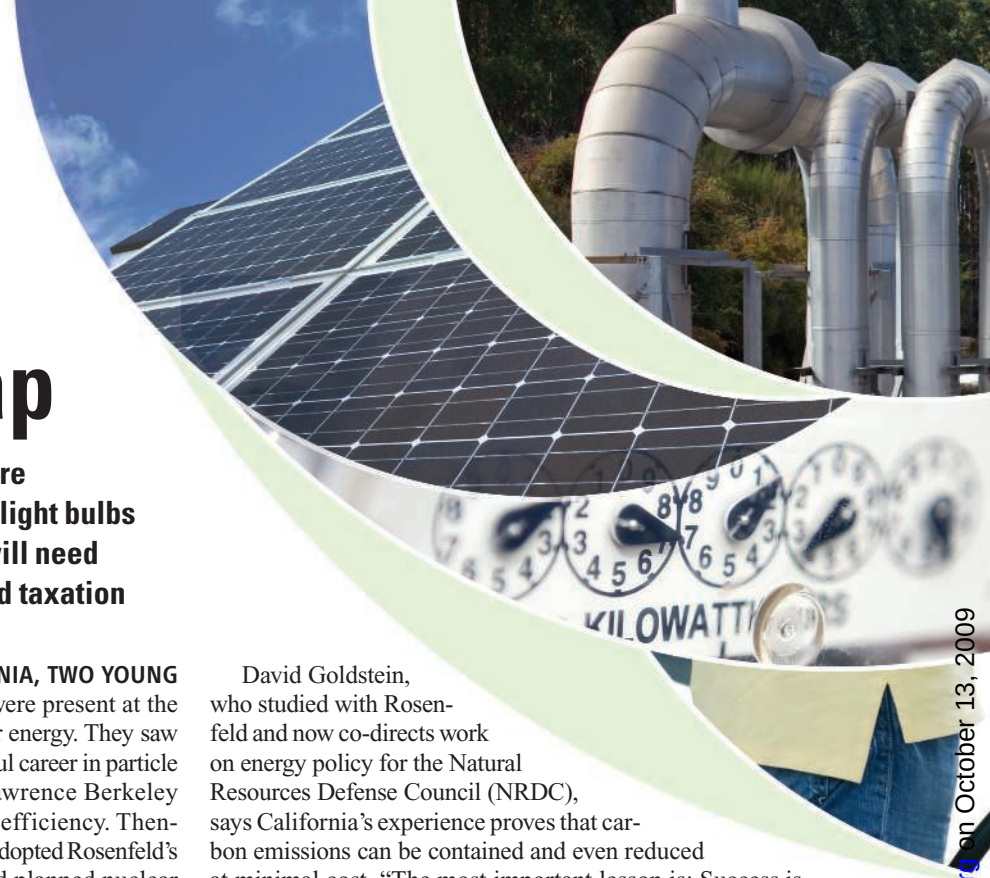


Leaping the Efficiency Gap

Experience has shown that there is more to saving energy than designing better light bulbs and refrigerators. Researchers say it will need a mixture of persuasion, regulation, and taxation

THIRTY-FIVE YEARS AGO IN BERKELEY, CALIFORNIA, TWO YOUNG physicists named Steven Chu and John Holdren were present at the birth of a campaign to curb Americans' appetite for energy. They saw their colleague Arthur Rosenfeld abandon a successful career in particle physics and set up a new research division at Lawrence Berkeley National Laboratory (LBNL) devoted to energy efficiency. Then-Governor Jerry Brown and state regulatory agencies adopted Rosenfeld's ideas with astonishing speed. California canceled planned nuclear power plants, passed pathbreaking efficiency standards for refrigerators and buildings, and ordered electric utilities to spend money persuading their customers to use less power.

Today, Chu, now the U.S. secretary of energy, cites Rosenfeld as a model for scientists and California as a example for the nation. He points out that per capita electricity consumption in California stayed flat for the past 30 years yet rose 40% in the rest of the United States. That flattened curve even has a name: the Rosenfeld Effect. Together with Holdren, now President Barack Obama's science adviser, Chu has made efficiency the heart of the Obama Administration's energy strategy. Tighter appliance standards are on a fast track through the Department of Energy bureaucracy. Billions of dollars from the stimulus package are pouring into programs to weatherize and retrofit homes with energy-saving technology. Chu says such investments quickly pay for themselves in lower energy bills: "Energy efficiency isn't just low hanging fruit; it's fruit lying on the ground."

Online
sciencemag.org
Podcast interview with author Dan Charles.

Efficiency pioneer. Arthur Rosenfeld traded particle physics for cutting-edge research into energy-saving technologies.

David Goldstein, who studied with Rosenfeld and now co-directs work on energy policy for the Natural Resources Defense Council (NRDC), says California's experience proves that carbon emissions can be contained and even reduced at minimal cost. "The most important lesson is: Success is possible, and a fairly limited set of policies gets you most of the way there," Goldstein says. And, he adds, it's not hard to go even further with energy saving: "The practical limits [of increased efficiency] have never been tested."

But not everyone views California's success story as so clear-cut. Alan Sanstad, an LBNL researcher who also worked with Rosenfeld, looks at the same data and concludes that California's efficiency offensive wasn't nearly effective enough. He points out that California's *total* energy use over the past 3 decades grew at almost the same rate as it did in the rest of the country, while the state's population soared. Anant Sudarshan and James Sweeney of Stanford University's Precourt Energy Efficiency Center (PEEC) recently calculated that the state's energy policies can take credit for only a quarter of California's lower per capita electricity use. The rest is due to "structural factors" such as mild weather, increasing urbanization, larger numbers of people in each household, and high prices for energy and land that drove heavy industry out of the state.

For Sanstad, there's a clear lesson: Meeting the more ambitious goal of reducing greenhouse gas emissions will require more aggressive measures that cause some economic pain. "The real potential of energy efficiency is not going to be realized until we get away from the idea that it has to pay for itself," he says.

The biggest challenge is not inventing new technology but persuading more people to adopt technology and practices that already exist. A new generation of researchers and government officials is now examining new strategies for energy efficiency, looking for the key—or a whole ring of keys—that will unlock its full potential. "It's a wonderful opportunity to which we have to rise," says Ashok Gadgil, an energy technology researcher at LBNL. "We were preparing for this for 20 years; now come under the spotlight and sing!"

The human dimension

Rosenfeld and Edward Vine had a friendly, long-running argument during their 2 decades as colleagues at LBNL. Rosenfeld believed in technology. When he testified before the U.S. Congress, as he did

Waste not, want not. Everywhere you look, energy can be used more efficiently, but doing so requires care and cash. The potential gains are huge, dwarfing expected increases in production of renewable energy.

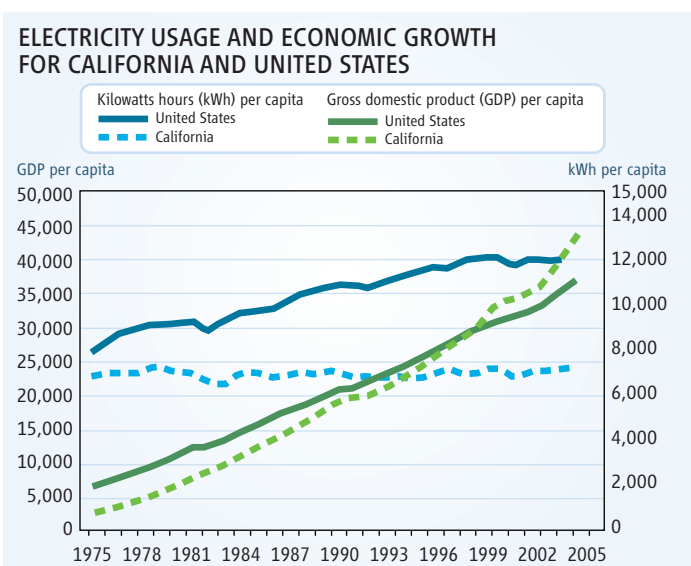
frequently in the early 1980s, he always came with props in hand: compact fluorescent light bulbs, heat-shielding windows, or computer programs for predicting the energy use of new buildings. But Vine, whose Ph.D. is in human ecology, wasn't convinced of technology's power. "We can't assume, if we have a great technology, that people will rush to stores and buy it," Vine says. "We need to find out how people behave, how they make decisions, how they use energy, and we need to work with them."

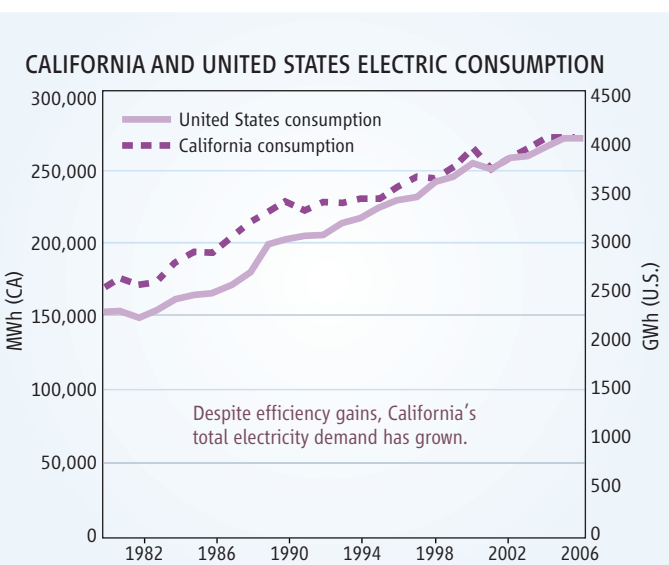
For the most part, energy-efficiency programs around the country have followed Rosenfeld's line. They offer financial incentives for adopting energy-saving, cost-effective technology, and trust that consumers will follow their economic self-interest.

Yet many researchers are now coming around to Vine's point of view. Consumers don't seem to act like fully informed, rational decision-makers when they make energy choices. Many avoid making choices at all. Give them a programmable thermostat, and they won't program it. Offer them an efficient light bulb that pays for itself in 2 years, and they won't buy it. Builders don't take full advantage of the cheapest source of lighting, the sun. Even profit-seeking businesses sometimes make little effort to control their energy use, says Ernst Worrell, who teaches at Utrecht University in the Netherlands and studies companies all over the world. "There are companies that spend 20% of their operating cost on energy, but upper management doesn't know where that money is going," Worrell says. "They see energy costs as an act of God."

Every once in a while, however, circumstances force people to focus on energy. When they do, the results can be astonishing. In April 2008, an avalanche cut a transmission line that supplied Juneau, Alaska, with cheap hydropower. The city switched over to diesel generators, but the electricity they produced cost five times as much. City officials went looking for help and contacted Alan Meier, an LBNL conservation expert.

"In a crisis, you can talk about behavior," says Meier. The city spread the word that "good citizens save electricity." And they did, lowering thermostats, turning off lights, and unplugging electronic equipment. Over 6 weeks, Juneau's electricity consumption fell by 40%, yet Juneau's economy did not falter. The transmission line was repaired within 3 months; electricity use rebounded, but it remains about 6% below its preavalanche level. A similar phenomenon, but on a much larger scale, happened during a 2001

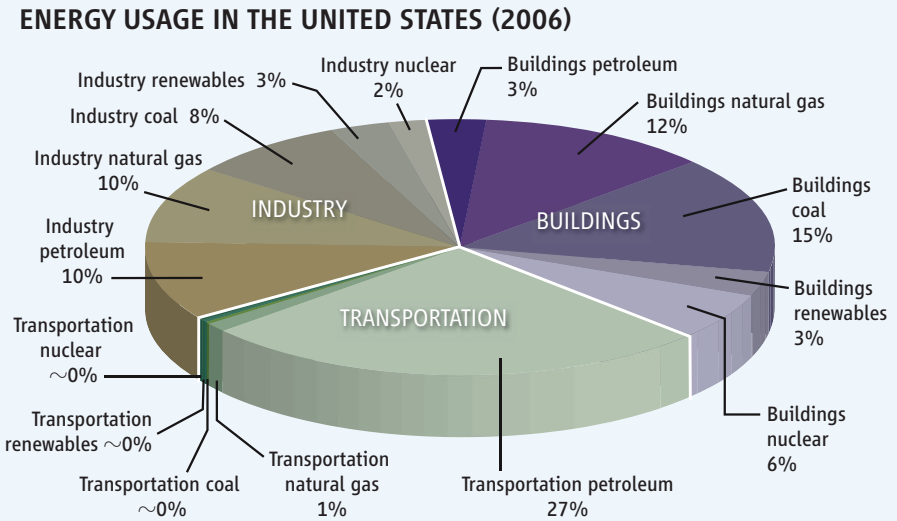




SOURCES (LEFT TO RIGHT): CALIFORNIA ENERGY COMMISSION; 2008 ELECTRIC POWER RESEARCH INSTITUTE

Rosenfeld effect. The average Californian uses less electricity than a typical person uses in the rest of the country. That gap has grown wider over the past 30 years, even though California has become relatively more wealthy.

Published by AAAS



Energy pie. Most energy in the United States is used for one of three purposes: transportation; heating, cooling, and lighting buildings; or industrial production.

"Every person I know who has a Prius, they get a big grin when I mention feedback, and they have to tell me their personal story about how they've reduced their energy use."

—CARRIE ARMEL, PRECOURT ENERGY EFFICIENCY CENTER, STANFORD UNIVERSITY

energy crisis in Brazil. The country "cut its power consumption by 20% in 6 weeks. That shows you how much behavior can get you," Meier says.

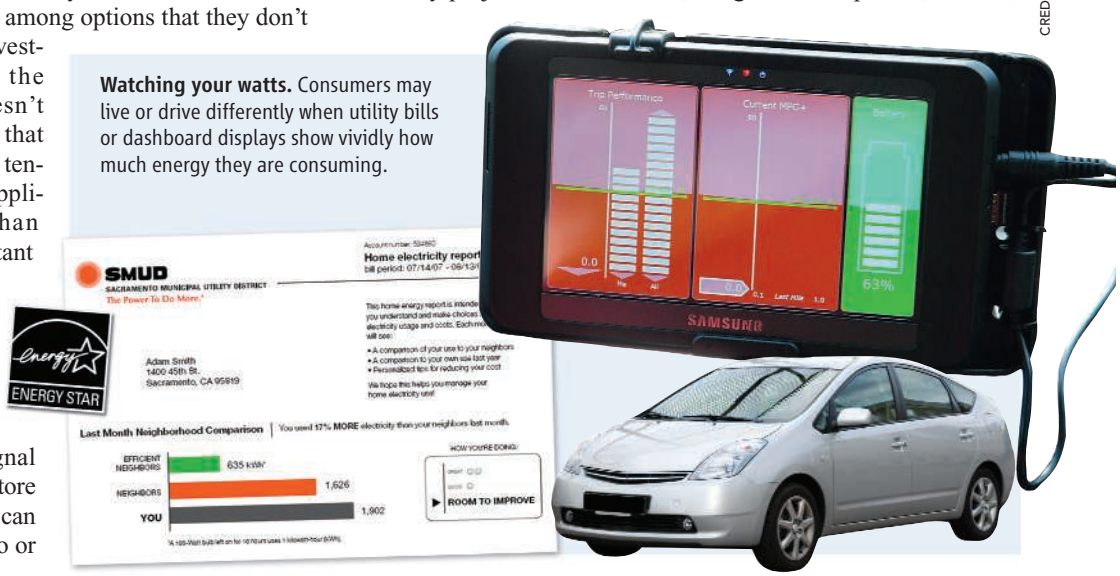
Stories such as this one have fueled a recent explosion of interest in ways to influence people's energy-using behavior. When Carrie Armel, a neuroscientist at Stanford's PEEC, helped organize a conference on the topic in 2007, "we were expecting 150 people and sold out at 500," she says. "Last year we were sold out at 700. This year we're opening it up to 800 people."

Research has produced some intriguing insights. For instance, people believe that others waste energy because of their inner characters, but they regard their own wasteful practices as the product of circumstances. More information doesn't usually produce energy-saving behavior; experts leave the lights on, too. The concrete example of a friend or neighbor who walks her children to school is much more powerful than any impersonal exhortation to drive less. And don't tell someone that he needs to save energy because nobody else does. "It could end up backfiring," Armel says, because most people don't like the feeling of being in the minority.

When people are asked to choose among options that they don't fully understand, such as a list of investment plans, they tend to select the "default option": the one that doesn't require them to change anything or that seems most popular. Right now, that tendency works against efficiency. In appliance stores, says LBNL's Jonathan Koomey, who also works as a consultant for companies, the most efficient "Energy Star" machines are usually aimed at high-end customers. They're manufactured in low volumes and come with additional features that drive up the price. The marketing strategy sends a clear signal that these are not appliances that the store expects most customers to buy. "You can change that," says Koomey. "If Costco or Wal-Mart announce that they are only carrying Energy Star products, suddenly the efficient product becomes the standard product."

A few utilities are now designing programs based on the conclusions of behavioral science. Because people like to keep up with their neighbors, the Sacramento Municipal Utility District (SMUD) began an experiment in competitive fuel saving. Starting in April 2008, 35,000 randomly selected customers got bills showing how their energy use stacked up against the average usage of their neighbors. According to SMUD, the typical customer in the experiment responded by cutting consumption by about 2%. SMUD also got some angry mail. "I resent being told I am below average," one customer wrote. "I pay my bill on time; … leave me alone." SMUD plans to expand the program to 50,000 customers next year.

Some energy-conservation advocates are rediscovering the old-fashioned virtues of porch conversations and town meetings, now renamed "social marketing." "There's more interest now in looking at people as part of a community, a culture, a neighborhood, a church group," says Vine. That approach paid off 20 years ago during energy-efficiency projects in Hood River, Oregon, and Espanola, Ontario,



Watching your watts. Consumers may live or drive differently when utility bills or dashboard displays show vividly how much energy they are consuming.

CREDITS (TOP): APS REPORT (SEPTEMBER 2008); LINDA A. CICERO/STANFORD NEWS SERVICE

which reached an impressive proportion of the citizenry. According to Hugh Peach, who helped manage the Hood River project for the energy company Pacific Power & Light, 85% of homes in the community received state-of-the-art energy audits and free efficiency upgrades. In Espanola, more than 90% of homes participated.

Peach compared the process to a political campaign. The utility sat down with local leaders, followed their advice, and relied heavily on local volunteers. The process was time-consuming and labor-intensive but, Peach says, a pleasure. There was "a lot of community spirit. People just saw it as the right thing to do."

The next big force for behavioral change may be technology that brings consumers face-to-face with their energy consumption. A simple version of such energy feedback is the dashboard of a Toyota Prius hybrid car, which displays the rate at which the car is burning gasoline. No one has carried out a controlled study of how drivers react to it, but "every person I know who has a Prius, they get a big grin when I mention feedback, and they have to tell me their personal story about how they've reduced their energy use," says Armel. At the Institute of Transportation Studies at the University of California, Davis, 12 Prius cars have been outfitted with more detailed dashboard displays. Researchers will use them to study how drivers react to different kinds of information, such as energy consumption, emissions, or the cost of fuel being burned.

The same feedback is now becoming available for homes and businesses. About 40 million homes will soon get "smart meters" that record every spike or dip in electricity use, hour by hour. Various companies, including Google, are devising ways to deliver that information directly to consumers, either via the Internet or by using displays that are linked to the smart meters themselves. Studies show that consumers usually respond to such feedback by cutting their energy use by 5% to 10%. But Sanstad thinks that may be only the first step because this information could create new markets for energy efficiency. "I think it will open a lot of doors," he says. "When people have

Soap Operas to Save Energy

In developing countries such as Mexico and Ethiopia, serial dramas on radio and television have proved to be successful tools for social change. Their fictional characters have become role models for real life, encouraging women to use birth control or stay in school.

Filmmaker John Johnson is deploying a similar technique, adapted to the YouTube age, to persuade Americans to act against climate change. Two years ago, he set up the Harmony Institute, an environmental media group based in New York City. Now it is collaborating with the creators of popular video programs on the Web to develop scripts that show people conserving energy and water and considering how their consumption choices might affect the planet. The first programs will go online later this year.

"We were fascinated by this amazing way of reaching people through the medium that they already are using," says the institute's deputy director, Debika Shome. Shome, who previously worked at Columbia University's Center for Research on Environmental Decisions, says the online dramas will harness ideas from behavioral science—for instance, that "people are more likely to make changes if it's not about sacrifice but about community."

Shome won't reveal where on the Web the institute's "product placement for ideas" will appear because she says publicity would make it harder to measure the show's impact. The Harmony Institute plans to survey viewers both before and after the new episodes to see if there's any change in their attitudes and behavior.

–DAN CHARLES

Many More More-Efficient Computers

Few technologies can match the efficiency gains made in computing. Compared with the first personal computers introduced in 1981, today's machines need a millionth as much energy to flip a bit. However, they also flip a million times as many bits per second, and there are more than a billion of them in the world. One watt in every 50 now goes to powering computers, and industry leaders are eager to keep that figure from growing.

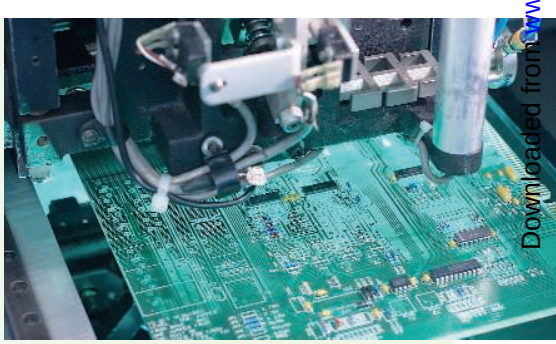
Big savings can still be made by using more-efficient power supplies and automatically putting idling computers into an energy-saving "sleep" mode. The 2-year-old Climate Savers Computing Initiative—begun by search-engine giant Google, chipmaker Intel, and the World Wildlife Fund—asks companies to pledge to do that in hopes of reducing annual carbon emissions from computing by 50%, or 54 million tons, by 2010.

Hardware engineers are applying the turn-out-the-lights strategy within microprocessors themselves. "The number-one issue with processors is that they've become pretty good at what they do, so they spend a lot of time waiting for something to do," says William Swope, vice president and general manager of Intel's Corporate Sustainability Group in Portland, Oregon. To prevent idling, Intel's latest high-end processor runs algorithms that slow down or stop parts of the chip that aren't being heavily used. The new chip consumes 90% less energy per computation than its predecessor from 4 years ago.

At the software level, engineers are making gains by using a process known as virtualization to run several copies of an operating system on a single processor and to shift those "virtual machines" from one physical processor to another. In times of low demand, a big data center can now shift work onto a fraction of its thousands of servers. Erik Teetzel, Google's energy program manager in Mountain View, California, predicts that "cloud computing" will move almost all computing into such highly efficient data centers. "You're going to have a lot of people with 5-watt devices accessing these centralized resources," Teetzel says.

Although computers' energy demand has increased, that expenditure must be weighed against the savings it brings to other machines such as cars and refrigerators, Swope says. "Computers consume about 2% of the power used in the world," he says. "And yet every aspect of computing has made the other 98% [of energy use] more efficient."

–ADRIAN CHO



Nap time. Computer chips can be designed to put subunits to "rest" when not needed.

CREDITS: (BOTTOM LEFTHAND PAGE TO RIGHTHAND PAGE) SMUD; TAI STILLWATER; JUPITERIMAGES

Published by AAAS

Wanted: Help With Building Design

Light, naturally. Movable glass shutters on this office building near Zurich, Switzerland, let in sunlight but keep out unwanted heat.

To create a truly efficient building, don't just buy more insulation, better windows, and efficient lighting. "That gets you a 10 to 30% improvement," says Stephen Selkowitz of Lawrence Berkeley National Laboratory (LBNL) in California. Bigger energy savings, at a lower cost, come from designing a whole building to manage heat and light in an energy-saving way. But current computer-aided design tools are not making it easy for architects to design for efficiency. New software is needed.

An inherently efficient building demands a delicate balance of opposing forces. Big windows provide natural light, for instance, but can place heavy demands on a cooling system in the summer. To make it work, architects need to predict the flow of air and heat through a structure, arranging windows and the heat-storing "thermal mass" of walls and floors in ways that maintain a stable, comfortable temperature inside.

Software can simulate all these phenomena, but the most accurate tools, such as the U.S. Department of Energy's (DOE's) EnergyPlus software, are "unfriendly to nonengineers," says LBNL's Ashok Gadgil. John Haymaker, a specialist on building design at Stanford University in Palo Alto, California, says architects and engineers often use EnergyPlus simply to show that a planned structure will meet building codes or satisfy a client's wishes. What's needed, he says, are more user-friendly tools that let architects experiment with different configurations of a building and find more energy-saving solutions.

Many groups are taking on that challenge. The software giant Autodesk and Integrated Environmental Solutions, based in Glasgow, U.K., are trying to incorporate more sophisticated energy simulations into their design software.

DOE, meanwhile, is funding an effort to mate EnergyPlus with Google's user-friendly SketchUp software. "I am encouraged that this will be the new face of design," says Haymaker.

All simulation tools have one big limitation, however. "You never know how people will use a building," Haymaker says. His own office building at Stanford is an example: It is not living up to its energy-saving promises because its inhabitants brought in unanticipated lighting, computer equipment, and space heaters. So the best design software will predict not just a building's behavior but also the actions of people inside.

–DAN CHARLES

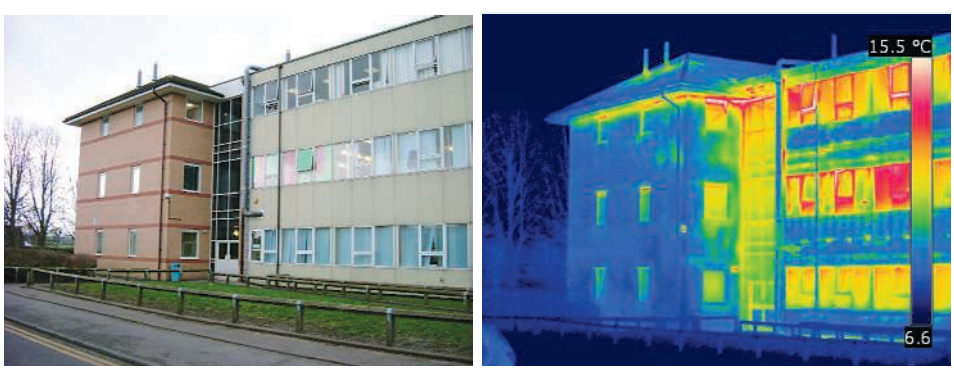
this, what new things will they want?" At a meeting of utility regulators in February, Jason Grumet, executive director of the National Commission on Energy Policy in Washington, D.C., said, "this may change the mood surrounding efficiency. It could make it cool."

Battling perverse incentives

Behavioral change was never a top priority for NRDC's Goldstein. "It's real and important," he says, but it's something "you can only do once." Technological innovation, on the other hand, leads down a path of continuous improvement. What keeps people from adopting efficient technology is not a quirk of human psychology, he says, but institutional roadblocks—what he calls "market failures."

Much has been written about market failures, with little demonstrated success in overcoming them. A prime offender is the "principal-agent problem," which occurs when someone gets to spend another person's money. Hotel guests, for instance, can waste hot water because they don't pay for it. Landlords buy cheap, inefficient appliances because their tenants pay the utility bills. LBNL's Meier found his own favorite example: the humble set-top box that comes with cable TV services. Each box can consume up to 40 watts of electricity continuously—more than an efficient refrigerator. Cable subscribers can't choose which box they get, and cable companies have no incentive to make the boxes more efficient.

"This situation is more important than you might think," says Meier. According to his calculations, some form of the principal-agent problem afflicts a quarter of all residential energy use in the United States. There are ways to solve it, he says. In Japan, companies that deliver a vend-



Snapshot of waste. Infrared cameras quickly show where heat is escaping from a building. The older building on the right, for instance, has leaky windows.

Published by AAAS

ing machine to a site also pay for the electricity that the vending machine consumes. Not surprisingly, those companies now use more energy-efficient vending machines.

Koomey has studied energy use in big data-processing centers and found similar problems. "The IT department and the facilities department have separate budgets," he says. "The IT department buys the equipment, but they don't pay the electric bill. They don't have an incentive to spend even $1 to buy a more efficient server."

Brazil "cut its power consumption by 20% in 6 weeks. That shows you how much behavior can get you."

—ALAN MEIER, LAWRENCE BERKELEY NATIONAL LABORATORY

Such institutional barriers bedevil the fragmented, tradition-bound construction industry. Buildings account for 40% of the country's energy use. Amory Lovins of the Rocky Mountain Institute, perhaps the country's most eloquent prophet of efficiency, wrote in 2005 that architects, engineers, builders, and maintenance workers are "systematically rewarded for inefficiency and penalized for efficiency." Builders are trained to satisfy the minimal standards of construction codes, but they rarely exceed them.

Energy Secretary Chu told a congressional committee in July that the average new building could use 40% less energy by simply adopting off-the-shelf technology such as automatic controls that turn off lights when they aren't needed and highly insulating windows that also reflect much of the sun's heat in summertime. Retrofits to older buildings, he said, could cut energy use in half and eventually pay for themselves. Innovative architectural designs, arranging windows, shade, and ventilation so as to minimize the need for additional light or cooling, could cut energy use by 80% below today's average (see sidebar, p. 808).

Frustratingly, "green" buildings often don't deliver what their designers promised because of mistakes in design, shoddy construction, or poor maintenance. "No one measures building performance," says Stephen Selkowitz, head of the Building Technologies Division at LBNL. "I'll ask 100 architects, 'How many of you design energy-efficient buildings?' Almost all of them. Then I'll ask, 'How many of you know the measured performance of your last building?' Not a soul! If you don't know how well you did, how will you ever do any better?"

The California Energy Commission plans to require all new buildings in California to consume no net energy by 2030. Rooftop solar panels will generate as much energy as the building requires. In Europe, an even more ambitious model is gaining ground: the superinsulated, airtight "passive house," born in Germany, which consumes 10% of the energy of a typical house.

Such buildings are possible, and hundreds already exist, but most are relatively small. When it comes to large office buildings,

many architects and developers struggle to reach more modest goals, such as cutting energy use in half. "A lot of people start down this path, but they get hung up on cost, they get hung up on complexity, they can't find vendors, they can't find designers who can do it. Owners lose faith," says Selkowitz.

Tougher efficiency standards for buildings could change that, creating a network of architects, equipment suppliers, and construction companies that know how to make highly efficient buildings. Such regulations were the first steps in California's efficiency campaign 30 years ago. The long-term benefits, especially if one includes benefits to the environment, can be substantial. "I'm slowly drifting to the position—let's mandate as much stuff as we can," Selkowitz says.

A few communities in California, including the city of Berkeley, are trying a new approach to overcoming the reluctance of many homeowners to spend money on energy-saving equipment. Instead of using tax breaks or subsidies to get their attention, local governments or counties are going ahead and funding the work themselves. Local

The Quest for White LEDs Hits the Home Stretch

White light–emitting diodes (LEDs) have already cracked several niche lighting markets, such as flashlights and bike lights. But they're still not ready to go head to head with cheaper incandescent bulbs and fluorescents that dominate the nearly $100 billion global lighting market. A new spate of advances, however, suggests that the whitecoats are coming. "There is steady movement and progress in the field," says E. Fred Schubert, an electrical engineer and LED expert at Rensselaer Polytechnic Institute (RPI) in Troy, New York.

Much of that progress is coming from the current generation of white LEDs that use a blue LED in combination with a yellow phosphor to produce white light. In April, North Carolina–based Cree reported that its latest commercial white LED bulb puts out an impressive 132 lumens of light per watt of electricity. Incandescent bulbs, by contrast, put out 15 lumens/watt (lm/W), and compact fluorescents bump that up to about 65 lm/W. And earlier this year, Nichia, a Japanese LED company, reported that in a lab demonstration white LEDs had turned out a stunning 249 lm/W at low current.

Progress is also coming in combining separate blue, green, and red LEDs that not only can combine their primary colors to produce bright white but also can be tuned to shine in any color. The holdup right now is that green LEDs are less efficient than the reds and blues. But over the past 2 years, key advances have come from the University of California, Santa Barbara (UCSB), Purdue University, and RPI.

Bright future? White light–emitting diodes could slash the need for electricity.

If progress continues, the payoff could be enormous. According to UCSB researchers, if an affordable 150-lm/W white LED were developed, the efficiency gains from replacing conventional bulbs would save the United States alone some $115 billion in lighting costs by 2025, alleviate the need for 133 power stations, and prevent the release of 258 million metric tons of carbon dioxide.

–ROBERT F. SERVICE

CREDITS (TOP TO BOTTOM): LBNL; JUPITERIMAGES

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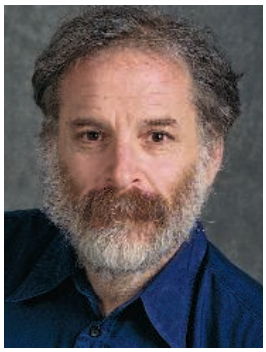
governments recover the cost of the retrofit by adding a small monthly charge to that home's property taxes or utilities bill. But homeowners should still come out ahead as their monthly energy savings are greater than the extra charge.



"There's a battle, and that battle is vicious. It's like abortion, gun control—it's one of those 'apple pie' things."

—LEE SCHIPPER, CENTER FOR GLOBAL METROPOLITAN STUDIES, UC BERKELEY, AND PRECOURT ENERGY EFFICIENCY CENTER, STANFORD UNIVERSITY

Paying the cost

Lee Schipper of Stanford's PEEC is a grizzled veteran of campaigns to save energy around the world. And after many years in the trenches, he's changed his mind. In the early 1970s, when Schipper was studying astrophysics at Berkeley (where he shared a graduate student office with Chu), he started teaching classes and giving lectures on the physics of energy. When the energy crisis hit, he quickly earned a reputation as an efficiency enthusiast of the most irrepressible sort. He eventually joined Rosenfeld's research team at LBNL.

Schipper couldn't restrain himself when, in 1977, President Jimmy Carter urged Americans to conserve energy using arguments that Schipper considered unfounded. Carter said that conserving energy "will demand that we make sacrifices and changes in our lives. To some degree, the sacrifices will be painful." Schipper wrote an angry letter to Representative John Dingell (D–MI), arguing that conserving energy did not, in fact, require painful sacrifices. He explained that new energy-saving lights, windows, and car engines allowed consumers to live just as they always had yet burn less oil and coal. "You know what?" Schipper says today. "I was wrong. Carter was right."

Schipper has worked at the International Energy Agency in Paris, the World Resources Institute Center for Sustainable Transport in Washington, D.C., and now at PEEC. He's seen the push for efficiency repeatedly run into limits. Some of those limits, he says, are perfectly understandable. Energy is not a big-ticket item for most people, and even when new technology is cost-effective, the switch often takes more time and effort than people feel it's worth. And sometimes the technology doesn't live up to its promise. Many con-

Aircraft Designers Shoot for Savings on the Wing

Since jet engines appeared in the mid-1950s, commercial aircraft have become steadily more fuel-efficient—simply in order to fly farther and cheaper. According to the International Air Transport Association, new aircraft are 70% more fuel-efficient than they were 40 years ago. In 1998, passenger aircraft averaged 4.8 liters of fuel per 100 kilometers per passenger; the newest models, the Airbus A380 and Boeing 787, claim 3 liters. Even so, as air travel expands while fuel prices spiral upward, there is more that aircraft designers can do.

The greatest gains in the past, says aerospace engineer Ian Poll of Cranfield University in the United Kingdom, have come from better engines. The earliest engines were turbojets in which all the air sucked in at the front is compressed, mixed with fuel, and burned, providing thrust through a jet out the back. Engineers soon realized that they could get greater efficiency by using some of the power of the jet to drive a fan that pushes some of the intake air through ducts around the core, a design known as a turbofan. Other boosts have come from better compressors and materials to let the core burn at higher pressure and temperature. Poll says engineers might make turbofans yet more efficient by leaving the fan in the open. Such a ductless "open rotor" design—essentially a high-tech propeller—would make possible larger fans, Poll says, if engineers could solve noise problems and figure out how to fit such engines onto the airframe.

Changes in aircraft bodies have led to more modest improvements. Computational fluid mechanics has enabled designers to refine the shape to reduce drag—an enemy of efficiency. Manufacturers have also reduced weight with lightweight materials such as plastic. The Boeing 787 is made of 50% composite materials by weight, mostly carbon fiber–reinforced plastic, and is the first airliner to use them extensively in the fuselage, wings, and tail. But increasing efficiency this way is a hard fight: Each 1% reduction in weight cuts fuel consumption by only about 0.75%.

Poll thinks manufacturers could wring another 50% greater efficiency by using open-rotor engines and more composite materials, but beyond that they may need to radically change the shape of the aircraft. In traditional airliners, the fuselage is a dead weight that contributes no lift. A possible alternative is a blended wing body (BWB) in which the fuselage flows into the wings and is itself a lift-generating airfoil.

NASA and Boeing have been collaborating on an experimental BWB craft known as the X-48B. Since 2007, they have been flight-testing a remotely piloted 6.4-meter-wide model of the plane. Making the jump to such a different technology carries enormous risks for manufacturers and airlines because of development and testing involved. They would take that step only if forced to by high fuel costs. "We know [a BWB] is more fuel efficient," says Poll. "But it's too early to say if it will be the next generation."

–DANIEL CLERY

Delta force. Boeing and NASA are testing fuel-efficient blended-wing body designs to see how they fly.

CREDITS: LEE SCHIPPER; BOEING IMAGE

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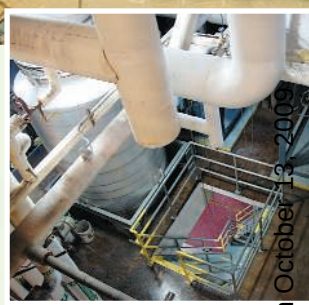
Green campus. Duquesne University, in the heart of Pittsburgh, built a cogeneration plant (*below*, with smokestack) that supplies the campus with electrical power and steam heating.



CREDITS: DUQUESNE UNIVERSITY

sumers haven't been happy with compact fluorescent lighting, either because they don't like the quality of the light or because the light bulbs haven't been as durable as advertised.

More important, efforts to push efficiency ran into intense political opposition, especially in the United States. "There's a battle, and that battle is vicious. It's like abortion, gun control—it's one of those 'apple pie' things," Schipper says.

Schipper's views are shaped by his own particular specialty: transportation, including cars. Since 1980, new cars have doubled the amount of mass they move with a gallon of gasoline, but U.S. car manufacturers used most of that efficiency gain to make cars bigger and more powerful, not more fuel-conserving. The simplest and cheapest way to reduce energy use in transportation, Schipper says, is simply to require cars that are lighter, smaller, and less powerful. But because of fierce resistance to that idea, "we get all these interesting technological fixes, like plug-in hybrids, that are actually quite expensive."

So Schipper has come around to the idea that conserving energy really does demand that people change their attitudes and the way they live. The single most important step in that direction, he says, is to make energy more expensive. "We're still playing 1970s games, thinking that we don't have to confront consumers and industries with the real price of energy and carbon," he says.

Some efficiency advocates are wary of such talk. "I'm a nonenthusiast about price. Low energy prices and efficiency can coexist," says Goldstein. He points to the example of Seattle, where electricity is cheap but people use relatively low amounts of it. Goldstein credits Seattle's tough building codes, cooperative electric utility, and a strong conservation ethic in the population. Koomey thinks conventional economic thinking may underestimate efficiency's growth potential. Perhaps, he says, it's more like the Internet: As more people adopt energy-conserving practices, the infrastructure of efficiency becomes more widespread, making it easier and cheaper for others as well. The phenomenon, he thinks, could gain momentum like a ball rolling downhill.

Rosenfeld, the man who once provided a professional home to many of these efficiency researchers, quietly agrees with Schipper. "Of course we need an energy tax," he says simply. The "father of energy efficiency" is modest in physical stature and demeanor. He still lives in Berkeley but spends just as much time in Sacramento, where he's a member of the California Energy Commission. It's a sad time in his life; his wife, Roz, died suddenly of a stroke in early June.

But it makes him feel "very well," he says, to hear Energy Secretary Chu extol his accomplishments. He's as devoted to saving energy today as he was 35 years ago. His latest cause: promoting white roofs that reflect sunlight, reducing the load on air conditioners and cooling the planet. "I get listened to," he says with a smile. "So I continue to say, 'Energy efficiency is the first thing you want to do, and I know a lot of tricks for doing it.' Steve Chu does answer my phone calls."

–DAN CHARLES

Making Use of Excess Heat

The single biggest opportunity to increase the "energy productivity" of American industry, according to a report issued in July by the consulting group McKinsey & Co., lies untapped in the furnaces of ethanol refineries, paper mills, and other heat-consuming industries. The key is to make use of heat that would otherwise be thrown away.

One way to do that is via cogeneration, or "combined heat and power" (CHP), a technique that is more than a century old but newly fashionable. "District heating," common in Scandinavia and Eastern Europe, uses leftover steam from power plants to heat nearby buildings. Alternatively, a factory that needs steam can build a gas-fired generating plant, sell the electricity or use it on-site, and use the waste heat to produce the steam it needs.

Such combined operations are very efficient. The McKinsey study estimates that linking heat and power generation in U.S. industry could save nearly a trillion megajoules of energy over the next 20 years, and the average project would generate a healthy financial return of 36%.

Currently, Denmark is the world's cogeneration leader; more than half of the country's electricity is produced in CHP plants. In many other countries, including Brazil, Canada, France, the United Kingdom, South Africa, and India, it's less than 8%. According to the International Energy Agency, these countries could double their CHP output in 10 years and triple it by 2030 if they set up the right incentives.

The Netherlands showed that it's possible. Starting in the mid-1980s, the Dutch government guaranteed favorable prices for electricity from CHP plants, then encouraged electric utilities to set up CHP plants as joint ventures with industrial companies. "Suddenly, utilities started to build cogen plants—because they weren't competition anymore!" says Ernst Worrell, an energy researcher at Utrecht University in the Netherlands. Between the early 1980s and the late 1990s, the share of Dutch electricity generation that came from CHP plants rose from 8% to almost 30%.

–DAN CHARLES

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