LAWRENCE BERKELEY NATIONAL LABORATORY

Environmental Energy Technologies Division

NEWS

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Understanding how effectively new technologies can save energy, water, and materials—as well as reduce energy costs and greenhouse gas emissions—is the goal of the Carbon Cycle 2.0 Energy and Environmental Analysis Team, a new team at the Environmental Energy Technologies Division. In a pair of articles, you'll learn more about how they combine economic modeling, life-cycle analysis, climate models, and other methods to understand the potential beneficial impacts of technologies still in the laboratory.

Also in this issue: a new technology that removes formaldehyde (a carcinogen) and other volatile organic compounds from indoor air with extremely high efficiency, cool coatings for cars, a new simulation tool for predicting the properties of materials from first principles, a project to help military base buildings achieve greater energy efficiency in lighting, and the latest on the solar PV market.

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**—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].

LAWRENCE BERKELEY NATIONAL LABORATORY

Environmental Energy Technologies Division

NEWS

# Carbon Cycle 2.0 Energy and Environmental Analysis Team Evaluates Impacts of Technology R&D

It's a grand challenge: develop clean, sustainable technologies that deliver a low-carbon energy future, and through innovation create jobs, new markets, and exports while increasing America's energy security.

Researchers at Lawrence Berkeley National Laboratory (Berkeley Lab) have made it their mission to develop low-carbon and energy-efficient technologies such as advanced materials and information technology for buildings; next-generation biofuels; new battery, fuel cell, and thermoelectric energy-storage technologies; and carbon capture and sequestration technologies. This Lab-wide effort, called Carbon Cycle 2.0, brings together teams of scientists from throughout Berkeley Lab to research and develop sustainable energy solutions at the lab where modern team-based science was first developed and practiced in the 1930s, by founding Director Ernest O. Lawrence.

But what impact will these technologies—still in the laboratory, but not yet in the marketplace—actually have? How much will they reduce the use of energy, water, and materials throughout their life cycles, how much could they mitigate climate change, and what are their health and economic impacts?

Scientists in Berkeley Lab's Environmental Energy Technologies Division (EETD), in cooperation with their Lab colleagues, have formed a team to evaluate these impacts: the Carbon Cycle 2.0 Energy and Environmental Analysis Team (E2AT), led by EETD's Eric Masanet.

"It's a fairly new approach for the Lab," says Masanet, "to use the analytic lenses we've developed here in EETD to analyze the costs, and energy, water, materials, and climate change impacts of technologies that are still in the research and development phases. This effort is scientifically much more challenging than analyses of technologies that are already in the marketplace."

"The ultimate goal of the work," he adds, "is to provide guidance to scientists, funding agencies, and policymakers about which technology options are the most beneficial to pursue—which have the largest potential impact cost-effectively."

## Research Portfolios Orient Toward Projects "Most Likely to Have an Impact"

Scientists and funding agencies are looking for analytical tools to help them create a balanced portfolio of research that will lead to new technologies with optimal economic and resource benefits. They need an assessment of technology impacts—not only whether a technology will reduce energy or water use, but whether it will do so cost-effectively, and how the cost-effectiveness varies according to factors such as different climates and geographies, cost of energy, changing energy and resource demands, and mix of fuels that supply energy. Will the technology produce additional jobs and revenue? What kinds of barriers face the entrance of new technologies into the marketplace? They also want to know the magnitude of the environmental benefits—including reductions in energy and resource use, human health impacts, and energy dependencies—and how those benefits might vary according to a technology's characteristics and patterns of adoption and use.

The kind of tools that E2AT is now applying to Berkeley Lab's own research are cross-sectoral (industry, commercial, residential, transportation) computer models with environmental indicators (relating to energy, water, materials, and public health) that evaluate the potential impacts of technologies.

However, these models only provide part of the picture. E2AT is also bringing energy resource modeling, life-cycle assessment, geographic information systems (GIS), and other analytical techniques to bear. Energy resource modeling looks at the inputs and outputs of technology to measure its total impact—how much energy, water, and materials are used to produce a technology—and how these impacts compare to competing technology alternatives.

Using output from these different tools, the Team is developing a set of scenarios—varying such factors as the mix of energy supply (from coal, nuclear, renewables, natural gas, and others); costs; the technology's market penetration; and strong, weak, or no policies to encourage market diffusion. These scenarios help clarify under which conditions a new energy technology is likely to have the largest impact in reducing costs, creating jobs and economic value, and reducing energy use or greenhouse gas emissions.

"An important element of the process," says Masanet, "is the feedback to researchers. We are trying to institutionalize information flows and collaborations between the basic, applied, and analysis research at Berkeley Lab. We plan on using web

portals and databases to encourage sharing of data, results, and technical information, and forming inter-divisional working groups to meet regularly, generate new scientific insights and foster ongoing collaboration between researchers who were previously operating mostly in isolation."

## Evaluating Four Technologies

With its initial funding, the Team chose to study four technologies in active development at Berkeley Lab: geologic carbon sequestration, next-generation coatings for energy-efficient windows, salt- and drought-tolerant switchgrass for biofuels, and large-scale solar photovoltaic installations.

## Case Study: Carbon Sequestration

The pilot project to develop a spatial and temporal life-cycle environmental and cost model for geologic carbon sequestration (GCS) furnishes an illuminating case study on how the Team works. Hanna Smith, Philip Price, and Tom McKone, together with Earth Sciences Division scientists Curt Oldenburg and Jens Birkholzer, are studying the economic and environmental characteristics of large-scale systems to capture carbon at the power plant and inject it into geological reservoirs.

Molecular Foundry

"Throughout the United States," Price explains, "are saline aquifers in large sedimentary basins, depleted oil and gas reservoirs, unmineable coal areas, and other formations which could serve as reservoirs for greenhouse gases produced at power plants." The carbon dioxide ($CO_2$) storage capacity of saline aquifers alone is estimated to be between 1.6 trillion and 20.2 trillion tonnes (metric tons).

The results of the team's work are described in more detail in the companion article, which can be read here [http://eetd.lbl.gov/newsletter/nl37/eetd-nl37-2-carbonstudy.html].

## Dynamic Window Coatings

Researchers in EETD and at the Lab's Molecular Foundry within the Materials Sciences Division are working to develop the next generation of advanced window coatings. By providing the ability to dynamically tune their optical properties, such coatings will allow for optimal utilization of solar resources. While many mature static coating technologies exist, dynamic technologies create the potential for even greater energy savings in the areas of heating, cooling, and lighting energy consumption within buildings.

Under this pilot project, they are investigating two distinct window technologies. The first technology is a new electrochromic coating that provides tunable blocking of near-infrared radiation (NIR). In tunable blocking, the coating can adjust itself to allow or block varying amounts of infrared radiation to pass through the window to the inside. During warm weather, the window can assume its blocking state to reduce solar heat gains, and during cold weather, heat gains through the unblocked window can supplement existing heat loads. Unlike existing electrochromic windows, this technology maintains transparency in the visible spectrum, so that in its blocking state, the windows allow daylight to come through—windows made with current electrochromic technology visibly darken in their blocking state.

The second technology is a micro-scale prismatic coating to redirect sunlight further into building spaces. With its dynamic functionality, such a coating can be tuned to redirect at an angle that both maximizes day-lit floorspace while simultaneously increasing occupant comfort by reducing glare.

The team is quantifying the potential energy savings of these technologies in different regions across the country, considering variations in building stock and climate. Results are helping to define performance targets that would make the coatings successful in the marketplace. They are also performing life-cycle assessment to better understand the environmental implications associated with the material use and manufacturing processes needed for large-scale implementation.

## Salt-tolerant Switchgrasss for Biofuels

A third pilot project focuses on next-generation biofuels. Converting agricultural crops to biofuel reduces U.S. dependence on oil imports and creates jobs. However, to be successful in the marketplace, agriculture for biofuels should not compete with food crops on arable land—this would drive up the price of food. Biofuels also need to be produced using as little fossil-energy-based fuel as possible to be nearly carbon-emissions-neutral.

Salt-tolerant switchgrass is an active area of biofuels research.

One approach under study through Berkeley Lab's Joint Bioenergy Institute is to engineer fast-growing crops, such as switchgrass, for marginal, salty agricultural land that is not in use for food crops. After assessing U.S. agricultural lands, an EETD research team, led by Larry Dale and Jim McMahon, determined that a more drought-tolerant switchgrass could have a greater impact, because there are far more dry unproductive lands than salty unproductive lands in the U.S. These land areas are currently unsuitable for food production but could potentially grow energy crops specially engineered for drought tolerance, producing a biofuels feedstock that does not compete with food production. Consequently, early feedback from Berkeley Lab to the genetic engineering team participating in the work resulted in genetic engineering focus moving to drought tolerance.

The E2AT team is working closely with Larry and Jim's team to provide life-cycle analysis for the entire marginal biofuels production cycle, as well as the entire supply chain economics from fields to vehicle tanks. This analysis identifies net societal benefits and costs associated with biofuels derived from drought-tolerant switchgrass. The economic analysis portion will also provide guidance to the genetic research team as to what switchgrass yield targets help ensure economically viable production supply chains.

## Large-scale Solar Photovoltaic Deployment

In the fourth pilot project, Team scientists are modeling the impacts of deploying large-scale solar photovoltaic installations. Solar PV produces electricity without direct greenhouse gas emissions, so its large-scale deployment should lead to lower regional emissions.

The manufacture of solar PV also affects materials and water resource use. In this project, the team members are studying the interrelationships of avoided emissions, land use, local and global weather change, and human health impacts from large-scale solar deployment, as well as the life-cycle energy use and costs of manufacturing and operating large solar PV installations.

This study projects avoided emissions in the U.S. power grid caused by the high penetration of PV. The team is calculating the avoided emissions of $CO_2$, sulfur dioxide ($SO_2$), and nitrogen oxides ($NO_X$), assuming different PV deployment scenarios. Because the generation resource mix in different regions of the U.S. varies, the avoided emissions vary significantly. The results will help guide policymakers and solar project developers to make decisions about how to deploy solar PV efficiently and economically.

## Future Plans

For evidence that the E2AT's approach is drawing wider interest, the U.S. Department of Energy recently awarded up to $1.9 million to members of the team to develop "total cost of ownership" models for low- and high-temperature stationary fuel cell systems up to 250 kilowatts.

The fuel cell research is an example of how Berkeley Lab and its Carbon Cycle 2.0 program is weaving together its development of cleaner energy technologies with research and development to evaluate the technologies' potential costs, benefits, and impacts on energy, materials, and climate.

"Analyzing the markets, performance, design and manufacturing options, societal benefits, and life-cycle costs of stationary fuel cell technologies will help manufacturers design better technology for specific markets, customers understand the costs and benefits of investing in the technology, and policymakers provide more effective incentives," says Masanet.

E2AT expects to apply its new analytical lenses to additional technologies from both Berkeley Lab and elsewhere."We hope that future collaborations with other Berkeley Lab researchers and other research institutions will improve the flow of information and scientific insights to researchers in technology and environmental assessment R&D," says Masanet."We are also working to improve the research's relevance to key global decision makers, including policy makers, technology investors, and research program managers."

**—Allen Chen**

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Additional information:

Eric Masanet
(510) 486-6794
ERMasanet@lbl.gov

Erin Claybaugh
(510) 495-2189
ESClaybaugh@lbl.gov
E2AT Communications and Outreach

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Read about the carbon sequestration analysis work here [http://eetd.lbl.gov/newsletter/nl37/eetd-nl37-2-carbonstudy.html].

This research was funded by the Lab-Directed R&D program of Lawrence Berkeley National Laboratory.

LAWRENCE BERKELEY NATIONAL LABORATORY

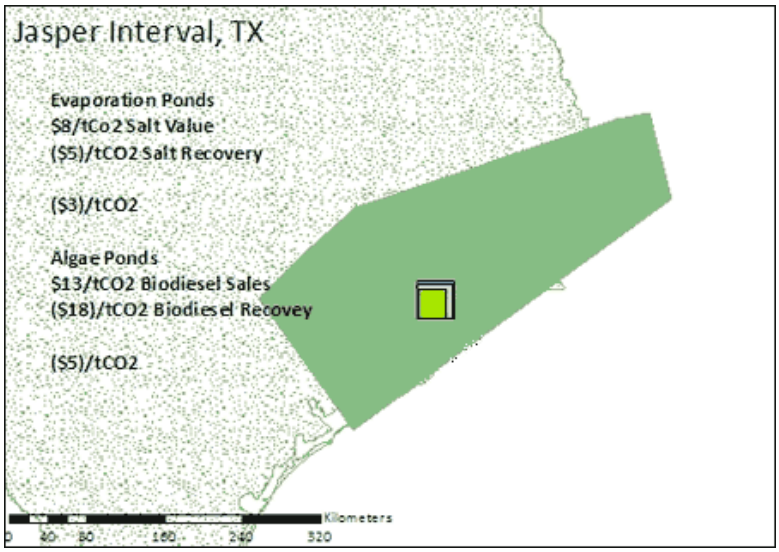
Environmental Energy Technologies Division

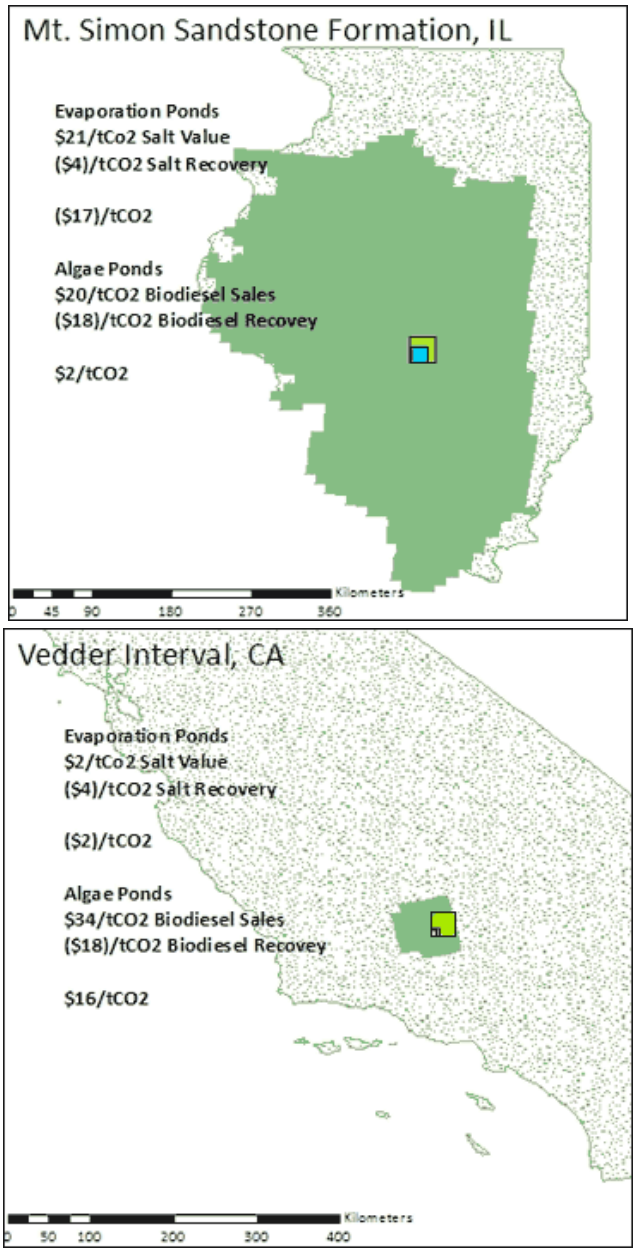
NEWS

# Carbon Cycle 2.0 Energy and Environmental Analysis Team Focuses on Carbon Sequestration

Scientists in Lawrence Berkeley National Laboratory's Environmental Energy Technologies Division (EETD), in cooperation with colleagues throughout the Lab, have formed a team to evaluate the impacts of low-carbon and energy-efficient technologies that are still in the laboratory. Development of these technologies is part of a Lab-wide effort called Carbon Cycle 2.0, focused on sustainable energy solutions such as advanced materials and information technology for buildings; next-generation biofuels; new battery, fuel cell, and thermoelectric energy-storage technologies; and carbon capture and sequestration technologies.

The work of the Carbon Cycle 2.0 Energy and Environmental Analysis Team (E2AT), led by EETD's Eric Masanet, has begun to bear fruit in the form of assessments of several technologies, including next-generation coatings for energy-efficient windows, salt- and drought-tolerant switchgrass for biofuels, and large-scale solar photovoltaic installations. Read more about these results, here [http://eetd.lbl.gov/newsletter/nl37/eetd-nl37-1-carboncycle.html].






**Max Surface Area for Algae Ponds:**

800 km2

**Surface Area for Evaporation Ponds without RO:**

Jasper Interval: 1400 km2

Mt. Simon Sandtone Formation: 360 km2

Vedder Interval: 100 km2

**Figure 1:** Aquifers are drawn in forest green on the map. The evaporation pond land footprints required for each saline aquifer are shown as blue squares on the map. They represent the area required to store the produced water for 10 coal-fired power plants with 24% energy penalty injecting 90% of their emissions. Adjustments to surface area requirements after reverse osmosis treatment are shown in grey. Algae green squares show the land footprint required if algae ponds were used to store the produced water from 10 similar coal-fired power plants.

The pilot project to develop a spatial and temporal life-cycle environmental and cost model for geologic carbon sequestration (GCS) furnishes an illuminating case study on how the Team works. Hanna Breunig, Philip Price, and Tom McKone, together with Earth Sciences Division scientists Curt Oldenburg and Jens Birkholzer, are studying the economic and environmental characteristics of large-scale systems to capture carbon at the power plant and inject it into geological reservoirs.

"Throughout the United States," Price explains, "are saline aquifers in large sedimentary basins, depleted oil and gas reservoirs, un-mineable coal areas, and other formations which could serve as reservoirs for greenhouse gases produced at power plants." The $CO_2$ storage capacity of saline aquifers alone is estimated to be between 1.6 trillion and 20.2 trillion tonnes (metric tons).

One of the barriers to using these reservoirs is that injecting carbon dioxide ($CO_2$) into these formations raises the pressure of saline water (brine) occupying pore space in the rocks. This reduces the amount of $CO_2$ that can be stored, and may cause small earthquakes or force some of the injected gas into drinking water aquifers. One way to address the problem is to maintain the pressure by removing the brine to the surface.

The brine production poses problems of its own. Geologic carbon sequestration will only be practical if there are cost-effective, sustainable ways of using or disposing of the brine.

For their analysis, the Berkeley Lab scientists selected three saline aquifers in different parts of the United States, to introduce geographic and regional economic variability: the southern Mt. Simon Sandstone Formation in the Illinois Basin; the Vedder Interval in the southern San Joaquin Basin, California; and the Jasper Interval in the eastern Texas Gulf Basin (see Figure 1.) Each aquifer is near a major greenhouse gas-emitting power plant, making it a candidate as a reservoir for those point sources emissions.

"There are several ways of using the brine from these aquifers," says Breunig."The approach is to treat the brine as a resource, using its minerals, energy, and water in applications such as geothermal energy extraction, salt harvesting, and saline algae ponds for biofuels production. Then the brine would be discharged into wastewater treatment facilities or evaporation basins."

In a basin, the evaporating water would leave behind minerals such as gypsum, magnesium, salt, potash, and boron, which have value and could be harvested and marketed. Workers would harvest salts year-round in California and Texas, and during warmer months in Illinois. The salts could be used for anti-icing roads during colder months in Illinois, while in all three locations, any remaining brine could be diluted and sent to a saline water body or re-injected underground.

Price and Breunig obtained the mineral concentrations of brine in each of the three locations. They calculated the cost of production and the value of salts that could be harvested in each location, taking into account the differing regional market prices and rates of evaporation (the Texas and California locations are hotter and drier, and evaporation continues year-round).

Geographic information systems (GIS) software is one of the tools they used in their analysis. It provides a cross-regional perspective, allowing the Team to understand the impacts of new technologies on resource use and emissions in different climates and geographies, with their variations in utility costs and other costs of living.

Their results are summarized in Figure 1. The brine from the Illinois site turned out to have the highest value. It has a very high concentration of dissolved salts, and researchers concluded that "a large profit could be obtained from harvesting salts during warmer months. In addition, the brine from this formation could be used for anti-icing roads in the wintertime. This substitute for mined rock salt would lower the pressure on depleted salt mines, avoid the production of synthetic deicing solutions…"

Even though brine evaporates at the southern California site year-round, its low total dissolved solids content means that harvesting these salts would not be cost-effective.

They also concluded that, "Texas [site's brine] also has high enough total dissolved solids that a profit may be obtained by harvesting salts through evaporation ponds. Due to heavy rain fall in Eastern Texas, ponds could be used for salt tolerant algae production for biofuels…"

The study illuminates how regional variations in economics and climate affect the viability of geologic carbon sequestration from place to place, and their analysis methods provide scientists developing the technology—as well as future investors, implementers, and policymakers—with results to make better decisions about where and when to use the technology cost-effectively.

**—Allen Chen**

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Additional information:

Hanna Breunig
(585) 217-7512
HannaMSmith@lbl.gov

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Read about the Carbon Cycle 2.0 Energy and Environmental Analysis Team (E2AT) here [http://eetd.lbl.gov/newsletter/nl37/eetd-nl37-1-carboncycle.html].

LAWRENCE BERKELEY NATIONAL LABORATORY

Environmental Energy Technologies Division

NEWS

# Berkeley Lab Teams with MIT to Develop Search Engine for Materials Research

New materials are crucial to building a clean energy economy—for everything from batteries to photovoltaics to lighter weight vehicles—but today the development cycle is too slow: around 18 years from conception to commercialization. To speed up this process, researchers from Lawrence Berkeley National Laboratory (Berkeley Lab) and the Massachusetts Institute of Technology (MIT) teamed up to develop a new tool, called the Materials Project [https://www.materialsproject.org/], which launches this month.

"Our vision is for this tool to become a dynamic 'Google' of material properties, which continually grows and changes as more users come on board to analyze the results, verify against experiments, and increase their knowledge," says Kristin Persson, a Berkeley Lab chemist and one of the founding scientists behind the Materials Project."So many scientists can benefit from this type of screening. Considering the demand for innovative clean energy technology, we needed most of these materials yesterday."


Berkeley Lab scientist Kristin Persson co-founded the Materials Project, to accelerate discovery of new materials. (Photo by Roy Kaltschmidt/Berkeley Lab)

The Materials Project employs an approach to materials science inspired by genomics. But rather than sequencing genomes, researchers are using supercomputers to characterize the properties of inorganic compounds, such as their stability, voltage, capacity, and oxidation state. The results are then organized into a database with a user-friendly web interface that gives all researchers free and easy access and searching.

"First-principles calculations have reached the point of accuracy where many materials properties—relevant for photovoltaics, batteries, and thermoelectrics—can be reliably predicted," says Gerbrand Ceder, an MIT professor of materials science and engineering, and founder of the Materials Project.

A better battery—one that is cheaper and has more power and energy while being safe—could finally make possible the dream of an electric vehicle reaching performance and cost parity with a gasoline-powered car. But beyond batteries, novel materials could transform a host of other industries, from food packaging to buildings. For example, the Materials Project is working with with several entities interested in making stronger, corrosion-resistant lightweight aluminum alloys, which could make possible lighter vehicles and airplanes.

"Materials innovation today is largely done by intuition, which is based on the experience of single investigators," says Persson, who works in Berkeley Lab's Environmental Energy Technologies Division."The lack of comprehensive knowledge of materials, organized for easy analysis and rational design, is one of the foremost reasons for the long process time in materials discovery."

President Obama has recognized the importance of advanced materials with his announcement in June of the Materials Genome Initiative [http://www.whitehouse.gov/blog/2011/06/24/materials-genome-initiative-renaissance-american-manufacturing] "to double the speed with which we discover, develop, and manufacture new materials." According to Persson, many of the concepts of that initiative were inspired by the Materials Project.

With the help of supercomputers at the Department of Energy's National Energy Research Scientific Computing Center (NERSC) [http://www.nersc.gov], the Berkeley Lab Lawrencium cluster, and systems at the University of Kentucky, the Materials Project database currently contains the structural and energetic properties of more than 15,000 inorganic compounds, and up to hundreds more are added every day. Researchers are continuously adding new properties to enable true rational design of new materials for a wide variety of applications.

## A Gateway For Science

To build the Materials Project web tool, the team approached computer systems engineers at the National Energy Research Scientific Computing Center (NERSC) who have extensive experience building web-based interfaces and technologies—called science gateways [https://www.nersc.gov/users/science-gateways/]—that make it easier for scientists to access computational resources and share data with the rest of their community.

"The Materials Project represents the next generation of the original Materials Genome Project, developed by Ceder's team at MIT," says Shreyas Cholia, a NERSC computer engineer who helped develop the Materials Project tool."The core science team worked with developers from NERSC and Berkeley Lab's Computational Research Division to expand this tool into a more permanent, flexible, and scalable data service built on top of rich, modern web interfaces and state-of-the-art NoSQL database technology."

**—Linda Vu**

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Additional information:

Kristin Persson
(510) 486-7218
KAPersson@lbl.gov

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The Materials Project [https://www.materialsproject.org/]

This article was adapted from: Accelerating Advanced Material Development: NERSC Science Gateway a 'Google of Material Properties' [http://www.nersc.gov/news-publications/news/nersc-center-news/2011/materials-research-in-the-information-age/]

LAWRENCE BERKELEY NATIONAL LABORATORY

Environmental Energy Technologies Division

NEWS

# Increased Ventilation Rates in Office Buildings Can Bring Billions of Dollars in Savings

Current standards for U.S. offices require approximately 8 liters per second (L/s) of outdoor air ventilation per person. Providing twice as much ventilation would reduce sick building syndrome symptoms (SBS) and absences, improve work performance, and result in billions of dollars in annual economic benefits in the U.S., according to a recent study from Lawrence Berkeley National Laboratory (Berkeley Lab).

A second study found that four remedial measures in U.S. offices—increasing low ventilation rates, improving temperature controls so that offices don't get too hot in winter, performing dampness and mold remediation, and adding economizers —would reduce adverse health effects and health care costs, decrease absence rates, improve thermal comfort, and improve work performance. The projected societal economic benefits of non-overlapping combinations of these remedial measures range from $17 billion to $26 billion per year.

These are among the conclusions of scientists at Berkeley Lab's Environmental Energy Technologies Division reported in two recently published journal articles.

## Two Studies Examine Costs and Benefits

Two articles describing the results were published in the peer-reviewed journals *Indoor Air* and *Building and Environment*.

The *Indoor Air* article estimates the benefits of selected improvements in indoor environmental quality (IEQ) in U.S. offices compared to the existing level of IEQ in U.S. office buildings. They studied four improvements:

- Increasing ventilation rates when they are below 10 or 15 L/s per person, (the current major standard in the U.S. specifies 8.3 L/s per person; 10 L/s is prevalent in other countries).
- Adding outdoor air economizers and controls where absent. Economizers are control systems that increase the supply of outdoor air (the ventilation rate) above a minimum value when the additional ventilation will reduce the energy costs of air conditioning.
- Avoiding office overheating—eliminating winter indoor temperatures greater than 23°C (73°F)—accomplished through adjustments in thermostat setpoints and other measures.
- Reducing dampness and mold problems—accomplished through better maintenance to prevent and fix water leaks, changes in design and construction practices, and improved humidity control systems in some buildings within hot and humid climates.

The authors created scenarios and evaluated the impacts of improving existing IEQ conditions with equations derived from research on how IEQ parameters affect SBS health symptoms, absence, and work performance. They also used EnergyPlus, a building simulation model developed by Berkeley Lab, to estimate how the addition of economizers would affect ventilation rates and building energy use.

"The estimates of health benefits rely on dozens of studies of the relationship of IEQ with health, absence, and office work performance," says William Fisk, the principal investigator and head of the Indoor Environment Department. The benefits from these four improvements in office building IEQ are the result of small increases in work performance, reductions in absence, and decreases in health care costs spread over a large population of workers.

"The estimated annual benefits of increased ventilation rates (increased outdoor air supply) in offices are as high as $22 billion," says Fisk, "with annual energy costs less than $0.1 billion." The addition of economizers was a particularly attractive method of increasing ventilation rates. Projected net benefits are $12 to $22 billion, annual energy cost savings are $0.2 billion, and annualized implementation costs are also $0.2 billion, according to the research.

The study found that the estimated benefit of avoiding office overheating is $3.4 billion. Avoiding overheating prevents 7.7 million weekly sick building syndrome symptoms during winter, improves wintertime work performance on average by 0.2 percent, reduces winter dissatisfaction with thermal comfort by 12 percent among 40.4 million workers, and saves energy (not quantified in this study). The annual implementation cost is estimated at less than $0.4 billion.

The estimated annual benefit of reducing dampness and mold in offices is $0.5 billion, resulting from the elimination of 1.5 million days of absence.

## Focus on Ventilation Rate Changes

The second article, appearing in the journal *Building and Environment,* estimates the benefits of increasing ventilation rates in U.S. offices, assuming that all existing offices have the minimum ventilation rate prescribed in the leading U.S. ventilation standard. The article is called "Changing Ventilation Rates in U.S. Offices: Implications for Health, Work Performance, Energy, and Associated Economics."

A body of prior research has shown that higher ventilation rates decrease indoor air pollutant levels, improve satisfaction with indoor air quality, lower SBS symptoms in office workers, and improve work performance. Some research also suggests that lower absence rates are linked to higher ventilation rates (VRs).

The study conducted by Fisk, Douglas Black of Berkeley Lab, and Gregory Brunner of the U.S. Environmental Protection Agency, assumed a baseline ventilation rate in U.S. office buildings of 8 L/s, which is slightly below the current ventilation rate recommended by ASHRAE (Association of Heating, Refrigeration, Air Conditioning Engineers). Eight liters of air per second is about 16 cubic feet per minute. ASHRAE sets voluntary minimum standards for buildings, and ventilation standards are designed to prevent high concentrations of indoor pollutants.

Two scenarios assumed that ventilation rates increased from 8 to 10 L/s per person and from 8 to 15 L/s per person. The third scenario assumed that ventilation rates decreased from 8 to 6.5 L/s per person. In a fourth scenario with an 8 L/s per person minimum ventilation rate, economizers were added to the 50 percent of U.S. office floor space in buildings that do not have them.

The result showed that with a 25 percent increase in ventilation rate to 10.0 L/s per person, the total economic benefit was $13.0 billion, and the estimated annual energy cost was $0.05 billion. The estimated benefits include prevention of SBS symptoms in half a million workers, elimination of 9.4 million days of short-term absence, and an average 0.3 percent increase in work performance.

With a 90 percent increase in ventilation rate to 15.0 L/s per person, the research showed a total benefit of $37.5 billion, at an estimated annual energy cost of $0.19 billion. The increased ventilation rate prevented SBS symptoms in 1.4 million workers, eliminated 30 million days of short-term absence, and increased work performance on average by 0.9 percent.

With a minimum ventilation rate of 8 L/s per person, adding economizers to buildings that do not have them was projected to save $0.32 billion in energy costs each year. In this scenario, the measure prevented SBS symptoms in 1.2 million workers, prevented 28 million days of short-term absence, and increased average work performance by 1.6 percent. The total annual economic benefit was estimated at $32.9 billion.

The benefits are again the result of small increases in work performance, reductions in absences, and decreases in health care costs spread over a large population of workers.

"Our study shows that the widespread benefits of increasing ventilation rates in office buildings far outweigh the energy costs by an order of magnitude, says Fisk, "and increasing the use of economizers in more commercial buildings would retain the benefits of higher VRs as well as result in energy savings."

Fisk cautions that there are several uncertainties in this study."Our understanding of how ventilation rate affects health, performance, and absence is the main source of uncertainty," he says.

"The value of this study to building owners and energy managers, architects and engineers, and policy makers is that, although there are uncertainties in the absolute magnitude of health benefits and energy costs, the study has shown that the economic benefits from improved health, reduced absenteeism, and improved work performance are far higher than the implementation cost."

"Most importantly," Fisk concludes, "there are opportunities to improve the health of building occupants and save on costs while reducing energy use simultaneously."

**—Allan Chen**

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For more information:

Fisk W. J., Black D., and Brunner G."Changing Ventilation Rates in U.S. Offices: Implications for Health, Work Performance, Energy, and Associated Economics," *Building and Environment* 47: 368-372 (2011)

Fisk W. J., Black D., and Brunner G."Benefits and Costs of Improved IEQ in U.S. Offices," *Indoor Air* 21: 357-367 (2011)

Indoor Air Quality (IAQ) Scientific Findings Resource Bank (IAQ-SFRB) [http://www.iaqscience.lbl.gov/]

This research was funded by the U.S. Environmental Protection Agency.

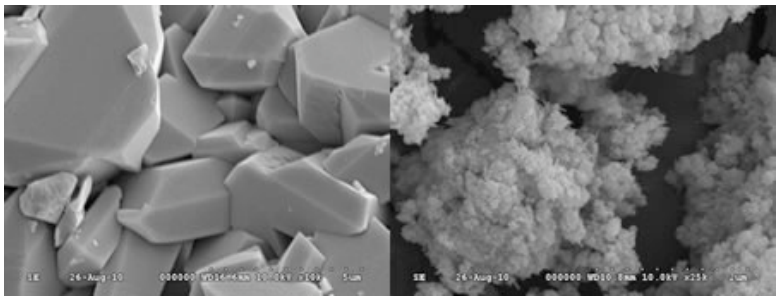
LAWRENCE BERKELEY NATIONAL LABORATORY

Environmental Energy Technologies Division

NEWS

# EETD Scientists Develop Effective Approaches for Removing VOCs from Indoor Air

Researchers estimate that those of us in developed countries spend 90 percent of our time indoors, which means that most of the time we are breathing air polluted by emissions from indoor sources. Providing more outdoor air ventilation can improve indoor air quality; however, energy is needed to heat, cool, humidify or dehumidify, and sometimes filter the ventilation air brought indoors from outdoors. Studies have shown that about 10 percent of the energy consumed in U.S. commercial buildings is used to thermally condition ventilation air. To improve a building's energy efficiency, we would like to *reduce* ventilation rates while maintaining good air quality—or better yet, to do so while *improving* indoor air quality.



Scanning Electron Microscopy (SEM) images of synthesized catalyst LBNL-100 (right) and of commercial manganese dioxide, showing the significantly smaller size of manganese oxide particles.

Through their work at the Indoor Environment Department of Lawrence Berkeley National Laboratory's Environmental Energy Technologies Division (EETD), William Fisk, Hugo Destaillats, and Meera Sidheswaran are devising solutions to this challenge. Recently, they have been evaluating two ways to reduce indoor air pollutants without increasing ventilation rates: by developing a synthetic catalyst to reduce indoor formaldehyde concentrations, and by evaluating the effectiveness of activated carbon fiber filters in reducing other volatile organic compound (VOC) concentrations.

## Tackling Formaldehyde with a Manganese Oxide Catalyst

Formaldehyde is a common indoor pollutant that the World Health Organization and the U.S. Department of Health and Human Services lists as a human carcinogen. Formaldehyde concentrations in indoor air are routinely above the maximum recommended indoor level, so efforts to improve indoor air quality often target formaldehyde.

"Mean formaldehyde concentrations in a typical U.S. building are about 17 parts per billion," says Destaillats, "although 20 to 50 parts per billion are fairly common." The California Environmental Protection Agency guideline for the maximum recommended long-term-average formaldehyde concentration is 9 parts per billion.

To reduce these formaldehyde concentrations, Fisk, Destaillats, and Sidheswaran developed a catalyst that could be applied to the filters routinely used to remove particles from airstreams. They formed the catalyst samples by co-precipitation of manganese-containing precursors, and cured them at different temperatures to compare their effectiveness. The synthesis resulted in a black powder containing agglomerates of particles smaller than 50 nanometers (nm) in diameter, giving the formaldehyde plenty of surface area with which to react. The research team used porosimetry and surface area analysis; X-ray diffractometry; SEM imaging analysis; and ICP-MS analysis to characterize the catalyst.

"Surface area and porosity are important for good reactivity with the formaldehyde," explains Fisk, "but the manganese oxide can also have a variety of crystal structures and chemical compositions that influence their effectiveness as a catalyst."

The team applied the catalyst to particle filters, passed air containing formaldehyde and other contaminants through the filters, and measured the formaldehyde removal rates by the treated filter over time. Experiments were performed with various air speeds and with variable humidity. For reference, they also tested a commercially available manganese oxide under the same conditions.

The results have been encouraging. With air velocities typical of those in particle filtration systems, the initial formaldehyde removal efficiency was 80 percent; and even after 2,300 hours of continuous operation, the formaldehyde removal efficiency was approximately 60 percent.

"Typically, particle filters are replaced approximately every 1,500 hours of ventilation system operation, so the catalyst remains effective over the necessary time frame," says Destaillats. "The catalyst is inexpensive enough to be able to deploy it on particle filters and not have to recover the material when the filter is changed out every three or four months," says Fisk.

The synthesized sample that was conditioned at 100°C (LBNL-100) performed significantly better than the commercial sample. In fact, even when the amount of the commercial catalyst used was three times that of the LBNL-100 catalyst, the LBNL-100 catalyst still performed better, showing consistent single-pass formaldehyde removal of > 80 percent—far outperforming the commercial catalyst, which removed only 5 to 10 percent of formaldehyde over four days. Tests currently under way have shown that the LBNL catalyst also removes other VOCs.

Destaillats and Fisk attribute the effectiveness of the LBNL-100 to its higher available surface area, and its intrinsic redox properties seem to contribute to its much-longer effective lifetime, compared to the commercial version."The synthesized catalyst has a much higher surface area, and a different particle size and chemical composition than the commercial product, which results in superior performance," says Fisk.

In a separate set of experiments, measurement of upstream and downstream formaldehyde and $CO_2$ concentrations showed that mineralization (breakdown of the formaldehyde into $CO_2$ and water) in both experiments reached 100 percent, without formation of formic acid, a potential by-product of an incomplete reaction."This indicates to us that the catalyst should be able to achieve complete mineralization in buildings with the typical level—tens of parts per billion—of formaldehyde," says Destaillats." Preliminary tests at high velocities indicate that particles from the catalyst are not being entrained into the airstream.

Relative humidity has minimal effect on the effectiveness of the LBNL-100 catalyst. High relative humidity (90 percent) slightly reduced its formaldehyde removal efficiency, but its efficiency returned once relative humidity levels were reduced.

The 60 to 80 percent formaldehyde removal efficiencies are more than adequate. In fact, even a 20 percent formaldehyde removal efficiency in the supply airstream in a commercial building ventilation system could counteract the expected indoor formaldehyde increases associated with a 50 percent reduction in minimum outdoor air supply.

In some commercial buildings, this formaldehyde control could, by itself, enable energy-saving reductions in ventilation rates. However, in many situations the catalyst-treated filters would need to be supplemented by air cleaning systems or by pollutant source control measures for other pollutants. That approach could result in improved indoor air quality and simultaneous, significant ventilation energy savings. One very promising approach is to use activated carbon fiber air cleaners to remove other air pollutants.

## Activated Carbon Fiber (ACF) Filters Prove Effective in Removing VOCs

While formaldehyde is a key indoor air pollutant, high concentrations of other VOCs in indoor spaces also pose health risks and inhibit the ability to decrease ventilation rates and energy use. In a separate study focusing on reducing ventilation and energy consumption while maintaining or improving indoor air quality, Fisk, Destaillats, and Sidheswaran evaluated the use of a commercial activated carbon fiber (ACF) media as a filter for cleaning air in heating, ventilating, and air conditioning (HVAC) systems.

Volatile organic compounds in the air flow adsorb to the ACF filter, removing them from the indoor air. To create space on the filter for more VOCs to adsorb, the VOCs must be desorbed from the filter periodically and exhausted outdoors—a process known as "regeneration." The research team studied three different regeneration methods for the filters, using outdoor air under ambient conditions, with humidified air, and with the filter or regeneration air heated. The best performance occurred when the ACF filter was regenerated for 15 minutes once every 12 hours using air heated to 150°C. The air flow during regeneration is only 1 percent of the airflow during the 12-hour period of air cleaning, so only a very small amount of air must be heated, and the amount of energy required for regeneration is small.

The research team studied ACF system performance with mixtures of VOCs, with VOC properties ranging from those of formaldehyde (with a molecular weight of 30 and a boiling point of -21°C) to undecane (with a molecular weight of 156 and a boiling point of 196°C). For all VOCs other than formaldehyde, the time-averaged VOC removal efficiency was above 70 percent. The efficiency of formaldehyde removal was approximately 20 percent. However, using a double layer of the ACF cloth, the efficiency of formaldehyde removal jumped to 40 percent, and the efficiency for other VOCs exceeded 90 percent. The ACF system imposed a low airflow resistance, so the system will have only a minor impact on fan energy use.

Modeling indicates that the combination of ACF air cleaning and a 50 percent reduction in ventilation can decrease indoor concentrations of VOCs by 60 to 80 percent and reduce formaldehyde concentrations by 12 to 40 percent. Thus, the system reduces exposures to VOCs and formaldehyde, while allowing the ventilation rate to be cut in half to save energy

"Energy modeling indicated the potential to reduce the energy required for heating and cooling of ventilation air by 35 percent to almost 50 percent," says Sidheswaran.

## Ongoing Work Looks at Associated Issues

Fisk, Destaillats, and Sidheswaran continue to evaluate both solutions; looking at the catalyst's lifespan, the effect of other VOCs on its effectiveness, and its ability to remove other VOCs, as well as a combined approach that uses both the LBNL catalyst and the ACF filter.

"We're really pleased with the results on both products so far," says Fisk."Often when you work on something like this, things go wrong, but overall, our results here have been very satisfying."

**—Mark Wilson**

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For more information, see LBNL Tech Transfer [http://www.lbl.gov/Tech-Transfer/techs/lbnl2970.html].

This research was funded by the Department of Energy's Office of Energy Efficiency and Renewable Energy.

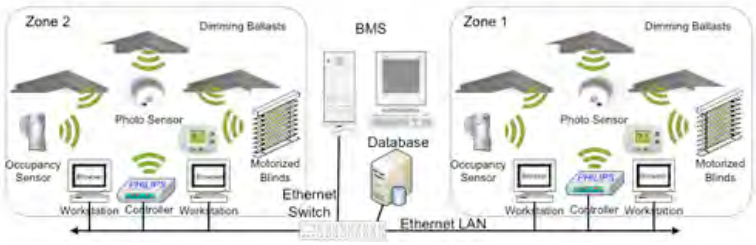
LAWRENCE BERKELEY NATIONAL LABORATORY

Environmental Energy Technologies Division

NEWS

# Berkeley Lab Helps the DoD Identify Substantial Energy Savings

Teaming up to fight against escalating energy costs, the U.S. Department of Defense (DoD), Lawrence Berkeley National Laboratory (Berkeley Lab), and Philips Corporation are demonstrating advanced energy-efficient lighting control technologies in Fort Irwin, California.




System architecture of an Integrated Lighting and Daylight Control system (Hybrid ILDC).

"The purpose of this study is to demonstrate that these technologies work in typical applications and buildings at Fort Irwin, and to provide the technical experience and data to support scaling up these energy-efficient systems at Department of Defense facilities throughout the U.S.," says Francis Rubinstein, a scientist in Berkeley Lab's Environmental Energy Technologies Division.

The nation's military is looking to apply advanced energy-efficient technologies in its facilities to help reduce its energy costs, and reduce the nation's dependence on external sources for its energy. It has long been a testbed and proving ground for technological innovation—DoD-sponsored research led to the integrated circuit and the Internet among many others.

At a speech in Virginia, Deputy Secretary of Defense William J. Lynn III recently said, "… in facilities, where the buildings and systems we use are the same as in commercial industry, any innovations we achieve in-house can directly transfer to the rest of the economy. And because of our size and ability to serve as a sophisticated first user and early customer, the military can jump-start the broader commercial adoption of innovative energy technologies. Our Installation Energy Test Bed program aims to do just this. Some of the technologies we are demonstrating are simple, like advanced lighting systems that calibrate their output to the amount of available daylight and use occupancy sensors to turn lights on-and-off."

The Environmental Security Technology Certification Program (ESTCP) is funding the work. The ESTCP is DoD's environmental technology demonstration and validation program. The program's goal is to identify and demonstrate cost-effective technologies that address DoD's highest-priority environmental requirements.

## Fort Irwin, California's DoD Lighting Testbed

Fort Irwin staff members are working with Rubinstein and Abby Enscoe of EETD, and with Philips, to demonstrate and evaluate three advanced, energy-efficient lighting systems in military buildings. Two of the systems use wireless technology for lighting control.

The DoD manages more than 300,000 structures and 2.2 billion square feet of space on its installations. It spends $4 billion a year just to buy the energy needed to run its facilities.

The research team estimates that in large military installations, lighting typically represents around 28 percent and cooling represents 33 percent of the total electrical energy used. They write: "At present, nearly 50 percent of the lighting energy consumed throughout DoD facilities is lost because their lighting systems are either outdated and/or inadequately controlled."

At Fort Irwin, an Army training facility in the Mojave desert near Barstow, California, a team composed of Enscoe, Rubinstein, Philips lighting experts Maulin Patel, Satyen Mukherjee, Matt Helm, and Dagnachew Birru, and Fort Irwin facilities managers have installed advanced lighting systems in three buildings, and are carefully monitoring and recording their use patterns and energy savings.

"Different buildings and use patterns require different retrofit and control strategies," says Enscoe."One of the purposes of this demonstration is to get experience with how well different lighting control systems perform in different types of buildings."

Each building has a different system adapted for its building type. In a building with large south-facing windows and plenty of available daylight, they installed a Hybrid Integrated Lighting and Daylight Control system (Hybrid ILDC), which maximizes the use of daylight and improves visual comfort using electric lights and motorized blinds that are automatically controlled.

They are testing a variety of control approaches—such as occupancy sensing, personal dimming controls, and automated glare avoidance—to see which control sequences provide the best combination of energy savings and user comfort. The system uses wireless technology to connect sensors and motorized blinds within a lighting zone, and wired connectivity to connect zones (thus, a hybrid) so that the control system can be deployed throughout a building.

In a building with a hard ceiling and lower daylight levels, they installed a fully wireless system, called OccuSwitch™ , which automatically turns lights off when a space is unoccupied and dims the electric lights in response to available daylight. OccuSwitch uses wireless communication between sensors and switches, which reduces retrofit costs, particularly in areas with hard ceilings.

In a headquarters building with a variety of different use types, they installed the wired Philips Networked Lighting Control System (PNLCS). This building-wide wired lighting control system includes personalized dimming controls, automatic scheduling, occupancy sensing, daylight harvesting, and distributed control—lighting in different zones can be controlled from different locations through different control devices. PNLCS can work with existing building management systems, including HVAC controls.

In each system, building occupants now have the ability to set their preferred light levels, which was not possible to do before the new controls were installed."Individual lighting control has been found to improve occupant satisfaction," says Enscoe."The win-win of saving energy and improving occupant control is one of the strong arguments for installing controls."

## Coupling Lighting and HVAC Control

To better understand how the hybrid system can save air conditioning and heating energy use, another EETD team, led by Vladimir Bazjanac, is using the EnergyPlus building energy simulation software to model the building in which it is installed. This will help the project team understand how to optimize the control system and the motorized blinds to minimize both air conditioning and lighting energy use. By reducing solar heat gain into the building, the system can reduce the need for air conditioning, but still allow in sufficient daylight to minimize the use of electric lights.

## Early Results Show Substantial Energy Savings

The results so far have been promising. Three months of post-retrofit energy data show that the hybrid system resulted in estimated annual energy savings of 28 percent compared to the measured baseline energy use before the retrofit. Compared to the baseline energy use of a "code building" with an old lighting system operating 10 hours per weekday, the estimated annual energy savings was 79 percent. The baseline code building represents buildings with existing DoD lighting systems that were installed more than 20 years ago and are in need of a retrofit. It provides a rough estimate of the magnitude of potential lighting energy savings throughout DoD buildings with the same type of older lighting systems.

The wireless OccuSwitch system, which turns off lights automatically when a space is unoccupied and dims electric lights in daylit areas, also resulted in energy savings. In this building, the team changed the configuration of lights so that they provide better, more even lighting levels for workers and meet lighting codes.

Adjusting for the changed configuration, three months of data show that the control system reduced lighting energy use 34 percent in perimeter offices, and 16 percent in central office areas, for an average of 22 percent savings. Compared to the code baseline, the system saved 62 percent of lighting energy use.

The PNLCS system has also performed well. As in the OccuSwitch building, an adjusted baseline was calculated to eliminate the effect of changes in the installed lighting and isolate controls savings. After three months of data, the control system has reduced lighting energy by 18 percent compared to this baseline, and by 40 percent compared to the code baseline. The system has also given occupants much more ability to control light levels in the building.

"We have anecdotal evidence that, on balance, building occupants like the new lighting systems," says Enscoe."We have also learned that details matter—the specific control algorithms and installation details make a big difference."

The buildings will continue to be monitored through the end of 2011. The DoD will review the results and develop a plan for scaling up the installation of energy-saving systems that have been shown to be cost-effective.

Rubinstein is confident that the wireless systems can be scaled up cost effectively."It is expensive to install wires in ceilings, but less expensive to put sensors into the lighting systems. Energy service companies know how to add wired control systems when necessary, but the wireless approach brings an additional cost advantage to a lighting improvement program."

**—Allan Chen**

For more information:

Abby Enscoe
(510) 486-6077
AIEnscoe@lbl.gov

Francis Rubinstein
(510) 486-4096
FMRubinstein@lbl.gov

- The Environmental Security Technology Certification Program of the Department of Defense [http://www.serdp-estcp.org/]
- "*Deputy Secretary of Defense Praises ESTCP'S Installation Energy Test Bed Initiative* [http://www.serdp-estcp.org/News-and-Events/News-Announcements/Program-News/Deputy-Secretary-of-Defense-praises-ESTCP-S-installation-energy-test-bed-initiative]"
- Deputy Secretary of Defense William J. Lynn, III's speech [http://www.defense.gov/speeches/speech.aspx?speechid=1594]

This research was funded by the Environmental Security Technology Certification Program of the Department of Defense.

LAWRENCE BERKELEY NATIONAL LABORATORY

Environmental Energy Technologies Division

NEWS

# Berkeley Lab Report Shows Significant Decline in the Installed Cost of Solar Photovoltaic Systems in the U.S.

The installed cost of solar photovoltaic (PV) power systems in the United States fell substantially in 2010 and into the first half of 2011, according to the latest edition of an annual Lawrence Berkeley National Laboratory (Berkeley Lab) PV cost-tracking report.

The average installed cost of residential and commercial PV systems completed in 2010 fell by roughly 17 percent from the year before, and by an additional 11 percent within the first six months of 2011. These recent installed cost reductions are attributable, in part, to dramatic reductions in the price of PV modules. Galen Barbose of Berkeley Lab's Environmental Energy Technologies Division and co-author of *Tracking the Sun IV*, which reports on PV systems from 1998 to 2010, explains: "Wholesale PV module prices have fallen precipitously since about 2008, and those upstream cost reductions have made their way through to consumers."

The report indicates that non-module costs—such as installation labor, marketing, overhead, inverters, and the balance of systems—also fell for residential and commercial PV systems in 2010."The drop in non-module costs is especially important," notes report co-author and Berkeley Lab scientist Ryan Wiser, "as those are the costs that can be most readily influenced by solar policies aimed at accelerating deployment and removing market barriers, as opposed to research and development programs that are also aimed at reducing module costs." According to the report, average non-module costs for residential and commercial systems declined by roughly 18 percent from 2009 to 2010.

Turning to utility-sector PV, costs varied over a wide range for systems installed in 2010, with the cost of systems greater than 5,000 kilowatts (kW) ranging from $2.90 per watt (W) to $6.20/W, reflecting differences in project size and system configuration, as well as the unique characteristics of certain individual projects. Consistent with continued cost reductions, current benchmarks for the installed cost of prototypical, large utility-scale PV projects generally range from $3.80/W to $4.40/W.

The market for solar PV systems in the United States has grown rapidly over the past decade, as national, state, and local governments offered various incentives to expand the solar market and accelerate cost reductions. This fourth study in Berkeley Lab's "Tracking the Sun" report series describes trends in the installed cost of PV in the United States. It examined more than 115,000 residential, commercial, and utility-sector PV systems installed between 1998 and 2010 across 42 states, representing roughly 78 percent of all grid-connected PV capacity installed in the United States. Berkeley Lab's Naïm Darghouth explains that "the study is intended to provide policy makers and industry observers with a reliable and detailed set of historical benchmarks for tracking and understanding past trends in the installed cost of PV."

## Costs Differ by Region and by Size and Type of System

The study also highlights differences in installed costs by region and by system size and installation type. Comparing costs across the United States, for example, the average cost of PV systems installed in 2010 and less than 10 kilowatts (kW) in size ranged from $6.30/W to $8.40/W, depending on the state. The report also found that residential PV systems installed on new homes had significantly lower average installed costs than those installed as retrofits to existing homes.

Based on these data and on installed cost data from the sizable German and Japanese PV markets, the authors suggest that PV costs may be driven lower through large-scale deployment programs, but that other factors are also important in achieving cost reductions.

The report also shows that PV installed costs exhibit significant economies of scale. Among systems installed in 2010, those smaller than 2 kW averaged $9.80/W, while large commercial systems >1,000 kW averaged $5.20/W; partial-year data for 2011 suggests that average costs declined even further in 2011. Large utility-sector systems installed in 2010 registered even lower costs, with a number of systems in the $3.00/W to $4.00/W range.

## Cost Declines for PV System Owners in 2010 Were Partially Offset by Falling Incentives

The average size of direct cash incentives provided through state and utility PV incentive programs has declined steadily since their peak in 2002. The dollar-per-watt benefit of the federal investment tax credit (ITC) and Treasury grant in lieu of the ITC, which are based on a percentage of installed cost, also fell in 2010 as a result of the drop in average installed costs.

The reduced value of federal, state, and utility incentives in 2010 partially offset the decline in installed costs. Therefore, while pre-incentive installed costs fell by $1.00/W and $1.50/W for residential and commercial PV in 2010, respectively, the decline in "net" (or post-incentive) installed costs fell by $0.40/W for residential PV and by $0.80/W for commercial PV.

The report, *Tracking the Sun IV: An Historical Summary of the Installed Cost of Photovoltaics in the United States from 1998 to 2010,* by Galen Barbose, Naïm Darghouth, and Ryan Wiser, may be downloaded here: [PDF [http://eetd.lbl.gov/ea/emp/reports/lbnl-5047e.pdf]].

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For more information:

Galen Barbose
(510) 495-2593
GLBarbose@lbl.gov

Ryan Wiser
(510) 486-5474
RHWiser@lbl.gov

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LAWRENCE BERKELEY NATIONAL LABORATORY

Environmental Energy Technologies Division

NEWS

# Cool Car Colors Could Improve Fuel Economy, Reduce Emissions

Nearly all cars sold in California have air conditioners—the most energy-consuming car accessory. Cars painted with reflective coatings stay cooler in the sun and are easier to air condition to a comfortable temperature, according to a recent study by researchers in Lawrence Berkeley National Laboratory's (Berkeley Lab's) Environmental Energy Technologies Division.

"Solar reflective paints can decrease the 'soak' temperature of the air in a car that has been parked in the sun," says Ronnen Levinson, scientist in the Heat Island Group and lead author of the study."This could improve the vehicle's fuel economy by letting the manufacturer install a smaller air conditioner that draws less power from the engine."

White, silver, and other light colors are coolest, reflecting about 60 percent of sunlight. However, the study showed that dark "cool colors," which reflect primarily in the invisible "near infrared" part of the solar spectrum, can also stay cooler than traditional dark colors.

## Soaking in the Sun

In the study, researchers parked two nearly identical Honda Civic four-door sedans, loaned by the California Department of General Services, in a lot in Sacramento, California. One was silver, and one was black. The shells (opaque elements) of the black and silver cars had solar reflectances of 0.05 and 0.58, respectively (on a scale of 0 to 1). Higher solar reflectance keeps a surface cooler in the sun.

**Figure 1.** Black and silver experimental vehicles parked facing south in Sacramento, California, on July 17, 2010.

During the course of a sunny summer day, the cars were run through five identical cycles of soaking in the sun. Each cycle consisted of an hour with the air conditioners off, followed by a half hour of cooling with the air conditioners running at maximum. The researchers continuously measured the roof, ceiling, dashboard, windshield, seat, door, vent air, and cabin air temperatures in each car, as well as the external weather conditions in the lot.

At the peak of the soak phases, the roof of the silver (high reflectance) car was as much as 25°C (45°F) cooler than the roof on the black (low reflectance) car. The study found that increasing the solar reflectance of the car's shell by about 0.5 lowered the "soak" temperature of cabin air by about 5°C to 6°C (9°F to 11°F).

## Downsizing the Air Conditioner

The researchers developed a thermal model that predicted the air conditioning capacity (rate of heat removal) required to cool each vehicle to a comfortable final temperature of 25°C (77°F) within 30 minutes—an industry standard for vehicle air conditioner performance. Based on the experimental measurements, the analysis predicted that the capacity required to cool the cabin air in the silver car is 13 percent less than that required in the black car.

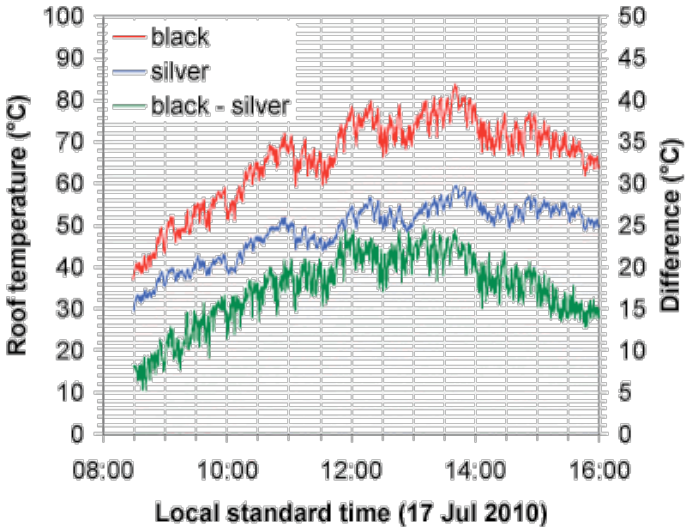


**Figure 2.** Comparison of roof surface temperatures measured during soaking and cooling trials.

Using a vehicle simulation tool called ADVISOR, the research team modeled the effect of air conditioner capacity on fuel consumption and pollutant emissions in each of several standard driving cycles. These include an urban cycle, a highway cycle, and a transient driving cycle with numerous increases and decreases in speed. They combined these simulations with the output of the thermal model to estimate the potential energy savings and emission reductions from using solar-reflective car paint to downsize the air conditioner.

Their results suggest that replacing a traditional black paint, which has a solar reflectance of 0.05, with a typical cool-colored paint that has a solar reflectance of 0.35 would increase fuel economy by 0.24 miles per gallon (mpg) (1.1 percent). This benefit would result from using a smaller air conditioner that draws less power from the car's engine. The change would also decrease carbon dioxide emissions by 1.1 percent, and reduce other automotive emissions, including nitrogen oxides, carbon monoxide, and hydrocarbons, by about 0.5 percent.

Using a white or silver paint (with a solar reflectance of 0.60) instead of a black paint would raise fuel economy by 0.44 mpg (2.0 percent). It would also decrease carbon dioxide emissions by 1.9 percent and reduce other automotive emissions by about 1 percent.

A roughly one- to two-percent improvement in fuel economy, when scaled to the fleet of light-duty vehicles in the U.S., represents an eventual potential savings of billions of gallons of gasoline, if these design changes are adopted by the automotive industry.

This research was supported by the California Energy Commission's Public Interest Energy Research (PIER) Program, and the U.S. Department of Energy.

**—Allen Chen**

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Additional information:

Ronnen Levinson, Heng Pan, George Ban-Weiss, Pablo Rosado, Riccardo Paolini, and Hashem Akbari."Potential benefits of solar reflective car shells: Cooler cabins, fuel savings and emission reductions. [http://dx.doi.org/10.1016/j.apenergy.2011.05.006]" *Applied Energy* 88: 4343–4357.

For more on the science of cool colored materials as applied to roofing, see:

- The *EETD Newsletter* article, "Cool Colors Project: Improved Materials for Cooler Roofs" [http://eetd.lbl.gov/newsletter/nl19/eetd-nl19-1-cool.html]
- Cool Materials and Shade Trees webpage [http://eetd.lbl.gov/l2m2/cool.html]
- EETD's Heat Island Group [http://heatisland.lbl.gov/]

LAWRENCE BERKELEY NATIONAL LABORATORY

Environmental Energy Technologies Division

NEWS

# Research Highlights

## Conductive Polymer Binder Awarded $240,000 UC Discovery Grant

A technology with the potential to increase the lithium-ion storage capacity of advanced batteries by eight times has been awarded a $240,000 grant from the University of California's Discovery Proof-of-Concept Grant program to accelerate its entrance into the marketplace. This project is led by Gao Liu (Principal Investigator) and Vince Battaglia (co-PI) in the Environmental Energy Technologies Division.

Developed by Gao Liu, the technology is a conductive polymer binder that significantly improves the performance of electrodes in silicon composite electrodes. Silicon is a high energy-capacity material for negative electrodes that also has a long life cycle in batteries. Lithium ion batteries with silicon electrodes could have up to 25 percent higher energy storage capacity than current batteries, and a longer product lifetime through many cycles of charging and discharging.

Given the equivalent vehicle weight, this means that an electric vehicle could travel 25 percent farther on one charge. The technology could lead to EVs with a 250-mile per charge range.

### The Promise of Silicon as an Electrode

"Silicon is a very promising material as a negative electrode [anode] for batteries," says Liu." It has ten times the capacity of graphite. The problem is that silicon is not stable. Its volume increases and decreases as electric charge travels to and from the electrode."

With existing binders, the pathway of the electric current will breach as the silicon expands, preventing the charges from moving—like breaking an electrical circuit.

"Our conductive polymer binder is very effective in lithium-ion batteries," says Liu."As it expands and contracts, it holds the silicon particles together, maintaining the conductive path."

"The conductive polymer binder," adds Liu, " cannot only be used with our silicon electrode, but with other battery chemistries and technologies as well. Many other battery-related applications are possible with this binder."

The research work that led to the technology has been funded by the Battery for Advanced Transportation Technologies program (BATT) of the Office of Vehicle Technologies, U.S. Department of Energy. The BATT program continues to fund the basic research.

The UC Discovery Fund is designed for technologies that have already demonstrated successful results in the research environment and are poised for commercialization but are in need of a specific, targeted demonstration, test result, or prototype.

### Technology Transfer Department Helps Identify Marketplace Barriers

The Technology Transfer Department's Shanshan Li worked closely with Liu to clarify the potential market applications and barriers to commercialization, as well as to develop tangible development milestones that will most likely attract commercial interest to license the technology.

"The technology has generated high-profile interest from battery manufacturers, suppliers, and investors," says Liu."But we identified two primary barriers to commercialization: providing a large quantity of samples for testing, and optimizing the performance of the electrode in battery systems. The UC Discovery Proof-of-Concept Grant serves an important role in making the lab-to-market transition of this technology possible."

Unlike the other UC Discovery grants, the Proof-of-Concept program does not require matching industry funds. However, for Berkeley Lab researchers, applying for the grant would have been impractical because the fund only covers the direct cost of research. In collaboration with Berkeley Lab leadership, The Technology Transfer Department found a way to use the licensing royalty funds to cover the indirect cost, making it possible for Berkeley Lab researchers like Liu to apply.

Read the UC Discovery Grant press release [http://www.universityofcalifornia.edu/news/article/26297].

For more information on the technologies, "conductive binder for lithium ion battery electrode" and "silicon composite electrode for advanced lithium ion batteries," see the Berkeley Lab Technology Transfer [http://www.lbl.gov/Tech-Transfer/techs/lbnl2643,2890.html] website.

Read a story about Proof-of-Concept grants [http://research.universityofcalifornia.edu/stories/2011/09/proof-concept-grants.html] here.

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## EETD Policy Brief Reviews the Value of Building Labels, Certifications, and Ratings

A new policy brief on the value of energy performance and green attributes in buildings, authored by Lawrence Berkeley National Laboratory's Elizabeth Stuart, is available.

Labels, certifications, and rating systems for energy efficiency performance and "green" attributes of buildings have been available in the U.S. for over 10 years, and used extensively in the European Union and Australia for longer. Such certifications and ratings can make energy efficiency more visible, and could help spur demand for energy efficiency if these designations are shown to have a positive impact on sales or rental prices. This policy brief discusses the findings and methodologies from recent studies on this topic and suggests recommendations for future research. Although there have been just a handful of studies within the last 10 years that have investigated these effects, a few key findings have emerged.

Download "The Value of Energy Performance and Green Attributes in Buildings: A Review of Existing Literature and Recommendations for Future Research" [PDF [http://eetd.lbl.gov/EAP/EMP/reports/ee-policybrief_090711.pdf]].

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## Berkeley Lab Helps NASA Bring Efficient Technologies to Earth

Lawrence Berkeley National Laboratory (Berkeley Lab) is collaborating with NASA's Ames Research Center to develop what may be the "greenest," highest-performing building in the federal government. The building, dubbed "Sustainability Base," will feature NASA-developed control and Integrated Systems Health Management (ISHM) technologies in a "closed-loop," sustainable building that uses NASA energy- and water-conserving technologies and draws on regional resources, such as natural lighting and the cool night air.

To help integrate NASA's "smart system" technologies, the Building Technologies Department at Berkeley Lab developed a Building Information Model (BIM) to serve as the repository for the building's systems information during its life cycle. In addition, Berkeley Lab developed an energy-performance simulation model to optimize the building's energy operations, using data from the BIM.

These tools will help NASA Ames monitor the building's performance for maximum efficiency and make suggestions for potential performance improvements. In addition, Berkeley Lab will provide advice regarding the new building's overall performance assessment. Data collected from the building will also provide information that will lead to better calibration and validation of the EnergyPlus simulation model and support the construction of future energy-efficient office buildings.

"It's a win-win situation for everyone when federal agencies work together sharing technologies and developing better business practices," said Steve Selkowitz, head of Berkeley Lab's Building Technologies Department.

For more information about Sustainability Base, please visit the NASA Sustainability Base [http://www.nasa.gov/centers/ames/greenspace/sustainability-base.html] website.

For more information about LBNL's Building Science program visit the Environmental Energy Technologies Division [http://eetd.lbl.gov] website.

LAWRENCE BERKELEY NATIONAL LABORATORY

Environmental Energy Technologies Division NEWS

# 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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**Editor**
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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.

## Ordering Information

*EETD News*
Lawrence Berkeley National Laboratory
University of California

Tel: (510) 486-4835
Fax: (510) 486-5394
Email: JMLambert@lbl.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.

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