2009)

## RECOVERY ACT MONEY INVESTED AT NREL



NREL senior scientist Howard Brantz explains his thin-film silicon PV research to U.S. Department of Energy Secretary Steven Chu (center) and Colorado Gov. Bill Ritter (left). Chu and Ritter visited NREL's Process Development Integration Laboratory during an April 29th visit. Credit: Jim Yost/PIX 16284

U.S. Department of Energy Secretary Steven Chu made his first visit to NREL as secretary an especially memorable one—announcing \$110 million in funding under the American Recovery and Reinvestment Act.

More than \$100 million will accelerate construction of the laboratory's Golden, Colorado, campus, dramatically expanding NREL's capacity for renewable energy research and partnerships while showcasing some of the world's most energy efficient buildings.

An additional \$10 million has been designated for improvements at the laboratory's National Wind Technology Center near Boulder.

"These investments are an unmistakable signal from DOE about the laboratory's central role in advancing President Obama's clean energy agenda," NREL Director Dan Arvizu said. "It is a significant investment in NREL's future."

### Secretary Outlines Energy Efforts

Secretary Chu announced the new funding in an hour-long presentation to laboratory staff and elected officials. He outlined the administration's efforts in its first 100 days to streamline DOE procedures and loan approval for \$26 billion authorized for clean energy projects nationwide since mid-February to create green jobs and promote economic recovery.

And, he reiterated the administration's goal of doubling the percentage that renewable energy contributes to the nation's electricity supply by 2012—from 5–10%.

"The goal is to set America on a course for a secure and sustainable energy future," Chu said.

At the same time, Secretary Chu said, a new generation of renewable energy technologies must be developed to stem potentially devastating climate changes driven largely by carbon emissions generated by fossil energy consumption.

### New, Transformative Technologies Are Key

Chu outlined the hurdles in several categories where the laboratory already performs critical research, including efficient building design, solar energy and improved energy storage for both personal vehicles and utility-scale power systems.

"It's a start," Chu said of the new investments. "By 2050 we need to reduce carbon emissions by 80% or more. To reach that goal we will need transformative new technologies."

The announcement was part of a half-day tour of NREL by the Secretary and Colorado Gov. Bill Ritter. With Director Arvizu, they spent 45 minutes touring the Process Development Integration Laboratory, NREL's unique collaborative facility where industry works directly with researchers to rapidly turn solar photovoltaic innovations into commercial products.

Over lunch, the Secretary was privately briefed by NREL executives and senior researchers on some of the laboratory's basic research into solar physics and advanced programs for future electricity and fuel technologies.

### Details of Recovery Act Funding

The Recovery Act funding to the laboratory includes:

- \$68 million to complete the Research Support Facilities (RSF) that are currently under construction, including a second phase known as RSF II. With completion scheduled in 2010, the 218,000 square foot complex will be the nation's most energy-efficient office building and a showcase of integrated, high-performance design, achieving LEED platinum certification, and reducing energy use by 50% over standard commercial office buildings.
- \$19.2 million for renewable energy systems and energy efficiency improvements to the campus, including additional onsite solar arrays and the potential addition of geothermal and fuel cell power sources. This investment allows the laboratory to replace conventional power purchased from utilities, reduce the purchase of renewable energy credits, and lower the laboratory's carbon footprint.
- \$13.5 million to expand and improve the Integrated Biorefinery Research Facility. The new funding will expand NREL's biomass-to-ethanol research capabilities at the current Alternative Fuels User Facility by allowing the laboratory to work simultaneously on multiple projects with multiple partners. The IBRF will accelerate methods to produce cellulosic ethanol on a commercial scale that is cost-competitive with petroleum-based fuels and reduce U.S. gasoline use.
- \$10 million for improvements at the National Wind Technology Center (NWTC), including doubling the capacity of the existing dynamometer to 5 MW to test the performance and reliability of the latest generation of large wind turbine drive trains. By producing variable speeds and torque levels, the dynamometer simulates extreme winds and other performance conditions and compresses 30 years of turbine use into a few months of endurance testing. The funding also pays for improvements to the NWTC's electrical distribution systems so that electricity generated by new utility-scale wind turbines tested at the center can be captured to power the center itself and even exported to local utilities.

—Joseph B. Verrengia (May 1, 2009)

## LABYRINTH TO STORE ENERGY IN BASEMENT FOR LATER USE



NREL Construction Manager Carl Cox, and Shawn Bradfield with NREL Construction Safety, discuss an upcoming cement pour that will lay the floor of the labyrinth. The staggered walls behind them force air flowing through the basement of the RSF to cool and heat the concrete. Credit: Heather Lammers/PIX 16874

There's a labyrinth in the basement of NREL's newest building. The maze wasn't designed to hem in a mythical beast or to confuse workers, but it is a trap—one that will capture the heat of the day or the cool of the night, hold onto it, and then slowly release the thermal energy to help warm or cool the building.

The Research Support Facilities now under construction on the U.S. Department of Energy's NREL campus will include two long wings, connected at the middle by a lobby and conference area. Each wing will rest on a low basement with concrete walls staggered to make the air take S-turns through the space, lingering awhile, losing its cool or—depending on the season—its heat.

"As the air goes through the maze, there's greater contact with the mass, thousands of tons of concrete," said NREL's Eric Telesmanich, project manager for the Research Support Facilities.

That way, the labyrinth acts as a thermal battery, storing the chill of the night air to reduce the building's cooling load in summer. In winter, the labyrinth will store heat drawn from the computers in the new data center and outside air warmed by the sun beating down on a transpired air collector.

### Waste Heat Won't Go Wasted

As the waste heat from the computer center and the air warmed by the sun wends through the staggered concrete walls of the labyrinth, pulled by fans, the slabs absorb the warmth. The next day, the stored heat can knock off some of the morning's chill, when fresh air is pulled through the labyrinth before being heated and pumped into offices. The heat the computers shed also will be used to heat the building.

The transpired air collector—a metal sheet with tiny strategically placed holes to pull air through—takes advantage of what comes naturally on a cold Colorado day.

"The air might be pretty nippy," said Phil Macey, a senior associate at RNL, the design firm for the RSF. "But when you stand in the sun, there's lots of warmth."

NREL's Telesmanich said that the building's original design called for two walls—or a double skin—on the south side to preheat air. But that raised a lot of technical, cost and maintenance challenges. RNL went looking for a different solution, and came up with the transpired air collector, a concept NREL won an award for in 1994.

"So, a technology developed at NREL turned out to be the perfect solution for NREL's new building," Telesmanich said.

Pulling outside air through the labyrinth can warm it 5 to 10 degrees before it is further heated to warm the building. "That may not sound like much," Macey said, "but it is meaningful across the whole year."

### Old Idea Brought Up To Date

The air flowing into the labyrinths starts two stories up and travels down ventilation shafts built into the RSF's stairwells. The labyrinth in the north wing of the office building will be for heating; the south wing labyrinth will help with both heating and cooling.

Storing heat or cool in a large dense mass isn't a new idea. Think of how refreshingly cool you feel walking into an adobe church or a gothic cathedral. Large masses absorb the heat of the day, slowly releasing it at night to keep the space warm. The reverse happens when the thermal mass has cooled and the outside temperatures begin to warm.

How can this effect be used to help save the energy it takes to heat or cool an office building? In the 1970s, drawing air across a bed of stones was considered. But, Macey said, because of the irregularity of stone sizes and shapes and the difficulty of controlling air flow through the rocks, the idea turned out to be impractical.

### Poetry From a Challenge

His firm and engineering consultant Stantec revisited the idea because of Colorado's clay soils and climate. Here, builders need to remove the clay soil before building a foundation to prevent expansion and shifting. Often, a basement is the solution. But in buildings where a basement is not called for, typically the clay soil is taken away and replaced by better soil that then is compacted. This can be expensive.

And, the RSF doesn't need a basement. On the contrary, the building's design called for letting in as much light as practical.

The solution was to make a shallow basement that, for a small investment, could be used as a thermal mass to help reduce the energy used for heating and cooling the building.

It was an idea that "made poetry out of a challenge," Macey said.

Figuring out what to build was another challenge. Macey said that Stantec spent a few weeks writing a unique computer program to optimize the size and shape of the labyrinths and to calculate air flow. But that work can be used by others working on similar projects in the future, since the experience of the RSF will be shared to help design and construct other highly efficient buildings.



This computer rendering shows the Research Support Facilities main entrance facing west, along with the three-story south wing (left) and the four-story north wing (right). Courtesy of RNL/PIX 16250

## Energy Requirements Drive Design

The RSF will use about one half to one-third the amount of energy as other office buildings, and could be one of the most energy-efficient office buildings in the world, Telesmanich said.

“The energy requirements drove the design of the building,” he said. “That’s a very different way of doing things.”

Macey agrees. “We’ve learned how powerful climate is. Mother Nature gets a powerful vote. So, we let the energy of the environment drive the design and think of ways to finesse nature rather than challenge it.”

Haselden Construction is building the 218,000 square-foot Research Support Facilities building, which is designed to be a model for sustainable, high-performance building design, and will provide DOE-owned work space for administrative staff who currently occupy leased space in the nearby Denver West Office Park. The RSF is planned achieve a LEED® (Leadership in Environmental and Energy Design) Platinum designation—the highest benchmark awarded by the U.S. Green Building Council. Construction on the RSF is expected to be completed in summer 2010.

— George Douglas (May 29, 2009)

## RECYCLED NATURAL GAS PIPES SHORE UP GREEN BUILDING



The rounded natural gas pipe will be visible in some areas of the RSF serving as a unique architectural feature. Credit: Pat Corkory/PIX 16440

Building a support structure of something, tried, true, and tested like “off-the-shelf” steel is standard practice in building construction. NREL’s effort to create the most energy efficient and “green” office building is putting a twist on an old standard. The columns that will carry the weight of floors and walls in the new Research Support Facilities (RSF) are actually castoffs from the natural gas industry—recycled pipe.

“It’s a perfect circle,” said Philip Macey, project manager for RNL, the design firm for the RSF. “There’s such elegance in this building in the fact that ‘old’ energy is providing the support for NREL’s new building where new energies will be developed.”

The RSF is under construction at NREL’s South Table Mountain Campus near Golden, Colorado. It was designed to achieve LEED Platinum status from the U.S. Green Building Council and its energy saving features will be shared with, and hopefully replicated by, commercial builders across the country.

“Early in the design process, the team chose to use reclaimed natural gas pipe in an effort to utilize a reclaimed product in the building for the purpose of LEED as well as demonstrating the use of a reclaimed product that is available to anyone,” said Derek Oliver, Haselden Construction’s pre-construction manager.

The steel natural gas pipe used in the RSF was purchased from a company that specializes in salvaging gas piping that has been removed from service. Typically, pipes sold by these salvage retailers come from fields in Texas or Louisiana, in this case, the RSF gas pipe was never used and was sold by the owners to the reclamation yard.

“There are steel stockpiles like this around the country, but you have to go hunting to get the right sizes and quantities,” Macey said.

### Unique Feature Required a Plan B

Using recycled steel, while a boon for the environment, it can leave builders at the mercy of what’s available when shopping for recycled steel versus what is actually available when you are ready to buy and build.

In case the natural gas pipe wasn’t available for the RSF, the architects also drew up the building with traditional steel. For a while, it looked like Plan B would have to be implemented. However, a week before it was needed, Haselden found enough recycled gas pipe to complete the building as designed, which greatly pleased the contractors.

“We feel we need to task ourselves with seeking recycled materials first,” Macey said. “As a culture, we need to not make ‘new’ the first choice because there is an urgent need to reduce energy consumption and our carbon footprint.”

### Steel Stays Strong, Doesn’t Go Bad

Recycled steel is a win-win for builders because of its green factor and because it can be purchased at a very competitive price. “Recycled steel doesn’t go bad,” said Macey. “You simply can clear the rust off and it’s a big resource worldwide.”

Once the team found the reclaimed pipe they envisioned for the project, they went extra lengths to make sure it would provide the support needed for an office building such as the RSF.

“Structural tests were performed on samples of the desired pipe to ensure that the material would meet the structural requirements of the building,” Oliver said.

While the recycled natural gas pipes used in the RSF passed the required strength and welding tests, the design team went the extra step to reinforce the pipe at the lower levels.

“We are filling the bottom two to three floors with concrete to help carry the building loads,” said NREL Senior Construction Manager Carl Cox. However, the steel tubes which average 33 feet in height are still hollow in the upper floors of the building and serve as a unique architectural feature in the office space.

“The end result of using reclaimed gas pipe for the RSF is a high quality, architecturally appealing product that helped reach the LEED Platinum requirement for the project,” Oliver added.

### Natural Beauty Shines Through

The natural gas pipes will be seen from the interior as columns in various areas of the RSF. To preserve this rare architectural feature, the pipes will be coated with a clear, environmentally safe finish typically used inside of ships to coat ballast tanks. The coating can be used in interior spaces (like an office) and meets EPA requirements for an environmentally sensitive product.

“We wanted to display the material in an honest way,” Macey noted. “And, getting round columns in a building is a bit of a dream. Out of 100 buildings, only one other would have honest round steel columns.”

Honesty in materials is a theme throughout construction; other interior elements such as Colorado beetle kill wood paneling and pre-cast, insulated wall panels using recycled materials will continue the theme of reuse in the RSF.

“There are a lot of recycled and regionally available materials for use in buildings,” Macey said. “Once people understand this, they will be surprised at how easy it is to make these choices.”

Haselden Construction and RNL are building the 218,000 square-foot RSF, which is designed to be a model for sustainable, high-performance building design, and will provide Department of Energy-owned work space for administrative staff who currently occupy leased space in the nearby Denver West Office Park. The RSF is planned to achieve a LEED® (Leadership in Environmental and Energy Design) Platinum designation—the highest benchmark awarded by the U.S. Green Building Council. Construction on the RSF is expected to be completed in summer 2010.

— Heather Lammers (July 17, 2009)

## BUILDING PANELS PROTECT, PROVIDE COMFORT



NREL Senior Construction Manager Carl Cox examines panels installed on the RSF, which benefit the building on many levels. The exterior keeps the weather out and helps regulate interior temperatures. The middle section provides insulation and the opposite side serves as the interior wall. Credit: Pat Corkery/PIX 16763

Walking into a building constructed before the days of heating systems and air conditioning, such as a southwestern adobe, still elicits a sense of comfort and coziness. The concept of using thermal mass in walls to help maintain the temperature of a building is not new. And now, this tried and true method is being used to regulate comfort systems of NREL's Research Support Facilities (RSF), one of the most energy efficient buildings in the world.

"In this case, the exterior skin of the building is doing more than just keeping the weather out," Philip Macey, project manager for RNL, the design firm for the RSF, said. "Precast panels installed as the walls are actually part of the heating and cooling system for the building.

"All of these ideas are based on principles that have been really tried and tested," Macey said. "They just haven't been used in an office building in modern times—till now."

The RSF is under construction at NREL's South Table Mountain Campus near Golden, Colorado, and is designed with a myriad of energy saving features, such as the precast exterior panels, which play a lead role in maintaining the temperature of the building's interior spaces. These energy efficient practices will be shared with, and, it's hoped, replicated by commercial builders across the country.

### It's Cool and Quiet... Too Quiet?

Another advanced feature in the RSF is how the windows also help regulate the inside temperatures. During warmer summer nights, the windows will automatically open to vent excess heat and allow the cool night air to naturally bring down the temperatures inside the office space. As the night progresses, the six inches of interior exposed concrete in the pre-cast panels of the RSF will lose their heat, cool down, and the process begins anew the next day. It's the same thing that happens in brick homes," Macey said. "During the day it's comfortable inside but if you don't open the windows at night, suddenly it can be 80° inside and you wonder how that happened." To help augment this system during warmer summer days, the building also has an underground concrete labyrinth that can store cool night air for later use.

So, unlike most commercial office buildings, the new RSF doesn't rely on a traditional forced air HVAC system and uses much

more outside air inside the building. According to NREL's Project Manager, Eric Telesmanich, this is possible because 95% of the work spaces don't have ceilings. Employees will assist the natural ventilation flow by opening and closing windows as necessary. They will also have the ability to control the amount of ventilation delivered to their work space through an under floor air distribution system when the natural ventilation is not enough.

In fact, the lack of a traditional forced-air system throughout most of the building means that it will be very quiet. Without the constant sound of moving air, the building will employ white noise to help mitigate background chatter that will take place in such an open office.

"What a great environment this will be for the employees," Erick Hartzell, RSF project manager for Haselden Construction said. "It's going to be the best possible environment to spend an eight to 10 hour day."

"Thermal comfort studies show that the most comfortable spaces are the ones that don't have drafts that push the air to control the temperature," Macey said. "Everything in the RSF will take on that even temperature."

### Panels Play on Both Sides

Environment also is a concern when it comes to the materials used in constructing the RSF. This includes the precast panels, which were fabricated in Denver. All of the concrete and aggregate used to make the panels is also from local sources within Colorado. Although the panels come in various sizes and shapes, on average, they measure 13 x 30 feet. Two hundred and eight have been installed on the RSF.

The panels did present a challenge to the Haselden crews during installation. Workers had to be very careful when lifting the large panels into place because unlike typical siding on buildings, these panels make up the entire wall of the building, both exterior and interior. "The panels are the finished wall on the inside as well as the outside," Hartzell said. "We've had to be very careful installing them because there is a huge finished surface that will show any blemishes. In addition, the whole thermal component of these walls was important during installation. You can't just put an anchor bolt anywhere you want into the wall, you have to be aware of how it will affect the heat loss for the building."

The interior walls will receive the typical coats of paint and primer, but the underneath surface is what will show through to the occupants. Colors also will be carefully selected with many of the precast walls being painted white to help with day lighting the interior work space. And, since the windows play a role in lighting and cooling the building, they are plentiful. "No one will be farther than 30 feet from a window in the RSF," Macey said. "The scale of the windows and the connection they bring to the outside environment is something I think people will notice most."

Haselden Construction and RNL are building the 218,000 square-foot RSF building, which is designed to be a model for sustainable, high-performance building design, and will provide U.S. Department of Energy-owned work space for administrative staff who currently occupy leased space in the nearby Denver West Office Park. The RSF is planned to achieve a LEED® (Leadership in Environmental and Energy Design) Platinum designation—the highest benchmark awarded by the U.S. Green Building Council. Construction on the RSF is expected to be completed in summer 2010.

—Heather Lammers (Oct. 30, 2009)



## NREL SETS THE BAR FOR OFFICE BUILDING ENERGY USE



Designers met NREL's aggressive energy use requirement for the Research Support Facilities by taking advantage Colorado's sunny climate. Large windows for daylighting and thermally sophisticated wall systems for solar heating are crucial to the net-zero energy design. Credit: Pat Corkery/PIX 16768

Technology—from sophisticated computer modeling to advanced windows *that actually open!*—will help the newest building at the U.S. Department of Energy's National Renewable Energy Laboratory (NREL) be one of the world's most energy efficient offices.

But making NREL's new Research Support Facilities (RSF) into a showcase for engineering net-zero energy office design didn't begin with rooftop solar panels on its distinctive "lazy-H" shape, or a subterranean "thermal labyrinth" that mimics a cave to help heat and cool the building—although the RSF will, in fact, use both sustainable strategies.

Nor did it start with aggressive window shading and advanced light reflecting devices to simultaneously provide daylighting and passive heating—although both systems are vital to the building's performance.

The RSF's origins as an intended symbol of energy efficiency goes back more than a decade to when DOE proposed an administrative facility setting the national standard for energy efficiency and can be traced in the project's exhaustive specifications document to a single number in section 8. 2 on page 10:

"...25 kBtu/sf/year..."

How little energy is 25,000 Btu per square foot per year?

By comparison, conventional office buildings built over the past 30 years typically use three times more energy than required in the RSF. That's like taking a 1980s-era family sedan and demanding that it get 60 mpg.

It's even aggressive by new construction standards. The NREL requirement is 50% more energy efficient than the new commercial energy code issued by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE).

And, the energy intensity figure is a requirement over and above the additional requirement that the RSF be built to LEED® Platinum status, the highest designation by the U.S. Green Building Council.

The number was not chosen arbitrarily. Researchers from NREL's Buildings Research and Development program performed computer simulations and collected data from high-performing buildings nationwide to create an energy specification that could be met within the project's budget, yet set an ambitious new energy efficiency benchmark for the nation.

### A First Time for Everything

Energy use intensity rarely is quantified in a building contract, even when project is designed to be a "green building." And never before, researchers say, has such an aggressive energy savings requirement been demanded up front in the contract long before groundbreaking.

"We set the energy efficiency requirement and everything in the RSF has cascaded from that number," said Ron Judkoff, manager of NREL's Buildings Research program.

"It is an unprecedented target and dominant design criteria," Judkoff said. "It required all of the players in the project to commit to real energy efficiency. When you are trying to go that low, an integrated design approach is needed."

"We set the energy efficiency requirement and everything in the RSF has cascaded from that number." — Ron Judkoff

The RSF is under construction at NREL's South Table Mountain Campus near Golden, Colorado. The RSF will be a 219,000 square-foot facility supporting more than 800 laboratory staff, along with an energy efficient information technology data center. It is scheduled to open in summer 2010.

Researchers say its design features will be shared with commercial developers in hopes it will be replicated as local conditions allow and without, as the researchers put it, "doing architectural gymnastics."

"The Department of Energy's goal was to make this a showcase for energy efficiency, and that's what drove the design of the Research Support Facilities," said Jeff Baker, Director of Laboratory Operations at the DOE Golden Field Office. Nineteen percent of the country's energy is used in commercial buildings, he said.

“The DOE expects the RSF project to help reduce the nation’s energy consumption by changing the way commercial buildings are designed and built,” Baker said. “Where better to demonstrate what can be done than on the campus of the Department’s primary national laboratory for renewable energy and energy efficiency research and development?”

## Buildings Can Do a Lot Better

NREL’s buildings R&D group has influenced the design of the laboratory’s facilities for more than two decades. Many of the campus buildings are among the most energy-efficient of their kinds, including the Thermal Test Facility, the Science & Technology Facility, the Solar Energy Research Facility, and the Visitors Center.

Researchers had already studied the energy use of newer commercial buildings around the country. While some of them, such as the Chesapeake Bay Foundation’s headquarters at the Merrill Environmental Center in Annapolis, Maryland, had been awarded LEED Platinum status, they still did not emphasize energy efficiency as much as NREL researchers thought they should.

Since RSF construction began spring 2008, the laboratory continues to grow rapidly. Because of its modular design that eschews structural columns, the interior has been creatively rearranged to accommodate nearly 100 additional staff. But more people require more energy, and so the energy use requirement for the office space has been nudged to 31.75 kBtu/sf/year.

Then came the large new data center, vital to the laboratory’s significant and growing computational needs, but more than what a typical office building would include.

Data centers usually have voracious energy appetites. But this late addition still had to fit with the RSF concept.

Researchers came up with a combination of evaporative cooling, outside air ventilation, waste heat capture and more efficient servers to reduce the center’s energy use by 50% over traditional approaches.

Because the data center serves the entire laboratory campus and not just the RSF, an energy allowance was added to reflect the exception to the project. Now the RSF energy use intensity including the data center is 35.1 kBtus/sf/year. That’s still better than most of today’s energy efficient buildings and well under half the energy used by a similar building built to code for the same budget.

“Our energy simulations told us that buildings can perform a lot better,” NREL Principal Group Manager Paul Torcellini said. “NREL needs to lead the industry. We’ve maximized our impact by integrating today’s technologies to build a zero-energy office building.”

When the \$64 million project was first reviewed by RNL Design and Haselden Construction, architect Phillip Macey admits he did not immediately recognize how aggressive the energy use requirement was. But it quickly became the project’s fundamental characteristic—so primary, in fact, that RNL

and Stantec, the project’s engineers, drafted an energy model that acted as a starting point for the building’s form.

Macey realized the building’s design also would have to embrace Colorado’s sunny climate and the entire spectrum of passive building knowledge to find enough “free clean energy.”

“The energy use requirement told me that energy was going to drive the architecture,” Macey said. “It is an old concept in architecture that the building form should reflect the climate in which the building is located.”

He compared the energy requirement to finding a key and figuring out which door it unlocked.

“That ‘locked door’ is the entry to the zero energy room,” Macey said. “We knew that if we could find a way to get to that energy level, it would likely unlock the zero-energy door for the entire building.”



The “lazy H” configuration of two narrow multi-story office wings connected by an enclosed bridge and courtyards allows daylight to penetrate the RSF’s work spaces. NREL recommended that the office wings be no wider than 60 feet across rather than a typical 120 feet. *Courtesy of Haselden Construction/PIX 16772*

## Many Steps to Energy Efficiency

Architects and engineers incorporated hundreds of strategies and technologies that combine to save energy by emphasizing daylighting and natural ventilation.

Some involve the building’s largest and most pervasive systems:

- A “lazy H” configuration of two narrow multi-story office wings connected by an enclosed bridge and courtyards. To allow daylight to penetrate the work spaces, NREL recommended that the office wings be no wider than 60 feet across rather than a typical 120 feet.

- Triple-glazed windows individually fitted with exterior overhanging shades and side-fins to reduce interior heat gain, heat loss and glare, while allowing for daylighting.
- Light-reflecting devices that push the daylight deeper into the office spaces.
- Insulated precast concrete walls for passive climate control, including transpired solar collectors for heating.
- Also for climate control, a dynamic network of automatically controlled windows, evaporative cooling, radiant heating and cooling, window glazing and heat recovery from the data center.

But it still wasn't enough. Many smaller decisions were made with energy efficiency in mind to reach the final calculation. NREL researchers and the design team found savings in every aspect of the building's use.

- Reducing kitchenettes from 1 for every 15 employees to every 20 employees.
- Using internet-tied telephones rather than standard models.
- Favoring laptop computers over PC workstations.
- More energy-efficient elevators including energy recapture.
- Highly reflective interior paint and workstations in neutral hues to enhance daylighting.
- Shutting off lights at night.
- Low workstation walls to encourage daylighting and natural airflow.

### Delivered at a Competitive Cost

The RSF is a "design-build" project in which the team will deliver the advanced building for a market-competitive price of about \$280 per square foot. That's another first for the project: laboratory researchers had to set their requirements for the building's performance up front and have relatively few opportunities to make changes later.

**"The energy use requirement told me that energy was going to drive the architecture. It is an old concept in architecture that the building form should reflect the climate in which the building is located."** – Phillip Macey

So when the specifications were completed, the RFP ran a staggering 780 pages. That's longer than Homer's epic poems, *The Iliad* and *The Odyssey*—combined.

But that exhaustive detail is meant to provide building owners and developers a proven method for net-zero energy office buildings.

"We want to take energy efficiency to Main Street," said NREL engineer Shanti Pless. "The key is to make it a requirement and integrate energy efficiency early in the design process."

Haselden Construction and RNL are building the 219,000 square-foot RSF, which is designed to be a model for sustainable, high-performance building design, and will provide DOE-owned work space for administrative staff who currently occupy leased space in the nearby Denver West Office Park. The RSF was designed by RNL. Stantec Consulting served as the project's engineering, energy modeling, and sustainability consultant.

### Comparison of Buildings Energy Use Intensity

- Average US office building: 90 kBtu/sf/year
- ASHRE code for new commercial space: 55 kBtu/sf/year
- Chesapeake Bay Foundation, Annapolis, Md.: 40 kBtu/sf/year
- Big Horn Hardware, Silverthorne, Colorado: 40 kBtu/sf/year
- NREL RSF: 35.1 kBtu/sf/yr, including the data center
- NREL Thermal Test Facility: 29 kBtu/sf/year.

— Joseph B. Verrengia (Dec. 7, 2009)

## UNIQUE RESEARCH TOOL AIMS TO REDUCE PV COST



Senior Scientist Maikel van Hest holds a sample of a substrate used to make thin film solar cells in the Atmospheric Processing Platform. The large sample size makes it easier for industrial partners to scale up the results of the prototyping.

Credit: Joe Verrengia/PIX 16881

**N**REL has installed its first Atmospheric Processing Platform to prototype lower-cost thin film solar cells from inks and other solutions.

Thin film technologies are spurring innovative new solar applications, such as modules that double as roof shingles, and semi-transparent modules that can be integrated into building walls or roofs. It has the potential to dramatically increase the generation of clean electricity.

But to become commercially successful, thin film manufacturing costs must be significantly reduced. The uniquely configured platform enables NREL scientists to work directly with industry partners to test novel designs and manufacturing methods using precise digital printing technologies under controlled conditions.

It allows collaborative research teams to isolate important steps in the thin-film manufacturing process and look for ways

to refine or accelerate those steps with the intent of reducing the cost of the finished solar cell.

At 6.2 x 6.2 inches, the thin film PV samples the platform produces are much larger than what's used in typical laboratory experiments, so the results can be more rapidly commercialized.

"There is no other laboratory platform quite like it in the world, and we're already running real samples through some of its chambers," senior scientist Maikel van Hest said. "We should be running samples continuously by the end of the summer."

### Less Heat, Less Pressure, Lower Costs

Traditionally, solar cells are made using intensive processes that includes depositing metal contacts and absorber layers. These processes typically require high temperatures and vacuum deposition, which adds expense and contributes to making solar electricity more expensive than electricity from conventional sources.

The new platform consists of several large glove boxes that are connected both by internal portals and a linear transport train that runs beneath the boxes. The system allows researchers to work with samples inside the glove boxes' controlled conditions.

The heart of the platform, van Hest says, is a pair of glove boxes fitted with a variety of solution deposition techniques that can be used for different aspects of thin film manufacturing at ambient pressures. The thin films are made from inks and other solutions made of material precursors and nanoparticles. They can be deposited on common substrates such as glass, plastic, and metal, and closely examined—one layer at a time.

The solution deposition techniques themselves are commercially available units, but the platform can use them in unconventional ways.

### Three Different Nozzles

Ink jet printers can replicate complex and specific images, and offer advantages for precisely adding patterns of metal contacts from solutions such as nickel and silver inks.

Aerosol jets provide a very fine mist to write a specific pattern, working much like a plotter moving back and forth.

Ultrasonic sprayers can be used to deposit homogenous layers of conducting, semiconducting, or dielectric materials

All three methods use very small amounts of ink in precise patterns to improve manufacturing efficiencies. Because the solution deposition tools don't make direct contact with the samples like screen printing, losses from breakage and blemishes are reduced, too.

**"There is no other laboratory platform quite like it in the world, and we're already running real samples through some of its chambers." – Maikel van Hest**

“There are significant cost savings especially as you scale up,” van Hest said.

The platform also includes work stations that allow researchers to assess prototype PV cells under the same controlled conditions, including X-ray fluorescence for compositional analysis and X-ray diffraction for structural analysis.

Prototype thin film cells move through the platform in about a minute. At the industrial scale, thin-film cells need to be manufactured in a few seconds or less.

“But speed is not our main concern—this isn’t a factory,” van Hest said.

“Doing this in a minute is sufficient to develop new materials, new contacts and new processing approaches. We know these deposition techniques can be sped up to industrial speeds.”

“If you can do it faster, it’s always better—and it will get faster,” he said. “But what this system really lets us do is go back and forth between the glove boxes and develop new concepts and materials.”

**“If you can do it faster, it’s always better—and it will get faster. But what this system really lets us do is go back and forth between the glove boxes and develop new concepts and materials.”** – Maikel van Hest

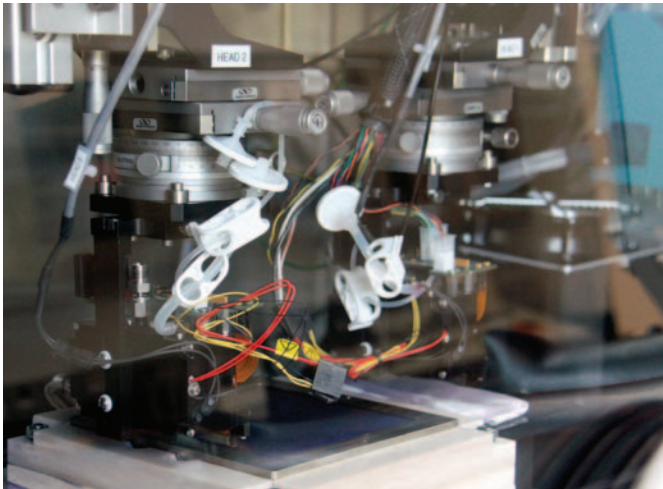
The Atmospheric Processing Platform is located in the Process and Development Integration Laboratory (PDIL) at NREL’s Scientific and Technology Facility.

The PDIL is a unique collaborative facility for scientists and industry to examine pressing questions related to the commercialization of next-generation photovoltaics. The PDIL integrates the most advanced equipment to optimize the productivity of new solar technologies and accelerate their commercialization.

### Advantages of the Atmospheric Processing Platform

- Low cost
- High thru-put
- Easy prototyping
- Compositional control
- Efficient use of materials.

— Joseph B. Verrengia (July 10, 2009)



An ink jet printer assembly inside a glove box of the Atmospheric Processing Platform. Credit: Joe Verrengia/PIX 16882

## NREL HELPS SORT GREEN TRANSPORTATION OPTIONS



New Belgium Brewery shows off one of the 31 Toyota Prius Hybrids that New Belgium uses in its light-duty fleet.

Credit: Heather Lammers/PIX 16866

Using a company vehicle used to be a simple (but not so green) routine. An employee filled up the car with gasoline at the fleet pump, turned the key and was on his way. Efforts to reduce the environmental impact of driving mean more choices, though. Fleet managers now can pick from green options such as E-85, biodiesel, propane and an assortment of hybrids. That can be a little confusing, but NREL and U.S. Department of Energy (DOE) are helping companies decide which transportation choices best fit their sustainability goals by providing a variety of online tools.

The Alternative Fuels and Advanced Vehicles Data Center (AFDC) is managed by NREL for DOE and has more than 3,000 sources of data that can serve as resources for fleet managers and consumers. “The AFDC Web site takes technical information and translates the information into user-friendly tools,” said Margo Melendez, Senior Project Leader, Clean Cities. “These tools help fleet managers make educated transportation choices and are geared toward helping consumers and fleets reduce petroleum consumption.”

Fleets regularly use the information offered on the AFDC Web site to help meet efficiency goals and the Web site also champions their success stories to encourage others. Here are just a few examples of organizations that have navigated to greener fleets.

### New Belgium Chooses Hybrids for Sales Team

New Belgium Brewing, maker of Fat Tire Amber Ale and other Belgian inspired beers, has always looked for ways to be energy efficient and socially responsible. Since its beginning, the company has participated in developing technologies.

“We think success lies not only in healthy profits, but in healthy people and planet,” Sustainability Specialist Katie Wallace said. “Our business decisions reflect these beliefs. We’re not profitable in spite of our progressive practices but because of them.”

New Belgium’s fleet is 99% light-duty vehicles, which are used by sales representatives in 18 states. In its fleet of 95 vehicles, there are 31 Prius hybrids, three Ford Escape hybrids, and one Nissan Altima hybrid. In addition, New Belgium has experimented with a B100 (100% biodiesel) made from yellow grease. The company currently is exploring options outside of first-generation biofuels.

“We’ve definitely taken advantage of the tools on the AFDC Web site to help with fleet decisions,” noted Wallace. “We’ve used the online data to compare the efficiencies of vehicles we might be considering.”

Wallace also thinks that the issues surrounding fleets at New Belgium still are evolving. “We are always looking for the next step in sustainable fuel. Electric hybrids are a good transition, but not the final solution.”

Another solution employees have embraced is old school, but very healthy—the bicycle. The emblem for one of New Belgium’s beers, the bicycle is a staple of the company’s culture. Bikes are available to employees to run errands during the day and encouraged for use in local sales calls and trips around Fort Collins, Colorado, where the company is headquartered. The company gives employees bikes on their one year anniversaries with the brewery.

**“We are always looking for the next step in sustainable fuel. Electric hybrids are a good transition, but not the final solution.”** – Katie Wallace

### Zion National Park Clears the Air with Propane

Zion National Park in Utah prides itself as a green parks leader and has earned a designation as a Climate Friendly Park by completing a Greenhouse Gas Emission Inventory and Action Plan to reduce greenhouse gases. The national park is committed to energy efficiency, and recycling, and supplies bicycles for employees to use on duty. Zion operates 30 propane-powered shuttle buses for visitors.

Handling the transportation pieces of their efforts is Parks Transportation, Inc. The program statistics are staggering. The park has more than 2.7 million visitors a year and has logged 14,951,190 shuttle passenger miles since the inception of the program in 2000. With an average of 1,076 Btu of energy used per passenger mile, the shuttle buses are about three times more fuel efficient than passenger cars. This helps account for a reduction in carbon dioxide emissions inside the park estimated at 6,263,250 pounds.

“The park is committed to continuing and expanding the use of energy efficient and green vehicles,” said Ron Terry, Chief of Interpretation and Visitor Services for Zion National Park. “The program has been well received and has been studied by other national parks considering a similar system.”

Guests in Zion National Park also have taken notice of the shuttle system, which stops at nine different locations throughout the park and at six locations in the neighboring town of Springdale. “Visitors especially notice how quiet the shuttles are,” Terry said. “The use of these vehicles fits perfectly with the purposes and mission of the national parks and is the right thing to do.”

Vehicles are only one aspect of Zion National Park’s sustainability efforts. NREL has worked with Zion officials to build an energy efficient Visitor’s Center which uses solar power, passive downdraft cooling and Trombe walls to store the heat for release into the building later in the day. Learn more about the Zion Visitor’s Center on the DOE Web site.

“We have energy efficient buildings and are continuing to add to our efforts with an expansion of solar technology,” Terry said “We are also heavily into recycling and purchasing ‘green products,’ all of these efforts are in support of our designation as a Climate Friendly Park.”

### L.L. Bean Embraces B20

In 2003, L.L. Bean was the first major Maine-based company to test market biodiesel in its distribution fleet and converted its heavy-duty truck fleet to B20 biodiesel fuel (20% non-petroleum based diesel mixed with 80% conventional petroleum based diesel).

Currently, L.L. Bean has 13 B20-fueled tractor rigs that move trailers between its warehouse locations. Seventeen of the company’s Maine Outdoor Discovery School shuttles, which transfer customers from retail stores to off-site locations for classes, are configured to run on biodiesel as well.

“We continue to monitor advances in commercial vehicles in regards to alternative fuels. The AFDC Web site serves as an excellent reference source for us when making these decisions.” – Laurie Brooks

The company’s history of environmental efforts has been noticed. “Our customers are very concerned about the environment and want assurances that we are taking the steps to protect and preserve our natural spaces,” Senior Public Relations Representative Laurie Brooks said. “Customers routinely visit the Environmental section of our Web site, which details our efforts and progress on environmental issues.”

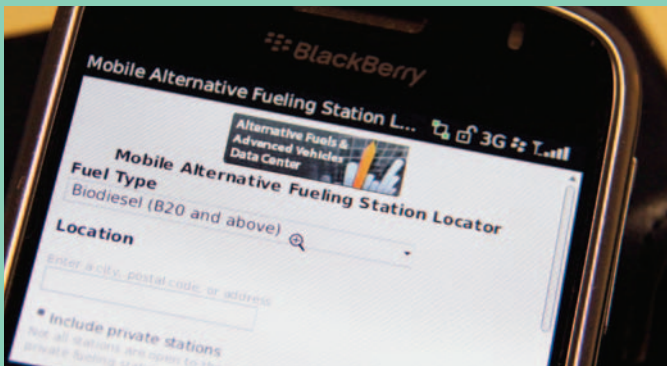
L.L. Bean continues to look at options when it comes to its fleet opportunities. In 2008, the company added a hybrid vehicle to the corporate vehicle fleet and is encouraging its employees to carpool to work through

ECOBean (Employee Commuting Options). The program provides prime parking spaces for employees who carpool.

“We continue to monitor advances in commercial vehicles in regards to alternative fuels,” Brooks said. “The AFDC Web site serves as an excellent reference source for us when making these decisions.”

— Heather Lammers (April 10, 2009)

## ON THE ROAD WITH ALTERNATIVE FUELS



Future upgrades to the MAFSL include automatic location detection using GPS installed in the device so users don't have to type in where they are. Credit: Heather Lammers/PIX 16883

Drivers now can take a popular tool on the road thanks to staff at the National Renewable Energy Laboratory (NREL). The Mobile Alternative Fueling Station Locator (MAFSL) helps on-the-go drivers find the five closest biodiesel, electricity, E85 (ethanol), hydrogen, natural gas, and propane fueling sites using any mobile device with Internet access.

"We heard from our users that it would be nice to have this tool with them on the road," NREL Deployment Application Lead Johanna Levene said. Before launching a mobile version, the Alternative Fueling Station Locator was consistently among the top five applications used on the U.S. Department of Energy's Alternative Fuels and Advanced Vehicles Data Center (AFDC) Web site. The station locator was developed by NREL, which manages the AFDC.

### Trip Planning Made Easy

The mobile station locator uses well-known, easy-to-navigate Google Maps to automatically generate maps to fueling sites. The mobile application also lists contact information and business hours for stations. A family road trip in an alternative fuel vehicle used to take a little extra effort and planning. But, the easy to use mapping tool is one of the reasons that Colorado resident Chad Scullion began using the MAFSL when driving his flex-fuel E-85 pickup to visit family in Wyoming. "The mapping feature is great for use on trips and the station information is constantly updated," said Scullion. "It used to be that there were only two stations I could find in Wyoming, now there are five."

Scullion made the switch to an alternative fuel vehicle in summer 2008, buying a flex-fuel E-85 Nissan truck, which is what he takes when he goes fishing in the Colorado high country. "About a month or so after I bought the truck I used the tool to find two stations in the mountains," Scullion said. Scullion is so happy with his alternative fuel vehicle that he is considering converting his wife's Volkswagen Jetta to E-85 as well. "Maybe she'll be a user too."

Renewable Energy and Efficiency Education on Wheels (RnE<sup>2</sup>EW) Coordinator Rick Shin also knows the importance of having a tool to help him find stations to fuel his propane powered 27-foot RnE<sup>2</sup>EW educational vehicle. "Although propane burns clean, it's something you can't get 24/7," Shin said. "I have to plan trips so that we can get to places to fuel up between 8 a.m. and 5 p.m."

RnE<sup>2</sup>EW is an educational-outreach vehicle designed to educate students, teachers, and the community in renewable energy and efficiency sciences as well as to showcase DOE/NREL research and technology.

Shin travels the country in the RnE<sup>2</sup>EW educational vehicle speaking to kindergarten through sixth grade students. He has taken RnE<sup>2</sup>EW from coast to coast with stops from Washington D.C to San Jose, California. Shin noted that in his travels he's only seen a few propane powered vehicles and publically available fueling stations can be hard to find.

"The locator is important because it gives you the name, address, and hours of the stations," Shin said. "This information is great to have because we have to call ahead to make sure that someone is really there who can pump the propane. This is especially true on Sundays because certain states will only let trained employees operate the pumps."

Before using the MAFSL, Shin would rely on major truck stops as fueling locations, which had issues of its own. "Other vehicles typically have a 300-mile range so you normally find major truck stops spaced that far apart," Shin said. "RnE<sup>2</sup>EW has a range of about 250 miles so we've used the locator tool to find other stops along the way, so it's really good to know the locator is out there."

### New Features in the Works

Once a tool is placed on the World Wide Web, it's easy for users to come up with suggestions for improvements. That type of user feedback is welcome and is taken into consideration as the developers work on enhancements. "Our users asked that we start including private fueling stations in the database," said Levene. "It's something we didn't think there would be a demand for but have added." Future upgrades to the MAFSL might also include:

- Automatic location detection using GPS installed in the device so users don't have to type in where they are
- An application for the popular iPhone
- Creating a similar stand-alone application for truck stop electrification sites.

Another priority for the team is keeping the data used by the MAFSL up to date. Currently, E-85 information is updated every other week and all other fuel information is updated monthly. Every year, all of the fueling stations are contacted to make sure their information is correct. And, any information sent to the AFDC Web site by users is updated as well.

"We want this tool to be intuitive and easy to use," said Levene. "We want you to get the information in two to three clicks so people can be on their way."

— Heather Lammers (July 24, 2009)



## BIGGER AND BETTER: LAB AIMS TO IMPROVE GIANT WIND TURBINES



Blades of the General Electric 1.5 MW turbine are being stored outside on cradles this winter at the National Wind Technology Center. They are secured with large concrete blocks to prevent them from being damaged during high winds and storms. Credit: Jim Green/PIX 16179

If the United States is going to generate 20% of its electricity from the wind in the next 20 years, wind turbines will need to evolve in every way—larger, taller, less expensive, more reliable, and more efficient.

At NREL's National Wind Technology Center (NWTC), engineers are preparing to install the two largest turbines ever tested at the laboratory. Key elements of a 1.5 MW General Electric (GE) turbine have begun arriving; instrumentation and equipment testing should begin by late summer. Installation of a 2.3 MW turbine from Siemens Power Generation is scheduled for late summer, too.

Both turbines will be erected on the NWTC's eastern perimeter, where they will run for years while serving as prominent sentinels overlooking metropolitan Denver.

"We need to understand how these big turbines respond," said senior project leader Jim Green, who is leading the GE tests. "Increasing their performance, reducing their loads, creating components that last longer—we'll need to learn about all those things if we're going to make more wind power."

### Supersized Wind Turbines

The GE turbine will operate atop a 262-foot steel tower. The diameter of its rotor will reach 250 feet. Its total weight, including the tower, will approach 220 tons.

The only visible part of the foundation will be the bolt circle for the tower itself, but looks can be deceiving. Covered with dirt for extra weight, its octagonal concrete foundation pad will measure 50 feet across and weigh about 500 tons.

"The pad has to be that big," Green said, "because that's what keeps the whole thing standing upright in high winds."

Special overland trucks started arriving at the NWTC in December carrying sections of the GE system. The trucks are up to 195 feet long—three times as long as a typical 18-wheeler. They use as many as 13 axles to distribute the weight of their huge cargo.

The trucks took a designated route on major roads that are designed to handle oversized loads and traveled at times that would not disrupt traffic. Two of the trucks were followed by a

separate escort vehicle that remotely steered the trailer's rear wheels by radio signals to help the long trucks negotiate tight corners.

In mid-December, the tower sections arrived from Tulsa, Oklahoma; the blades from Aberdeen, South Dakota; and the generator housing and rotor hub from Pensacola, Florida.

During the spring, NREL will build new access roads to the planned turbine pads and provide other site preparation. NREL is purchasing the turbine for the U.S. Department of Energy under a subcontract with GE.

The GE turbine is already a workhorse commercial model, accounting for nearly half of all turbine sales in the United States. The NREL tests are intended to discover ways to squeeze more power out of existing wind farms and improve the durability of the turbine's components.

"Any improvements we can make will have a lot of leverage in the wind industry," Green said.

### Bigger than a Football Field

The Siemens 2.3 MW turbine will be noticeably larger than the GE. It will use a similar tower, but its rotor diameter is a whopping 331 feet—more than the length of a football field!

Unlike the GE, the Siemens model is a late-stage prototype. It features a novel blade design that captures more of the wind's energy, but is not supposed to force any more load onto the turbine's moving parts and control systems. It will be heavily instrumented to produce a constant stream of data on aerodynamics, power characteristics, vibrations, system fatigue, acoustics, and other key measurements.

The tests will be conducted in three phases through late 2011.

"These tests will verify the performance of the new blades under real and challenging conditions," said NREL senior engineer, Lee Jay Fingersh, who is project lead for the Siemens turbine.

"It looks very graceful and simple, but the aerodynamics of a wind turbine are harder to understand than an airplane or a helicopter," he said.

Siemens is providing the turbine, engineering support and maintenance from its new R&D office in nearby Boulder. NREL is providing the site, installation services and expertise in field aerodynamics testing, structure and reliability testing and meteorological analysis.

The NWTC would make a poor commercial wind farm, but the location downwind from Eldorado Canyon and the Continental Divide provides gusty conditions that challenge turbine and blade designs and generate data at the equipment's limits. Motorists on Highways 93 and 128 can expect to see the giant turbines operating regularly.

"The turbines generate more power than we can use at the NWTC," Fingersh said. "We'll become an exporter of electricity and be able to offset some of the program's costs."

— Joseph B. Verrengia (Jan. 30, 2009)

## NREL GEARBOX STUDY AIMS TO GREASE WIND POWER'S FUTURE



NREL senior engineer Shuangwen Sheng inspects the monitoring system for the long-term gearbox reliability study at the National Wind Technology Center. Credit: Joseph B. Verrengia/PIX 16867

Wind turbines appear so simple—tall white sentinels cranking gracefully on the horizon.

But up close, a wind turbine is an industrial workhorse. Inside the nacelle hundreds of feet off the ground, hot metal gears grind and strain as shifting winds pull and twist the long flexible blades.

At NREL, senior engineers are expanding a research partnership with operators, utilities and turbine manufacturers to determine why some key wind turbine components tend to wear too soon—sometimes within a few years of installation.

That's a problem because wind turbines are expected to operate for 20 years. Early equipment fatigue, especially in turbine gearboxes, threatens to reduce performance and drive up wind power costs just as the industry is poised to capture a greater share of U.S. generating capacity.

Improving their reliability is key to generating a consistently competitive power source, and a healthy return on investment. Both are needed if wind power is to meet 20% of the nation's electricity needs by 2030, a scenario a U.S. Department of Energy report issued in 2008 says is possible.

"The end users and the owner-operators say we're only getting five years, or in some cases, three years out of these gearboxes," said NREL principal engineer Sandy Butterfield, who is leading the cooperative study.

Newer turbine designs may work, but without the NREL study it will take a number of operating years in the field to prove that the reliability problems have been resolved.

"This project is designed to search for any residual gaps in the design process and confirm a robust design practice used in current production turbines," Butterfield said. "We can't wait five more years to discover any residual gaps."

### Collective Examination

In 2007, Butterfield, senior engineer Walt Musial and consultant Brian McNiff began assembling the Gearbox Reliability Collaborative among turbine manufacturers, utilities and suppliers. The collaborative tests extensively instrumented gearboxes to

identify weakness in current design approaches and pointed out ways to improve initial designs and retrofit packages.

The project identifies equipment failures that are common throughout the industry and targets deficiencies in the design process that are contributing to these problems.

NREL hopes to limit intellectual property concerns by running tests on representative wind turbine configurations and parts, but not replicating any specific manufacturer's wind turbine model.

At the same time, the participants are expected to openly examine turbine problems and question every assumption of the design process.

Focusing on design is especially important, Butterfield said, because the expanding wind industry is trying to rapidly meet market demand for new and larger-capacity turbines. Designers and manufacturers are all following very stringent design quality, in some cases matching aircraft tolerances. Yet the problems persist. This implies the design standards are missing some critical loads or conditions that are unique to wind turbines. Without identifying the fundamental issues behind previous failures, he said, the same flaws could find their ways into new generations of turbines.

### Nitty-Gritty of Gearboxes

The tests at the National Wind Technology Center (NWTC) focus on several aspects of gearbox performance:

- Automated spray lubrication. Wind turbines crank at low RPMs under high torque, especially in the first stage of gearing where heat and pressure are high. New designs have lubrication channeled directly to the bearing races.
- Oil cleanliness. New turbines have more aggressive filtration systems.
- Automated gearbox monitoring instruments. These systems are supposed to detect damaging operating conditions before a failure occurs.
- Micro-pitting. This phenomenon occurs as metal fatigue creates microscopic weak spots in gears that degrade the equipment over time.
- Load distributions on the gear tooth contacts and the bearing roller elements.

Initially, the gearboxes under review are being tested on the NWTC dynamometer, where Butterfield and others will simulate a variety of loads and measure the results.

Later, they will put one gearbox into test turbines at the Xcel Energy Ponnequin wind farm and monitor them under real load conditions.

A second testing phase is likely to follow.

Butterfield also intends to build a significant failure database to baseline current failure rates and verify reliability improvements in the future.

"I know we'll discover a tremendous amount in the first year," he said. "We hope we can quickly transfer this experience to the industry."

— Joseph B. Verrengia (April 17, 2009)

## WIND TECHNOLOGY CENTER INSTALLING A DYNAMIC DUO



Blue skies and calm conditions contributed to a smooth installation of a General Electric 1.5 MW wind turbine at the National Wind Technology Center. Credit: Pat Corkery/PIX 16570

The clean wind energy industry must expand significantly in the next two decades to fulfill a strategy of generating 20% of the nation's electricity. To provide the technological foundation for that dramatic growth, the National Renewable Energy Laboratory (NREL) is embarking on significant improvements at its National Wind Technology Center (NWTC).

Engineers are installing the two largest turbines ever tested at the laboratory—a 1.5 MW turbine manufactured by General Electric (GE) and a 2.3 MW turbine from Siemens Power Generation.

Both turbines are being erected on the NWTC's eastern perimeter for commissioning and operations in October. They will run for years under close observation and elaborate instrumentation. With data from these experiments, researchers will be working with the wind industry to increase turbine performance, improve durability and decrease loads.

The new turbines also allow NREL to take a significant step forward in generating its own clean electricity and meeting the laboratory's aggressive sustainability goals and reduce greenhouse gas emissions for its expanding research campus and support facilities. The new turbines are expected to generate twice as much energy as the NWTC uses. The U.S. Department of Energy (DOE), NREL, and Xcel Energy are working to define an agreement that will allow surplus energy to be exported and sold to the local utility grid.

### DOE Purchase for the NWTC

DOE purchased the 1.5 MW turbine for the NWTC. Crews using a crane assembled it over three days. The rotor was expected to fly—or be attached—on August 21, 2009.

The DOE turbine will operate atop a 262-foot steel tower. The diameter of its rotor will reach 253 feet.

"The DOE turbine is a national asset for the NWTC to operate as a test bed for wind energy research and development," said NWTC assistant director for Testing and Operations, David Simms. "They would like us to offer it as a test bed for the best and brightest researchers from universities, laboratories, and companies around the country."

The DOE turbine was manufactured by GE and is a workhorse of the domestic wind power industry. More than 10,000 now operate at commercial wind farms around the nation, accounting for about 50% of the U.S. market. Because of its market share, NREL researchers say it is important to more fully understand the turbine's performance in the field and look for ways to help advance its design.

Among the questions researchers will address are the microclimate in which the turbine operates, the aerodynamics of the turbine design and the effects of turbulence on its load and performance—and how all these factors may combine in potentially unforeseen ways. The NWTC was located at the base of the Rocky Mountains to take advantage of particularly gusty, challenging winds in order to challenge turbine designs in conditions not typically seen at commercial locations.

"If we could improve performance, thousands of turbines could remain in operation for years beyond the industry's original expectations," said NREL senior project leader Jim Green.

Additional trucks will be delivering the Siemens wind turbine, the cranes, and other installation equipment in August and September of 2009. The Siemens turbine will use a second tower of the same height, but its rotor diameter is 331 feet, or more than 30% bigger than the DOE turbine. The Siemens turbine employs an advanced new rotor design that needs field testing in the NWTC's gusty and challenging conditions. Siemens has opened a research office in Boulder to provide engineering support and maintenance.

### Siemens Turbine Among the Largest in the United States

"It's as large as any turbine in North America," said project leader Lee Jay Fingersh. "The final design is different than most turbines with a different blade shape. Land-based turbines are getting larger to meet the demand for wind energy. This is the direction of the wind industry and we want to understand the aerodynamics of these new, larger machines."

NREL is providing the site, the foundation and the electrical connection for the turbine, the cost of delivery, installation services and expertise in field aerodynamics testing, structure and reliability testing and meteorological analysis. NREL and Siemens have signed a cooperative research and development agreement that is expected to continue into 2014.

The Siemens turbine was selected for testing by the DOE after a national competition.

### More Than Meets the Eye

As considerable as the new turbines are, NREL researchers are equally interested in what is required beneath the ground in order to support such imposing machines, which can weigh more than 300 tons.

NREL engineers worked with Renewable Energy Systems (RES) Americas, Inc., to pour the large customized concrete foundations for the turbines. The concrete was delivered in July in impressive convoy of more than 80 trucks.

NREL and RES Americas have signed a cooperative research and development agreement to study the design and performance of turbine foundations to increase the reliability of non-turbine components and lower the cost of wind-generated power. RES Americas recently established its U.S. headquarters in Broomfield, Colorado, near the NWTC.

Research questions include structural loads on foundations of operating wind turbines, thermal performance of underground collection system electrical cables, and side-by-side comparisons of alternative wind speed measurement systems.

“This CRADA will result in some of the first-ever measurements of loads inside and under the foundation of an operating wind turbine,” Green said.

After the two new turbines are operating, NWTC engineers will erect two new meteorological towers to the west of the turbines. Each tower will stand 440 feet high and feature more than 60 instruments to collect the most advanced information on the wind, temperature, dew point, precipitation, and other weather features that can influence the performance and lifespan of a wind turbine.

NREL and the wind energy industry are turning to taller towers to characterize the wind resources and conditions higher up where new, larger turbines operate.

The new towers also will feature LED lights that require virtually no maintenance and use a fraction of the energy of conventional lights.

After the towers are completed this fall, crews will remove the red flashing warning lights atop the new wind turbines and three of the existing meteorological towers, too, leaving the NWTC with a total of three lighted towers.



A worker waits for a crane to gently deliver a section of the metal tower supporting a General Electric 1.5 MW wind turbine at the National Wind Technology Center. Credit: Pat Corkery/PIX 16565

### DOE/GE 1.5 MW Vital Statistics

- Hub height – 80 meters (262.5 feet)
- Radius – 38.5 meters (126.3 feet)
- Total ground to tip = 118.5 meters (388.8 feet).

### Siemens 2.3 MW Vital Statistics

- Hub Height – 80 meters (262.5 feet)
- Radius – 50.5m (165.7 feet)
- Total ground to tip = 130.5 meters (428.2 feet).

### Power Generation

- Average US home monthly electricity consumption in 2007 = 936 kWh
- DOE/GE estimated production from DOE/GE turbine at the NWTC\* = 1,600,000 kWh/year (enough to serve 142 homes)
- Siemens 2.3 MW estimated production at the NWTC\* = 2,800,000 kWh/year (enough to serve 249 homes).

\*The NWTC is a testing site. Production at more typical commercial wind farm would be higher.

— Joseph B. Verrengia (Aug. 21, 2009)

## LARGEST WIND R&D STUDY UNDERWAY AT NREL



Colorado Gov. Bill Ritter, NREL Director Dan Arvizu and Siemens Senior Vice President Barry Nicholls flip the ceremonial switch to start the rotors on the new wind turbine. Courtesy of Siemens/PIX 16895

Strong winds are a common research partner for scientists working at NREL's National Wind Technology Center (NWTC). Recently, those gusting Colorado winds helped usher in a new milestone for wind technology research and development. NREL and Siemens Power Generation "flipped the switch" starting the blades on a Siemens 2.3 megawatt wind turbine installed as part of a cooperative research and development agreement (CRADA) for testing turbine aerodynamics, structure, and reliability.

"The state-of-the-art wind turbine you see before us is the focal point for the largest and most significant government-industry wind power R&D project ever to be undertaken," NREL Director Dan Arvizu said. "Under the cooperative research and development agreement we have in place, Siemens Energy, NREL, and the U.S. Department of Energy will put this 2.3 megawatt turbine through all of its paces, in all kinds of conditions, in a rigorous testing regime that will continue for a minimum of three years, at a shared cost of \$14 million."

NREL's Arvizu was joined at a turbine commissioning event by executives from Siemens and the U.S. Department of Energy (DOE), as well as Colorado Gov. Bill Ritter, who lauded the latest partner to join NREL's clean energy research portfolio.

**"The state-of-the-art wind turbine you see before us is the focal point for the largest and most significant government-industry wind power R&D project ever to be undertaken." – Dan Arvizu**

"Siemens joins an inspiring list of visionary companies that are becoming part of Colorado's New Energy Economy," Ritter said. "Together, with public and private partners like these, we are leading America toward a new, cleaner and more secure energy future."

The Siemens 2.3 MW turbine is among the largest land-based turbines deployed in the marketplace. As visitors sat below the massive 331-foot-diameter rotor resting atop a 262-foot tower, event speakers noted the primary objective for the joint NREL-Siemens research is to better understand the aerodynamics of these new, larger-land based machines. Under the CRADA, teams will test the turbine and its features for a minimum of three years involving a full range of real-world operating conditions, including severe weather. To split the cost of the \$14 million research program, Siemens will contribute \$9 million and NREL \$5 million.

"At Siemens, innovation is one of our core values. That's why we are especially pleased to join forces with our nation's leading wind research facility," Senior Vice President of Siemens Energy Barry Nicholls said. "This important new research program will help us further enhance the performance of our turbines and lower the cost of clean, wind-generated power, which in turn will help diversify the overall mix of power generation sources in the U.S."

### New Technology to Be Put through the Paces

NREL engineers began installing the massive turbine this summer. Although similar to turbines currently being used to generate power, the Siemens wind turbine at the NWTC is a late-stage prototype that features a new blade designed to capture more of the wind's energy without increasing the loads that can cause wear on the other turbine parts.

The turbine also is fitted with many instruments that will provide turbine performance data including:

- Aerodynamics
- Power characteristics
- Vibration monitoring
- System fatigue
- Acoustics, and others.

"This is the best place in the world (for these kinds of tests), this is the hot house of aerodynamic and atmospheric research," Siemens Chief Technology Officer Henrik Stiesdal said. "We want pressure and blade variations (data) as it rotates; we want it to be beaten up here. This ... will enable us to reduce the cost of energy."

CRADA partners believe the research will support the wind industry's efforts to enhance the reliability and performance of utility-scale commercial wind turbines. If this is achieved, it will enable the industry to improve its manufacturing processes—another factor that will help continue bringing down the price of wind energy.

“Colorado has the leading corridor for renewable energy R&D in America and the world. And I know this is true because no one has openly disagreed with me,” Gov. Ritter said, smiling. “Our energy future is transforming beneath our feet. Our children and grandchildren will produce and consume energy far differently than we do today.”

In addition to the turbines themselves, NREL researchers are studying the foundations needed to support large wind turbines. NREL and Renewable Energy Systems Americas (RES) have entered into a separate but coordinated agreement to examine the design and performance of turbine foundations, with goals of increasing the reliability of non-turbine components. This will also help reduce turbine installation costs.

### Turbine Helps Green NREL and the Country

The new turbine and other new projects underway at the NWTC will allow NREL to take a significant step forward in generating its own clean electricity. The laboratory has aggressive sustainability goals—including the reduction of greenhouse gas emissions while at the same time meeting the energy needs of NREL’s expanding campus. The Siemens turbine coupled with a recently installed 1.5 MW GE turbine will allow the NWTC to generate more electricity than it uses. DOE and Xcel Energy are negotiating an agreement for surplus energy to be exported and sold to the local utility grid.

Another important goal for the turbine research project is to help policy makers better understand how we can generate 20% of the country’s electricity from wind over the next 20 years.

“Last year, NREL worked with the Department of Energy to publish the most comprehensive examination of wind power potential in the United States,” Arvizu said. “The study for the first time demonstrated that it’s feasible to produce 20% of our nation’s electricity needs from wind energy. And that is a crucial understanding—because achieving 20% wind energy will create hundreds of thousands of jobs, dramatically reduce our greenhouse gas emissions, and help free us from our dependence on foreign fuel supplies.”

Arvizu also noted that with NREL’s participation in these types of CRADAs, the lab will help position the United States as a leader in developing the most advanced wind turbines in the world.



The new turbine will allow NREL to take a significant step forward in generating its own clean electricity. The Siemens turbine coupled with a recently installed 1.5 MW GE turbine will allow the NWTC to generate more electricity than it uses. DOE and Xcel Energy are negotiating an agreement for surplus energy to be exported and sold to the local utility grid. Credit: George Douglas/PIX 16896

The NREL-Siemens CRADA is part of a coordinated wind research program supported by DOE’s Office of Energy Efficiency and Renewable Energy.

### Siemens 2.3 MW Turbine Fast Facts

- Model - Siemens 2.3-101
- Production (NWTC Site) - 2,800 MWh/year
- Production (Typical Site) - 7,050 MWh/year
- Homes Powered (Typical Site) - 630
- Tower Height - 80 m / 262.5 ft
- Rotor Diameter - 101 m / 331.4 ft
- Swept Area - 8k m<sup>2</sup> / 86.2 ft<sup>2</sup>
- Total Height - 131 m / 428.1 ft.

— Heather Lammers (Oct. 23, 2009)

## SCIENCE BOWL IS FUN WITH A FUTURE



Crucibles team captain David Wu congratulates Shreesh Naik on winning the Colorado Science Bowl while teammate Alex Wu looks on. Credit: Jack Dempsey/PIX 16901

Quick—you have just a few seconds to come up with an answer to the following question, “Which of the following terms best describes the albedo of a planet: A) electromagnetic energy B) density C) reflectivity D) absorption”. The answer is... we’ll tell you at the end of this story. High school students from across the country are currently spending hours quizzing each other on questions like this in preparation for the 2009 National Science Bowl.

Don’t jump to conclusions about what you’ll find at the science bowl—it isn’t just honor roll students strutting their stuff through quick Q & A. From tie-dyed lab coats, to duct-tape gladiator costumes, students also creatively express their enthusiasm and excitement for the sciences. “We truly enjoy science,” said Arapahoe High School student Jon Karr, “with science there are so many places you can go in life.”

And there’s an air of sportsmanship both on and off the “field.”

“Our team hasn’t competed in a science bowl before, so some of our team members went and practiced with a team from another high school,” said Peter Eliot, of The Crucibles Science Club.

### More than Competition at Stake

The U.S. Department of Energy began the science bowl tradition nearly 20 years ago as a way to encourage high school students to explore math and science. In fact, these future scientists, engineers and mathematicians came up with

split second answers to questions in physics, math, biology, astronomy, chemistry, computers, and general sciences at the recent NREL-sponsored Colorado Science Bowl.

But, for those watching the friendly competition, there is more at stake.

“The Colorado Science Bowl provides a venue for Colorado’s highly achieving academic students to test their science and math knowledge in a fun and exciting competition,” said NREL’s Education Programs Coordinator Linda Lung. “We are hoping that once these students start college, they will consider internships and eventually employment at the Department of Energy laboratories. These students are the workforce of the future.”

### They’ve Got Goals

The students seem to share the Department of Energy’s goal to see them in science careers. Across the board—from computer science to materials engineering—students at this year’s Colorado Science Bowl are happy to tell you what math, computer or sciences field they hope to pursue after graduation.

“I want to help find environmentally friendly and new ways to find energy,” said Arapahoe High School team captain Alyse White. She participated as a senior in this year’s Science Bowl on a predominately girls team, which that made it in to the final rounds of completion. She plans to enter the University of Wyoming to study courses in renewable energy and petroleum engineering as part of the university’s Energy Resource Science Undergraduate program. She’s also setting her sights on a future at NREL, “I’m hoping to be an intern at NREL and help look for new ways to find energy.”

### Team Spirit and a Love of Science

White’s team from Arapahoe High School did well in the final rounds of the competition, but in the end it was The Crucibles who took home the first-place trophy. The Crucibles entered two teams made up of students whose love of science led them form their own science club in order to participate in this year’s Science Bowl.

“The Crucibles Science team exemplifies the Department of Energy’s goal in forming this competition,” said NREL Education Programs Manager, Cynthia Howell. “Their team spirit and love of science bodes well for the future of science, technology, engineering and mathematics in our country.”

The Crucibles and other future scientists will converge on Washington, D.C., on April 30, 2009, where more than 450 students will compete for the National Science Bowl title.

The answer to the question at the top of this story is: C) reflectivity.

— Heather Lammers (Feb. 6, 2009)

## SOLAR, HYDROGEN MODEL CARS RACE TOWARD NEW ENERGY FUTURE



A fast start is everything when racing renewably fueled model cars at the annual statewide competition for middle school teams on May 16. Woodlands Academy (Castle Rock) students, cheering in yellow T-shirts, won first place in hydrogen fuel cell car design for their model “Tim the Tiny Taxi.” Credit: Jack Dempsey/PIX 16872

**A**fter four weeks of tinkering, seven hours of racing, and more than a few cans of soda, it all came down to this:

Two model solar-powered race cars deadlocked at 5:23 seconds.

“There’s a tie for first place and we need to break it!” thundered announcer James Bosch. “It’s time for a throw-down!”

NREL has hosted the statewide Junior Solar Sprint and Hydrogen Fuel Car Competition for 19 years, and nobody could remember a tighter finish than this year’s event. More than 300 people attended the student races at Dakota Ridge High School, just a few miles south of Bandimere Speedway where conventional drag-racers reach 230 mph.

Students from Bell Middle School in Golden and Drake Middle School in Arvada crouched one more time at the top of the 20-meter rubberized black track, tired and tense.

Race conditions were perfect. The morning’s fog had burned off. The midday skies were clear and the sun was glaring.

### Ladies and Gentlemen, Lift Your Cardboard!

At the horn, the students raised the cardboard covers from their models’ solar panels and the cars were off ... Well, sort of.

Bell’s car #4 lived up to its nickname “Destroyer” as it zipped straight down the strip in 5.12 seconds—its best time of the day.

The Drake car #18 sputtered down the first 10 feet of track before finding its wheels again. It came in a distant second with a time of 10.17 seconds, or nearly twice its normal pace.

Bell’s Josh Van Laar, 13, shielded the delicate car with his oversized hooded sweatshirt as spectators rushed in celebration.

His first words reflected how edgy the competition had become.

“We won this time, right?” he wondered. Only when he saw his teammates A.J. Nadolsky and Nate Medina did he smile.

Nadolsky described their winning car “a plank with a solar panel on it.” They started with a basic car kit and then experimented with different axles, gear ratios and solar panel angles. They added rubber bands to the wheels for traction.

“This time we ran from a dead start with the panel flat,” Nadolsky said. “We had not done that before.”

### Hydrogen Cars Faster by 25%

Competition in the hydrogen fuel cell races was nearly as tight, with 0.64 seconds separating the top three teams.

Manning Middle School car #41, nicknamed “Splatta,” won first place with a time of 5:02 seconds on a 10-meter track—half the length of the solar race.

The winning Manning team was one of several that the Golden middle school fielded. Their renewable energy model car club has 28 students. Students experimented with at least seven designs since January and repeatedly raced against each other to refine their design.

Unlike the solar cars, the winning time in the hydrogen car final was nearly two seconds slower than the best time of the day for a hydrogen car at 3.48 seconds. That mark was set at 10 a.m. under cloudy, cool skies. In contrast, the winning time for a hydrogen car at the 2008 event was 4.63 seconds.

“As the day hot grew hotter, the density of the hydrogen decreased and it was escaping our tanks,” explained Manning science teacher Susan Coveyduck. “And, the track got hot and sticky.”

### NREL’s Education Commitment

The Colorado competition is organized by NREL’s education program, which supports similar competitions in 29 states nationwide. It is designed to generate enthusiasm for science, technology, engineering and math (STEM) skills, as well as extend students’ experiences with renewable energy technologies.

Linda Lung, NREL’s program coordinator for the car competition, said teams often compete for three consecutive years, beginning with a simple design in 6th grade. By the time they reach 8th grade, they have learned how to build a clean-energy racer.

Along the way, their teachers work renewable energy into the science curriculum, too.

“This is a wonderful engineering challenge for middle school students to tackle,” Lung said. “In order to meet the challenges of this new energy future, we want to get solar and hydrogen technologies into the hands of the next generation of scientists and energy decision makers.”

NREL’s Junior Solar Sprint and Hydrogen Fuel Cell car competitions are sponsored by the U.S. Department of Energy, Xcel Energy Foundation, General Motors, Jefferson County Public Schools, The Alliance for Sustainable Energy, LLC and NREL.

— Joseph B. Verrengia (May 22, 2009)



## VETS AND 'GRAY FIELDS' GO GREEN WITH NREL



Graduate Steve Gutierrez smiles after completing green energy training. He's heading to Oklahoma to perform home weatherization audits. Credit: Heather Lammers/PIX 16876

**N**REL had the honor of hosting a special and very green graduation ceremony. The Colorado-based Veterans Green Jobs (VGJ) Academy saw its first class of graduates eagerly take their diplomas as a first step on the road to renewed livelihoods in the green energy economy. The smiles and cheers for the 15 grads who successfully completed a tough eight-week training program were accompanied by speeches vividly lauding the new careers that these veterans had chosen.

"Veterans Green Jobs empowers military veterans to become leaders in the new green economy to embody a new era of shaping swords into plowshares," VGJ Executive Director Brett KenCairn said. "Transitioning from humvees to PVs, from infrared rifle scopes to infrared energy cameras, from Striker Brigades to weatherization teams, these 15 men came from all over the United States and from many different personal circumstances because they believed in this new mission and pledged themselves to learn these new tools."

In his commencement address, Colorado Gov. Bill Ritter praised the former military men for accepting new roles as environmental stewards. "When they returned home from duty, these gentlemen were not done serving our country. They volunteered again, this time, to become leaders in protecting the environment," Ritter said.

### Vets Find Green Opportunities across the United States

Graduate Steve Gutierrez served in the Marines from 1983 to 1987 and is looking forward to another chapter in life his after working a variety of jobs, including construction and sales. "I thought that with all of my experience this is an organization I can be a part of," Gutierrez said. "I find that people open up to me and can tell me about the issues they are having with their homes."

Gutierrez is one of two veterans who will be heading to Oklahoma to help families learn about home energy efficiency, specifically weatherization. Gutierrez and his fellow classmates are graduates of HEAT—the Home Energy Auditor Training

program. HEAT provides the vets with training in energy surveying, auditing, energy conservation and weatherization. The work includes time in classroom as well as the field and lasts about the same time as basic training—only this program is a green "boot camp" where students deploy to work as energy auditors and new home energy rating professionals.

The new grads will soon spread out across the country. Four are planning to work in New Orleans, three will help launch Veterans Green Corps doing forest stewardship work in the Southwest, and four will establish new VGJ programs in green buildings, energy efficiency and working with homeless veterans to replant urban forests. Graduate Joe Stepzinski, who served nine years in the Navy and two years in the Army, is heading to Georgia where he will work on decommissioning projects at the U.S. Department of Energy's Savannah River Nuclear Site. "What I am now doing is environmental stewardship," Stepzinski said. "Thanks to this program, I was able to get a great job—this concept needs to be expanded and more people need to be involved."

### NREL and Vets Green Jobs to Create Clean Energy Training Center

Plans to expand the program are on the horizon. At the graduation ceremony, Gov. Ritter announced that VGJ, in collaboration with NREL Education Programs, will establish Colorado's first National Training and Demonstration Center in Energy Efficiency.

"This initiative will retrofit unused commercial property, for example, a big-box store now standing vacant on acres of empty parking lots," Ritter said. "These gray fields would become green fields of opportunity, retraining not only veterans but other people who might otherwise not have access to training in green jobs."

VGJ, NREL, and other academic partners are currently looking to identify unoccupied industrial and commercial property that can be recycled into the envisioned training center. One area currently under consideration is a vacant Wal-Mart in Lafayette, Colorado. The Wal-Mart Foundation recently awarded nearly \$750,000 to Veterans Green Jobs to support the development of four such training sites. The Colorado site is seen as a potential pilot project that can serve as a model for other regional training facilities.

"NREL Education Programs has placed workforce development as a high priority and an important focus throughout our work," NREL Education Programs Manager Cynthia Howell said. "We could not be more pleased to join forces with VGJ in developing energy efficiency training and outreach programs for Colorado and the nation. NREL will extend its reach locally and nationally as veterans and other intern ambassadors apply energy efficiency and conservation technologies promoted and developed here at our lab."

The training centers, while focusing on immediate workforce development, could also be used as public demonstration and education centers for reuse, energy efficiency and conservation.

"Veterans tell us repeatedly that being able to serve their country through meaningful, restorative work is the most healing thing they could experience post combat," KenCairn said.

— Heather Lammers (June 5, 2009)

## LAWMAKERS VISIT NREL FOR CLEAN ENERGY SOLUTIONS



Idaho State Rep. George Eskridge sifts through a sample of corn stover while listening to a presentation on cellulosic ethanol at the Alternative Fuels Users Facility. In the background is Tennessee State Rep. Jim Hackworth. Credit: Joe Verrengia/PIX 16879

More than half of the states in the U.S. have embraced renewable energy portfolio standards (RPS). Now comes the hard part—complying with those aggressive mandates and building clean energy economies during the deepest national recession in 70 years.

Two dozen lawmakers and legislative staffers from Maryland to Washington state visited NREL for three days to learn about clean energy technologies and market incentives. They are members of a special non-partisan Advisory Council on Energy for the National Conference of State Legislators.

State officials regulate utilities and establish laws that develop markets for renewable energy and energy efficiency. The briefings the council develops with NREL's help will be distributed to state officials nationwide.

"The world's big new renewable energy market is the United States," NREL Director Dan Arvizu told the lawmakers. "If it doesn't happen where you live and in the communities you represent, then it's not going to happen. We have to find ways to move these technologies into the marketplace faster and differently than how we've done it in the past."

### "Everything on the Table"

NREL scientists and analysts presented the lawmakers with in-depth views of clean energy strategies to help their states meet aggressive renewable energy portfolio standards, retool their economies and replenish depleted state budgets—while reducing carbon emissions that threaten the Earth's climate.

Among the programs they visited were the National Center for Photovoltaics, the National Wind Technology Center and wind-to-hydrogen storage, the National Bioenergy Center, including cellulosic ethanol and algae fuels research, and the VIBE virtual dashboard display of state and community biofuels information.

The group also was briefed on new building design, advanced batteries, plug-in hybrid electric vehicles, and analytical

capabilities and tools developed by the Strategic Energy Analysis and Applications Center.

"The timing of this visit is perfect with the Recovery Act programs and the needs of our states," said Kansas State Rep. Carl Holmes, who chairs the council. Holmes' district in southwest Kansas has ethanol plants and wind farms, as well as significant transmission lines.

"If we're going to move forward with the economy and the environment, we need to put everything on the table and work through it," he said.

### Abundant Resources, Pressing Needs

Perhaps the most compelling example is Nevada. It has a RPS of 25% renewable energy by 2025 and some of the nation's best solar and geothermal resources. Utility-scale photovoltaic and concentrating solar power plants are being developed near Las Vegas along with existing hydropower facilities.

But the brilliantly-lit Las Vegas strip also is a symbol of the nation's energy consumption and sustainability concerns. Nevada's economy depends heavily on tourism—Las Vegas alone has 160,000 hotel rooms. Revenues are down 45% from two years ago, and lawmakers have both raised taxes and cut \$1.35 billion in spending, said state Sen. Mike Schneider. He chairs a special state committee on energy, transportation and infrastructure.

Schneider said Nevada is trying to "look at the whole picture"—new utility-scale generation, research funding, workforce training and realistic industry incentives—while absorbing "devastating" budget cuts in social services and other programs.

"We don't just need renewable energy—we need to bring renewable energy manufacturing to Las Vegas," Schneider said. "A PV plant or a wind farm is great, but they don't employ many people. And once they are built, you have a lot of unemployed construction workers."

### For Most, a Portfolio of Answers

Most states have slimmer resources. For lawmakers, pursuing aggressive weatherization and energy efficiency programs—along with smaller, distributed renewable power technologies—became a more appealing combination strategy.

For example, the Maryland General Assembly recently voted to reduce statewide energy consumption by 15% by 2015 and adopted a RPS of 20% by 2022.

Maryland's historic communities are crowded with vintage buildings fitted with out-dated systems in need of weatherization. Its hazy skies can't match Nevada's solar horsepower, but it has enough sunshine for effective distributed PV systems on residential and commercial rooftops. It also has biomass possibilities.

"Now I can go to county commissions in my district and talk with them about new zoning and building codes that can make this possible," said Maryland state delegate Sally Y. Jameson. "I can talk to them about a solar canopy on the parking lot at the mall so we can generate power while we shade vehicles."

— Joseph B. Verrengia (June 26, 2009)

## NREL SUMMER LABS SEASON SCIENCE STUDENTS



2009 Summer Intern Patrick Brown will head to MIT after a summer working in NREL's organic solar cell lab and sharing the results of his carbon nano-tube research.

Credit: Heather Lammers/PIX 16884

No more school, no more books... Students across the country routinely spend their summers avoiding anything that smacks of scholarship, but for a dedicated group of college and graduate students at NREL, summer is embraced as a time of new discoveries and learning.

In June, the National Renewable Energy Laboratory (NREL) welcomed participants into its 2009 summer internship programs. "NREL's intern programs represent one of our greatest R&D workforce and deployment tools; these students become ambassadors for NREL's great work," said NREL Education Programs Manager Cynthia Howell said. "We open our labs to bright young minds who look at our research in new ways and bring new ideas to the table."

NREL's 10-week summer program is well known and students clamor to get into it. "Students get to take knowledge from the classroom and apply it in a real-world setting," Howell said. "At the end of each summer, I have numerous students tell me that they've learned more in just over two months with NREL than in their first years of college."

As summer winds to a close, the interns present research results to the NREL mentors, staff, and other interns. Massachusetts Institute of Technology (MIT) undergraduate

Jennifer Paek said her experience at NREL researching the use of nickel contacts on thin photovoltaic silicon wafers has helped further her desire to work in renewable energy. "The program at NREL is pretty fantastic. It's not many labs that allow students to work on current problems and then give us the opportunity to fix them."

In fact, the students like the program so much that some are repeat researchers at NREL.

### Back for More

Patrick Brown is a veteran; 2009 marks his second summer working as an intern at NREL. "The summer after my junior year I looked into a number of different programs," Brown said. "NREL turned out to be the best choice."

Brown is a recent graduate of the University of Notre Dame and this fall will begin graduate studies at MIT. Over the last couple of summers at NREL, he's been working with carbon nano-structures and this summer expanded his internship to include applying carbon nano-structures to organic solar cells. Brown said that being a NREL intern is educational, no matter how the research goes. "It's tough to complete your project in 10 weeks or to get as far as you want, but you get to learn from other scientists," Brown said. "My results this year didn't turn out the best, but I still learned a lot about the whole process."

In 2008, Brown focused his research on using carbon nano-tubes for hydrogen storage. His work was one of two NREL intern research projects selected through a peer-review process to be presented at the American Association for the Advancement of Science's (AAAS) annual meeting in Chicago. As a result of being selected to present at the AAAS meeting, Brown's research will be published this fall in the U.S. Department of Energy's (DOE) *Journal of Undergraduate Research*.

"This was my first chance to go to a professional conference and present," Brown said. "It was a very good experience and I got to meet other interns from all of the national laboratories."

Brown is certain his time at NREL will boost his academic career. "I hope to be working in the renewable energy field applying nano-technology to solar both in graduate school and as a post doc."

### Some Interns Set Up Shop

Besides having the opportunity to mentor the brightest students in academia, NREL reaps other rewards from the internship program. "We are seeing more summer interns hired on at NREL," said Howell. "It shows the value of the program and how it gives back to the lab."

That's just what happened for 2008 summer intern Jessica Olstad. In summer 2008, she was a student intern while attending Colorado School of Mines working toward her degree in chemical and biochemical engineering. It was after a roommate told her about a great experience at NREL that Olstad decided to apply. She spent her summer developing

"NREL's intern programs represent one of our greatest R&D workforce and deployment tools; these students become ambassadors for NREL's great work." – Cynthia Howell

a carbon dioxide absorbent material that cleans a synthesis gas. In fact, her research into using Lithium Zirconate was so successful, she also was selected to present her findings at the AAAS meeting in Chicago. And, like Brown, her final research paper will be published the *Journal of Undergraduate Research*. But, it turned out that her tenure with NREL was just beginning.

This year when Olstad heard about a job opening at NREL she took notice. "I jumped at the chance to come back," Olstad said. "I really enjoy it here and everyone is great to work with." She was recently hired as a full-time employee at NREL and now splits her time between analyzing biomass catalysts and working in the concentrating solar power program.

"One of my ideal goals was to work in renewable energy and change the world," Olstad said. "I'm glad it's ended up that way."



Jessica Olstad analyzes biomass particles taken from the Thermochemical Users Facility. Once a summer intern, she is now a full-time NREL employee.

Credit: Heather Lammers/PIX 16885

**"One of my ideal goals was to work in renewable energy and change the world. I'm glad it's ended up that way." – Jessica Olstad**

## All Work and No Play?

Although learning and research are key goals for summer interns, getting to know people from all across the country is another bonus to being involved in the program. NREL summer interns network on various social Web sites and according to Brown, have planned group activities that focus on the Colorado outdoors such as camping, hiking and white water rafting. "It's great to get to know people from

all over, and I think many of us will stay in touch after working here," Brown said.

This year's interns will be able to leave NREL with more professional contacts than ever. This year's summer class was the largest in NREL's history with 80 undergrads, graduate students, and postdoctoral students. While the summer season marks a peak in internship program participation, a variety of programs run year-round:

- DOE's Science Undergraduate Laboratory Internship Program (SULI)
- Community College Institute (CCI) for Science and Technology sponsored by the U.S. Department of Energy Office of Science and the American Association of Community Colleges
- DOE Pre-Service Teacher (PST) Internship Program
- NREL's Research Participant Program where university students have the opportunity to participate in the laboratory's research and development programs, initiate new areas of research, and establish a base for ongoing collaborations.

"Of course, this program would not be possible without the full support of NREL, DOE's Office of Science and the amazing scientists and staff here at NREL," Howell said.

— Heather Lammers (Aug. 7, 2009)

## NREL ENERGY EXECS MAKE AN IMPACT NATIONALLY



2009 Energy Execs participants pose for a photo atop the Denver Museum of Nature & Science while on a field trip to learn about this class project which grabbed national attention.

Credit: Heather Lammers/PIX 16887

The National Renewable Energy Laboratory (NREL) is no stranger to the spotlight when it comes to the discussion of renewable energy solutions for the country. But now alumni from the NREL Executive Energy Leadership program (Energy Execs) are also finding themselves in the national spotlight for their energy saving ways.

Energy Execs is a six-month leadership program that gives executives an in-depth look at solar and wind power, biofuels and transportation, and energy efficient building technologies. Participants get first hand briefings by NREL technology experts, visit research laboratories as well as visit working applications of renewable energy technologies in the field. At the end of the program, participants demonstrate what they've learned by presenting a viable project on renewable energy or energy efficiency.

### Energy Exec Project Garners Presidential Visit

The 2009 class got to walk in the footsteps of President Obama when they toured the 100 kilowatt solar array atop the Denver Museum of Nature & Science (DMNS). In February, Obama selected the museum as the location where he signed the American Recovery and Reinvestment Act (ARRA) into law. Just before the ceremony, Obama, along with Vice President Joe Biden and Namaste Solar CEO Blake Jones, walked among the solar panels that showed green energy in practice at the museum. While Namaste solar was recognized for installing the roof-top solar panels, what wasn't publicized was that the solar array was the final project for 2007 Energy Exec grad Dave Noel.

"The people at NREL inspired me to push the envelope," Dave Noel, DMNS vice president of operations, said. "It helped me become a lot more aggressive with what I wanted to do at the museum."

"I came into the program as an engineer with a different perspective than others," he said. "I looked at it as a great opportunity for some technical knowledge, but it was a pretty broadening experience and eye opening to see the related policy issues."

In addition to completing the rooftop solar project at the museum, Noel said the program inspired him to expand his renewable energy knowledge to other projects. The DMNS is in the process of constructing a 100,000 sq foot addition to its exhibit space. Noel is steering the expansion toward LEED® Platinum status from the U.S. Green Building Council and is working toward a zero carbon footprint for the new addition.

"One of the biggest things I took away from the program is that I now have great contacts," Noel said. "I know that if there is something I'm trying to figure out, there's someone I can talk to."

### Tapping Solar in Portland

Another company that is reaping the benefits of having its employees attend the NREL Energy Execs program is ProLogis. ProLogis is headquartered in Denver and provides industrial warehouse and distribution space across the globe. ProLogis has 475 million square feet of this type of space which means it is one of the largest owners of roof space in the world. This vast amount of roof space is what got Drew Torbin, director of global renewable energy for the company, thinking when he participated in the 2007 Energy Execs program and is why his colleague, Matt Singleton, vice president for new development, was a member of the 2009 class.

"The timing was great; I saw a press release for this program just as we were putting together an internal team that would focus on renewable energy projects," Torbin said. "We saw renewable energy as valuable and something we should be spending our time on."

According to Torbin, even though the company had received a variety of ideas and offers for ways to use their roofs across the globe—from large movie posters to cell phone towers—the company held out for the right project.

"We wanted focus on creating value from our existing assets and our roofs and our buildings are perfect for solar," said Torbin. The large, flat roofs make them ideal for rooftop photovoltaic (PV) systems, and their locations near major population centers make good host sites from which to generate and export energy back into the electric grid.

Exporting power from installation sites on ProLogis roofs ultimately creates the greatest impact. While it would be possible for ProLogis' customers inside these distribution centers to use the energy produced, they wouldn't come close to using all of it. The main use for ProLogis' industrial space is storage and distribution, and although the buildings are large, their energy consumption is small, since the buildings typically contains racks upon racks of merchandise and are not air conditioned.

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One of Torbin's recent accomplishments at ProLogis also doubled as his Energy Execs final project, which focused on working with Portland General Electric to install thin film solar panels on three ProLogis warehouses in Portland, Oregon. The 1.1-megawatt solar project is currently the largest thin film PV installation in the Northwest.

But, ProLogis hasn't stopped there. Team members also have worked with Southern California Edison in California to complete a 2.4-megawatt installation—which at the time of installation was the largest single rooftop solar installation in the United States. In total, the company currently has 10 PV projects completed in three continents, resulting in just over 6 megawatts of solar power. These 10 ProLogis PV projects occupy roughly 3 million square feet of roof space. Torbin lightheartedly pointed out that the company has roughly 470 million square feet of roof to go.

"What has really helped us in terms of NREL's Energy Execs program was being able to get out and see the technology as well as take advantage of the people and speakers that are introduced to us," said Singleton. "We have found the Energy Execs program to be such a great value that we believe NREL could easily charge participants to be in the program."

### **NREL Benefits, Too**

2009 marked the third year for the Energy Execs program with a record 31 participants. In 2008, 19 representatives of industry, local government, and non-profit organizations completed the program. The executives' final projects show the success of a program, which in the long run helps NREL technologies make it to the marketplace.

"The NREL Executive Energy Leadership Program offers an important opportunity for community leaders to embrace clean energy technologies," NREL Director Dan Arvizu said. "Moving these technologies to the marketplace at speed and scale requires well thought-out systems and grassroots implementation. Given the increasing interest in our leadership program, I'm confident NREL is on the right path in helping statewide leaders gain access to our important work accelerating clean energy technologies. Energy Execs alumni are emerging as shining stars on the statewide and national energy scene."

### **2009 Executive Energy Leadership Program Participants**

- Tom Acre - Deputy City Manager, City of Commerce City
- Matthew Appelbaum - Mayor, City of Boulder
- Sharon Barrett - Senior Director, Cushman & Wakefield
- Karen Benker - Mayor Pro Tem, City of Longmont
- Jim Benson - City Council Member, City of Commerce City
- Bruce Biggi - Economic Development Manager, City of Greeley

- James Bosch - Visitors Program/National Bioenergy Center, NREL
- Steve Catanach - Light & Power Manager, City of Fort Collins
- Bob Churchwell - City Administrator, City of Burlington
- Peter Dawson - County Commissioner/Chair, Baca County
- Frances Draper - Executive Director, Boulder Economic Council
- Keith Fife - Long Range Planning Division Director, Mesa County
- Robert FitzGerald - City Council Member/Mayor Pro Tem, City of Aurora
- John Hall - Business Development Officer, Office of Economic Development - City of Westminster
- Stephen Hall - Executive Director, Western TechSet
- Anne Hayes - Vice President, Westfield Company
- Michael Kirk - Director of Facilities Services, Larimer County
- Irene Pérez Law - Chief Operating Officer American Solar Energy Society
- Michael Masciola - Vice President, Northern Colorado Economic Development Corporation
- Lisa Nolder - Economic Development Director, Southeast Colorado Business, Retention, Expansion & Attraction (SEBREA)
- David November - Environmental Manager, Keystone & Breckenridge Resorts (Vail Resorts)
- Susan Osborne - City Council Member, City of Boulder
- Frank Phillips - City Council Member, City of Lafayette
- Scott Prestidge - Senate Staff, Colorado Senator Mark Udall
- Scott Randall - Town Manager, Town of Superior
- Kathleen Seelye - Managing Partner, Ricca Newmark Design
- Greg Severance - Director of Public Works, Pueblo County
- Matthew Singleton - Vice President, Project Management, Prologis
- Christopher Smith - Program Manager, Denver Office of Economic Development
- Virgil Turner - Administrative Services Director, City of Montrose
- Debra Wilcox - Vice President, Biofuels Project Manager, Bye Energy, Inc.

— Heather Lammers (Sept. 4, 2009)

## IT TAKES A SOLAR VILLAGE



Team Germany's winning "Cube House" featured silicon and thin-film solar panels on all visible sides of the house. The design's solar panel operates a toy on the front porch of the home. Credit: Stefano Paltera/U.S. Department of Energy Solar Decathlon/PIX 16893

Rain usually spoils a solar power contest. But three days of showers—and thin-film photovoltaic technology—actually helped Team Germany win the 2009 U.S. Department of Energy's Solar Decathlon.

Team Germany's Cube House was one of the most technologically advanced among the 20 clean energy prototype designs on the National Mall. Every exposed face of the building was covered with power-generating panels.

On the roof: a 11.1-kW photovoltaic (PV) system of 40 monocrystalline silicon panels. On the sides: 250 thin-film panels that look like glossy clapboards. The thin films used copper-indium-gallium-diselenide layers, or CIGS.

The combination system was expected to produce 200% of the energy needed by the house. The thin-film panels, while less efficient than conventional silicon, were projected to perform better in cloudy weather than silicon.

Team Germany got its proof on the competition's fifth day when skies turned slate gray and a cold rain splattered the solar village. By late afternoon, as federal commuters started streaming home and electricity demand throughout the city began climbing, the Team Germany house was producing 12.68 kW and consuming 12.33 kW, for a net export of .35 kW.

**"Team Germany built a gingerbread house packed with solar panels. In the rain, the thin-film panels were making electricity. It made the difference."** – Richard King

Team Illinois' house finished a close second, emphasizing energy efficiency over power production.

"Team Germany built a gingerbread house packed with solar panels," said Richard King, DOE Solar Decathlon director. "In the rain, the thin-film panels were making electricity. It made the difference."

### NREL Manages the Decathlon

NREL has managed the biannual Solar Decathlon for DOE since the contest's inception in 2001. Selection of the 20 university teams from North America and Europe begins two years before the actual competition.

The laboratory sent 30 people to run the week-long contest on the National Mall, including installation of the homes with trucks and cranes, connecting them to Washington's municipal power grid, running the judged contests, and monitoring the homes' continual performance.

NREL senior engineer Byron Stafford has managed the Decathlon's technical systems since its inception. Jamming his floppy blue beach hat over his ears and sloshing through deep muddy puddles, Stafford made a beeline for the Team Germany house to confirm the data his equipment was reporting.

"I can't believe they are net exporting in this weather!" Stafford said. "That's totally cool. It's reflective of where the world has gone."

### Glowing with Grid-Connected Power

Inside the Cube House, a wall-mounted control panel showed each side of the house and the roof glowing with power production, even as digital readouts showed appliances and the climate system consuming power by the second. Team

Germany was relaxing around the dining room table in shirtsleeves, relying on dim natural twilight seeping through windows.

"Every 15 minutes I check our systems and what the other homes are doing," Team Germany electrical engineer Andreas Schreiber explained. "Today the light is indirect, so every side of the house is making power."

Being grid-connected and exporting power was the most notable change in the 2009 contest. In previous years, the homes' solar panels charged batteries to power the homes' lighting and appliances.

NREL's Sara Farrar-Nagy, who is the Decathlon's project manager, compared the event to building a new high-tech subdivision overnight in one of the world's most iconic and supervised locations—between the U.S. Capitol and the Washington Monument and across from the Smithsonian Institution's "Castle" headquarters.

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Complicating the laboratory's efforts was the local utility's older transmission network that, like most municipal power grids, was established decades ago to deliver power to customers, but it was not built for two-way power flows.

"One house pushing power back onto the grid is no big deal," Farrar-Nagy said. "But on sunny days this week, all of the homes were exporting power. It was a quirky challenge. Building a grid-connected contest is a real accomplishment."

## Real World, Zero Energy

In the Decathlon, 20 teams of college and university students compete to design, build, and operate the most attractive, effective, and energy-efficient solar-powered house.

In addition to educating the next generation of renewable energy engineers, architects, and green builders, the Solar Decathlon is intended to propel solar energy and energy efficient products into the marketplace and to demonstrate to the potential of zero energy homes.

Some of the homes in the competition already have been sold or donated for public and private use. The Rice University "ZeRow House" is scheduled to be relocated to that city's Third Ward in cooperation with Project Row House, a non-profit.

The Rice House finished eighth in the competition, but at about \$200,000, it cost one-quarter of the Team Germany's winning design. It emphasizes skylights over windows and reduces the house's total energy use for lighting fixtures to the equivalent of three 100-watt light bulbs. The PV system is rated at 4.2 kW—a fraction of the German system, but is appropriately sized for the expected load of the house.

"The Rice team did amazing things with limited lighting and no windows on three sides," Farrar-Nagy said. "It's a testament to what is possible. A real family is going to live in that house in Houston."

**"The Rice team did amazing things with limited lighting and no windows on three sides. It's a testament to what is possible. A real family is going to live in that house in Houston."** – Sara Farrar-Nagy

## Today's Students Explore Their Future Homes

More than 200,000 people visited Decathlon homes in 2009—including Energy Secretary Steven Chu, members of Congress and other dignitaries, as well as thousands of schoolchildren. Even on rainy days, visitors with umbrellas waited for 30 minutes outside each of the homes.

Parkland Middle Magnet School of Rockville, Maryland, closed for a day so it could send all 700 of its students to tour the Decathlon homes. The students split into small groups to interview university team hosts and complete homework assignments.

The middle school students were drawn to the prominent flat-screen TVs, sliding room dividers, and touchpad controls for lighting and climate systems. Predictably, they skipped past the energy-efficient laundry centers.

At the Ohio State University house, students pointed to juxtaposition of century-old reclaimed barn siding with new silicon solar panels that are not encased in a sealed frame. With the backside of the panels exposed, sunlight reflects off the home's white roof to the cells and generates up to 4% additional power.

"When I grow up I think this is going to be like my college dorm room," said Joi Rice, 11.

"I like this house because I can watch the TV while I'm in bed," said Andy Zhang, 12.

"The California house, because it was more spacious," said Sayer Sampson, 12. "I think it looks better."

"I already live in a small home so this would be OK," said Lilly Diaz, 11. "I like the touch pads."

## 2009 Solar Decathlon House Rules

- Maintain an average indoor temperature of 72°F–76°F (22°C–24°C)
- Maintain humidity of 40–55%.
- 800 square feet
- Wash and dry 10 loads of laundry during the contest
- Operate refrigerator and freezer between 40° and -5°F.
- Run dishwasher during contest
- Run the television 6 hours per day
- Cook and host an evening dinner party.

— Joseph B. Verrengia (Oct. 16, 2009)



## GENERATION-Y START-UP STUNS NREL GROWTH FORUM



Judges mark their scorecards after an entrepreneur's presentation at the 22nd Industry Growth Forum. The forum featured 32 competitive presentations by start-up companies seeking financing. The judges were from private investment and clean energy firms. Credit: Pat Corkery/PIX 16897

**E**covative won the NREL Growth Forum!"

Fingers flying on his cell phone, Ecovative Design co-founder Eben Bayer was tweeting news of his start-up's stunning victory at NREL's 22nd Clean Energy Growth Forum even as potential investors were circling him at the awards banquet and slipping business cards under his dessert plate.

Bayer and Ecovative co-founder Gavin McIntyre make organic, compostable insulation and shipping packaging made from fungal mycelium—billions of threadlike mushroom roots—and agricultural wastes such as rice hulls and cotton gin trash. Their bio-manufacturing process uses about 10 times less energy per unit of material than the manufacture of synthetic foams using fossil fuels.

And unlike other green packaging, their product can be custom-molded while also offering thermal protection.

"Winning the NREL growth forum is very important validation of our product and our company," said the 24-year old Bayer, whose Generation-Y business was incubated while he and McIntyre were students at Rensselaer Polytechnic Institute in upstate New York. "It changes how we are perceived by investors and the clean energy industry."

**"We need to approach energy differently and the key will be innovation. This forum brings together the clean energy innovators, investors, and policymakers needed to bring about transformational change."** – Dan Arvizu

### Forum Raises \$2.5 Billion

NREL's 2009 Clean Energy Industry Growth Forum attracted nearly 600 investors, entrepreneurs, scientists, and policy-makers. Since 2003, more than \$2.5 billion has been raised by companies presenting at the forum.

The three-day conference highlighted clean energy industry technology and business developments. The forum featured new programs such as seminars on partnering with the laboratory in research and commercialization agreements, as well as a "speed dating" format that helped entrepreneurs briefly meet with many potential investors.

In opening remarks, NREL Director Dan Arvizu directly challenged forum participants to compete differently in the clean energy marketplace.

China, India, Brazil, and other nations already are embracing existing renewable energy technologies both as a source of carbon-free power and economic growth, while the United States has slipped behind many nations in clean energy generation and manufacturing.

Jobs and growth must come from the next generation of clean energy technologies that NREL is helping to both develop and commercialize, Director Arvizu said.

"China is particularly alarming," he told the forum. "Of the top 10 photovoltaic companies in the world, five are in China. They are manufacturing technologies that were developed here in very high volumes.

"We need to approach energy differently and the key will be innovation. This forum brings together the clean energy innovators, investors, and policymakers needed to bring about transformational change."

### Hundreds of Applicants, Three Winners

At the forum, 34 companies were selected from 285 applicants to present their business plans to panels of judges. Three firms won 2009 Clean Energy Venture Awards sponsored by NREL and Deutsche Bank Climate Change Advisors.

Cash prizes include \$10,000 for Best Venture and \$5,000 each for the two Outstanding Ventures. NREL provides the winners with in-kind commercialization support matching the cash award to help increase their chances of commercial success.

Ecovative Design of Green Island, New York, took the top prize as the Best Venture.

Exro Technologies of West Vancouver, British Columbia, Canada, won an Outstanding Venture award for its unique electrical generator capable of delivering double-digit increases to the annual kilowatt hours produced out of a wind turbine, or tidal and current turbines, without increasing

capital costs. Exro has raised \$2.5 million and is seeking another \$10 million in outside financing.

Evolutionary Genomics of Lafayette, Colorado, also won an Outstanding Venture award for developing and successfully patenting a cost-effective technology to identify key genes that control fundamental biofuel plant and algae traits. Evolutionary Genomics was recognized at the 2008 forum. The firm has raised \$7.7 million and is seeing another \$3 million in Series B financing.

### Promising Innovations, Difficult Economy

Presentations of promising clean energy technologies were balanced by sobering comments by some of clean energy's most prominent investors.

The global recession has reduced large institutional investors in the sector from 16 in 2007 to just six in 2009. Private investors told the forum they are seeking deeper and more detailed information from start-ups because their portfolios have shrunk and their margin for investment error has been erased. Even solar projects in the desert southwest are having difficulty finding financing right now, they said.

Yet demand for renewable energy technologies remains high, with backlogs for wind turbines, solar panels, and related equipment running as high as two years in some cases.

And, two-thirds of the 50 U.S. states have adopted renewable energy portfolio standards and other policies to establish clean energy markets over the next two decades.

"Just as the renewable energy industry was growing for the first time, we fell off a cliff," said Jeffery Leonard, CEO of the Global Environmental Fund. "But the key government mandates will change markets. There is a revolution going on."

**"Just as the renewable energy industry was growing for the first time, we fell off a cliff. But the key government mandates will change markets. There is a revolution going on." – Jeffery Leonard**

The recession's hangover could be felt during the company presentations, as panels of judges sharply questioned entrepreneurs about their revenue projections, potential competitors

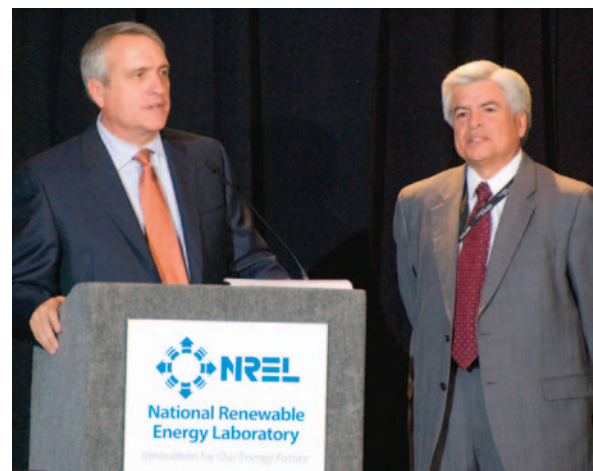
and manufacturing risks. Companies that came to the forum less prepared may have left disappointed. But even award winners such as Ecovative's Bayer said the judges' cross-examination "really bored into the details" of his company.

"They all were sitting there very straight-faced and I definitely didn't feel as if I was nailing it," said Bayer. So far, his company has received \$1.15 million in grants and awards. He is seeing \$3.65 million in early stage

financing to build a scalable manufacturing plant closer to agricultural feedstock sources.

"One of the judges was incredibly knowledgeable about Styrofoam manufacturing," Bayer said, with a weary shake of his head. "Our technology is disruptive and we have to prove that our product is 1,000% better."

— Joseph B. Verrengia (Nov. 6, 2009)



Colorado Gov. Bill Ritter, left, and NREL Director Dan Arvizu field questions about the clean energy economy at the 22nd Industry Growth Forum in Denver. The forum is organized by the laboratory.

Credit: Pat Corkery/PIX 16898



**National Renewable Energy Laboratory**

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