LAWRENCE BERKELEY NATIONAL LABORATORY

Environmental Energy Technologies Division

NEWS

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This month, *EETD News* highlights some of its research activities in fuel cells; an energy efficiency expert describes how Japan can save energy in a hurry to help offset supply losses from Fukushima; and a lighting expert discusses why fluorescent lighting is still alive and well. Also covered: a report on the effect of solar PV installations on home resale value, measuring the usability of programmable thermostats, and a self-cleaning nanostructure coating technology, now available for licensing, that can help keep solar thermal plants dust-free and operating at their optimum level.

If you are new to EETD News, please subscribe [http://eetd.lbl.gov/newsletter/sub/newsletter_signup.php].

—Allan Chen

EETD News reports on research conducted at Lawrence Berkeley National Laboratory's Environmental Energy Technologies Division, whose mission is to perform research and development leading to better energy technologies that reduce adverse energy-related environmental impacts. The Division's staff of nearly 400 conducts research on energy efficiency in buildings, indoor environmental quality, U.S. and international energy issues, and advanced energy technologies. The newsletter is published online once a quarter. For more information, contact Allan Chen, (510) 486-4210.

The *Center for Building Science News* was published between 1993 and 1998. It covered news of the Division's research in energy efficiency and buildings, the indoor environment, and energy analysis. You'll find all back issues, from Winter 1993 through Summer 1998, available here [http://eetd.lbl.gov/newsletter/cbs_nl/cbsnews.html].

Spring Newsletter: Vol. 9, No. 4 [http://eetd.lbl.gov/newsletter/nl35/]
Environmental Energy Technologies Division News [http://eetd.lbl.gov/newsletter/]

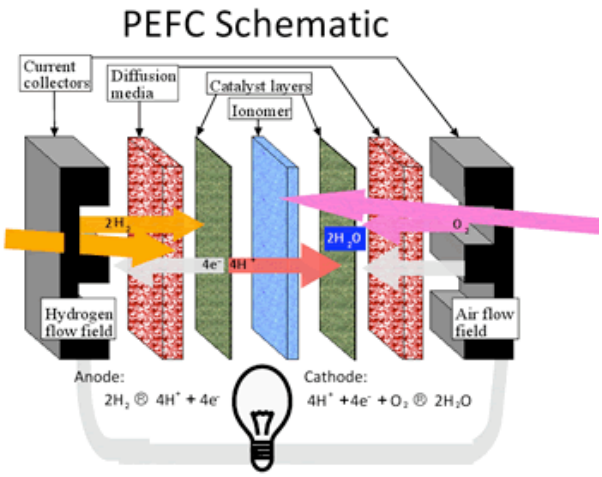
LAWRENCE BERKELEY NATIONAL LABORATORY

Environmental Energy Technologies Division

NEWS

Berkeley Lab Research Helps Fuel Cells Meet Their Potential

Fuel cells as a power generator simply look too good to be true. They're quiet, they don't produce criteria pollutants, and they're efficient electricity producers. They can be placed right next to a building without adding miles of transmission lines, and they won't bother passers-by any more than a fire hydrant or a dumpster—less than a dumpster.



Schematic view of a proton-exchange-membrane fuel cell (PEMFC).

But they're not the perfect power source, not yet. They cost too much for some applications, lifetime issues still need to be resolved, and some units are too large for their desired applications. So although the technologies have powered buildings and buses for years (even lighting the Academy Awards last year), there are challenges to meet before they fulfill their potential.

That's where Lawrence Berkeley National Laboratory's (Berkeley Lab's) Fuel Cell program comes in. Located in the Environmental Energy Technologies Division, Berkley Lab's fuel-cell researchers work with the U.S. Department of Energy and industry partners to address fuel-cell challenges. Adam Weber, program manager and one of the two primary principle investigators for Berkeley Lab's fuel-cell work, is confident that they will play a strong role in providing energy in the twenty-first century.

"Performance is getting better, and there are viable devices for a lot of applications," he says. "There is a rich market out there today for fuel cells in fleet and industrial applications, and many more opportunities in the future."

Some prominent corporations tend to agree. Google, Staples, FedEx, and eBay are all using fuel cells to power facilities. In 2011, healthcare leader Kaiser Permanente plans to install fuel cells at seven of their facilities around California, amounting to a total of 4 megawatts (MW) of capacity.

Weber's program has expanded over the past four years. While much of the research is funded by the Office of Fuel Cell Technologies of the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy, some of the funding increase is the result of partnerships with commercial enterprises interested in improving fuel-cell performance to meet their products' needs.

"We've established a number of successful partnerships with companies such as Toyota, 3M, and Ballard," says Weber. "It's interesting work."

Berkeley Lab Fuel Cell Projects

Fuel-cell research at Berkeley Lab is divided into roughly two areas. Weber's area concentrates on performance and diagnostics issues, using such techniques as mathematical modeling to examine transport within cells, and on establishing diagnostics to evaluate performance. John Kerr heads the other group, which studies membrane synthesis and new materials development for

non-precious metal catalysts. Collaborations are an essential part of Berkeley Lab's fuel-cell work. Both groups collaborate extensively with outside national laboratories, industry, and academia, as well as with internal collaborators from the Earth Science, Materials Science, and Chemical Science Divisions.

Although a variety of fuel cell technologies exist, most fuel cell research at Berkeley Lab focuses on proton-exchange-membrane fuel cells (PEMFCs), with some work also being done on solid-oxide fuel cells (SOFCs). Berkeley Lab researcher Michael Tucker heads the SOFC work, which he brought over from the Material Sciences Division.

Currently, seven projects are underway, and others are being developed, to help solve practical fuel-cell issues. For example, fuel-cell performance is reduced at low temperatures, especially with the nanostructured thin-film catalysts that are an order of magnitude thinner than traditional catalyst layers. These thin-film catalysts perform as well as traditional ones, but allow the fuel cell to require less platinum. However, at subzero temperatures, there is a possibility of ice formation. This complicates the already complex water and thermal management issues of keeping the membrane hydrated and conductive without flooding the catalytic reaction sites with water. Researchers are evaluating PEMFC performance at low and sub-zero temperatures with the goal of finding solutions to this critical barrier.

In another two projects, Berkeley Lab is working with Los Alamos National Laboratory (LANL) to understand fundamental PEMFC degradation mechanisms. One issue they are examining is the fundamental nature of the proton exchange membrane (PEM), which is the heart of the fuel cell. Studies in Weber's lab and at Berkeley Lab's Advanced Light Source are revealing insights into PEM water-sorption behavior and combined mechanical and chemical durability. The activities with LANL also include analyzing the efficacy and real-world applicability of accelerated lifetime tests. Researchers are gathering fuel cell data from buses in field service and linking that information with lab data to see how well the protocols evaluate lifetime performance.

Manufacturing costs can make or break an energy technology's marketability, and fuel cells are no exception. In collaboration with the National Renewable Energy Laboratory (NREL), Berkeley Lab is examining PEMFC manufacturing to develop ways to detect defects such as pinholes in membranes and platinum-loading variations. The project is working to develop online diagnostics and to better understand how these defects affect performance.

Department of Energy-funded fuel cell research has traditionally focused on transportation applications, and much of Berkeley Lab's fuel-cell work has shared that focus. However, DOE is expanding that vision to include industrial equipment such as forklifts, and the Lab is a big part of this research. In collaboration with Nuvera Fuel Cells, Berkeley Lab is conducting a project to improve PEMFCs for both the automobile and forklift markets. The concept is that one can reduce cost if fuel cells can be operated at higher current densities and slightly lower efficiency from smaller cell size. However, there are implications for heat and thermal management. They include membrane dehydration and too much self-heating.

To evaluate those issues, Weber's group is developing submodels of membrane and catalyst layers that work with a model developed at the University of Tennessee, Knoxville. Modeling has shown that the thin coating of membrane in the catalyst layer can result in unexpected mass-transport limitations, where reactant oxygen gas cannot reach the reaction site; an effect that is especially apparent with lower platinum loadings. The study has also shown that extrapolating from high-loading to low-loading situations does not produce accurate performance measurements; performance is fundamentally different at high and low loads.

"The primary application of most of the work is transportation," says Weber. "But if it works for transportation, it can work in stationary applications as well."

While most of Berkeley Lab's fuel cell projects address current challenges faced by the fuel-cell industry, some look at more basic science. For example, the Lab is currently engaged in a project with Sandia National Laboratory to model how water exits a PEMFC gas-diffusion layer. The research team is developing an experimental technique to quantify the energy required for a droplet to leave the surface, with the aim of optimizing water removal and increasing fuel-cell performance.

Fuel Cell Vehicles

A hydrogen fueling station is slated to open in Emeryville, California (near Berkeley) soon, and once it does, Weber's group is in talks to get a fuel-cell vehicle from Mercedes Benz for technical validation and to evaluate its real-world response under daily driving conditions. "Once we get the vehicle, I'm interested in having people drive it as much as possible, to give fuel cell vehicles more visibility in the community," says Weber. "These vehicles show great performance and good long-term durability, and when mass-produced in high volumes, the stacks are expected to cost in the range of $50/kW."

Fuel Cell-Like Systems

In addition to the primary PEMFC and SOFC systems, Berkeley Lab is also working on very similar systems that use essentially the same framework (and sometimes materials) as those of fuel cells. Examples include work now ongoing on hydrogen/bromine flow batteries for grid-level energy storage. This work is funded by DOE's Advanced Research Projects Agency - Energy (ARPA-E), which seeks innovative and game-changing research ideas.

"The hydrogen/bromine flow battery is essentially a reversible fuel cell, with many of the same components but different issues," says Weber.

Another system similar to a fuel cell is a design being considered in the Joint Center for Artificial Photosynthesis (JCAP), one of DOE's Energy Innovation Hubs, led by CalTech in association with Berkeley Lab and other California research institutes. The produced hydrogen from the artificial photosynthesis can be used in typical PEMFCs, and the actual cell design is similar, except that the electricity is generated internally within the membrane from solar irradiation.

Worldwide Interest in Fuel Cells

Competition in the fuel cell market has increased, with worldwide fuel cell shipments now surpassing those of the United States. In recent years, Japan, China, Korea, and Germany have all increased production of fuel cells and their underlying hydrogen infrastructure. In Japan, they are even selling fuel cells for residential use. Called ENE-FARM, they are marketed as a natural-gas-fueled home cogeneration that produces electricity and hot water.

"There are so many applications for fuel cells—in transportation, industry, appliances, and buildings. Their potential growth is immense as a clean energy conversion technology," says Weber. "Our work here is fundamental in supporting that growth by helping to diagnose and eliminate performance and durability problems."

—Mark Wilson

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This research is funded by the Office of Fuel Cell Technologies of the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy and partnerships with companies including Toyota, 3M, and Ballard.

LAWRENCE BERKELEY NATIONAL LABORATORY

Environmental Energy Technologies Division

NEWS

Measuring the Usability of Programmable Thermostats

That fancy programmable thermostat on your living room wall, the one with a backlit digital screen, several tiny buttons, and unintelligible instruction manual, may be making it more difficult to save energy.

A research team at the Lawrence Berkeley National Laboratory (Berkeley Lab) is beginning to figure out why. They are determining how to measure the usability of a thermostat—that is, the ease of accomplishing the things people want to do with them, like switching them on and setting back the temperature while away. This research will lead ultimately to heating controls that do a better job of regulating your home's temperature as energy-efficiently as possible.

Programmable thermostats were originally promoted as an energy-saving technology that would help homes use heating energy more efficiently by regulating temperature automatically. People frequently forget to adjust their older-technology manual thermostats whenever they left the house.

But in 2008, the ENERGY STAR program concluded that homes with programmable thermostats were not saving as much energy as expected—and might even be using more compared to homes without them. The suspected cause was that people were programming their thermostats incorrectly, or not bothering at all. They terminated the existing thermostat program and began developing a new specification.

Alan Meier, of Berkeley Lab's Environmental Energy Technologies Division, began a project to understand how people actually use thermostats in their homes, and to develop a way of quantifying thermostat usability.

Meier's team first sought to document the extent of current usability problems. One survey revealed two striking facts: half of the homes had their thermostats set to long-term hold, and 20 percent had the wrong time of day set on their thermostats' internal clocks. Long-term hold erases the energy-efficiency benefits of programming a temperature setpoint by leaving it at the same temperature, no matter the day or time. Leaving a thermostat set to the wrong clock time has a similar effect. It negates the programming that's intended to turn the heat down at times of the day when not needed.

The team gathered these data through an online survey they designed using the Amazon Mechanical Turk program. This tool allows those who respond to receive a small payment after carrying out a set of tasks. The responders were asked, in this survey, to take and upload a picture of the home's thermostat (which supplied the actual clock time) and answer some questions about the device's settings. In 24 hours, Meier's team had 63 responses from around the United States.

By using this program, the team demonstrated a totally new approach to gathering information, one that other research groups might replicate.

In a separate survey, a crew weatherizing homes in Minnesota recorded information about the thermostat in each home they visited, and supplied the data to Meier's study. Out of 20 homes visited, the crew found that about half had the thermostat set to indefinite hold, and one home actually had the thermostat switched off.

Although these samples are small, the results are striking. "If these numbers are anywhere near the same on a national scale, it's clear that millions of homes are not getting the benefits of energy savings that are possible from a fully programmed, functioning thermostat," says Meier.

Designing a Usability Test

Next, the team turned to the problem of figuring out how to measure usability in a thermostat. "We asked, 'is it possible to quantify the confusion, annoyance, and lack of clarity in some designs of thermostats?'" says Meier.

They set up a test facility with five models of thermostats—four of them wall boxes, and one a new type of thermostat with a control interface displayed on a computer screen. The wall boxes were mounted at heights that are typical of actual home installation, forcing users to stand while performing the test actions. The 32 study participants were asked to perform six adjustment and programming tasks on each thermostat, including setting the correct time and setting the thermostat from "off" to "heat." The test subjects were given no training in how to use the thermostats, as would be the case in real life.

The study team made videos of the test subjects as they tried to accomplish each task—372 videos in all. These videos revealed that the time required to accomplish a task, such as setting the clock time or programming a setpoint for a certain hour, varied wildly. Some people accomplished the task in twenty seconds, others took many minutes, and some never figured out how to program it. And the time it took to perform a particular task varied from one make and model of thermostat to another.

The research team then compared the time it took to complete each of the six tasks and the average time to complete each task by model. There were distinct differences in how fast the same task took test subjects when using the various models of thermostats tested. In fact, the research team was able to rank-order the five models in terms of their usability. Using the raw data, they also developed a quantitative metric of usability.

"Our study has demonstrated that it is possible to develop a metric and measure the usability of thermostats," says Meier, "and we think that the same approach can be used for the usability of other controls such as TV sets, heat pump water heaters, and lighting controls."

"We've also learned that many homes fail to use the features of programmable thermostats, and so are probably not getting the benefits of automatic energy management and the energy savings that they are capable of providing."

Meier added, "We weren't aiming to change anyone's behavior, but we can facilitate energy-saving behavior by minimizing barriers."

The team is now working to expand their user surveys of thermostat operation to more homes and developing a usability metric for other appliance controls where settings can strongly influence energy consumption. One intention is to develop a computed "score" based on the usability metrics they developed.

Researchers who participated in the project are: with Cecilia Aragon of Berkeley Lab's Computational Research Division, Therese Peffer and Daniel Perry of the University of California (UC), Berkeley, and Marco Pritoni of UC Davis.

—Allan Chen

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A talk on this research at UC Berkeley's Center for Information Technology Research in the Interest of Society is available here [http://www.youtube.com/watch?v=KCzCPvjkWIg].

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LAWRENCE BERKELEY NATIONAL LABORATORY

Environmental Energy Technologies Division

NEWS

Berkeley Lab Study Finds That Residential Photovoltaic Systems Boost the Sales Price of California Homes

New research by scientists at the Lawrence Berkeley National Laboratory (Berkeley Lab) finds strong evidence that homes with solar photovoltaic (PV) systems sell for a premium over homes without solar systems. "We find compelling evidence that solar PV systems in California have boosted home sales prices," says lead author Ben Hoen, a researcher in Berkeley Lab's Environmental Energy Technologies Division (EETD). "These average sales price premiums appear to be comparable with the average investment that homeowners have made to install PV systems in California, and of course, homeowners also benefit from energy bill savings after PV system installation and prior to home sale."

The research finds that homes with PV in California have sold for a premium (expressed in dollars per watt of installed PV) of approximately $3.9 to $6.4/watt (W). This corresponds to an average home sales price premium of approximately $17,000 for a relatively new 3,100 watt PV system (the average size of PV systems in the Berkeley Lab dataset). That amount compares to the average investment that homeowners made to install PV systems in California—approximately $5/W over the 2001-2009 period.

"This is a sizeable effect," says Ryan Wiser, an EETD scientist and co-author of the study. "This research might influence the decisions of homeowners considering whether or not to install a PV system and of home buyers considering whether to buy a home with PV already installed. Even new home builders that are contemplating PV as a component of their homes can benefit from this research."

Approximately 2,100 megawatts (MW) of grid-connected solar PV have been installed in the United States. California has been and continues to be the country's largest market for PV, with nearly 1,000 MW of installed capacity. California is also approaching 100,000 individual PV systems installed, more than 90 percent of which are residential. Though an increasing number of homes with PV systems have sold, relatively little research has been performed to estimate the impacts of those PV systems on home sales prices.

The Berkeley Lab research is the first study to empirically explore the existence and magnitude of residential PV sales price impacts across a large number of homes and over a wide geographic area. The research analyzed a dataset of more than 72,000 California homes that sold from 2000 through mid-2009—approximately 2,000 of which had a PV system at the time of sale. "This is the most comprehensive and data-rich analysis to date of the potential influence of PV systems on home sales prices," says co-author and San Diego State University Economics Department Chair Mark Thayer.

The research controlled for a large number of factors that might influence results, such as housing market fluctuations, neighborhood effects, the age of the home, and the size of the home and the parcel on which it was located. The resulting premiums associated with PV systems were consistent across a large number of model specifications and robustness tests.

The research also shows that as PV systems age, the premium enjoyed at the time of home sale decreases. Additionally, existing homes with PV systems are found to have commanded a larger sales price premium than new homes with similarly sized PV systems.

"One reason for the disparity between existing and new homes with PV might be that new home builders also gain value from PV as a market differentiator that speeds the home sales process, a factor not analyzed in the Berkeley Lab study," says Berkeley Lab researcher and co-author Peter Cappers. "More research is warranted to better understand these and related impacts."

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Additional information:

- *An Analysis of the Effects of Residential Photovoltaic Energy Systems on Home Sales Prices in California* [PDF [http://eetd.lbl.gov/ea/emp/reports/lbnl-4476e.pdf]]
- Two-page summary of the report's key findings [PDF [http://eetd.lbl.gov/ea/emp/reports/lbnl-4476e-rs.pdf]]
- DOE's Solar Energy Technologies Program [http://www1.eere.energy.gov/solar/]
- National Renewable Energy Laboratory [http://www.nrel.gov/]
- Clean Energy States Alliance [http://www.cleanenergystates.org/]

This work was supported by the Office of Energy Efficiency and Renewable Energy (Solar Energy Technologies Program) of the U.S. Department of Energy, by the National Renewable Energy Laboratory, and by the Clean Energy States Alliance.

LAWRENCE BERKELEY NATIONAL LABORATORY

Environmental Energy Technologies Division

NEWS

Saving Electricity in a Hurry: Tokyo Has Done It Before and Can Do It Again

Not long ago, Japan faced a major power crisis. In September 2002, the Tokyo Electric Power Company (TEPCO) was forced to shut down 17 nuclear power plants for emergency safety inspections.

The winter of 2002-2003 was approaching, and the plants, which were expected to remain closed for months, turned out to be unavailable through summer 2003, a time when demand from summertime air conditioning would normally require those plants to be operational to meet demand.

How Tokyo successfully found ways to conserve electricity and avoid blackouts for months, even without 17 nuclear plants, is related in the book *Saving Electricity in a Hurry*, published by the International Energy Agency (IEA).

The book was researched and written by Alan Meier, a scientist in the Environmental Energy Technologies Division of Lawrence Berkeley National Laboratory, while he was on leave as a senior advisor at the IEA. One of the other ten "vignettes" examines how California coped with its electricity crisis of 2000-2001.

Among the many challenges faced by Japan today in the aftermath of its earthquake-tsunami-nuclear plant crisis is the problem of meeting electricity demand after the loss of power from its stricken plants. "Today's supply-demand situation in Japan is almost a repeat of 2003 but without the luxury of advance warning," says Meier. At that time, TEPCO was concerned about the summer, because it anticipated a peak demand of 64.5 GW (gigawatts, or trillion watts of electricity), and without the 17 nuclear plants, it would be 15 percent short of capacity.

In late 2002, TEPCO began negotiating for additional supplies from neighboring utilities. However, the ability to trade electric power is limited because, as the book notes, "there is relatively little transmission capacity between Japanese utilities." TEPCO and utilities to its east operate at 50 hertz (Hz), and western Japanese utilities operate at 60 Hz, making it impossible to transfer power between these regions.

Hastening the opening of new thermal power plants under construction would not get the needed spare capacity by summertime, so in January 2003, TEPCO began to encourage its customers to conserve energy, and the Japanese government launched its own media campaign. By April 2003, all 17 nuclear plants were shut down.

"With the looming threat of power cuts," says the book, "manufacturers began reviewing their production schedules. Toshiba, Hitachi, and Kobe Steel created plans to increase production at night or on weekends, when electricity demand is lower."

A TEPCO spokesperson providing an update during Tokyo's 2003 power shortfall.

Some factories planned to use less electricity in areas where it would not affect production; others switched off air conditioners or moved their setpoints higher. TEPCO teams visited large customers to help them develop conservation plans, while the government formed energy-saving teams (led by a popular Japanese actress) to visit local companies and shops, asking them to help out by conserving.

As the air conditioning season began in June, TEPCO offered electricity demand information on television every day. They also started a website that displayed power demand and available capacity in real-time. This was modeled on a website created by Meier and a Berkeley Lab team during California's own electricity crisis of 2000-2001. (California's electricity demand and capacity are now tracked and displayed in real time by the California Independent System Operator [http://www.caiso.com].)

TEPCO's program to save electricity in a hurry was a success. The company estimated that it saved 1.4 GW by adjusting its contracts with large industrial and other customers, and another 1.3 GW from other conservation programs for non-industrial customers. But, perhaps more important, Tokyo got a break from the weather, when the summer proved to be cooler than normal, and peak demand never exceeded 57 GW.

The combined 2.7 GW savings was about 4.5 percent of TEPCO's peak demand of 60 GW. Some mothballed thermal power plants returned to service later in the summer, and the utility declared the crisis ended in September.

A survey conducted by the Center for Consumer Studies of Dentsu, Inc. found that 80 percent of respondents claimed to have taken measures to reduce their electricity use—77 percent by dimming lights, 60 percent by raising the setpoint of air conditioners, and 50 percent by reducing air conditioning use.

"These savings were probably enough to have prevented blackouts," said Meier, " But it's difficult to be sure because of the cooler than normal summer."

In 2008, Meier was able to apply the lessons of his IEA study to help the city of Juneau, Alaska, with its own power crisis. There, an avalanche severed the electrical transmission line that supplied 85 percent of the city's electricity needs. Meier flew to Juneau and advised city leaders on how they could save electricity in a hurry. Juneau managed to reduce its electricity use by 30 percent. That story is told here [http://www.lbl.gov/publicinfo/newscenter/features/2008/EETD-alaska.html].

Meier believes that Tokyo can save electricity in a hurry again. "The first step is establishing a positive, constructive, electricity-saving campaign that makes the consumers feel like they are part of the solution," he says.

Meier adds, "A tragedy caused the problem, but now we need to avoid compounding it."

—Allan Chen

Additional information:

- Download the book *Saving Electricity in a Hurry* [PDF [http://www.iea.org/textbase/nppdf/free/2005/savingElec.pdf]]
- Read the article, "Powering Down in Juneau [http://www.lbl.gov/publicinfo/newscenter/features/2008/EETD-alaska.html]"

LAWRENCE BERKELEY NATIONAL LABORATORY

Environmental Energy Technologies Division

NEWS

Berkeley Lab Develops Antifogging Coating With Nanostructured Materials

A coating consisting of nanoparticles of titanium dioxide can keep surfaces such as solar panels, windows, and safety goggles free of fog and dust particles with no additional inputs of chemical catalysts or energy. The coating was developed by Sam Mao, Vasileia Zormpa, and Xiaobo Chen of the Environmental Energy Technologies Division (EETD).

Keeping the surfaces free of fog and dirt is a surprisingly difficult technical problem to solve effectively. The antifogging technology currently in the marketplace is either temporary, such as spray or liquid coating that eventually washes away, or requires additional inputs such as chemical catalysts or ultraviolet radiation to work.

Figure 1. Nanostructured antifogging coatings have been applied to the right side (b) of the surface, which remains clear, while the untreated left side (a) forms condensation.

Laboratory testing has shown that the EETD-developed Nanostructured Antifogging Coating is continuously self-cleaning. It prevents water droplets from forming on the surface it covers (**Figure 1**) without reducing the transparency of its substrate material. The testing also suggests that it resists scratching and does not lose its ability to prevent fogging.

This self-cleaning coating can keep photovoltaic solar panels and solar thermal collectors free of dirt, maximizing their energy conversion efficiency. Desert areas where solar facilities are being planned are known to be subject to windstorms that scatter considerable dust.

In concentrating solar power plants that are built in deserts and other dusty areas, wind deposits dust onto collectors, and can reduce their efficiency to the point where the plant generates insufficient heat to provide any power at all.

In these power plants, the working fluid, when vaporized, moves through the system under pressure and turns a turbine to generate electricity. If enough fog or dust is coating the mirror, it can prevent the working fluid (such as water) from reaching the threshold temperature required to vaporize it. Therefore, a self-cleaning film allows solar energy-related applications to harvest energy to their maximum potential.

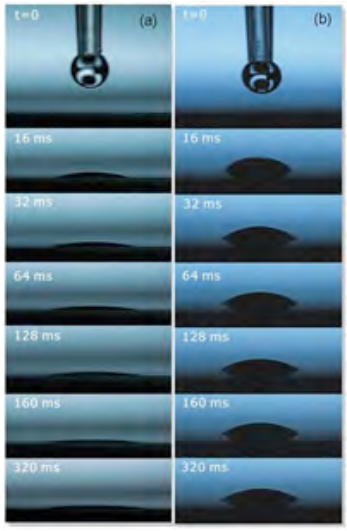

Figure 2a and b. Time sequence photos of water spreading on a surface (a) treated with titanium dioxide superhydrophilic nanostructure coating and (b) on an untreated surface.

The core of the Nanostructured Antifogging Coating is the use of titanium dioxide (TiO_2) nanoparticles that are formed into self-similar porous clusters. (The *self-similar* surface is one in which the nanoparticles have the same rough geometry at the level of the aggregate clusters, the smaller porous clusters, and the nanoparticles themselves.) These porous clusters are, in turn, formed into aggregate clusters, which are used to coat a substrate material such as glass, plastic, mirrored surfaces, or any other solid substrate for which antifogging properties are desired.

The self-similar hydrophilic nanoparticles provide water droplets with a surface of angled particles at several different order-of-magnitude length scales[1] that form low angles with the walls of water droplets. As a result, these droplets do not retain their shape for very long, collapsing and flattening out into the surface in fractions of a second.

The geometry of the particles provides the mechanism of the antifogging effect—no activation process is required. The angular nanostructure of the particles also provides the coating with its self-cleaning properties. Because nanoparticles extend out from the surface at low angles everywhere, water vapor can infiltrate the spaces formed by nanoparticle overhangs, dislodging dust and grime from the surface.

The initial spreading stages of a water droplet on a glass coated with the self-similar porous TiO_2 and on an untreated glass surface are shown in **Figures 2a and 2b**. The water droplet penetrates into the recessed areas and spreads out, within a couple hundred milliseconds, on the surface. The self-similar porous TiO_2 surface exhibits a contact angle that vanishes to zero, while the contact angle for water droplets on a glass substrate is approximately 34 degrees.

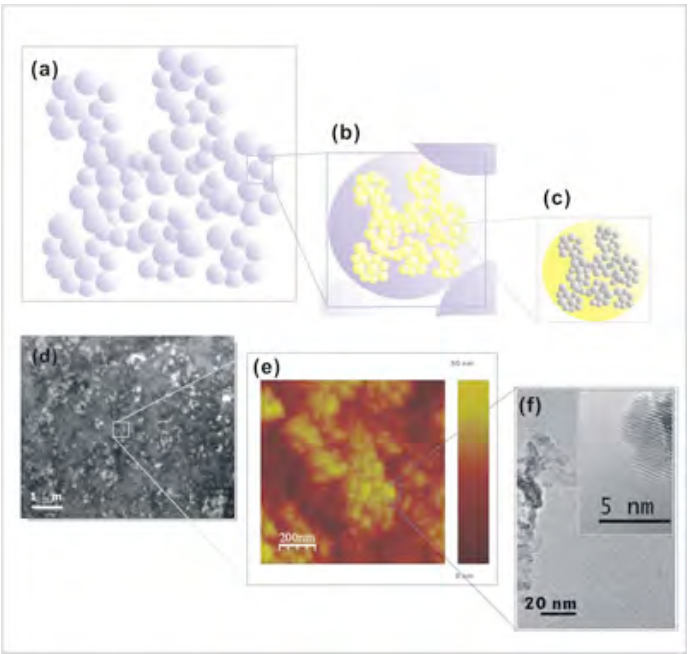

Figure 3 (a—c) Schematic representations of clusters of superhydrophilic nanostructures. The superhydrophilic coating consists of clusters of aggregates of titanium dioxide particles. (d–f). Electron micrographs of titanium dioxide particles forming the superhydrophilic nanostructure coating.

The coating consists of TiO_2 formed into a coating of superhydrophilic nanostructures. **Figure 3 a, b, and c** depicts a group of aggregate clusters, in the form of ovals (although in the actual material, each cluster could have any one of several different shapes). The dimensions of the aggregate clusters may be within the range of about 150 nanometers (nm) to 5 micrometers (μm). **Figure 3 d, e, and f** is a set of electron micrographs of a single aggregate cluster, which consists of a set of porous clusters that may be spherically shaped, as shown, or have other shapes or including a mixture of shapes. These particles are in the range of 50 to 600 nm.

The technology's antifogging property can be applied to surfaces that need to be free of fog to reduce safety hazards. Possibilities include sport goggles, auto windshields, windows in public transit vehicles, ships, railway locomotives, sun-wind-dust goggles, laser safety eye protective spectacles, chemical/biological protective face masks, ballistic shields for explosive ordnance disposal personnel, and vision blocks for light tactical vehicles. It can also be used to help keep the solar collectors used in concentrating solar power plants and solar photovoltaic panels clear of dust and water, and maintaining the highest efficiency of solar radiation reflection and transmission.

—Allan Chen

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This technology is available for licensing through Berkeley Lab's Technology Transfer Department.

- LBNL Technology Transfer and Intellectual Property Management webpage [http://www.lbl.gov/tech-transfer/techs/lbnl2687.html]
- Published patent application US2010/033927 available at the WIPO website [http://www.wipo.int/patentscope/search/en/search.jsf].

[1] Hundreds of nanometers, tens of nanometers, and under ten nanometers in length. One nanometer equals one-billionth of a meter.

LAWRENCE BERKELEY NATIONAL LABORATORY

Environmental Energy Technologies Division

NEWS

Why Fluorescent Lighting Isn't Dead

The future of energy-efficient lighting, many experts will tell you, is the solid-state LED (light-emitting diode). You have already begun to see these tiny, bead-like lights in special applications such as traffic signals, exit signs, automotive headlights, and lightweight flashlights. Maybe you have begun to see them in high-end ambient room lighting applications, such as energy-efficient desk lamps and kitchen underlights.

"The common view," says Francis Rubinstein, a scientist and energy-efficient lighting expert at Lawrence Berkeley National Laboratory's Environmental Energy Technologies Division, "is that LED lighting is replacing fluorescent lighting with the same inevitability that mammals replaced dinosaurs as the dominant large life forms on Earth."

The Challenge for Replacement Technologies

Paraphrasing from Nathan Lewis (of Caltech's Powering the Planet project), Rubinstein says: "We already have [light] coming out of everybody's [lighting fixtures]. This is not a new function we're seeking. It's a substitution. It's not like NASA sending a man to the moon. It's like finding a new way to send a man to the moon when Southwest Airlines is already flying there every hour handing out peanuts."

Ongoing research at national laboratories and in the lighting industry is focusing on improving the light output, lifetime, and durability of LEDs, as well as driving their costs down. Many lighting experts expect that LEDs will eventually be used widely in general lighting applications, replacing inefficient incandescent bulbs, as well as energy-efficient fluorescent lamps (both the linear and compact varieties). LEDs have the potential to be more energy-efficient than fluorescent lights.

But wait, says Rubinstein, who has been delivering a talk to lighting industry audiences titled "Why Fluorescent Lighting Isn't Dead." He believes that modern fluorescent lighting will continue to dominate the general lighting market and that solid-state LED lighting will coexist in the marketplace with fluorescent lighting for some time to come. Rubinstein sees a near-term future in which LED and fluorescent lighting coexist in hybrid systems that will be more adaptable to the lighting needs of a wide variety of residential, commercial, and industrial building types and space configurations.

Rubinstein has been studying lighting systems in buildings for some thirty years. He has participated in energy efficiency improvement projects at the White House, congressional office buildings, the San Francisco and Oakland federal buildings, public and private buildings, and military bases. In his current research, much of which takes place in real buildings such as federal offices and large commercial facilities, he's been studying lighting systems combined with advanced wireless control systems, personal and workstation controls, and daylighting, to manage the lighting needs of work spaces energy efficiently.

In some recent studies, Rubinstein and his research team have installed an advanced lighting and wireless control system in a testbed on one or more floors of a building, monitored the energy use, and surveyed the user satisfaction with the new system. Such systems now on the market, or in prototype, use lighting industry standards such as BacNet and DALI, and leverage wireless protocols such as ZigBee and Wi-Fi.

"Modern fluorescent lighting is the most energy-efficient, cost-effective source for general lighting available today," says Rubinstein. "Although solid-state LED technology has advanced, fluorescent lighting technology is also improving in energy efficiency and new features."

Where Edison's Fixture Still Rules

Residential lighting is dominated by the Edison fixture, into which occupants screw incandescent bulbs or compact fluorescent lamps. There are about 4.5 billion of these in the U.S. In commercial buildings, there are about one billion linear fixtures and anywhere from two to three billion lampholder pair fixtures.

"LEDs already have two strikes against them in this market," says Rubinstein, "They have to fit into an electrical infrastructure that isn't designed for LED replacements, and incandescent sockets work best with point sources such as the CFL or incandescent, while the fluorescent works best with line sources such as the linear fixtures everyone knows from office buildings."

Although researchers are working to improve the performance of LEDs and drive down their cost, fluorescent lamp and fixture technology is not standing still either. The lighting industry, Rubinstein points out, has improved ballast technology in fluorescent lighting substantially.

Figure 1. Improved ballasts and innovative fixture design have brought offices better efficiency and lighting distribution.

Ballasts are the electronics that regulate the power flowing into the fluorescent lamp. Back in the 1970s, most fluorescent lamps used magnetic ballasts. At that time, EETD researchers began developing electronic ballasts, which are 20 percent or more energy efficient than magnetic ballasts, and they worked with the lighting industry to field-test and commercialize the technology.

Today, the lighting industry has run with it. Manufacturers have introduced and improved the energy efficiency of instant-start ballasts, and they have introduced and increased the performance and efficiency of ballasts designed for dimming fluorescent lamps.

The industry has also improved the light distribution efficiency of its fixtures (see **Figure 1**). Rubinstein has measured the fixture efficiency of 1990s-vintage parabolic louvered fixtures at around 60 percent. Current-technology recessed direct/indirect fixtures distribute 90 percent of the light coming from the fluorescent lamp into the space (see illustration).

"My key point," says Rubinstein, "is that if you use LEDs to replace fluorescents, then you are on a battleground where cost is king, and the performance of fluorescents has slowly, but continually improved over the years." LEDs have not yet caught up to fluorescent lighting in cost per lumens of light delivered—they are sometimes ten times more expensive per lumen than fluorescent lighting, and in the lighting market, decisions about which technology to install are cost-driven.

"We are so blasé about how good and cheap modern fluorescent lighting has become, that we forget what a well-evolved technical tour de force it really is," says Rubinstein.

Opportunities in Hybrid Lighting

Modern fixtures present lighting designers with the opportunity to adapt the lighting to the needs of the space. Adjustable features such as open wings allow certain fixtures to throw more light onto a ceiling and flatten the light out evenly, providing even illumination that is ideal for low-ceilinged rooms.

Rubinstein argues that "until research drives the cost of LEDs down substantially, the greatest potential for improvements in lighting energy efficiency will come from combining advanced lighting controls with hybrid (fluorescent and LED) lighting systems, and designing the lighting to fit the space and occupant requirements in which they're used."

Figure 2. Modern hybrid lighting combines fluorescents with LEDs to deliver pleasing ambient light and strong targeted light for tasks.

Figure 2 illustrates a hybrid lighting solution called task-ambient lighting, which some lighting designers are using more frequently. An overhead or undercabinet fluorescent fixture provides low ambient lighting to the pictured office, while an LED desk lamp provides task lighting to the office occupant at the desk and screen levels.

But Rubinstein believes that the real future of energy-efficient lighting is in hybrid systems with control devices. "As time goes on we're going to get smarter and smarter, and develop smart furniture with built-in occupancy and light sensors. The sensors, as part of a larger automated building energy control system will reduce the energy we waste from lighting we don't need."

Using a wireless lighting control system such as that pictured schematically in **Figure 3**, the lighting can respond automatically to increases or decreases in daylight coming through nearby windows if these are present; shut down and turn on automatically when office occupants leave and re-enter their office space; and even respond to the conditions on the electricity grid such as high prices or unusually high demand prefiguring grid failure (another technology known as *automatic demand response*).

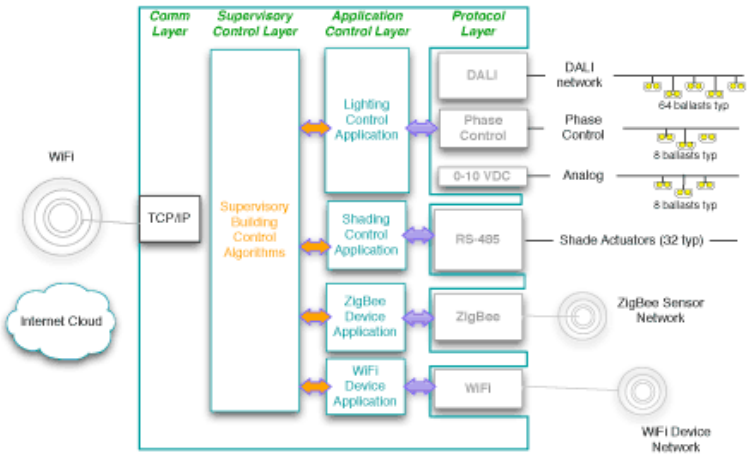

Figure 3. Wireless lighting control systems such as this Integrated Building Environmental Communications System (IBECS) communications network can respond automatically to ambient lighting conditions and other signals, to maintain optimal light levels while saving energy.

An important component of this system will be personal controls. "Study after study has shown that lighting systems which give user personal control over the lighting in their work area results in saved energy," says Rubinstein. "They give users who don't want the full level of ambient lighting the option to set lighting at the level they're comfortable with."

A study by Rubinstein in a federal building showed that occupant-responsive lighting and personal controls resulted in 40 percent less lighting energy use than an energy code-compliant baseline system that had low power density but was manually switched. By giving occupants control over their environment, and the ability to adjust the overhead light level to their satisfaction, they make occupants feel happier with their surroundings—despite other shortcomings in their environment.

"Modern fluorescent lighting is the most efficient, cost-effective source for general lighting available today," he concludes. "Until LEDs become cost-competitive with modern fluorescents for general lighting, hybrid solutions are still the most energy-efficient lighting systems in the marketplace. And whatever lighting technology is used, the key to maximum energy savings and comfort is an intelligent control system that combines automatic with manual controls."

—Allan Chen

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Additional information:

View a YouTube video of Rubsintein's talk [http://www.youtube.com/watch?v=obkqIETtrv0&feature=relmfu].

LAWRENCE BERKELEY NATIONAL LABORATORY

Environmental Energy Technologies Division

NEWS

Research Highlights

Art Rosenfeld Wins Global Energy Prize

Art Rosenfeld

Lawrence Berkeley National Laboratory Distinguished Scientist Art Rosenfeld has been awarded the Global Energy International Prize for his contributions to the field of energy efficiency.

The Global Energy International Prize was established by Russian scientists in 2002 "for outstanding scientific achievements in the field of energy which have proved of benefit to the entire human race."

In announcing the prize, the organization said: "Arthur Rosenfeld is known for his innovation and technological research in the field of construction of energy-efficient buildings. Arthur Rosenfeld has been honored by fellow scientists by giving his name to a unit of energy savings equaling three billion kilowatt-hours."

The prize was announced by Nikolay Laverov, vice-president of the Russian Academy of Sciences, and was also awarded to Russian academician Philipp Rutberg for developing energy plasma technologies. The prize fund of 33 million rubles (USD 1.18 million) will be divided equally between the two laureates. The awards ceremony will be held in June in St. Petersburg, Russia.

UV Waterworks Wins Ashok Gadgil a European Inventor Award

Ashok Gadgil

Berkeley Lab scientist Ashok Gadgil recently received the European Inventor Award for UV Waterworks, an innovative portable water purification device based on ultraviolet light. Gadgil shares the award, presented by the European Patent Office (EPO) in the non-European category, with co-inventor Vikas Garud. This simple, low-cost device has been licensed by WaterHealth International and has been installed in more than 10 countries around the world. Thus far, it has brought clean water to more than 2 million people. At the presentation, EPO President Benoît Battistelli complimented the inventors. "(The winners) have not only contributed to the economic development of their companies and research institutions, but have also helped to create jobs and improve people's daily lives."

For more information, see:

- The European Patent Office press release [http://www.epo.org/news-issues/press/releases/archive/2011/20110519.html].
- View a video [http://www.youtube.com/watch?v=DE_nngoNAVI] about the invention.

Ashok Gadgil Receives 2011 Olympus Innovation Award

Pictured left to right: Dr. Ashok Gadgil, the 2011 Olympus Lifetime of Educational Innovation Award winner; Dr. Soumyadipta Acharya, the 2011 Olympus Emerging Educational Leader Award; Dr. Laura Ferguson, Group Manager, Market Strategy and Research, Scientific Equipment Group, Olympus America; Amy Smith, the 2011 Olympus Innovation Award; and Phil Weilerstein, Executive Director, NCIIA.

Ashok Gadgil, Director of the Environmental Energy Technologies Division, has received the 2011 Olympus Lifetime of Educational Innovation Award. The award recognizes "faculty members who have demonstrated a sustained contribution throughout their careers to stimulating and inspiring innovative thinking in students in their own universities and throughout academia." Gadgil, one of three 2011 winners, was cited for "the significant impact his [UC Berkeley] interdisciplinary graduate course, Design for Sustainable Communities, has had on faculty, students, and in turn, developing countries." The citation also singles out his work on the Darfur Stove Project.

The award is a joint presentation of the Olympus Corporation and the National Collegiate Inventors and Innovators Alliance.

More information is available at the Olympus Innovation Awards website [http://www.olympusamerica.com/presspass/press_pass_cut/opp_innovationaward.asp].

International Workshop on Advances in Cool Roof Research: Protocols, Standards & Policies for Accelerated Aging

Thursday, July 28th - Friday, July 29th

Doubletree Hotel at Berkeley Marina, Berkeley, CA USA

This two-day workshop is sponsored by the Heat Island Group at Lawrence Berkeley National Laboratory, Oak Ridge National Laboratory, Concordia University, and the US Department of Energy. It will address accelerated soiling and weathering methods for roofing materials; incorporation of accelerated age ratings into policies, standards, and rating systems; and other topics, such as marketplace trends in cool roofing.

Please view the workshop website [http://coolroofs2011.lbl.gov/] or download [http://coolroofs2011.lbl.gov/files/AdvancesinCoolRoofResearchworkshopannouncementv00605-02-11.pdf?attredirects=0] the one-page flier to learn more and register.

Two-Tier Loan Structure Offers New Energy Efficiency Financing and Research Data

New York State is offering New Yorkers expanded access to low-cost financing of energy-efficiency upgrades. The Green Jobs-Green New York (GJGNY) Program, operated by the New York State Energy Research and Development Authority (NYSERDA), is using innovative underwriting criteria to help ensure that more homeowners obtain financing to participate in the state's Home Performance with ENERGY STAR (HPwES) program.

In November 2010, NYSERDA began to apply two tiers of underwriting standards to qualify applicants for unsecured loans. The Tier 1 standards still apply the traditional loan standard (credit scores); but the Tier 2 standards use consistency of utility bill and mortgage payments as a guide to determine whether or not a borrower qualifies.

This program will help determine: whether Tier 2 households will assume debt for energy upgrades, if they can afford it, if the Tier 2 standards are effective measures of determining creditworthiness, whether investors will invest in bonds that bundle loans using both Tier 1 and Tier 2 standards, and if the upgrades save households money.

Already the program has revealed that a more streamlined application process and assurance that the loan terms are identical for both tiers would persuade people who were denied a Tier 1 loan to apply for a Tier 2 loan.

For more information on the GJGNY program, see the New York State Energy Research and Development Authority website [http://www.nyserda.org/].

Austin's Home Performance With ENERGY STAR Program Achieves Success With Partner Velocity Credit Union

Launched in 2006, Austin Energy's Home Performance with ENERGY STAR (HPwES) program has completed over 8,700 residential energy upgrades. The program's lending partner, Velocity Credit Union, has originated almost 1,800 loans totaling approximately $12.5 million. Residential energy-efficiency loans are typically small, and expensive to originate and service relative to larger financing products. National lenders have been hesitant to deliver attractive loan products to this small, but growing residential market. In response, energy-efficiency programs have found ways to partner with local and regional banks, credit unions, community development finance institutions (CDFIs), and co-ops to deliver energy-efficiency financing to homeowners. Velocity Credit Union's experience with the Austin Energy HPwES program highlights the potential benefits of energy-efficiency programs to a lending partner.

For more information, read the Clean Energy Program Policy Brief, "Austin's Home Performance with ENERGY STAR Program: Making a Compelling Offer to a Financial Institution Partner." [PDF [http://eetd.lbl.gov/EA/EMP/reports/ee-policybrief_032211.pdf]]

Berkeley Lab Scientists' Work Supports IPCC Report Conclusion That Renewables Can Meet Much of World's Energy Needs

Jayant Sathaye

A recent report examining renewable energy's potential role in reducing emissions of climate-altering greenhouse gases concludes that a high percentage of the world's energy supply could be met by renewables by mid-century, if backed by the right enabling public policies.

Two researchers in the Environmental Energy Technologies Division of Lawrence Berkeley National Laboratory (Berkeley Lab), Jayant Sathaye and Ryan Wiser, were Coordinating Lead Authors of the study, which represents the scientific work of 120 contributors. Wiser was the lead contributor to the chapter on wind power, and was also primarily responsible for Section 3 of the summary, "Renewable Energy Technologies and Markets."

Ryan Wiser

Sathaye was the lead contributor on the chapter "Renewable Energy in the Context of Sustainable Development." His work appears in Section 5, which addresses the social and economic impacts of renewable energy, energy security, access to energy, and climate change and other environmental impacts.

"We found that the median value of the lifecycle emissions of greenhouse gases from all renewable energy technologies was a small fraction of those of fossil fuels," says Sathaye.

Says Wiser, "This was an ambitious effort—a comprehensive, global assessment of the potential role of renewable energy in mitigating global climate change. The report's findings are clear: that renewable energy can play a large role in reducing carbon emissions, but only if framework conditions are established to support market growth."

The study indicates that the rising penetration of renewable energy technologies could lead to cumulative greenhouse gas savings equivalent to 220 to 560 gigatonnes of carbon dioxide ($GtCO_2eq$) between 2010 and 2050. The higher estimate of emissions reduction represents a cut of approximately one-third in greenhouse gas emissions from business-as-usual projections.

—Allan Chen

For more information, see:

- Report website [http://srren.ipcc-wg3.de/]
- IPCC press release [http://srren.ipcc-wg3.de/press]
- Download "Summary for Policymakers, Special Report Renewable Energy Resources." [PDF [http://srren.ipcc-wg3.de/report/IPCC_SRREN_SPM]]

LAWRENCE BERKELEY NATIONAL LABORATORY

Environmental Energy Technologies Division NEWS

Sources and Credits

Sources

DOE's Consumer Information Fact Sheets

These web pages [http://www.eere.energy.gov/consumer/] provide information about energy efficiency and renewable energy for your home or workplace.

DOE's Energy Information Administration (EIA)

EIA [http://www.eia.doe.gov/] offers official energy statistics from the U.S. Government in formats of your choice, by geography, by fuel, by sector, or by price; or by specific subject areas like process, environment, forecasts, or analysis.

DOE's Fuel Economy Guide

This website [http://www.fueleconomy.gov/] is an aid to consumers considering the purchase of a new vehicle.

DOE's Office of Energy Efficiency & Renewable Energy (EERE)

EERE's [http://www.eere.energy.gov/] mission is to pursue a better energy future where energy is clean, abundant, reliable, and affordable; strengthening energy security and enhancing energy choices for all Americans while protecting the environment.

U.S. DOE, Office of Science [http://science.energy.gov/]

U.S. EPA, ENERGY STAR Program [http://energystar.gov/]

California Energy Commission [http://energy.ca.gov/]

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The mission of the Environmental Energy Technologies Division is to perform research and development leading to better energy technologies and the reduction of adverse energy-related environmental impacts.

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Ernest Orlando Lawrence Berkeley National Laboratory is a multiprogram national laboratory managed by the University of California for the U.S. Department of Energy. The oldest of the nine national laboratories, Berkeley Lab is located in the hills above the campus of the University of California, Berkeley.

With more than 4,000 employees, Berkeley Lab's total annual budget of nearly $600 million supports a wide range of unclassified research activities in the biological, physical, computational, materials, chemical, energy, and environmental sciences. The Laboratory's role is to serve the nation and its scientific, educational, and business communities through research performed in its unique facilities, to train future scientists and engineers, and to create productive ties to industry. As a testimony to its success, Berkeley Lab has had 11 Nobel laureates. EETD is one of 14 scientific divisions at Berkeley Lab, with a staff of 400 and a budget of $40 million.
