LAWRENCE BERKELEY NATIONAL LABORATORY

Environmental Energy Technologies Division

NEWS

SPRING 2012:
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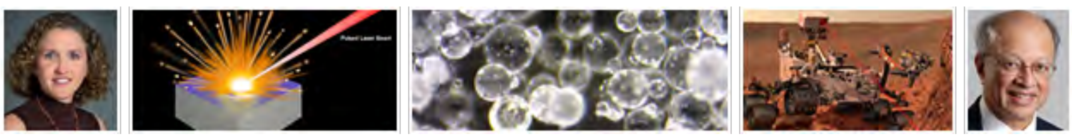
Environmental Energy Technologies Division (EETD) scientist Margaret Taylor's new study, published in the *Proceedings of the National Academy of Sciences,* suggests that the use of cap-and-trade markets to reduce pollutant emissions are successful in their short-term goals, but they cannot be counted on to encourage long-term technological innovation. Her study has generated considerable discussion in the public policy community about how to keep the innovation pipeline going strong.

Ashok Gadgil, Director of the Environmental Energy Technologies Division, has won the 2012 Lemelson-MIT Award for Global Innovation—congratulations!

We also report on a new study quantifying the impact of soot on the melting of snow and ice, a scientific problem which has great relevance to validating climate change models; a green-chemistry, laser-based technology for detecting isotopes of a chemical elements in materials; and the work of John Kerr's research group to find untapped materials and processes to improve fuel cell efficiency and reduce costs.

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. 10, No. 4 [http://eetd.lbl.gov/newsletter/nl39/]
Environmental Energy Technologies Division News [http://eetd.lbl.gov/newsletter/]

New Research Suggests Cap-and-Trade Programs Do Not Provide Sufficient Incentives for Energy Technology Innovation

Berkeley Lab researcher Margaret Taylor

Cap-and-trade programs to reduce emissions do not inherently induce the private sector to develop innovative technologies to address climate change, according to a new study in the journal *Proceedings of the National Academy of Sciences*.

In fact, said author Margaret Taylor [http://eetd.lbl.gov/staff/margaret-taylor], a researcher at Lawrence Berkeley National Laboratory (Berkeley Lab), the success of some cap-and-trade programs in achieving predetermined pollution reduction targets at low cost seems to have reduced incentives for research and development that could help develop more appropriate pollution control targets. Taylor is a scientist in the Environmental Energy Technologies Division of Berkeley Lab. She conducted the study while an assistant professor at the University of California, Berkeley's Goldman School of Public Policy.

"Policymakers rarely see with perfect foresight what the appropriate emissions targets are to protect the public health and environment—the history is that these targets usually need to get stricter," said Taylor. "Yet policymakers also seldom set targets they don't have evidence that industry can meet. This is where R&D that can lead to the development of innovative technologies over the longer term is essential."

In the study, Taylor explored the relationship between innovation and cap-and-trade programs (CTPs). She used empirical data from the world's two most successful CTPs: the U.S. national market for sulfur dioxide (SO_2) control, and the northeast and mid-Atlantic states' market for nitrogen oxide (NOx) control (respectively, Title IV of the 1990 Clean Air Act and the Ozone Transport Commission/NOx Budget Program.)

Taylor's research shows that before trading began for these CTPs, analysts overestimated how difficult it would be for emissions sources to achieve targets, in a pattern frequently observed in environmental health, safety, and energy-efficiency regulation—including all of the world's CTPs. This was seen in overestimates of the value of allowances, which are permits to release a certain volume of emissions under a CTP. If an entity can reduce emissions cheaply, it can either sell these allowances for whatever price it can get on the market, or it can bank these allowances to meet later emissions restrictions.

The cap-and-trade programs Taylor studied exhibited lower-than-expected allowance prices, in part because program participants adopted an unexpected range of approaches for reducing emissions sources in the lead-up to trading. A large bank of allowances grew in response, particularly in the SO_2 program, signaling that allowance prices would remain relaxed for many years.

But this low-price message did not cause the policy targets in the CTPs to change, despite evidence that it would not only be cheaper than expected to meet these targets, but it would also be more important to public health to tighten the targets, based on scientific advances. The lower-than-expected price signal did cause emissions sources to reassess their clean technology investments, however, and led to significant cancellations, Taylor reported.

Meanwhile, the low price also signaled to innovators working to develop clean technologies—which are often distinct from the emissions sources that hold allowances—that potential returns to their research and development programs, which generally have uncertain and longer-term payoffs, would be lower than expected.

This effect also helps explain the study's finding that patenting activity, the dominant indicator of commercially oriented research and development, peaked before these CTPs were passed and then dropped once allowance markets began operating, reaching low levels not seen since national SO_2 and NOx regulation began in 1970.

"There are usually relatively cheap and easy things to do at the start of any new environmental policy program," said Taylor, who specializes in policy analysis, environmental and energy policy, and innovation. "But if doing these things has the tradeoff of dampening the incentives for longer-term innovation, there can be a real problem, particularly when dramatic levels of technological change are needed, such as in the case of stabilizing the global climate."

—Allan Chen

Additional information:

- Innovation Under Cap-and-Trade Programs [http://www.pnas.org/content/early/2012/03/08/1113462109], *Proceedings of the National Academy of Sciences*
- Margaret Taylor's research [http://eetd.lbl.gov/staff/margaret-taylor]

Berkeley Lab's Ashok Gadgil Wins 2012 Lemelson-MIT Award for Global Innovation

The Lemelson-MIT Program [http://web.mit.edu/invent/] today announced Dr. Ashok Gadgil as the recipient of the 2012 $100,000 Lemelson-MIT Award for Global Innovation [http://web.mit.edu/invent/a-award.html] in recognition of his steady pursuit to blend research, invention, and humanitarianism for broad social impact. Gadgil is the Director of the Environmental Energy Technologies Division of Lawrence Berkeley National Laboratory (Berkeley Lab) and a professor of civil and environmental engineering at the University of California, Berkeley. The Lemelson-MIT Program [http://web.mit.edu/invent/] celebrates outstanding innovators and inspires young people to pursue creative lives and careers through invention.

"I am honored and thrilled that the Lemelson-MIT Program has chosen to recognize innovations to help improve lives of poor people in the developing world," said Gadgil. "We can make a positive difference to the lives of large numbers of people by addressing big problems with low-cost but high-impact innovative solutions."

Gadgil's inventions and innovations are improving the livelihood of more than 100 million people in more than 41 countries on four continents, with estimated annual societal economic benefits exceeding $5 billion/year.

He developed UV Waterworks, a technology for developing countries that uses ultraviolet light to inexpensively disinfect drinking water. UV Waterworks earned Gadgil the Discover Award in 1996 for the most significant environmental invention of the year, as well as the Popular Science award for "Best of What is New-1996." UV Waterworks is now deployed in villages by WaterHealth International. It provides affordable, safe drinking water to more than four million people in India, the Philippines, Nigeria, Liberia, and Ghana, with plans for expansion to Bangladesh. Gadgil estimates that with five million people served, UV Waterworks would now annually avoid about 1,000 statistical deaths of children from diarrheal diseases in the serviced population.

Current projects by his research team include developing low-cost ways of removing high levels of naturally occurring arsenic from groundwater used for drinking—a serious problem in rural Bangladesh, neighboring parts of India, and some other parts of the world.

His research team developed a fuel-efficient stove for Darfur [http://darfurstoves.org] to help reduce the firewood demand of Darfur displaced persons, most of whom are women at risk of violence as they forage for firewood outside of camp boundaries. To date, more than 20,000 Berkeley-Darfur Stoves have been distributed, helping 125,000 displaced women and their dependents. A survey in 2010 in North Darfur found that the $20 stove saves $330 in fuel costs annually for each recipient household. Thus, over their five-year estimated life, the 20,000 stoves will save $33 million for the recipient households. Gadgil is currently working on an iteration of the stove for dissemination in Ethiopia.

The utility-sponsored compact fluorescent lamp leasing programs that he pioneered are being successfully implemented in 38 countries in Eastern Europe, Asia, Africa, and Latin America.

Gadgil has received several other awards and honors for his work, including the Pew Fellowship in Conservation and the Environment in 1991 for his work on accelerating energy efficiency in developing countries, the World Technology Award [http://www.wtn.net/2002/winners.html] for Energy in 2002, the Tech Laureate Award [http://thetechawards.thetech.org/] in 2004, the Heinz Award [http://www.heinzawards.net/recipients/ashok-gadgil] in 2009, the European Inventor Award [http://www.epo.org/news-issues/european-inventor/finalists/2011/gadgil.html] in 2011, and the Zayed Future Energy Prize [http://www.zayedfutureenergyprize.com] for sustainable energy in early 2012.

He serves on several international and national advisory committees dealing with energy efficiency, invention and innovation, and issues of development and the environment. During the 2004-2005 academic year Dr. Gadgil was the MAP/Ming Visiting Professor in Civil and Environmental Engineering at Stanford University [http://www.stanford.edu/].

—Allen Chen

Additional information:

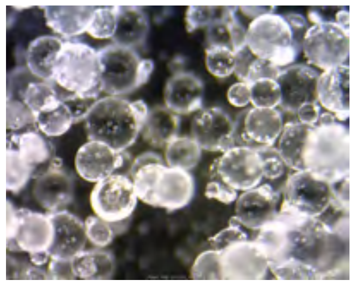
- Read the Lemelson MIT press announcement here [http://web.mit.edu/invent/n-pressreleases/n-press-12LMA.html].
- Ashok Gadgil's web page [http://energy.lbl.gov/staff/gadgil/agadgil.html]
- Darfur Stoves Project (Potential Energy) [http://darfurstoves.org]
- Arsenic removal research [http://arsenic.lbl.gov]
- UV Waterworks and WaterHealth International [http://www.waterhealth.com]
- Energy-efficient lighting for the developing world [http://www.enlighten-initiative.org]

LAWRENCE BERKELEY NATIONAL LABORATORY

Environmental Energy Technologies Division

NEWS

Berkeley Lab Quantifies the Effect of Soot on Snow and Ice Albedo



Snow manufactured in the laboratory, magnified 500x.

A new study from scientists at Lawrence Berkeley National Laboratory (Berkeley Lab), published in *Nature Climate Change,* has quantitatively demonstrated that black carbon reduces the reflectance of snow and ice, an effect that increases the rate of global climate change. Black carbon is also known as *soot,* a pollutant emitted from power plants, diesel engines, residential cooking and heating, and forest fires.

Soot can travel great distances and settle back to Earth in remote areas far from the emission source. If it deposits on snow-covered areas such as the poles or glaciers, it darkens the snow and ice, which results in less solar radiation reflected back into space. More heat is retained near the Earth's surface, speeding up global warming.

Although computer models of global climate have estimated this effect, the impact of soot on snow and ice albedo (reflectance) had not been thoroughly measured until now.

Odelle Hadley and Thomas Kirchstetter, of Berkeley Lab's Environmental Energy Technologies Division, developed new techniques to generate snow in the laboratory and to mix it in varying concentrations with soot, which normally does not mix well in water. Using these methods, they measured the reflectance of snow with concentrations of soot varying from none to 1,700 parts per billion (ppb), which spans the range of concentrations measured in snow worldwide.

"We were able to demonstrate clearly that soot in snow reduces its albedo," says Kirchstetter. "We also showed that as you increase the concentration of soot in the snow, you further decrease its reflectance."

Adds Hadley: "Another goal of our study was to validate the snow radiation modules used in general circulation models that predict anthropogenic climate change."

The researchers also demonstrated that the greater the grain size of snow, the larger the decrease in its reflectance associated with a fixed amount of soot. Larger-grained snow allows sunlight to travel deeper into the snowpack than it can in smaller-grained snow. Grain size is a proxy for the snow's age because larger-grained snow is older than smaller-grained snow.

Black carbon depositing on snow may cause it to melt and refreeze into larger grains more quickly than would normally occur. The same amount of black carbon causes a bigger decrease in reflectance of large-grained snow than smaller-grained snow. The researchers were able to work out the quantitative relationship between increasing black carbon deposition and snow reflectance reduction with increasing snow grain size—a relationship that had been estimated in computer models, but not verified until now.

These results are significant because they provide an experimental check on the methods used to calculate the impact of black carbon on global climate in computer models. Hadley and Kirchstetter's research show that there is good agreement between their lab measurements and the Snow, Ice, and Aerosol Radiation (SNICAR) model used by the Intergovernmental Panel on Climate Change in its next climate assessment report.

How Soot Accelerates Climate Warming

Emissions of carbon dioxide are the largest contributor to global climate change. Black carbon, a particle emitted during fossil fuel and biomass combustion, adds further warming.

"Theoretical calculations suggest that small amounts of soot, 10 to 100 parts per billion by mass, can decrease the reflectance of snow 1 to 5 percent," says Hadley. "This reduction contributes to climate change because it allow less of the sun's radiation to reflect back into space. Snow is the most reflective natural surface on Earth." As snow falls, it washes black carbon out of the air onto the snow pack. Typical field concentrations of black carbon are measured at 10 to 20 parts per billion (ppb), but in places scientists have measured concentrations as high as 500 ppb.

In snow-covered regions, including the Arctic and the Himalayas, the local radiative forcing due to soot deposition is comparable to that exerted by carbon dioxide added to the atmosphere since preindustrial times. (Radiative forcing is a measure of how pollutants alter Earth's radiation balance with space, and scientists use it to compare the relative impacts of various pollutants on climate.)

Snow-making in the Lab

"We needed to pioneer new techniques to do this study, including developing a way to make snow in the laboratory, and to get soot into water," says Hadley. The researchers solved the first problem with a stack of Styrofoam coolers, liquid nitrogen, and a pressurized spray vessel. They sprayed the water into the top of the cooler stack with liquid nitrogen at the bottom. As the water droplets met the cold air (-100°C to -130°C) below, it turned to snow. They learned to control the size of the snow grains by changing the nozzle size and water pressure through the nozzle.

They then developed a method of generating soot with no other contaminants (such as oil) with the help of a type of non-premixed methane-air flame created by another Berkeley Lab scientist, Don Lucas. And they captured the soot they created using a filter, and exposed it to ozone, which is known to render soot particles chemically more prone to distribute themselves evenly in water. They developed, as well, a new method for measuring the amount of soot in water.

With these methods in place, the team now had a way of creating water with any desired soot concentration, and then turning it into snow, whose reflectance they could measure. They developed ways of using an integrating sphere-equipped spectrometer to measure the reflectance of snow.

In addition to the experimental work, they estimated the effect of black carbon on snow using the SNICAR model as a step toward verifying the impacts predicted by climate models. SNICAR was developed by former Berkeley Lab researcher Mark Flanner, now at the University of Michigan.

Next Steps

Hadley's and Kirchstetter's research provides strong experimental evidence that the climate models are correctly estimating the effect on climate of less solar radiation reflected back into space because of the decrease in snow and ice's reflectance. In future work, they aim to investigate if the black carbon is causing the Earth's snow and ice to melt faster, an effect that scientists suspect may be happening, but has not yet been demonstrated. Previous research by former Berkeley Lab scientist Surabi Menon suggests that black carbon contributes significantly to the melting of glaciers [http://newscenter.lbl.gov/feature-stories/2010/02/03/black-carbon-himalayan-glaciers/] in the Himalayas.

They are also working with the University of California's Central Sierra Snow Lab to begin studying how black carbon travels through snow as the snow pack melts.

This research was supported by the California Energy Commission's Public Interest Energy Research program, the U.S. Department of Energy Office of Science, and a Lawrence Berkeley National Laboratory E.O. Lawrence Fellowship for Hadley. The article "Black-Carbon Reduction of Snow Albedo" can be found online here [http://www.nature.com/nclimate/journal/vaop/ncurrent/full/nclimate1433.html].

—Allen Chen

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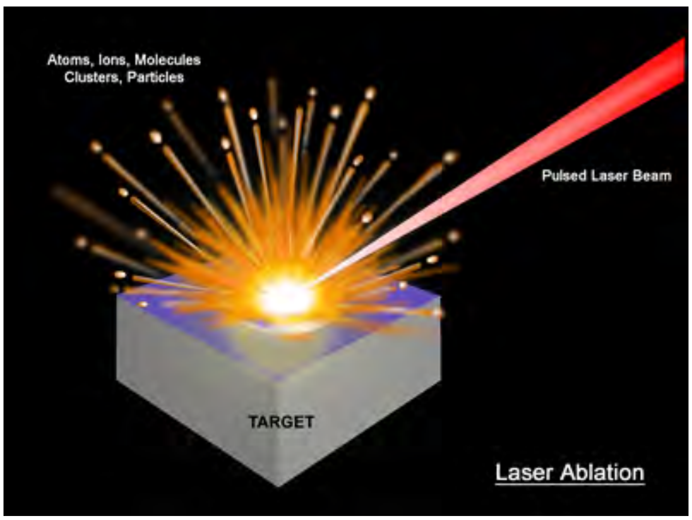
Berkeley Lab Technology Improves Laser Spectroscopy; Geochronology Analyses

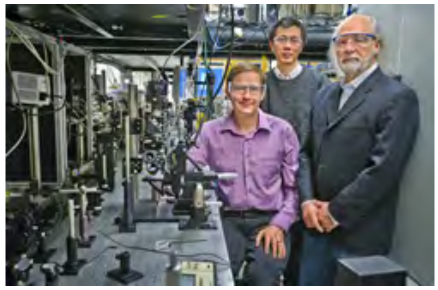
At some point this year, after NASA's rover *Curiosity* has landed on Mars, it will fire a beam of infrared light at a rock or soil sample. This will "ablate" or vaporize a microgram-sized piece of the target, generating a plume of ionized gas or plasma that will be analyzed by spectrometers to identify the target's constituent elements. Future Mars rovers, however, will be able to do even more. Researchers with the U.S. Department of Energy's Lawrence Berkeley National Laboratory (Berkeley Lab), in collaboration with Applied Spectra, Inc., have developed an advanced version of this laser technology that can also analyze a target's constituent isotopes. This expanded capability will enable future rovers for the first time to precisely date the geological age of Martian samples.



LAMIS uses a high-powered laser beam to ablate a tiny spot on a sample, creating a plasma plume for spectroscopic analysis that reveals chemical elements and their isotopes. (Image courtesy of Applied Spectra, Inc.)

Rick Russo, a scientist with Berkeley Lab's Environmental Energy Technologies Division and a pioneer in laser ablation spectroscopy, led the development of LAMIS (Laser Ablation Molecular Isotopic Spectrometry). As with the earlier Laser Induced Breakdown Spectroscopy (LIBS) technology being used by *Curiosity*, it uses the energy of a high-powered laser beam focused to a tiny spot on the surface of a sample to create a plasma plume for analysis. Each species of atoms or ions within the plasma will emit light with signature spectral emission peaks. However, whereas LIBS only measures the optical emission spectra of atoms and ions, LAMIS measures the emission spectra of molecules and molecular ions. This enables LAMIS to identify the specific isotopes of a chemical element within the plasma plume.

"Relative to atomic emission, molecular spectra can exhibit significantly larger isotopic shifts due to the contributions of the vibrational and rotational motion in the molecule," Russo says. "The trick is to be patient and wait for the hot atoms and ions in the plasma to collide and merge with the ambient environment to form an oxide, or a nitride or fluoride, and then collect the molecular light emissions."



From left, Alexander Bol'shakov, Xianglei Mao, and Rick Russo are part of the research team that developed LAMIS, a green chemistry laser spectroscopy technology that can be operated across vast distances. (Photo by Roy Kaltschmidt, Berkeley Lab)

Russo and his research group have been using LAMIS to study isotopes of strontium, an alkaline earth metal commonly found in geological and natural materials. Although strontium's major isotopes are stable (strontium-90 being a notable exception), the percentage of strontium-87 will naturally increase over time as a result of the decay of radioactive rubidium. Comparing the ratio of strontium-87 to strontium-86 is a standard tool for age dating in geochronology, oceanography, and archeology. The ratio of these strontium isotopes is also used to date the origin of historic or forensic samples. Currently, the standard means of measuring strontium isotopic ratios is by mass spectrometry technologies that involve time-consuming, labor-intensive laboratory sample dissolution work with an extensive array of instrumentation. This sample dissolution work generates substantial chemical waste. LAMIS offers a green chemistry alternative that is faster, less expensive, and can be carried out from across vast distances.

"LAMIS is not yet as sensitive or precise as mass spectrometry but unlike mass spectrometry it does not require chemical dissolution sample preparation, vacuum chambers, and a laboratory infrastructure," Russo says. "All we need is a laser beam and an optical spectrometer, and we can perform real-time isotopic analyses of samples at ambient pressures and temperatures."

Artist’s concept of rover Curiosity with LIBS technology firing a beam of infrared light at Martian rock for spectroscopic analysis. (Image courtesy of NASA)

LAMIS represents what may be the only practical means of determining the geochronology of samples on Mars or other celestial bodies in the Solar System (current age estimates of such bodies suffer from uncertainties in the billions of years). LAMIS also has many important applications here on Earth. Strontium isotope ratios have been a focus in the field of medicine for both treatment and diagnostics. Measuring these ratios can also provide valuable information about atmospheric chemistry. They also can be used to trace the origins and movements of early humans. But perhaps the most immediate and important application of LAMIS will be in nuclear forensics aimed at non-proliferation and terrorism.

"Uranium and plutonium, like every chemical element, has a spectral signature that's as unique as every human's DNA or fingerprint," Russo says. "With LAMIS, we can factor in isotopic ratios, giving us an additional level of identification that could be critical."

For example, "yellow cake," the powdered concentrate made from uranium ore that is a main ingredient of nuclear fuel, can also be used to fabricate a nuclear weapon. Measuring the elemental composition of yellow cake is one way of identifying the geographic locale where the yellow cake was produced, but because uranium ore is ubiquitous to our planet's surface, being able to also measure isotopic ratios in a sample of yellow cake can be a huge advantage for pinpointing its original location.

"The natural ratio of uranium-235 to uranium-238 is defined by the geology of our planet," Russo says. "If you find a modified ratio in a sample then you know someone has been enriching that uranium. Other isotopic ratios within a nuclear reaction chain also can tell you how a nuclear weapon was made and where it might have originated."

Much of this research was done in collaboration with Applied Spectra, a company Russo created in 2004 with the help of Small Business Innovation Research grants, to bring laser ablation spectroscopy technology to the marketplace.

"The next step is to improve the sensitivity and precision of LAMIS," Russo says. "Our immediate target is parts-per-million, which should be relatively easy for us to reach, but ultimately we want to get to parts-per-billion sensitivity, which will be a challenge. However, 50 years ago, the parts-per-billion sensitivity of today's mass spectrometry technologies would have been thought impossible."

Russo and his colleagues have described their work on LAMIS in several papers, including one in which the technique was shown to be effective for measuring isotopes of boron. The most recent paper appeared in the journal *Spectrochimica Acta Part B*. The paper is titled "Laser Ablation Molecular Isotopic Spectrometry: Strontium and its isotopes." Co-authoring this paper were Xianglei Mao, Alexander Bol'shakov, Inhee Choi, Christopher McKay, Dale Perry, and Osman Sorkhabi. Co-author Bol'shakov, with Applied Spectra, says his company is eager to commercialize this technology.

"We envision multiple applications for LAMIS in industry, medical diagnostics, nuclear safeguarding, and other areas," he says.

Support for this research came from the Defense Threat Reduction Administration of the U.S. Department of Defense, DOE's National Nuclear Security Administration, and NASA through Applied Spectra, Inc.

—Lynn Yarris

Additional information:

For more information about the research of Rick Russo and his group, visit the website [http://teamd.lbl.gov/].

For more information about Applied Spectra, Inc., visit the website [http://www.appliedspectra.com/].

Traveling the Road Not Taken in Fuel Cell Research

Scientific advancements often arise from patiently building upon previous efforts, clarifying the path to a desired outcome, and following that path to a successful conclusion. Then again, there are times when it's prudent to draw on the past, but cut a new path altogether; heading for the same destination along a different route.

When it comes to Lawrence Berkeley National Laboratory's (Berkeley Lab's) fuel cell work, John Kerr takes the second approach. His group's work complements that of Berkeley Lab researcher Adam Weber's group, which examines fuel cell issues through mathematical modeling and diagnostics. Read a story about Adam Weber's research here [http://eetd.lbl.gov/newsletter/nl35/eetd-nl35-1-fuelcell.html].) Both groups collaborate with private industry, universities, and other national laboratories to overcome operational and economic barriers to fuel cell use, but Kerr's group employs a different strategy.

"We're more far out there," he laughs. "As an engineer, Adam is focused on understanding what we have already and how to make it work better. I'm a chemist. I don't need to make it work. My job is to find out why it doesn't work and figure out how it might. There is a strong emphasis on the chemistry."

Kerr's group examines the fundamental mechanisms of fuel cells from a molecular level on up, looking at entirely different materials and processes than those used currently.

"Some fuel cells out there are working better than others, but no one—including the people who developed them—are absolutely certain *why* they are working better. We look at the *why*, so that we can find untapped materials and processes to improve overall fuel cell efficiency and reduce costs."

Overcoming Traditional Barriers

Despite their increasing use in both stationary and transportation applications, fuel cells continue to suffer from some persistent weaknesses. In particular, they are only 50% (or less) efficient in converting the hydrogen (H) fuel to electricity. The rest of the energy from the reaction is converted to heat, which, for most applications, must be dissipated. The chemical reaction also produces water. Therefore, there must be efficient mechanisms to manage the heat and the water.

When fuel cells are being used in a vehicle, the equipment needed to store the energy (the hydrogen tank) and get rid of the heat (the radiator) and the water can take up a lot of space. As Kerr says, "There's no room for left for the golf clubs, the groceries—or even the kids." Those kinds of limitations prevent fuel cells from taking what could be a solid game-changing role in marketable vehicles.

For example, the automakers developing fuel cell cars right now have only a brief track record of how well the technology is going to work and hold up in the field. They need a better understanding of the underlying processes to be able to improve the technology, to help bolster confidence in it and improve marketability.

At a technical level, fuel cells only produce about half of their theoretical energy potential, primarily for three reasons:

- Too much resistance to the protons conducted through the membrane
- The inability of oxygen (O_2) and H to move efficiently through the cell
- Sluggish rates of the electrochemical processes with the catalysts currently being used

To help fuel cells overcome these barriers and reach their true technical and economic potential, three major issues need to be resolved: (1) catalysts need to use less expensive and more efficient materials, (2) membranes need to conduct the protons that produce electricity without much water and at high temperatures, and (3) the fuel needs to be low volume, liquid, and pumpable, so the existing infrastructure can be used. Increased fuel cell efficiency will mitigate the thermal and water issues, and less infrastructure will be necessary to deal with them.

Kerr is reasonably confident that the issues can be resolved. "The challenges that we're looking at are significant, but tractable," he says. "We do have a handle on the processes underlying fuel cell operation—we're not invoking magic."

Fuel Cell Work of the Kerr Group

At present, Kerr's group is working with General Electric, Yale University, and Stanford University to develop a new high-intensity energy storage system that combines the advantages of a fuel cell and a flow battery. The work, led by GE, is sponsored through the U.S. Department of Energy's Energy Frontier Research Centers (EFRC). Kerr's group is focusing on three areas: replacing platinum catalysts with a cheaper metal, replacing hydrogen with a pumpable liquid fuel, and developing membranes with appropriate selectivity for liquid fuel use.

"None of this work is redundant with other fuel cell work," he says.

The Search for Non-Platinum Catalysts

Platinum group metals (PGM) are the best materials currently known for fuel cell catalysts, and they been used in fuel cells for 150 years. However, they are expensive and the supply chain is unstable. Moreover, platinum is also in demand for other industries, which further affects its price and supply. For example, in 2002, when Intel began mass-producing its dual-core chip, it needed platinum for a switch, which tripled the cost of the already expensive metal. Replacing the metals with less-expensive options such as copper, iron, or cobalt will help ensure that fuel cells can be produced reliably and at a reasonable, consistent cost.

"Some of the replacement metal alternatives that we have evaluated have turned out to be too expensive as well," says Kerr. "However, we've established a clear path for improving performance, and after two years of development work on the catalysts, we are really doing something that is very significant at this point."

Rechargeable Fuel Systems

Devising a rechargeable fuel system could alleviate some of the other challenges that fuel cells continue to face: storing the fuel onboard and generating and distributing the hydrogen. Currently, on-board storage can provide enough energy to carry fuel cell vehicles about 120 miles, limiting their market and requiring the development of an extensive refueling infrastructure. The hydrogen is currently made from natural gas, which is not very efficient and does little to reduce carbon emissions. Using solar energy to split the hydrogen from water continues to be inefficient and cost-prohibitive. And distributing hydrogen in existing pipelines makes them brittle; replacing them with more compatible pipelines would be time-consuming and expensive.

So how are these issues resolved? One approach is to create a liquid fuel system—an idea first posed by Guido Pez at Air Products. In the system being developed for this project, an organic liquid carries the hydrogen. This liquid is charged with hydrogen ("hydrogenated," as is done with trans fats, a very common process) and the hydrogenated liquid fuels the cell by an electrochemical reaction that removes protons and electrons from the fuel. The depleted liquid flows back to a tank. At this point, two options exist for recharging the liquid: (1) the vehicle could be plugged in, and the liquid fuel could be recharged as a hybrid fuel cell/electric vehicle, or (2) when the vehicle is refueled at a fueling station, the depleted fuel would be dropped off and tankers could transport it to a refinery for recharging.

A back-of-the-envelope calculation estimates that a fuel cell vehicle using this method could achieve a range of 300 miles on a 20-gallon tank with a 50 kilowatt fuel cell—all while maintaining the fueling and refinery jobs that currently exist. The system is the answer to all the shortcomings of batteries (no range anxiety, since you can always fill up) and of fuel cells (hydrogen storage and distribution, and better efficiency).

To make this a reality, the project team is conducting research to:

- select the optimal carrier liquids;
- identify the best non-PGM electrocatalysts to facilitate the hydrogenation and dehydrogenation reactions, and the oxygen reduction and evolution;
- develop a membrane and membrane electron assembly (MEA) that will support high proton transport without transporting the fuel across the membrane; and
- ensure component durability.

All of the group's projects involve collaboration among project partners. For the catalyst work, Los Alamos National Laboratory and the University of California, Berkeley, are modeling the actual catalysts to determine how to get the correct reactivity, while 3M is contributing membrane materials for use in the fuel cells. There is considerable overlap among the group's projects.

"We're working with GE and Stanford, and expect to build a complete system for the EFRC program. That will be about a year from now—the operating device is within reach. And we expect to build a non-platinum stack in a couple years. If we're successful, that will be quite significant for fuel cell development."

The collaborations even extend to those who may be developing fuel cell systems in the future. "This summer we plan to engage the summer undergraduate programs like the Science Undergraduate Laboratory Internships, to have students build and run real systems that will give us some hard experience," says Kerr. "It should be fun!"

Leveraging Non-Energy Applications

Kerr is pleased that the membrane and catalyst work is applicable to activities outside of the energy sector, since it offers an opportunity to get technologies into marketable products sooner. For example, the group's catalyst work is similar to the technology used in glucose blood sensors.

"It's difficult to make money right away with the energy applications because energy is so cheap," says Kerr. "Energy is cheaper than bottled water, so it's hard to get a marketplace foothold without government support. By applying the technology to areas that are easier to introduce and getting products out, it's easier to develop the technology and make money to support the energy applications."

Often these technologies can support biotechnology applications, where they can be ramped up to a higher volume scale. In an era of ever-deepening budget cuts, Kerr plans to use this strategy whenever possible to support all of his projects.

From Molecules to Market

"Our work runs the gamut from computation of molecules to MEA design," says Kerr, "all of it based on readily available materials. Some of these projects are based on work that I've done for 30 years, but it's the first time I've had a chance to test it out. We're getting to a point now for much of this where the engineers are getting involved. It's very interesting."

—Mark Wilson

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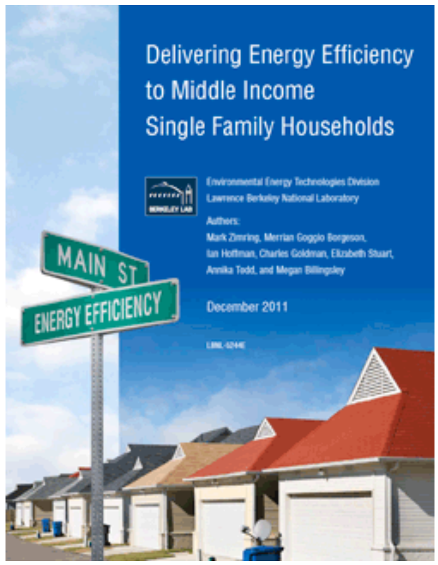
Research Highlights

New Clean Energy Program Policy Brief—Boulder, Colorado's SmartRegs for Residential Rental Housing

EETD researchers have released a Clean Energy Policy Brief about Boulder, Colorado's SmartRegs ordinances.



In 2011 the City of Boulder, Colorado enacted its "SmartRegs" ordinances that require all single-family and multifamily rental properties to meet a minimum energy-efficiency standard by January 2019. The SmartRegs initiative is designed to help the city achieve its ambitious carbon emissions-reduction goals and to improve the quality, safety, and marketability of Boulder's rental housing stock.

The effort involved two years of extensive stakeholder engagement and a sophisticated strategy that included dividing the SmartRegs provisions among three different ordinances to improve the chances that at least some components would be approved. All three ordinances ultimately won community and city council support by including a long (eight-year) compliance period, offering financial incentives and technical assistance to building owners, and providing owners with a streamlined prescriptive process for meeting compliance.

One year after the regulations went into effect, the city had handily exceeded its first-year goals of 1,000 units inspected and 500 units achieving compliance. The program is also experiencing an unexpected bonus: some property owners are voluntarily choosing to upgrade beyond the minimum requirements. Given its broad support and successful early rollout, SmartRegs shows promise for overcoming transaction costs and reducing barriers to energy-efficiency gains in the residential rental sector.

You can download the policy brief here [http://eetd.lbl.gov/ea/emp/reports/lbnl-5244e.pdf] or at the Middle Income website [http://middleincome.lbl.gov/].

The 80% Solution for Greenhouse Gas Emissions in California

An article just published in *Issues in Science and Technology*, a journal of the National Academy of Sciences, summarizes what California will need to do to reduce greenhouse gas emissions by 80 percent below the 1990 level. In the article, Jane Long, co-chair of the California's Energy Future committee, and Jeff Greenblatt, a scientist in Lawrence Berkeley National Laboratory's Environmental Energy Technologies Division, discuss the results of the California Energy Futures Project of the California Council of Science and Technology. They write "the technology and knowledge exist to take the state most of the way to its ambitious 2050 goal, but more research will be needed in a few key areas to achieve full success."

Download the article, "The 80% Solution: Radical Carbon Emission Cuts for California. [http://eetd.lbl.gov/sites/all/files/news/pdf/longgreenblat.pdf]"

Get the full-length report, *California's Energy Future - The View to 2050* [http://ccst.us/publications/2011/2011energy.php], from the California Council for Science and Technology. It was released in 2011.

California's Energy Future: Electricity from Renewable Energy and Fossil Fuels with Carbon Capture and Sequestration

A report released by the California Council for Science and Technology examines pathways for achieving California's aggressive greenhouse gas (GHG) reduction target. The report, titled *California's Energy Future: Electricity from Renewable Energy and Fossil Fuels with Carbon Capture and Sequestration*, looks at how California could achieve GHG reductions 80% below the 1990 level by 2050 through electricity generation from fossil fuel combustion with carbon dioxide capture and sequestration (fossil/CCS) or renewable energy technologies (e.g., wind, solar, geothermal, biomass, hydropower).

Jeffery Greenblatt

The report by Jane Long, co-chair of California's Energy Futures Committee, Jeffery Greenblatt of the Environmental Energy Technologies Division at Lawrence Berkeley National Laboratory, and Bryan Hannegan of the Electric Power Research Institute, is a follow-up to the study *California's Energy Future— The View to 2050*, published in May 2011. The analysis first estimated how emissions could be reduced through modifications to demand, including aggressive efficiency and electrification.

The authors developed two scenarios of electricity demand in the state through 2050. In the first, they assumed that maximum electricity demand that would result from business-as-usual plus economic and population growth, without aggressive efficiency measures, but using very high levels of electrification. In this case, the total demand for electricity would be about 1,200 terawatt-hours/year (TWh/yr), with average generation of about 130 gigawatts (GW). In the second case, they used a much smaller estimate of demand that included aggressive, but realistic, amounts of both efficiency improvement and electrification in all energy sectors. The resulting demand for electricity is about 500 TWh/yr, with average generation of about 60 GW. By comparison, California's electricity demand in 2005 was about 270 TWh/yr.

The report assumes there are three major ways to provide the rest of the electricity: nuclear power, fossil/CCS, and more renewable energy. It focuses on the latter two solutions. There is also a section exploring approaches for implementing load balancing without GHG emissions.

The report concludes that:

- Developing generation capacity is not a technical issue. Generation capacity to meet either the high or low level of demand could be developed with any of the three electricity supply choices.
- All of the electricity cases require load balancing to address peaking, ramping, and intermittency of electricity supply resulting from the inherent variability of wind and solar resources. The use of natural gas for load balancing at the scales envisioned to be necessary in 2050 would produce significant amounts of GHG emissions. This problem is significantly larger for intermittent renewable energy.

The California Council on Science and Technology is publishing a series of reports detailing the results of its Clean Energy Futures project exploring the remaining challenges—and possible solutions—to achieving California's ambitious GHG target. This is the third follow-up to its initial Summary Report published last year. Additional reports will be released later this year.

Download the report, *California's Energy Future: Electricity from Renewable Energy and Fossil Fuels with Carbon Capture and Sequestration* from the California Council on Science and Technology website [http://www.ccst.us/].

Berkeley Lab Chosen to Lead U.S.-India Clean Energy Research Center

Lawrence Berkeley National Laboratory (Berkeley Lab) has been selected to lead a new joint U.S.-India research center focusing on energy-efficiency technologies for buildings. It is one of three consortia that will make up the U.S.-India Joint Clean Energy Research and Development Center (JCERDC). The other two consortia will focus on biofuels (led by the University of Florida) and solar energy (led by the National Renewable Energy Laboratory, with participation by Berkeley Lab). Together, these three groups will receive a total of $5 million this year from the U.S. Department of Energy to develop clean energy technologies.

Berkeley Lab's U.S.-India Joint Center for Building Energy Research and Development (CBERD) will conduct research with Indian counterparts focused on the integration of information technology with building systems in commercial and high-rise residential buildings. Berkeley Lab also will collaborate with a number of academic and third-party partners, some of whom will provide matching funding and in-kind contributions. The project will enable researchers to take advantage of test beds for buildings technologies at Berkeley Lab.

This work offers enormous potential for reducing energy use in both countries, and is of particular importance in India. "India has an opportunity to leapfrog other countries and build cities with a new generation of high-performance buildings," said Ashok Gadgil, head of Berkeley Lab's Environmental Energy Technologies Division and CBERD director. "This collaboration between two of the world's largest economies can not only spur technology breakthroughs but also create new market opportunities for U.S. companies."

Sources and Credits

Sources

Energy Efficiency & Renewable Energy's Energy Savers

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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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.

Spring Newsletter: Vol. 10, No. 4 [http://eetd.lbl.gov/newsletter/nl39/]
Environmental Energy Technologies Division News [http://eetd.lbl.gov/newsletter/]