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Subject: Comments relating to the COL EIS for Grand Gulf 3
Attachments: Addendum for COL EIS scoping meeting due 072908.doc; Art of Energy EfficiencyArt Rosenfeld.pdf; Lovins The Nuclear Illusion.doc; RenewableEnergyMississippi.pdf; Co-op America Utility Solar Study.pdf; Price of Nuclear Saloncom.doc; Scientific American_ A Solar Grand Plan2007.pdf

These comments (Addendum for COL EIS scoping meeting due 072908.doc) and the attached supporting documents are being submitted as additions to my oral comments at the June 19, 2008 scoping meeting in Port Gibson, MS.

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Thank you.

Ruth Pullen

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Lovins The Nuclear Illusion.doc	99904	
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Addendum to my oral comments presented at the June 19, 2008 scoping meeting in Port Gibson, MS for the Grand Gulf Unit 3(GG3) COL application.
Submitted 28 July 2008

Ruth Pullen
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Byram, MS 39272

I urge NRC staff to read the attached document ***Lovins The Nuclear Illusion.doc,*** **(** http://www.rmi.org/images/PDFs/Energy/E08-01_AmbioNucIllusion.pdf) which addresses many issues discussed in these comments including concerns raised by the NRC such as base load power, peaking power, and backup power. The document also shows the advantage of renewables, cogeneration, efficiency, etc, over nuclear power. Amory Lovins, Rocky Mountain Institute Cofounder, Chairman, and Chief Scientist is an award- winning, nationally and internationally recognized consultant on energy issues and puts to rest the argument that nuclear power is a viable and better solution to our energy needs than the numerous other solutions available today. (contact information: (303) 245-1003, (970) 927-3851, www.rmi.org).

I believe the following are issues that NRC staff should consider when preparing the EIS:

I. Need for Power

According to the Final Environmental Impact Statement(EIS) for the Early Site Permit(ESP); 'An ESP environmental report is not required to include a benefits assessment (e.g., the need for power) (10 CFR 52.17) or a discussion of energy alternatives (NRC 2003a); **these may be deferred to the CP or COL application** (emphasis mine) (Introduction, page 1-3).

Since we are at the COL stage, it is time for the benefits assessment discussed above to be produced and evaluated in the EIS. The fact that Entergy is considering designating GG3 a merchant plant, indicates that more power is not needed in Mississippi. Because building a plant, the plant's discharges, wastes, etc., affect the environment, **the need for power should be one of the first and major considerations in this EIS.**

Entergy Mississippi, Inc. provides electricity to more than 433,000 customers in 45 Mississippi counties, approximately 17% of its customer base of about 2.6 million in portions of Arkansas, Louisiana, Mississippi, and Texas. Based on these numbers, it is impossible to justify building another reactor in Mississippi. The facility should not be built at all, but if it is, it should be built where demand is greatest.

Furthermore, advances and successes in energy efficiency, conservation, cogeneration, and renewables, make the need for a new reactor unnecessary at any location. References and attachments discussed in section II. will clarify this statement.

II. Alternative Energy. This issue was not adequately addressed in the FEIS for the ESP and therefore should be considered in this EIS. Looking only at the Port Gibson site when reviewing possible alternatives does not take into account one of the primary advantages of renewable energy, i.e. distributed resources. Nor does it account for the entire service area, or the Gulf of Mexico, which has wind resources for Mississippi and surrounding states of at least Class 4-Class 7, not Class 1 as the ESP FEIS stated for Mississippi and Louisiana. (see attached

Renewable Energy Mississippi.pdf page 1
http://www.citizen.org/documents/RenewableEnergyMississippi.pdf)

In Section 9.2.2.2 of its ESP application, SERI established a target value for the desired electrical output of 2000 MW(e) for a new nuclear generating facility constructed at the Grand Gulf ESP site and used this value in its analysis of energy alternatives (SERI 2005). (ESP FEIS, pg 8.3,), yet it has not been established that any new power is needed, and certainly not 2000MW.

In section 8.2.1(ESP FEIS page 8-3) it is stated that 'The Commission determined (NRC 2005) that conservation or demand side management programs are not a reasonable alternative to an ESP for a base load nuclear power plant. Consequently, this alternative is not further considered.' This is an outdated and inaccurate assessment of modern day programs and needs to be reconsidered. I urge the NRC staff to read papers (see attached *Art of Energy EfficiencyArt Rosenfeld.pdf)* written by Arthur H. Rosenfeld, Commissioner, California Energy Commission, and to contact him to discuss these issues.((916) 654-4930, ARosenfe@Energy.State.CA.US). Mr. Rosenfeld is an award- winning innovator in energy efficiency and California has implemented energy efficiency standards that are emulated both nationally and internationally. The attached Amory Lovins document also discusses these issues.

I also urge NRC staff to read *California Illuminates the World* by Craig Canine. http://www.nrdc.org/onearth/06spr/ca1.asp Below are a couple of quotes from the article, which discuss California's policies and Art Rosenfeld's accomplishments:

> 'Since 2001, California has bounced back, fashioning a new framework of utility regulations that places greater emphasis on efficiency than ever before. Through 2008, utility companies plan to spend $2 billion -- a record for any state -- to help Californians save energy. The investment will yield a net gain of $3 billion in economic benefits for the state by reducing utility bills. "**This efficiency campaign will avoid the need to build three large power plants**," says Brian Prusnek, a senior staff member at the California Public Utilities Commission…. **How many other investments yield a 50 percent financial return and reduce pollution?'** (emphasis mine)
>
> …'California's efficiency standards for new buildings, introduced in 1978 and known as Title 24, have been replicated all over the world. The code governing new construction in Russia, for example, is **cutting energy use by more than 40 percent, thanks to California.'** (emphasis mine) Examples such as these show the benefits of alternatives not only to the consumer, but also to Entergy itself.

According to Heather Staley, Chief Executive of the Energy Efficiency and Conservation Authority (EECA), '**Investment in energy efficiency is often the cheapest solution and should always be considered when looking at future needs**.(emphasis mine) Locking in energy efficiency now means gains into the future'. …'Many energy efficiency measures are instant. **We can realise the benefits right now, including cheaper power bills and reduced environmental impacts.'(**emphasis mine) (http://www.eeca.govt.nz/news/media-releases/future-energy-needs.html)

Furthermore, the cost of renewable energy is rapidly dropping because of improvements in technology, and, as market share continues to grow, some at over 20% per year, some such as solar increasing even more. (see attached document *Co-op America Utility Solar Study.pdf* *http://www.solarcatalyst.com/research.html*). In addition, according to the U. S. Department of Energy's National Energy Renewable Energy laboratory(NREL), 'Customer choice programs are proving to be a powerful stimulus for growth in renewable energy supply. In 2007, total utility green power sales exceeded 4.5 billion kilowatt-hours (kWh), about a 20% increase over 2006.' Utility green pricing programs are one segment of a larger green power marketing industry that counts Fortune 500 companies, government agencies and colleges and universities among its customers… **In addition, the rate premium that customers pay for green power continues to drop.** (emphasis mine). http://www.nrel.gov/news/press/2008/348.html

As will be discussed in the Socioeconomic Effects section of this document, reduction in power bills will be of great benefit to Claiborne County, one of the poorest counties in Mississippi, and indeed to Mississippi, one of the lowest per capita income states in the U.S.

Also, distributed energy ' technologies are playing an increasingly important role in the nation's energy portfolio. **They can be used to meet base load power, peaking power, backup power, remote power, power quality, as well as cooling and heating needs**.' (emphasis mine) http://www.nrel.gov/learning/delivery_storage.html

III. Socioeconomic effects: As the price of nuclear energy continues to climb(Lovins attached document and also attached document *Price of Nuclear Saloncom.doc*), the cost of renewable sources of energy and energy efficiency continues to drop. Entergy has requested, and the Mississippi Legislature has passed, provisions to allow a rate hike to pay for the new plant construction, whether or not the GG3 facility is ever completed or put on-line. Claiborne County is one of the poorest counties in the state and this rate increase would cause economic hardship for many of its residents. It would also cause economic hardship for many other Entergy customers in various parts of Mississippi and other States in the service area. In addition Entergy has requested a 28 % rate increase because of higher Natural Gas prices, adding an additional burden to ratepayers.

At the same time Entergy is requesting rate increases, it has programs to help needy families pay utility bills. 'Across Entergy's four-state utility system, almost one-quarter of all households have incomes that fall below the poverty level.' Entergy has revenues of more than $10 billion, and the utility worked with others to help approximately 18,000 needy families and individuals with utility bills in 2007. (http://www.entergy-mississippi.com/news_room/newsrelease.aspx?NR_ID=275) The company acknowledges economic problems in Mississippi, yet requested a rate increase to build a facility that is not needed.

I am also concerned about the inadequate emergency planning and infrastructure in Claiborne County and beyond. Claiborne County's emergency planning infrastructure is too under-funded to deal with the present nuclear plant-let alone a new plant. There is not adequate money available to fund the Sheriff's Department, Civil Defense, Fire Department or hospital. No new reactors should be considered until these inadequacies have been remedied.

IV. Terrorist attacks

The fact that 10 CFR Part 52 states that 'an applicant for a license to manufacture, construct, and operate a utilization facility… is [not]required to provide for design features or other measures for the specific purpose of protection against the effects of — (a) Attacks and destructive acts, including sabotage, directed against the facility by an enemy of the United States, whether a foreign government or other person' shows how biased this entire process is towards the utility companies. Not only should these safety features be considered, but the environmental impact statement should contain an evaluation of the effects of contamination of the Mississippi River resulting from a catastrophic accident or terrorist attach at the reactor site. Why would terrorists select this site when Port Gibson is not an area of economic significance like New York? Because of the site's proximity to the Mississippi River. An accident or act of sabotage at this facility and its stored nuclear waste could contaminate the Mississippi River and the Gulf of Mexico. Many communities downstream depend on the River for drinking water and the River is a major commercial transportation artery, used for shipping large amounts of cargo both upstream and downstream. In addition, the extensive industrial corridor between Baton Rouge and New Orleans depends on River water for processing. In the event of an accident, these industries might have to be shut down. Contamination of vital wetlands that provide nurseries for larval and other developmental stages of fish, for shrimp, oysters, etc., could devastate the seafood industry. Certainly the tourist industries in Florida, Mississippi, Louisiana, and Texas would be affected. Thus the economic consequences of a severe accident or attack could affect not only this region, but the entire country- just the type of effect that terrorists accomplished with 911 and would want to cause again. Because of these factors, another reactor at Port Gibson would greatly increase the likelihood of a terrorist attack. I am attaching a document presented by John Large at a United Nations Disarmament Forum on terrorism entitled *The Implications of 11 September for the Nuclear Industry* (http://www.unidir.org/bdd/fiche-article.php?ref_article=1910) (some of his credentials are as follows: 'He has published on the safety of nuclear systems, irradiated fuel and nuclear weapons transport, insurance, risks and risk management, on decommissioning of large-scale nuclear facilities, radioactive emissions and discharges, and the safety of nuclear reactor propulsion units at sea, as well as advised several governments on nuclear related issues') .

The 911 terrorists were considering an attack on a nuclear facility, therefore a terrorist attack and the resulting consequences should be considered as a Design Basis Threat (DBT) and should be included in the EIS.

V. Issues not considered and resolved in the ESP FEIS.

I quote from the ESP FEIS. 'The CP or COL applicant must address any other issue not considered and not resolved in the EIS for the ESP.' (ESP FEIS introduction, page 1-4) 'Moreover, pursuant to 10 CFR 51.70(b), the NRC is required to independently evaluate and be responsible for the reliability of all information used in an EIS prepared for a CP or COL application, and the staff may (1) inquire into the continued validity of information disclosed in an EIS for an ESP that is referenced in a COL application and (2) look for any new information that may affect the assumptions, analyses, or conclusions reached in the ESP EIS.' (ESP FEIS introduction, page 1-4, 1-5). Other stipulations are also required which I am sure NRC staff will follow diligently, including verification of all assumptions listed in Appendix J and also the need for power.

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THE ART OF ENERGY EFFICIENCY: Protecting the Environment with Better Technology

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Key Words conservation, efficiency, technology, Lawrence Berkeley Laboratory, building science, policy, cost of conserved energy and avoided carbon

■ **Abstract** After a first career as Professor of Physics, University of California at Berkeley, working in experimental particle physics at Lawrence Berkeley National Laboratory (LBNL), I was prompted by the 1973 Organization of Petroleum Exporting Countries (OPEC) oil embargo to switch to improving energy end-use efficiency, particularly in buildings. I cofounded and directed the Energy Efficient Buildings program at LBNL, which later became the Center for Building Science. At the Center we developed high-frequency solid-state ballasts for fluorescent lamps, low-emissivity and selective windows, and the DOE-2 computer program for the energy analysis and design of buildings. The ballasts in turn stimulated Philips lighting to produce compact fluorescent lamps. When they achieve their expected market share, energy savings from products started or developed at the Center for Building Sciences are projected to save American consumers $30 billion/year, net of the cost of the better buildings and products. In terms of pollution control, this is equivalent to displacing approximately 100 million cars. We did the analysis on which the California and later the U.S. appliance standards are based, and we also worked on indoor air quality and discovered how radon is sucked into homes. We worked closely with the California utilities to develop programs in "Demand Side Management" and "Integrated Utility Planning." I also worked in California and New England on utility "collaboratives" under which we changed their profit rules to favor investment in customer energy efficiency (and sharing the savings with the customer) over selling raw electricity. I cofounded a successful nonprofit, the American Council for an Energy-Efficient Economy, and a University of California research unit, the California Institute for Energy Efficiency, and I served on the steering Committee of Pacific Gas and Electric's ACT^2 project, in which we cost-effectively cut the energy use of six sites by one half. Starting in l994, my third career has been as Senior Advisor to the U.S. Department of Energy Assistant Secretary for Energy Efficiency and Renewable Energy.

CONTENTS

1944–1975: FROM PHYSICS TO ENERGY EFFICIENCY

Particle Physics

This is my story of how I came to switch in mid-career from doing experimental particle physics to developing efficient uses of energy and what I've learned along the way. It's also a story of why many of my colleagues made the same switch, ultimately providing a surprisingly large segment of the leadership in the new, politicized field of conservation/energy efficiency.

I briefly cover my 19-year career in elementary particle physics, which began at the University of Chicago, where Enrico Fermi signed my thesis on Pion production in the UC cyclotron in 1954 (1a, 1b) and ended with the Oil Producing and Exporting Countries (OPEC) oil embargo in l973.

I received my Bachelor of Science degree in physics at age 18, in l944. After serving 2 years in the U.S. Navy at the end of World War II, I entered graduate school at the University of Chicago and achieved a record that got me accepted by Enrico Fermi as one of his students. My first taste of publication success was as a coauthor of a widely read and translated textbook, *Nuclear Physics* by Fermi, Orear, Rosenfeld, and Schluter (1c). Shortly before Fermi's death in l954, Professor Luis Alvarez, at the University of California at Berkeley (UC Berkeley), had started building a series of hydrogen bubble chambers to detect particles produced in the new Bevatron at the Radiation Laboratory [now Lawrence Berkeley National Laboratory (LBNL)] overlooking the Berkeley campus. The opportunities at Berkeley seemed endless. Fermi wrote me a wonderful recommendation as his "second most promising graduate student" (he coyly declined to identify his first) and soon, with my bride Roz, I moved to Berkeley as an assistant professor, teaching and helping Luis organize his growing research group.

The bubble chambers worked wonderfully well. Our data analysis hardware and computer programs (my primary responsibility) kept up with a flood of photographs. Soon we were discovering most of the particles and resonant states that led Murray Gell-Mann to propose a sort of periodic table of elementary particles—SU3, the "eightfold way"—and to predict quarks.

By 1969 we had identified a dozen new particles, and Luis was awarded the Nobel Prize in Physics. Luis was the first to acknowledge that his prize was the result of a group effort, and he took eight of us, with spouses or partners, to Stockholm for the celebrations. But Luis strongly preferred individual research and invention and had grown tired of managing a group of 200 physicists, scanners, data analysts, and engineers, so he used the opportunity of the Nobel Prize to switch to astrophysics. So by October 17, 1973, I was serving as chairman of Group A (the old Alvarez group) when OPEC embargoed oil sales to the West.

The Oil Embargo

When the first gasoline shortage struck, I knew only two facts about energy use: (*a*) the developed countries are expected to burn up half the world's oil in my generation (it seemed rather selfish); and (*b*) European energy "intensities" [per capita, or per dollar of gross domestic product (GDP)] were only about half of ours, yet they had a comparable standard of living. I had learned this from the time I spent at the Centre Européen pour la Recherche Nucléaire (CERN) in Switzerland and at other European accelerator laboratories, where I observed that my colleagues did not freeze in the dark. They did, however, drive smaller cars and turn off lights in unoccupied rooms and buildings.

I noted that if we Americans used energy as efficiently as do the Europeans or Japanese, we would have been *exporting* oil in 1973, so OPEC would have posed little threat to the U.S. economy. I quickly discovered that many of my physicist friends had independently concluded that it would be more profitable to attack our own wasteful energy use than to attack OPEC.

One small incident strengthened my hunch that it would be easy to save energy. At the office, late one Friday night in November 1973, I knew I'd have to wait in a half-hour line on Saturday to buy gasoline. I compared that with the equivalent gallons used by my office over the 60-h weekend. My too-brightly-lit (1 kW!) office burned the equivalent of 5 gal/weekend of natural gas back at the power plant. I was one of only a few on my 20-office floor who ever switched off the lights in our offices and perhaps in the hall, but on the way to my car that evening, I decided to switch off the lights in the other 19 offices. The problem was to find the switches. A few were only hidden behind books. The challenge was finding the rest that were hidden by file cabinets, bookcases, and posters. After 20 min of uncovering light switches (and saving 100 gal for the weekend), I decided that UC Berkeley and its Radiation Laboratory should do something about conservation.

In December 1973, I had the first of my thousands of contacts with the local utility, Pacific Gas and Electric (PG&E). PG&E had purchased a large ad in the *San Francisco Chronicle*, with the following message:

> "Don't mess with the Thermostat. You'll use more gas heating your house in the morning than you'll save overnight."

Shocked by this unscientific claim, I called PG&E's research manager Stan Blois, and asked him if he kept his coffee hot on the stove all night, to avoid having to reheat it in the morning. Blois quickly agreed that the ad showed dismal incompetence; and he must have responded quickly, because it never reappeared. But the incident raised some nagging concerns about the motivations and competence of utilities.

Princeton Summer Study

In January 1974, at the Annual Meeting of the American Physical Society in New York, Professor Sam Berman of Stanford University and I ran into my former

Berkeley colleague Robert Socolow, who had by then joined the Princeton Center for Energy and Environmental Studies. Rob reminded us that the American Physical Society had foreseen the need for a summer study on efficient use of energy and was looking for leaders. We decided on the spot to volunteer to organize a 1-month study in the summer of l974, if we could work that fast. Along with Marc Ross of the University of Michigan, we easily found financing from the National Science Foundation and the Federal Energy Agency, which was the predecessor to the Energy R&D Administration (ERDA), which ultimately became the present Department of Energy (DoE). We promptly invited participants and "briefers"—experts in buildings, industry, transportation, and utilities. Life was simpler then—and spurred on by an atmosphere of crisis—we managed in five months to move from an idea in New York to our first meeting at Princeton.

Once convened, it took us only a few days to understand why we in the United States used so much energy; oil and gas were as cheap as dirt or water, and so they were treated like dirt or water. (Even today, gasoline is only one-third the price of milk). I realized that, because the Europeans and Japanese had no domestic gas or oil, the cost of imported fuels naturally entered into their considerations of balance of trade, national security, and tax policy. Abroad, energy efficiency was a respectable form of engineering. Whereas Americans largely purchased by least "first cost," Europeans understood and operated under the concept of "life cycle cost."

By the end of the first week, we realized that we were discovering (or had blundered into) a huge oil and gas field buried in our cities (buildings), factories, and roads (cars), which could be "extracted" at pennies per gallon of gasoline equivalent.

We began to write a book *Efficient Use of Energy* (2), which for many years was the best seller of the American Institute of Physics. In it we pointed out that fluorescent lamps were l5% more efficient if powered at frequencies much higher than 60 Hz directly from the power lines. (This led later to the development at LBNL of solid-state, high-frequency ballasts, or power supplies, for fluorescent lamps.) Sam Berman, David Claridge, and Seth Silverstein wrote a whole chapter on the design and use of advanced windows. They pointed out that the heat leaking out of windows in U.S. buildings every winter, if averaged over a full year, corresponds to the energy content of 1—2 million barrels of oil per day (Mbod), which was the same as the oil flow projected via the trans-Alaska pipeline from the new Prudhoe Bay Field. They then described how, in 1968, three Russians had already coated a thin film of low-emissivity (low-E) semiconductor material on to the inside surface of double-glazed windows, thus virtually stopping radiation transfer and doubling their thermal resistance. Applied to U.S. windows, this would save half of Prudhoe Bay's daily production.

In 1974, the U.S. car fleet averaged 14 miles/gal [mpg (16.7 liter/100 km)], but we learned enough about auto economics to estimate that a "least-cost" (life cycle optimized) six-passenger car should get ∼35 mpg (7 liter/100 km). [By 1999 standards, this seems modest, because the year 2002 goal of the Partnership for a New Generation Vehicle is 80 mpg (www.uscar.org/pngv/index.htm)].

During that month in Princeton, many of us became aware that our new knowledge would soon change our lives. We returned home to edit the book for publication in Spring 1975. In Washington, Congressman Richard Ottinger of New York, Chair of the House Subcommittee on Energy and Power, decided not to wait for the American Institute of Physics version, so he had it reproduced as a committee print. Five years later Ottinger would help us again in a bolder way, when the Reagan transition team sidetracked the 1980 Solar Energy Research Institute (SERI) Solar/Conservation study.

1974–1985: EARLY GAINS

Energy-Efficient Buildings

I returned to Berkeley and to experiments at Stanford's Linear Accelerator Center, but at least two forces were pushing me to work (at least temporarily, I thought) on energy efficiency.

First, the California Energy Commission (CEC) was created in 1974, with authority, among other things, to approve or deny site applications for new power plants, to write energy performance standards for new buildings, and to sponsor research and development (R&D). At the time, as shown in Figure 1, installed power was running $\sim$30 GW and growing about 6% per year. This required building two huge power plants every year, typically 1-GW and nuclear or fossil fueled. More than half of that new electricity (i.e. more than one plant per year) would be used to supply new homes and buildings, many of them heated by electric resistance and by lights in commercial buildings. (Such lighting systems, in l974, were designed to burn 24 h/day all winter). I began thinking about the economic tradeoff between constructing a new $2-billion power plant and designing more efficient buildings.

Second, in the fall of 1974 I gave some talks on our Princeton study, both on campus and at LBNL, and immediately discovered that there were graduate students eager to do research in efficient use of energy.

I should note that, about 1971, the same concerns that had led the California State Legislature to plan the Energy Commission had led UC Berkeley to create an interdisciplinary graduate program, the Energy and Resources Group (ERG), and to attract a young physicist, John Holdren,[1] as our first Professor of Energy and Resources. Under his inspired leadership, ERG hired a five-person core faculty, attracted scores of associated faculty from other departments, and admitted some of the best students in the world. I served as vice-chair for many years, taught a course on "Efficient Use of Energy," and was able to place many ERG students in

[1]Shortly after I left Berkeley for DoE in l994, Holdren accepted a distinguished chair at Harvard's Kennedy School of Government, and soon was appointed vice-chair of President Clinton's Council of Advisors on Science and Technology.

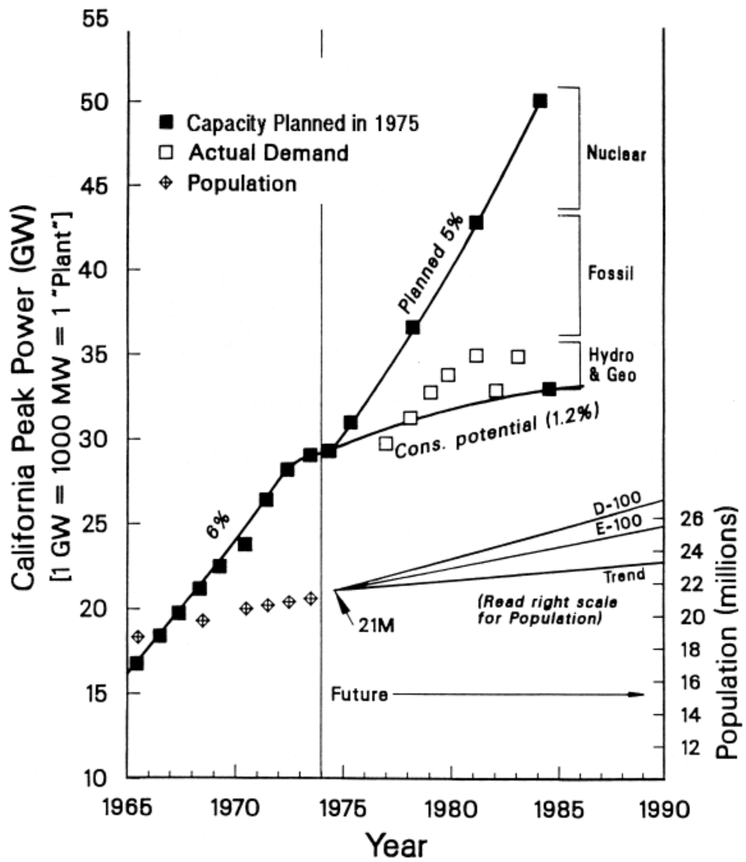

Figure 1 California peak power, historic (1965–1974) and projected (1975–1984) by utilities (5% annual growth), by Goldstein & Rosenfeld [1.2% (39)], and actual (2%). Although the ordinate is labeled "Peak Power," it is really capacity, derived from peak gigawatts $\times$ 1.06 to provide a 10% reserve margin and 4% downward correction for coincident demand. Source: Goldstein & Rosenfeld (4).

research projects at LBNL. Thus the successes of ERG and of LBNL programs in energy and environment are inextricably and synergistically intertwined.

During the fall of 1974, Berman and I, in our frequent talks while editing our parts of the Princeton study, decided to sponsor a 1975 summer study on energy-efficient buildings, at the UC Berkeley School of Architecture. Here we learned much more about lighting, windows, and heating, ventilation, and air-conditioning (HVAC) equipment. In those days, compared with today, the building thermal efficiency was worse by nearly a factor of two, and, in addition, chillers (machines that provide cold refrigerant for air conditioning) were oversized by $\sim$50%.

The CEC's draft "Title 24" residential building standard proposed to limit window area to 15% of wall area, without distinguishing among north, south, east, and west. Indeed I don't think the standard even mentioned the sun! I contacted the CEC and discovered why they thought that windows wasted heat in winter and "coolth" in summer. The CEC staff had a choice of only two public-domain computer programs, the "Post Office " program, which was user hostile (although a few experts could use it successfully) and a newer program of the National Bureau of Standards, National Bureau of Standards (thermal) loads (NBSLD). They chose NBSLD, but unfortunately had run it in a "fixed-thermostat" mode that kept the conditioned space at 72°F (22°C) all year, thus calling for heat or cooling or both every day of the year. The indoor temperature was not permitted to float up (storing solar heat as it entered the house through windows or walls) or down (coasting on the stored heat). NBSLD's author, Tamami Kusuda, had written a "floating-temperature" option, but it was more complicated and still had bugs, and neither Tamami nor anybody at CEC could get it to work satisfactorily. No wonder the CEC concluded that windows wasted energy! I decided that California needed two programs for energy analysis in buildings: first and immediately, a simple program for the design of single-family dwellings and, second and later, a comprehensive program for the design of large buildings, with a floating-indoor-temperature option and the ability to simulate HVAC distribution systems.

Architecture professor Ed Dean and I promptly wrote a thermal simulator for a house and named it Two-Zone, because it distinguished between the north and south halves of the house. We easily convinced the CEC to drop their proposed cap on window area for non-north windows, as long as the building provided enough thermally accessible mass (e.g. uncarpeted tile floor or water-filled benches) to store solar heat (3). We didn't know the words "passive solar architecture" and so didn't realize that we had inadvertently written this concept into Title 24.

In 1976, the CEC temporarily adopted Two-Zone for calculating the residential standard. They also put up the first $200,000 to develop "Cal-ERDA," to be matched by support from ERDA (the predecessor to DoE), which also wanted a public-domain computer tool to design energy-efficient buildings. Cal-ERDA started as a collaboration of three national labs—LBNL, Argonne, and Los Alamos.

Version 1.0 was completed in about 2 years and delivered to the CEC for T-24 calculation. The then-new DoE took over Cal-ERDA at LBNL, under the name of DOE-1, to support planned national-building-performance standards. The DoE has supported DOE-1 and later DOE-2 ever since, and the American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE) soon chose DOE-2 as the tool for calculating and updating its "Standard 90" series of building performance standards, which has been adopted by most states. Today DOE-2 is used to design ∼15% of all new commercial space to beat existing standards by >20% and save more money.

Standards in general and building standards in particular have been the most successful and profitable ways for society to save energy and money. New building

HVAC energy intensity (i.e. energy use per square foot for heating and cooling) dropped to ∼50% between 1975 and 1985 (excluding the growth of computers and other "plug" loads). When I left California in l994, the CEC estimated that efficient buildings, those built under Title 24, were saving $1.5 billion annually, $0.5 billion in natural gas and $1 billion in electricity, which is the annual output of 2.5 huge 1-GW power plants. Since 1994, of course, the initial $1.5 billion/year has grown every year, as new buildings appear. Because other states have adopted building standards over a period of years, it would be tedious to calculate expanding this $1.5 billion/year to cover the whole United States, with eightfold the population of California, but I estimate that annual U.S. savings are roughly $10 billion.

What was the contribution of the DOE-2 group to this estimated annual $10-billion savings? I believe that the fortunate combination of our collaboration with CEC/T-24 and our provision of a credible, public-domain tool advanced the adoption of standards throughout the United States by 1–3 years, for a societal saving in energy bills of $10 billion–$30 billion.

DOE-2, now led by Fred Winkelmann, went on to become the tool of choice for the design of both real buildings and their performance standards in the United States. It has since been adopted in Canada and some Asian nations.

Goldstein-Rosenfeld's Controversial Low-Electricity Scenario

In 1975, the new CEC was still trying to set its priorities—how to balance supplying more energy against extracting more "service" from available energy. This debate was colored and politicized by a proposed ballot initiative, Proposition 15, to halt the construction of nuclear power plants. My new graduate student, Dave Goldstein [now Senior Scientist and codirector of Energy Programs at the National Resources Defense Council (NRDC)] and I did our first serious study of the potential for slowing electricity growth with cost-effective standards for buildings and appliances, and we came to the remarkable conclusion that our annual growth rate could drop from 5% (projected by the utilities) to 1.2% (4). We were invited by Assemblyman Charles Warren to testify on December 8, 1975, at which time we showed Figure 1 and discussed the engineering economic analysis behind it (5). Note that Figure 1 questions the need not only for ∼10 GW of *nuclear* power, but also ∼10 GW more power from *fossil* fuel.

The utilities were shocked by our estimates of potential savings. PG&E called LBNL's then-director Andy Sessler to complain that physicists were unqualified to project electricity-demand scenarios and to suggest that I be fired. Because my wife and my colleagues, including Sessler, had been telling me that I was overqualified to work on energy efficiency, I found the PG&E complaint somewhat comforting. To add to the heat, the Atomic Energy Commission's San Francisco Operations Office found an obscure rule, never before observed, that prohibited us from distributing copies of our report without their approval, which would not be forthcoming. They agreed to drop the ban a few months later, when the Operations

Office was caught printing tens of thousands of pronuclear brochures for the Stop Proposition 15 campaign.

California did indeed start to conserve electricity with two steps: Federal "Energy Guide" labels appeared on appliances (and mpg labels on cars), and the California Appliance Standards and Building Standards (Title 24) went into effect in l977. Title 24 forbade the installation of electric resistance heating for either space or water unless (as is seldom the case) it is cost effective over the full life of the building.

Actual peak demand is shown in Figure 1. Annual growth did in fact drop to 2.2%, much closer to our potential than to the utility forecasts. We were slowly being vindicated, and the hostility of PG&E was replaced with the first steps in a long productive collaboration, leading up to the 1989 ACT^2 project discussed in a later section ("California Pioneers Energy Efficiency"). Because nuclear power was proving to be surprisingly expensive, proposed nuclear plants were abandoned. Next followed the cancellation of new traditional thermal plants. The decline of nuclear power is well known, but the reader may be surprised that no application to site any large central power plant (nuclear, coal, or gas) has been filed in California since l974. Of course, demand has continued to grow at 2%/year, but that new power has come from small independent producers and cogenerators, from renewables (hydroelectric, geothermal, and wind resources), and from sources outside the state. But it is improved efficiency that has been the largest single generator of new electric services for California's growing economy.

The Energy Analysis Program at Lawrence Berkeley National Laboratory—Building and Appliance Standards

Although all of us in the new Energy Efficient Buildings or EEB program were paid by DoE to develop technology or study building-related topics, we were also interested in energy policy and analysis, and we collaborated with an existing small but official Energy Analysis Program under Will Siri. Early in 1978, while I was on sabbatical introducing DOE-2 in Paris, Siri hired a chemist, Mark Levine, who soon energized the program, eventually became its leader, and expanded it 10-fold. My life has been pleasantly entwined with Levine's ever since.

In his first year at LBNL, Levine teamed up with David Goldstein to lead the analysis of building energy performance standards for new residential buildings. The analysis soon resulted in the largest application of the DOE-2 program ever undertaken. We ran thousands of cases to evaluate the effects of energy efficiency measures on different types of houses in different locations throughout the nation. This massive analytical effort challenged the computer code, which needed to be modified in several important ways to account for such factors as window management, different strategies for insulation in basements, whole-house fans, and different types of thermal mass.

We were highly successful in identifying and documenting the economic and energy impacts of energy efficiency measures for houses and the cost-effective levels of such measures in different house types and locations throughout the nation. We were much less successful in helping DoE in its legislative efforts. Both Mark Levine and I testified on building energy performance standards for congressional committees (6), explaining their logic and likely economic benefits. However, the regulations prepared by DoE were—under the legislation at the time—submitted to the Senate, where they were defeated by one vote.

Congress has left new building energy standards to the states, except for federal buildings. But this has made little difference. Most states have adopted standards derived from ASHRAE's voluntary standards (which are based on DOE-2 simulations), and most of the energy efficiency measures that we recommended in l981—multiple glazings for windows in cold climates, reduced air infiltration, increased insulation in roofs, walls, and foundations, and more efficient furnaces—have gone from rarities to common practice.

Windows and Lighting

By 1976 DoE had been formed and, like the CEC, was debating its priorities, focused mainly on energy supply. But it did have a small Office of Conservation and Solar Energy, and we found support for Sam Berman to develop both high-frequency ballasts for fluorescent lamps and "heat mirror" windows. Despite the risk that DoE's support might be unreliable, Berman courageously resigned his tenured professorship at Stanford University and moved to LBNL. Soon we also attracted Steven Selkowitz, a physicist-turned-architect, to lead the work on windows.

The years 1976–1985 were notable for the EEB Program at LBNL. Berman's group developed high-frequency ballasts, piloted them tediously through Underwriters' Laboratories, and arranged an invaluable field test, hosted by PG&E in its San Francisco skyscraper, which demonstrated electricity savings of $\sim$30%. This attracted the interest of lamp manufacturers, particularly Philips, who reasoned correctly that, if large electronic ballasts were effective for traditional tubular fluorescent lamps, Philips could miniaturize the ballasts and produce very efficient compact fluorescent lamps (CFLs) to replace incandescent lamps. Thus there soon appeared 16-watt CFLs that radiated as much light as a 70-W incandescent light and would burn for 10,000 h instead of 750 h.

Selkowitz' group developed "heat mirror" windows that, although transparent to visible light, kept invisible heat from leaking out and would save the gas-equivalent of half of Prudhoe Bay's daily oil production. This class of window is now called "low-E" because the more descriptive name "Heat Mirror" was quickly copyrighted by Southwall, one of our partner companies. Later, low-E variants were designed for commercial buildings or buildings in hot climates, where cooling is more important than heating. They exploit the fact that only half of solar heat is visible; the other half is "near-infrared" radiation. These advanced windows are termed "selective" because, although they are transparent to visible light and so *look* just like traditional windows, they *reflect* the near infrared. They keep out as much heat as the familiar reflective “solar control” glazing used on all office towers, yet the light transmitted through the clear windows permits occupants to use the daylight near the windows and to turn off the artificial light (this is called “harvesting” daylight).

Improving Indoor Air Quality

At the new DoE, we found support not only for Berman, but also for Craig Hollowell, an air quality chemist who wanted to shift his attention from outdoor to indoor air. We spend 90% of our time indoors, and the Ventilation and Indoor Air Quality (VIAQ) group soon was to show that indoor air is several times more polluted than outdoor air. An indoor-air study was an essential prerequisite to DoE’s program to save energy by sealing homes against drafts and reducing the air change rate in commercial buildings.

Hollowell and colleagues, who had been working on traditional outdoor air pollutants—mainly the products of combustion—had already decided to use their equipment to check indoor pollution in homes around Berkeley. They found that concentrations of nitrogen oxides and of course carbon monoxide were often substantially higher indoors than outdoors, indicating cracks in the heating systems or poor (or nonexistent) venting of other combustion appliances (7).

With the new funding from DOE, Hollowell undertook by 1979 to form a broad program on “building ventilation and indoor air quality,” to understand how to avoid any deterioration of indoor air quality that might be associated with changes of ventilation rates to reduce energy use. The practical requirement for accomplishing this became the main theme of the program—that is, to understand the concentrations and factors controlling them, for three main classes of pollutant: (*a*) combustion products, such as the oxides of carbon and nitrogen already mentioned; (*b*) chemicals of various kinds, arising from furnishings, cleaners, and other household products; and (*c*) radon and its decay products, arising naturally from the earth and from building material such as concrete and brick.

Paradoxically, the broadest and most important conclusion of the program’s work of the first several years was that, for each of these pollutant classes, indoor concentrations—for example, in homes—varied over extremely large ranges even in ordinary structures (for radon, easily a factor of a thousand from low concentrations to very high), and there was rather little correlation with ventilation rate or with the implementation of energy-conserving measures. The main determinant of indoor concentrations—what we had to learn to control—was the “source term,” the rate at which the pollutant of interest entered the indoor air.

Unfortunately in 1982, during these exciting discoveries, Craig died suddenly of a heart attack. Fortunately he had assembled a world-class team including Dave Grimsrud, Tony Nero, and Rich Sextro, who were able to continue despite this severe loss.

A major challenge for them was radon, a radioactive, chemically inert decay product of uranium. Radon is found in soil gas and gets sucked into buildings, particularly in winter. Indoors, radon decays into other radioactive nuclei, which are inhaled by occupants, stick in their lungs, decay by alpha-particle emission, damage lung tissue, and increase the risk of cancer, particularly for smokers (8).

Even before Hollowell's death, it was very clear that—energy efficiency aside—indoor radon would pose a special problem for the scientific and regulatory communities, because even a typical concentration posed an estimated lifetime risk of lung cancer (extrapolated from the observed risk among miners) of perhaps 0.1% for nonsmokers and perhaps 1% for smokers. Even the 0.1% is far above the risk limits used for control of pollutants (and for radiation exposures of the public) in other circumstances. And some people were receiving radon exposures (and putative risks) far higher, in the range where elevated lung cancer rates have been observed among miners. There are ~100,000 lung cancer deaths annually in the United States, and the radon contribution is ~10,000.

The LBNL indoor radon group (led by Tony Nero) discovered—based on long-term continuous data acquisition in homes—that a surprising amount of radon entered homes because it was sucked in from the ground by a "stack" or "chimney" effect, that is, by small pressure differences across the building shell generated by temperature differences (between the indoors and outdoors), by winds, and sometimes by combustion appliances that depressurize the house (9). These are the same pressures that cause infiltration of air across the building shell, causing a significant part of the heating load, but in this case the issue is the small amount of radioactive soil gas that is drawn from the ground underneath the house and that carries radon generated in the ground.

With this understanding it quickly became cost effective to find and fix homes with dangerous levels of radon and to build precautions into new homes in high-radon regions so that radon cannot be sucked in (10–12).

Going After Appliances

In 1976 California Governor Jerry Brown was looking for a way to disapprove Sundesert, the only still pending application for a 1-GW nuclear power plant. The Title 24 standard for buildings was an accepted idea, but somehow standards for appliances seemed more like a federal responsibility, so appliance standards were still controversial. David Goldstein and I then discovered that there was absolutely no correlation between refrigerator retail price and efficiency, although we controlled for every feature we could imagine. Figure 2 (13) shows 22 refrigerators, 11 with a life cycle cost of >\$1700 (averaging ~\$1900) and 11 more below the \$1700 line (averaging ~\$1550). Both sets of 11 had the same distribution of purchase prices. So if standards eliminated the least efficient half of the units, the consumer would notice no change in *purchase* prices, but would save some \$350 over the 16-year appliance service life. (Of course as standards began to motivate the design of even more efficient units, savings opportunities would grow). I pointed out to Governor Brown that California refrigerators were already using the output of five Sundeserts, and that even minimal standards would avoid the

(a)

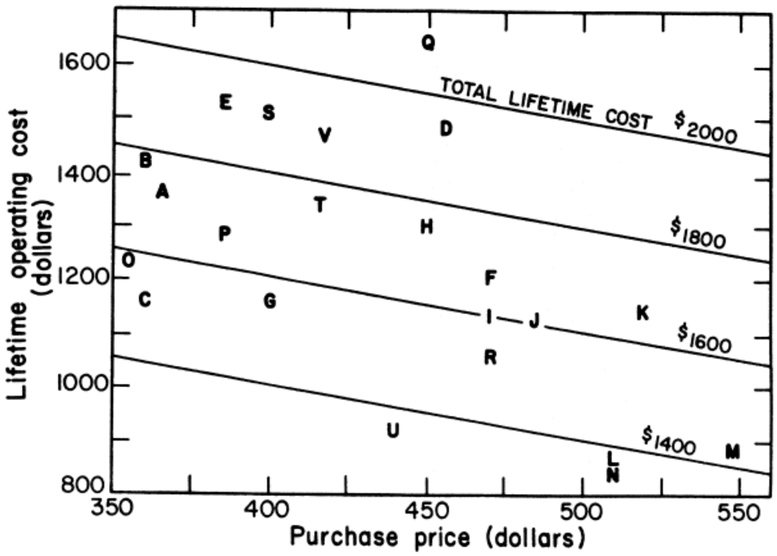

Figure 2 Scatter plot and cost data on 22 1976 refrigerators. The scatter plot (and Table on page 47) show little correlation between purchase price and efficiency. Source: Goldstein & Rosenfeld (13).

need for 1.5 Sundeserts, at no additional consumer cost. Brown promptly called Energy Commissioner Gene Varanini, who corroborated our claim.

After that, standards for new refrigerators and freezers were developed quickly and put into effect in l977, and they quickly contributed to the drama illustrated in Figure 3. (14). I say "contributed" because the striking discontinuity in slope at 1974 (from an annual energy use *growth* of 7%/year to a *drop* of 5%/year) actually results from the introduction of two policies (Federal appliance efficiency labels in l975 and California standards in l977) and a new technology (blown-in foam insulation.) Figure 3 shows that the California standards were tightened in 1980 and 1987, followed by federal standards for 1990, 1993, and 2001. In the 27 years between the 1974 peak annual usage of 1800 kWh and the 2001 federal standard of 450 kWh, we will have seen energy use drop to one quarter, making no correction for the 10% growth of average volume from 18 ft^3 to 20 ft^3. This corresponds to a remarkable compound annual efficiency gain of 5.1%. It is impossible to disentangle the contribution of standards and of accelerated improvement in technology, but clearly the combination has served society very well.

The right vertical (macro) scale of Figure 3 is in units of "Sundeserts" (or typical 1-GW–baseload power plants running an average of 5000 h/year), not just for the 12 million refrigerators and freezers in California in l976, but for 150 million now running in the whole United States. By the time the 2001 standards take effect, we will have avoided needing 40 1-GW plants, selling 200 billion kWh to homes

(b)

SYMBOL	BRAND	PRICE	REF VOL	FZ VOL	TOT VOL	ENERGY USE kWh/MONTH	ANN. OPER. COST	LIFECYCLE COST	DEFROST
A	COLDSPOT 7655110	$365.	10.92	4.25	15.17	161.	$68.	$1717.	A
B	COLDSPOT 7657110	360.	12.30	4.77	17.07	169.	71.	1780.	A
C	COLDSPOT 7657010	360.	12.40	4.60	17.00	136.	57.	1502.	A
D	COLDSPOT 7657411	455.	12.31	4.75	17.06	175.	74.	1925.	A
E	COLDSPOT 7657210	385.	12.31	4.75	17.06	182.	76.	1914.	A
F	FRIGIDAIRE FPS-170TA	470.	12.26	4.75	17.01	144.	60.	1680.	A
G	GENERAL ELECTRIC TBF16VR	400.	11.28	4.30	15.58	139.	58.	1568.	A
H	GENERAL ELECTRIC TBF18ER	450.	12.92	4.65	17.57	155.	65.	1752.	A
I	GIBSON RT17F3	470.	12.40	4.60	17.00	136.	57.	1612.	A
J	KELVINATOR TSK170KN	488.	12.40	4.60	17.00	136.	57.	1630.	A
K	KELVINATOR TSK170KN	520.	12.40	4.60	17.00	136.	57.	1662.	A
L	PHILCO COLD GUARD RD 1667	510.	11.99	3.62	15.61	103.	43.	1375.	A
M	PHILCO COLD GUARD RD17G8	550.	12.37	4.65	17.02	104.	44.	1424.	A
N	PHILCO COLD GUARD RD17G7	510.	12.40	4.65	17.05	101.	42.	1358.	A
O	SIGNATURE UFO-1525-00	355.	10.44	4.74	15.18	146.	61.	1581.	A
P	SIGNATURE UFO-1715-20	385.	12.28	4.74	17.02	153.	64.	1670.	A
Q	SIGNATURE UFO-1625-00	450.	10.46	6.05	16.51	196.	82.	2096.	A
R	WESTINGHOUSE RT170R	470.	12.45	4.65	17.10	127	53.	1537.	A
S	WHIRLPOOL EAT17NK	400.	12.31	4.75	17.06	175.	74.	1870.	A
T	WHIRLPOOL EAT15PK	415.	10.86	4.19	15.05	160.	67.	1759.	A
U	WHIRLPOOL EAT171HK	440.	12.31	4.75	17.06	110.	46.	1364.	A
V	WHIRLPOOL EAT17PM	418.	12.46	4.75	17.21	175.	74.	1888.	A

M = MANUAL DEFROST, REFRIGERATOR AND FREEZER
P = AUTOMATIC DEFROST REFRIGERATOR, MANUAL DEFROST FREEZER
A = AUTOMATIC DEFROST, REFRIGERATOR AND FREEZER

NOTE: LIFECYCLE COST ASSUMES 20 YEAR LIFE.
ELECTRICITY IS ASSUMED TO COST 3.5 CENTS PER KW-HR AND FUEL INFLATION RATE (IN CONSTANT DOLLARS) CANCELS INTEREST RATE

Figure 2 (*Continued*)

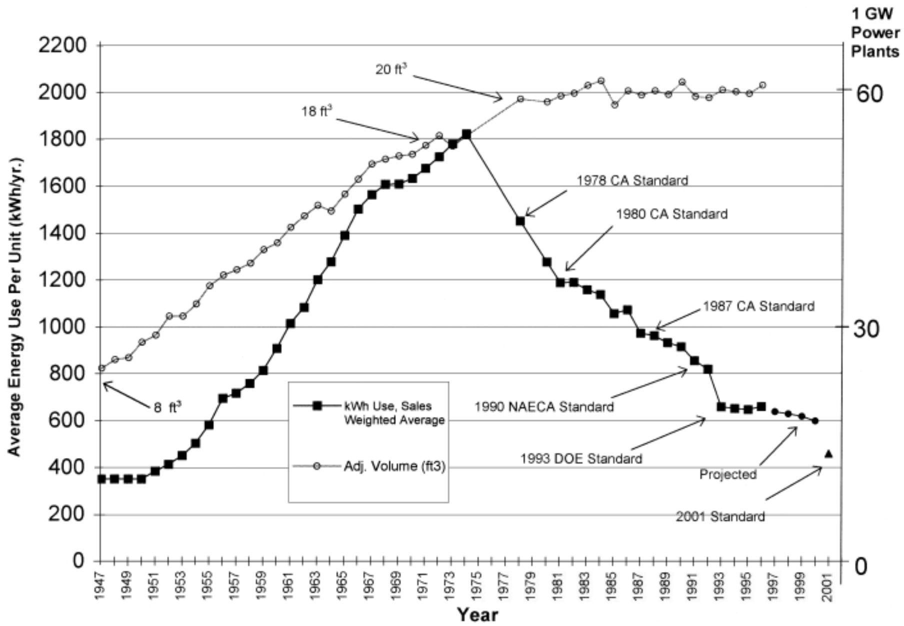

Figure 3 Electricity use by new U.S. refrigerators, 1947–2001. The *heavy line with dark squares* is the sales-weighted average annual kWh use of new refrigerators, unadjusted for increasing volume. The volume growth, from 8 cubic feet to 20, is the *lighter line with open circles*. The right-hand scale shows the number of large (1 GW) base-load (5000 hours/year) power plants required to power 150 million refrigerators + freezers, each with the kWh use on the left scale. The difference between 1974 (1800 kWh) and 2001 (450 kWh) is 1350 KwH. The eventual saving from 1350 kWh/year $\times$ 150 million units is 200 TWh/year, equivalent to 50 avoided 1 GW plants. At 8 cents/kWh, the avoided annual cost is $16 billion.

for total savings of $16 billion. The actual net savings to homeowners is only $10 billion–$11 billion, because we have to correct for the premium cost of the better refrigerators[2]. This cost premium cancels one-fifth to one-third of the savings, leaving a net of $10 billion–$13 billion/year.

[2]The cost premium is usually related to the annual saving in terms of Simple Payback Time (SPT). Thus the original 1977 California standards (illustrated in Figure 3) saved about 500 kWh/year, worth $80/year, but there was a retail cost premium of about $80, so we say that the SPT was 1 year. But as equipment improves and electricity use drops, we find diminishing returns, so that going from the 1993 federal standard to that for 2001 saves only 200 kWh/year, worth $15/year, and the cost premium is again about $80, for an SPT of about 5 years. Averaged over the current (1982–1988) generation of refrigerators (which have a service life of ~16 years), the SPT is about 3 years. In summary, to save $1/year, we have to pay an annualized premium cost of $0.33. This estimate is conservative, because the actual cost of refrigerators has declined steadily in real dollars, with no visible spikes

Although I take up this point again in Table 1, *I want to compare the $16 billion annual electricity savings from just refrigerators with the entire $17 billion wholesale ("bus-bar") value of all U.S. nuclear electricity today*. The point I want to make here for end-use efficiency (versus additional central power plants) is that an efficient appliance saves electricity at your meter, priced at $0.08/kWh, whereas 1 kWh of new wholesale supply is worth only $0.02–$0.03 at the bus-bar. Thus even if electricity from some future wonderful new central power plant is "too cheap to meter," it still must be transmitted, distributed, and managed, for $0.05–$0.06/kWh.

CO_2-Avoided and 32 Million Equivalent Cars

Although I also take up CO_2 and cars when we get to Table 1, I point out here that a 1-GW power plant running the typical 5000 h/year emits annually CO_2 containing 0.8 million tons of carbon (MtC), equivalent to the emission from 0.8 million cars (at 25 mpg and 12,000 miles/year). So our 40 avoided plants correspond to avoiding 32 million cars.

In 1979, Mark Levine convinced DoE to engage LBNL to analyze planned federal appliance efficiency standards. I strongly supported this effort, but was somewhat less directly involved in it initially than I was in building energy performance standards. I hoped at the time that the appliance standards would become an important legacy of our activities, as it indeed did. But we were severely tested in this effort, first by the Reagan Administration's efforts to kill the standards by administrative means and later by the industry's lobbying of the 1992 Congress, led by Newt Gingrich. I strongly supported keeping this effort alive, and am thankful to this day for the critical role that Howard Geller and David Goldstein played in dealing with DoE and Congress in the face of much opposition in the early 1980s and again in the early 1990s. The extraordinary annual economic benefits of existing federal appliance standards—about $8 billion in l999, growing to $18 billion in 2015, and the avoidance in 1999 of 20 GW of power plant construction (14)—owes a great deal to the perseverance and leadership of Mark Levine and the analysis team of Jim McMahon, Isaac Turiel, and other key LBNL staff members.

Before moving on to discuss some national issues, I want to point out our good luck that the LBNL EEB program was located in the visionary state of California.

Pre-oil embargo concerns about nuclear electricity had created the CEC and helped elect Governor Jerry Brown, whose antinuclear policies kept the state from building too many power plants. This in turn created an incentive for energy efficiency that was lacking in most states. The majority of states had overestimated demand and built excess power plants, forcing them to sell their electricity to pay off their debt.

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near the years that new standards took effect. The estimate of 40 1-GW power plants is also conservative, because it assumes that refrigerator efficiency would have leveled off suddenly in l974, whereas conventional wisdom was that it would continue to grow 6% per year.

Before the October 17, l973, embargo, the creation of the CEC had actually been vetoed by then-Governor Ronald Reagan, who reversed his position in light of the embargo and agreed to form the CEC. The CEC quickly implemented standards and services that convinced Californians that efficiency was a smart idea. In turn, LBNL and many UC Berkeley graduate students helped the CEC and the California utilities with technology and analysis. We at LBNL even trained PG&E's first residential auditors, their "house doctors." Synergistically, our morale and reputation were fueled by these mutually successful interactions.

1979–1986: PLAYING POLITICS

Forming the American Council for an Energy Efficient Economy

When Jimmy Carter was elected president in l976, we hoped that he would emphasize efficient use of energy, but he didn't "get it," at least not at first. He did support solar tax credits, even if solar energy was not ready for prime time, but he offered little besides sweaters for "conservation." In 1979 he proposed an $88 billion "Energy Bank" to promote 2 Mbod of synthetic fuel and alternative gas, at an estimated cost of $38/barrel (bbl), wholesale. By the time this fuel was delivered to the consumer in the form of heating gas or gasoline, it would have cost >$50/bbl. This was in stark contrast with our estimates that the United States could save 9–12 Mbod (fivefold more) in buildings and cars alone, at ∼$10/bbl (fivefold less). Efficiency advocates were simply too invisible to be noticed. That was when seven of us (15) decided to form a new, nonprofit think tank, the American Council for an Energy Efficient Economy, (ACEEE). In our frustration with a Democratic president, we did not foresee that, after the 1980 Ronald Reagan landslide election, we would be battling an even less-energy-sympathetic Republican administration for the following eight years.

ACEEE leadership was centered in Berkeley and Princeton, but we soon opened a Washington, DC, office. Robert Williams of Princeton and I served as Chairman and President, respectively, for the first 10 years, with notable leadership coming also from Carl Blumstein of UC Berkeley and Robert Socolow of Princeton. One of Williams' great contributions was to attract a graduate of Socolow's Center for Energy and Environmental Studies, Howard Geller, as ACEEE Director. Under Geller, ACEEE has become extraordinarily influential with officials at DoE, members of Congress, and other energy and environmental groups.

ACEEE conducts in-depth technical and policy assessments; advises governments and utilities; works collaboratively with businesses, standards agencies, and appliance manufacturers; publishes books, conference proceedings, and reports; organizes conferences and workshops, and informs consumers. ACEEE has an annual budget of $1.5 million–$2.0 million and, over the last 10 years, has sold $1.5 million worth of books, consumer guides, and reports. It is not a membership organization, but has an active mailing list of 25,000. I recommend their web site, http://aceee.org. I return to Geller and ACEEE shortly, when I discuss the "Alternative Conservation Budget."

SERI STUDY: "A NEW PROSPERITY—A SUSTAINABLE ENERGY FUTURE"

In 1979 Congressman Richard Ottinger, the champion of energy efficiency and renewable energy (who had preprinted the Princeton study in 1975) asked John Sawhill, Deputy Secretary of Energy under President Carter, to undertake the first in-depth solar/conservation study. Sawhill provided $1 million, and Director of the Solar Energy Research Institute Denis Hayes asked his deputy, Henry Kelly, a Harvard-trained physicist on leave from the Congressional Office of Technology Assessment, to lead the study along with Carl Gawell. They split the work into the standard four sectors: buildings, industry, transportation, and utilities, and asked me to lead the buildings study, as well as help steer the overall study. I in turn relied on help from David Goldstein and Alan Meier at LBNL and Jeffrey Harris, an economist/city planner at the CEC (now at LBNL's Washington, DC, office).

We were half through this work when President Reagan was elected in l980. There followed an exciting sequence of near-death moments for the study (under the 1980 Reagan transition team) and resurrection (under Ottinger). The skirmishing between November 1980 and March 1981 is summarized below.

The buildings chapter of the study contains 175 pages of conservation/solar-supply curves, which show that the United States was planning to build ∼35-GW more electrical capacity than needed. This can be compared with the 250 GW then supplying buildings. The industry chapter estimates forthcoming efficiency gains that would "unload" another 15 GW, compared with 150 GW then supplying industry.

So our message to the U.S. utility industry was, "Be wary before you invest prematurely in 50 GW of new plants (at $1 billion–$2 billion each), the need for which is many years off." We had come to this conclusion by November 1980, when Ronald Reagan was elected. His transition team was horrified by our draft report, and they threatened each of us that we would be fired if we even sent drafts out for review. For emphasis they fired Denis Hayes, after which Henry Kelly promptly resigned, returned to the Office of Technology Assessment, and strategized with Ottinger.

Ottinger held a hearing on the report, in which DoE representatives testified that our analysis was flawed. Ottinger then reproduced our report as a committee print, which brought it into the public domain. Brick House Press then published it (16). By about 1985 it became evident that the capacity of U.S. power plants built too early was indeed at least 50 GW. These plants remain a problem to this day. Their output tends to be uncompetitive in a deregulated generation market, and their expense, called stranded assets, is a serious problem in utility restructuring.

Testifying to Preserve Conservation and Renewable Energy

Reagan took office in January 1981, and he soon produced a DoE budget that "zeroed out" the Office of Conservation and Renewable Energy. Committees of the Democratic House of Representatives were ready to hold hearings to protect conservation, but who would be allowed to testify? DoE officials obviously could not contradict the administration, and DoE dissuaded testimony by staff of its National Laboratories. I was not on the DoE payroll, although I directed the Center for Building Science at LBNL, so I could testify as a professor of physics. And three courageous scientists at Oak Ridge National Laboratory chose to testify whenever invited. They were Roger Carlsmith, William Fulkerson, and Eric Hirst. There may have been others, but these are the three I ran into frequently.

My division director at LBNL was cautious, so we agreed that, whenever I flew to Washington to testify, I would take vacation and pay my own expenses. Fortunately, that spring People's Express airline offered $198 round trips from Oakland to Baltimore, and I made half a dozen trips. I always insisted on being allowed to use an overhead projector to show transparencies loaded with data on energy efficiency success stories, much like Figures 1–3 of this paper. And of course I showed high-frequency ballasts, CFLs, low-E windows, and other technologies developed by our sister national laboratories. There were no serious repercussions. DoE called my laboratory director once to complain that I was in Washington again, but he explained that I had been formally invited to testify, and he felt that was my duty. Bill Fulkerson was admonished once by the DoE Assistant Secretary for Conservation and Renewable Energy, but Bill also had been officially invited, and the Assistant Secretary backed down.

When the dust settled after a frantic spring and summer, the conservation budget was down to about one-third of the previous Carter budget, but it was not zero. We had demonstrated, with the help of a Democratic House and the goodwill of a Republican Senate, that it was possible to stand up to the Reagan cuts and retain the best of worthy programs. The director of LBNL grew bolder, creating an Office of Planning and Development to communicate our cause to Congress. He also approved payment for my expenses when I was invited to testify, although, through l988, I continued to identify myself only as "Professor of Physics."

OPEC Collapses and the "Alternative Conservation Budget"

In late 1985 the OPEC cartel collapsed, causing oil prices to crash from $50/bbl to $25/bbl (in 1998 dollars). My view was that efficiency gains had made a significant contribution to reducing the demand that fed OPEC's near monopoly. Ronald Reagan and Margaret Thatcher proclaimed that the energy crisis was over, and the Reagan administration again moved to eliminate DoE's Office of Conservation and Renewable Energy.

After considerable discussion with our colleagues, Howard Geller (Director of ACEEE) and I decided that the best response was to craft an alternative budget for fiscal year (FY) 1987 (FY 87) and to distribute it to conservation supporters in Congress. We met with colleagues from environmental groups and congressional staff to craft a complete budget request for conservation. We conducted informal interviews with the DoE Deputy Assistant Secretaries for Buildings, Industry, and Transportation, and we received recommendations for changes. We printed a budget in the traditional government format, but labeled it "Alternative Conservation Budget, submitted by the Energy Conservation Coalition," and distributed it to friendly Congressmen, particularly those on the appropriations committees. It must have helped, because the FY 87 Conservation appropriation was only a little less than for FY 86. This strategy worked so well we decided to follow it throughout Reagan's administration. Indeed the budget remained stable and increased after George Bush was elected in 1988.

American Physical Society's Award for Physics in the Public Interest

On April 26, 1986, I received the American Physical Society's Leo Szilard Award for Physics in the Public Interest. I was particularly pleased for two reasons. First, previous recipients included many great physicists, Richard Garwin, Hans Bethe, and Andrei Sakharov among them. My LBNL colleague Tony Nero was to receive it in 1989. Second, I had known Szilard at Chicago and had helped him to organize the Council for a Livable World.

I wrote an activist acceptance speech, detailing the improvements in efficiency that helped defeat OPEC, including the benefits of efficiency even when prices were low, and the need to change utility rules to make it more profitable for utilities to sell efficiency than to sell electricity. With a few phone calls I got some reporters to the prespeech dinner, but while there one of them got an urgent phone call about an accident at the nuclear power station at Chernobyl, near Kiev. That totally ended my press coverage. But perhaps Chernobyl illustrated the environmental costs of both nuclear and coal-based electricity and hence made an indirect case for efficient use of electricity.

1982: SUCCESS STORIES

Compiling the Economic Benefits of New, Efficient Products

I had realized in 1981 that for at least the next 4 years I would be testifying regularly, so Jeff Harris, Mark Levine, and I began to prepare and update detailed tables on the economic successes of projects at the DoE national laboratories. The best documentation is in the 1987 *Annual Review of Energy* (17), but because this is an autobiography about developments with which I have been closely associated, I reproduce instead Table 1, a shorter version of the main table in the *Annual Review of Energy*, Vol. 12, which focuses on LBNL and was updated to l994 for presentation at my Carnot prize award in January l994 (which I discuss shortly).

TABLE 1 Economics of Three New Energy Efficiency Technologies and Appliance Standards. (A 1994 update of Tables 1 & 4 of Ref. 17)

	Research & Development				Standards
	High frequency ballasts vs core coil ballasts	**Compact fluorescent lamps (1) vs incadescents**	**Low-E (R-4) windows vs. double glazed windows per small window (10 ft^2)**	**Total**	**Refrigerators and freezers '76 base case vs '92 CA Stds.**
1. Unit cost premium(2)					
a. Wholesale	$8	$5	$10		$100
b. Retail	($12)	($10)	($20)		($170)
2. Characteristics					
a. % energy saved	33%	75%	50%		60%
b. Useful life(3)	10 years	3 years	20 years		20 years
c. Simple payback time (SPT)(4)	0.8 year	0.5 year	2.9 years		1.3 year
3. Unit lifetime savings					
a. Gross energy	1330 kWh	440 kWh	10 MBtu		20,720 kWh
b. Gross $(5)	$100	$33	$70		$1550
c. Net $ [3b−1a]	$92	$28	$60(6)		$1450
d. Gross equivalent gallons(7)	106	35	69		1660
e. Miles in 25 mpg car	2660	880	1720		41,440
4. Savings 1985–1993					
a. 1993 sales	25 M	42 M	20 M		6 M
b. Sales 1985 through 1993	54 M	147 M	96 M		50 M
c. Cum. net savings [4b × 3c]	$5.0 B	$4.1 B	$5.8 B	$15B/8yr	$73 B

5. Savings at saturation[8]					
a. U.S. units	600 M	750 M	1400 M		125 M
b. U.S. annual sales	60 M	250 M	70 M		6 M
c. Annual energy savings [5b × 3a]	80 BkWh	110 BkWh	0.3 Mbod		130 BkWh
d. Annual net $ savings [5b × 3c][9]	$6 B	$7 B	$4 B	$17 B/yr	$9 B
e. Equivalent power plants[10]	16 “plants”	22 “plants”		38	26 “plants”
f. Equivalent offshore platforms[10]	45 “platforms”	60 “platforms”	35 “platforms”	140	70 “platforms”
g. Autos offset[11]	16 M	22 M	12 M	50 M	26 M
6. Project benefits					
a. Advance in commercialization	5 years	5 years	5 years		5 years
b. Net project savings [6a × 5d]	$28 B	$35 B	$21 B	$84 B	$45 B
7. Cost of DOE for R&D	$3M	$0[12]	$3M	$6M	$2M
8. Benefits/R&D cost [6b/7]	9,000:1		7000:1	14,000:1	23,000:1

From: “The Role of Federal Research and Development in Advancing Energy Efficiency,” Statement of Arthur H. Rosenfeld before James H. Scheuer, Chairman, Subcommittee on Environment, Committee on Science, Space, and Technology, U.S. House of Representatives, April 1991. Available from Center for Building Science, LBL, (510) 486–4834.

(1) Calculations for CFLs based on one 16-watt CFL replacing thirteen 60-watt incandescents burning about 3300 hours/year, assuming that a CFL costs $9 wholesale, or $5 more than the wholesale cost of thirteen incandescents. For retail we take a lamp cost of $18.

(2) Unit cost premium is the difference between one unit of the more efficient product (e.g. one high-frequency ballast) and one unit of the existing product (e.g. one core-coil ballast).

(3) Useful life is the assumed calendar life of the product (as opposed to operating life such as burning hours for a lamp) under normal operating conditions. A commercial use is assumed for CFLs, but labor savings are not included.

(4) SPT is the number of years required to recoup the initial incremental investment in an energy-efficient measure through the resulting reduction in energy bills.

(5) Assuming price of 7.5¢/kWh for commercial sector electricity and a retail natural gas price of $7/MBtu (70¢/therm).

(6) For hot weather applications where low-E windows substantially reduce cooling loads, air conditioners in new buildings can be down-sized, saving more than the initial cost of the low-E window.

(7) Assuming marginal electricity comes from oil or gas at 11,600 BTU/kWh, thermally equivalent to 0.08 gallons of gasoline.

(8) Saturation is 100% of the market for all products excepts CFLs. It is unrealistic to assume that CFLs will replace infrequently used incandescents; thus, we have defined market saturation for CFLs as 50% of current energy used by incandescents.

(9) Net annual savings are in 1990 dollars, uncorrected for growth in building stock, changes in real energy costs, or discounted future values. See Ref. 17, Table 1. Note that we attribute energy saved by the product over its useful life to the year it gets sold.

(10) One 1000 MW baseload power plant supplying about 5 BkWh/year $= 57 \times 10^{12}$ Btu $= 0.1\times$ Alaskan Arctic National Wildlife Refuge (ANWR). One offshore oil platform $= 10,000$ bod. To convert “plants” burning natural gas to “platforms”: 1 “plant” $= 27,000$ bod $= 2.7$ “platforms.” ANWR, at 0.3 Mbod, is equivalent to about 30 “platforms.”

(11) 1 automobile (400 gallons/year) generates 1 tonne carbon per year. Thus electricity and gas savings can be converted to “autos offset” (1000 MW power plant is equivalent to 1 M autos).

(12) Descended from high-frequency ballasts (only DOE assistance was in testing).

I would prefer to use a later version because the savings estimates have doubled, and there are indeed excellent, but lengthy, later versions by Evan Mills[3], but they no longer fit on one page. Instead I shall discuss Table 1 and then explain why the annual net savings have grown from $17 billion to $30 billion.

The columns of Table 1 correspond to three technologies and one appliance standard. High-frequency ballasts for fluorescent lamps and low-E windows were developed in the EEB program at LBNL. CFLs were certainly not developed in EEB, but as I mentioned earlier, we know that our development of high-frequency ballasts advanced the decision of Philips and others to produce CFLs. I have included the first of the standards we developed (i.e. for refrigerators), which has shown dramatic energy savings. LBNL does only the engineering economic analysis for appliance standards; the R&D is done entirely by the manufacturers, with some assistance from Oak Ridge National Laboratory.

Rows 1 through 3c of Table 1 show the economics for a single unit (e.g. a ballast, a CFL, or a small window). Note the short SPTs in row 2c: <1 year for a better ballast or a CFL, 1.3 years for a l992 refrigerator compared with a 1974 model shown in Figure 3, and so on.

Because of the threat of greenhouse warming, we must contemplate a world in which the use of fossil fuel is constrained. If we save a gallon of gas today, perhaps our children will have it to burn when they need it. So row 3d shows equivalent gallons saved, and 3e shows the energy service "stockpiled," for example, miles driven in the family car at 25 mpg. Thus consider a refrigerator that conforms to the l992 standard of 650 kWh/year as compared with 1800 kWh/year back in 1974. Over the 16-year life of the refrigerator, that difference saves 1600 equivalent gallons—enough to run the family car for 3.5 years (i.e. to drive 41,000 miles).

Comparison of rows 4a and 5b shows that the three technologies already have significant market shares (typically 30% and growing), so they will likely saturate the market (row 5b) unless they lose out to some even more efficient competitor. So the net annual savings at saturation, row 5d, is plausible: $17 billion from the three technologies advanced by LBNL and tens of billions of dollars from many different standards.

When the savings are electrical, row 5c uses units of billions of kilowatt-hours (BkWh), but BkWh are unfamiliar to most readers, so we note that the average large plant (1 GW, like Chernobyl, Three Mile Island, or a big coal-burning plant) sells ~5 BkWh/year. We use this fact to convert a drab 190 BkWh saved by ballasts and CFLs to the total annual output of 38 huge power plants.

When the savings are natural gas, row 5c uses equivalent Mbod. Thus, compared with traditional double-glazing in homes, low-E windows will save 0.3 Mbod. Although 0.3 Mbod equals the anticipated yield of gas from the Arctic National Wildlife Refuge, it doesn't relate to anything as familiar as cars. So on row 5g we

[3]Mills, who succeeded me at the Center for Building Sciences when I left for DoE in 1994, has written "From the Lab to the Marketplace," a valuable 42-page amplification of the ideas above (18).

show that the 0.3 Mbod of natural gas saved corresponds to a steady supply of fuel sufficient to run 12 million cars!

Finally we can add *fuel* conserved at electric power plants to *gas* saved by low-E windows to get a total for all three technology columns of Table 1. This totals an impressive 50 million cars (one-third of U.S. cars), and also corresponds to 50 MtC in avoided CO_2. To comply with the Kyoto greenhouse gas protocol, the United States must conserve domestically ∼400 MtC/year, so 50 MtC is a 12% step.

DOE-2 to Beat Current Standards, and Cool Communities In 1995, LBNL polled architecture/engineering firms about their use of DOE-2, not just to comply with standards, but to exceed them. The poll showed that 15% of new commercial space is designed with DOE-2 and that its users typically beat applicable standards by 22%. Improved practices in just 15% of new space today soon become standard practice. So we assume that, by 2010 or 2020, half of U.S. commercial space will have been designed or retrofitted to save 20% in energy use. This gives an overall savings of 10% of the annual commercial building energy bill of $105 billion, i.e. $10 billion/year. This poll and savings estimate came after Table 1 was prepared. Nor does Table 1 include a predicted $4 billion/year to come from reduced air conditioning in "Cool Communities," in which buildings have white roofs, shade trees, and lighter colored pavement (see the later section dealing with "Cooling Summer Heat Islands").

Thus, my updated 1990 estimate for the net annual savings from these five LBNL-initiated technologies or tools is not $17 billion but $30 billion. And there are more recent successes in the pipeline, such as Mark Modera's AeroSeal to seal leaks in ducts ($3 billion/year) and Helmut Feustel's nonturbulent fume hoods for chemistry laboratories ($0.5 billion/year). (These two successes are discussed below in the section entitled, "Putting It All Together at LBNL.")

For drama, I like to compare the annual $30 billion efficiency savings, initiated by a single center at LBNL, with the smaller $13-billion–$20-billion wholesale value of all electricity produced by all U.S. nuclear power plants.[4] Everyone has heard of nuclear power, and most view it as a national asset. Few have heard of LBNL's Center for Building Science or would consider it a comparable asset. This is an enduring and difficult problem. It's human nature to be proud of a large visible investment, like a power plant or even an array of photovoltaic (PV) cells, and to ignore many small purchases, usually invisible, like ballasts, lamps, windows, and

[4]In 1997 sales of nuclear electricity were 666 BkWh, and "bus-bar" (wholesale) prices averaged $0.02–$0.03/kWh. For the first 6 summer 1998 months of operation of the California Power Exchange, the average market clearing price was $0.025/kWh. Because nuclear plants cannot reduce their output to follow load, they must sell at night when the price is very low. Hence their average price on the California PX would be <$0.025/kWh. A $0.025 bus-bar price is only one-fifth of the 1998 PG&E residential rate (Tier 1 = $0.116, Tier 2 = $0.132). By 2000, these rates should drop about $0.02 as "stranded assets" are paid off, but residential prices will still run about $0.10/kWh. So there will be an ∼4:1 cost advantage to shedding 1 kWh at the meter as opposed to supplying the kWh to the bus-bar.

refrigerators. That makes it hard to convince most people that, for any given year in the foreseeable future, it will be cheaper and cleaner to improve efficiency by a few percent than to increase supply by the same amount. Give a congressman the choice of funding energy supply or energy efficiency, and he will go for supply almost every time.

Benefit/Cost Ratio of Department of Energy-Funded Research and Development

In row 6 of Table 1, we translate the savings of Table 1 into the language of benefit/cost—specifically the *societal* benefit achieved for a certain *government* cost.

My view is that science grows and technology improves inexorably and that, if there had been no OPEC and no DoE, eventually somewhere (probably abroad) somebody would have developed each of the technologies of Table 1 and a computer program like DOE-2. However, LBNL clearly advanced the commercialization of these technologies and tools by at least a year. In Table 1, line 6a, I actually estimated 5 years. We can then calculate the remarkable benefits and benefit/cost ratios in row 8 for each column of Table 1. But these amazing numbers immediately raise the question "But what about the failures?"

So now we switch to the "portfolio" approach to benefit/cost analysis for all R&D at LBNL. Specifically, we calculate the benefit by assuming that projects initiated at LBNL have brought about the happy day when our society is saving $17 billion/year in energy 5 years earlier than might otherwise have happened, for a total benefit of $84 billion over 5 years. Let me add a small fraction of the later successes and round off this net benefit to $100 billion.

The cost to the federal government of the entire LBNL program (successes plus failures) was ∼$10 million annually for each of the 20 years before 1994, or $0.2 billion total. The benefit/cost ratio is then $100 billion/$0.2 billion or 500/1. If the reader is more conservative and prefers to think of advancing technology by only 1 year, we still get 100/1. I conclude that Congress and DoE underinvest in the profitable R&D that has been carried out at our national laboratories.

1982–1993: PUTTING IT ALL TOGETHER AT LAWRENCE BERKELEY NATIONAL LABORATORY

Conservation Supply Curves

Back in 1977, Roger Sant, my friend who invented the phrase "least-cost energy services," and who founded Applied Energy Services, suggested that the best metric for an energy efficiency investment was the "cost of conserved energy" (CCE) or the "cost of conserved electricity," or, in these days of global warming, the "cost of conserved carbon."

At LBNL we promptly took up CCE for all of our analyses. This led to "conservation supply curves," which are now in general use (19). Two of my ERG graduate students, Alan Meier and Janice Wright, developed conservation supply curves in their theses, and, in 1983, we finally got around to writing a book about them (20). If you want to pick up only one interesting analytic idea about the economics of energy efficiency, I recommend Box 1 and our book. Or you can go to the Internet. The National Academy of Sciences study, *Policy Implications of Greenhouse Warming* (21), is on the web and has an appendix on CCE and conservation supply curves. Amory Lovins uses CCE in many papers and books, for example, Von Weizsacker & Lovins (22, 23).

Box 1: Cost of Conserved Energy and Supply Curves of Conserved Energy

In the mid 1970s, many researchers proposed substituting risky or expensive energy supplies with affordable conservation. One of the drawbacks in these discussions was their inability to easily compare both the economics and the scale of conservation with new energy supplies. Energy conservation is typically a diffuse resource and results in reducing costs, whereas new energy supplies tend to be huge, lumpy, and expensive. The solution was a new investment metric, "the cost of conserved energy," and bookkeeping techniques to create the "supply curve of conserved energy."

Most conservation measures require an initial investment that, in turn, creates a stream of energy savings for the lifetime of the measure. The *cost of conserved energy* (CCE) is calculated by dividing the annualized payment by the annual energy savings. Thus

$$\text{CCE} = [\text{annualized investment cost}]/[\text{annual energy savings}].$$

The annualized cost corresponds to equal ("levelized") repayment, including interest, of the investment, with the payments extending over its useful life. The energy savings can be electricity (measured in kW) or gas (measured in MBtu), or even CO_2 (MtC). For example, if the measure saves electricity, then the CCE will be in units of $/kWh. A measure is cost effective if its CCE is less than the price of the energy that it displaces. This permits easy comparison of the costs of supplying energy, such as from a new power plant, a new oil field, or even a wind farm. Furthermore, the cost of conserved energy is "portable"; that is, it does not depend on local prices of the displaced energy. By contrast, the price of displaced electricity may vary from a few cents per kilowatt hour in Oregon to $0.15/kWh in New York or $0.25/kWh in Japan.

Conservation steps can be "stacked," cheapest first, in order of increasing CCE to form a staircase called a "supply curve of conserved energy." Each step on the supply curve represents a conservation measure, whose width is its energy savings and height is its CCE. A "micro" conservation supply curve displays the cumulative impact of efficiency improvements to a single refrigerator, house, or cement factory. A "macro" curve then addresses the problems of aggregation. In the macro case, each step represents the measure applied to millions of refrigerators, houses, or autos. Certain energy and cost bookkeeping rules were outlined by Meier et al (20) to ensure consistency and to avoid double-counting and to understand the energy and cost consequences of implementing measures out of order. The resulting supply curves of conserved energy provide a simple way to compare new energy supply technologies with the contribution of millions of individual energy-saving actions. Most of the conservation supply curves of the late 1970s and early 1980s demonstrated huge reserves of conserved energy at CCEs of $<$\$0.05/kWh. Many curves turned up sharply at higher CCEs giving the false impression that conservation was a limited resource. In fact this inflection was not a consequence of diminished conservation, but simply reflected the failure of anyone to investigate and market cost-effective energy-saving measures above \$0.06/kWh.

Figure 4 is adapted from Figure 3–14 of Meier et al (20). It is a "macro" curve showing the CCE for six cost-effective residential lighting steps plotted against the electricity saved in California for each step (measured in gigawatt hours per year). One can see at a glance that two more steps (7 and 8) are not economic.

Dollars Saved The annual dollars saved by, say, step 2 ("fluorescent kitchen lighting") are of course the area between step 2 and the "price" line, that is, a savings of \$0.05/kWh $\times$ 600 GWh = \$30 million. Thus the total societal annual saving for the first six steps is just to the entire shaded area between the steps and the price line, in this case $\sim$\$60 million.

Downsizing The Hvac System Figure 4 is too simple to illustrate an interesting issue in plotting conservation supply curves. Consider a step representing the choice of roof color (white vs traditional) for each 1000 ft^2 of roof (or reroof) for a home in Los Angeles. One thousand ft^2 shingle roof ordered in white will cost \$15 extra (once every 20 years), but it will stay cooler in midafternoon. Using Burbank weather, the DoE-2 program shows that each summer it will save about 500 kWh in air conditioning. One might say, wrongly, that it's CCE was a small positive quantity, $\sim$\$0.003/kWh, which is much less than the price of the avoided electricity, so, although a cool roof is a wise investment, it's still an investment with a small positive first cost. That's wrong, or at least it's the least interesting issue, because we have so far forgotten that the cool roof reduces peak cooling load by $\sim$0.2 kW and thus permits the homeowner to downsize the chiller by $\sim$0.2 kW of electricity, corresponding to 0.2 "tons" of air-conditioning capacity. This then saves $\sim$\$120 on the first cost of the air conditioner (or the next air conditioner if we are replacing an existing roof). Thus the correct (combined) CCE is not +\$0.003/kWh, but is negative at $-$\$0.02/kWh. Thus,

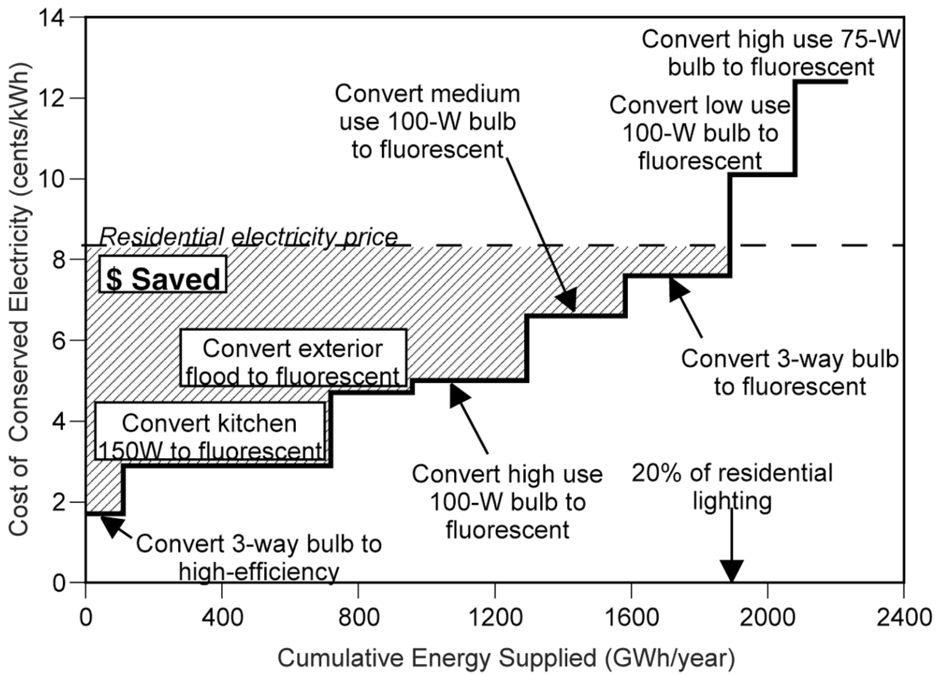

Figure 4 Macro supply curve of conserved residential lighting in California. Although the last cost-effective step costs 7.6 cents/kWh, the average CCE is only 4.8 c/kWh. This is adapted from Figures 3–12 of Meier et al (20).

in the words of Amory Lovins, this is not just a free lunch, but one they prepay you to eat. Lovins prefers to describe this as a two-step process, first one with a positive CCE ("select white color") and then a second step with a negative CCE ("downsize air conditioner"). He calls this "tunneling through the cost barrier" and ending up saving money. It doesn't matter whether we talk about one combined step or two linked steps; it does matter that we account for downsizing HVAC, which many inexperienced analysts fail to do. Perhaps we can fix DOE-2 and it successor to do this accounting automatically.

Forming the Center for Building Science

I insert this brief section mainly to explain why I change names for the LBNL Buildings Program.

By 1985, despite budgetary problems in Washington, the EEB Program had grown to half the size of our whole division, which also contained Mark Levine's Energy Analysis Program and, among others, a solar program. So we formed the Center for Building Science (CBS) with four programs: windows and lighting, indoor environment, energy analysis, and building systems. As director, my job was to coordinate research among the programs and to represent them to the outside world, including Washington, DC, and the UC campus.

Forming the California Institute for Energy Efficiency

Before the oil price crash of l985, EEB/CBS had a synergistic relation with the California utilities. They advised us on R&D priorities, we developed technologies, and they marketed them through Demand Side Management (DSM) programs to improve customers' use of energy. But with the collapse of OPEC, it appeared that DoE's support would dwindle to "generic, long-range, high-risk research," and we foresaw that the utilities would have to pay for our previously free services. With my long-time colleagues Carl Blumstein of the UC Energy Institute, Don Grether, deputy director of our Applied Science Division at LBNL, and Jeff Harris and Mark Levine, we proposed a new UC California Institute for Energy Efficiency (CIEE), funded by a utility contribution of 1/5000th of their revenues, which would provide $5 million/year. The utilities were skeptical, but the California Public Utilities Commission decided that a rate increase of 1/5000 was a good public investment, and we finally formed CIEE in l988. I headed it during the search for the director, James Cole, who has since led CIEE to sponsor multimillion dollar, multiyear projects spanning several institutions (e.g. intercampus institutions and often LBNL) on the scale of successful national laboratory or industrial R&D projects.

One of CIEE's success stories was to support Mark Modera of LBNL, who studied leaks from air ducts running through unconditioned spaces in the attics, crawlspaces, and basements of homes. He showed that on average about one-fourth of the hot or cold air leaked out, doing no good, and in fact doing some harm. (Blowing cold air out of a duct in the *attic* creates a partial vacuum in the *house*, which sucks in warm outside air.) To be more specific, a 4-kW air-conditioning unit with typical dust losses typically delivered only 3 kW of cooling. Multiplied by 20 million centrally air-conditioned homes (and including a "coincidence factor"), that's a waste of 10 GW, corresponding to ∼$1 million/h on a hot afternoon, $1 billion for a whole summer, and about $2 billion more in excess heating fuel in a winter. With CIEE help, Modera developed the aerosol technique, described below, which quickly seals all leaks up to the size of a dime. This has led to a new private company, Aeroseal, Inc. (http://www.aeroseal.com). Next, CIEE is attacking duct leaks in commercial buildings.

Modera's idea was to pressurize ductwork with a fog of small sealant particles. By temporarily blocking off the registers and the HVAC equipment, he forces the air to leave the ducts only via the leaks. But there it has to make sharp turns, which the heavy suspended particles cannot follow; so they crash into the sides of the leak, and stick there.

He carefully adjusts the particle size—too heavy and they settle out, too light and they can follow the air out of the leak. The particles must also solidify before they reach the leak; this helps them bridge a gap quickly (24).

Another CIEE success involves the hoods used to contain and remove fumes from research laboratories and high-technology manufacturing facilities. Annually, each unit typically exhausts \$500–\$1000 worth of heated or cooled indoor air. Helmut Feustel of LBNL invented the idea below to safely reduce the exhaust rate to one-fourth, saving \$375–\$750 per new unit (and there are about a million fume hoods in the United States). The cost premium for a new hood is ~\$1000, but the building air conditioner can be downsized and that saves >\$1000, so the net first cost is negative. CIEE and DoE supported Feustel to build, test, and optimize a prototype. Now LBNL is looking for a licensee.

Feustel's idea stems from an earlier observation by his colleague Ashok Gadgil that, when air rushes past the body of a worker at a fume hood (or a spray booth), it forms a turbulent eddy just downstream of his body, that is, between the worker and the work. This turbulent eddy tends to blow fumes back out of the hood opening, so the hood air intake has to be speeded up to compensate. Feustel's simple solution was to introduce less air, but smoothly, from inside the hood. The air to be exhausted can then be reduced to one quarter, and only ~10% of that is drawn from outside the hood, past the worker, so turbulence, if any, is reduced to 1/40 (25).

Urban Heat Islands and Cool Communities

Back in 1985 my LBNL colleagues Hashem Akbari, Haider Taha, and I realized that hot, dark roofs and pavements were half of the cause of summer urban heat islands, which in turn increased the smog (ozone, O_3) in Los Angeles and many other large cities. We already disliked hot roofs because they raise air-conditioning demand by 20%, and we had long been trying to get building energy codes to give credit for cool roofs. Today, 14 years later, the U.S. Environmental Protection Agency (EPA) is indeed preparing to recommend cool surfaces and shade trees as preferred ozone compliance measures for many of the cities that will exceed the 1998 air quality standards.

Throughout the world, cities are summer heat islands. They are 3–10°F hotter than their surroundings, and as cities grow, they typically add 1°F each decade. A few percent of this heating is manmade (e.g. from cars or air conditioners), but overwhelmingly it comes from two roughly comparable sources: air blows over dark-colored roofs and pavements and warms by conduction, and trees, which cool the air by evaporation, are disappearing.

We started the Heat Islands Research Project at LBNL in 1985 to investigate a strategy for switching to cooler roofs and pavements and planting trees on the west side of buildings. We modeled individual buildings and showed air-conditioning savings of 20% from cooler roofs plus similar savings from shade trees. We confirmed these results on real buildings, using white paint and with trees in large containers. Next we modified the urban solar reflectivity in the Los Angeles meteorologic model, the cooling impacts for Los Angeles and found a summer 3 PM temperature reduction ΔT of 6°F. (To our surprise, the then current official Los Angeles meteorological model did not even address spacial dependence of solar reflectivity!) Finally we fed ΔT into the urban airshed smog model, which already took into account the steep temperature dependence of ozone formation. The airshed model estimated a reduction in population-weighted O_3 of $>10\%$!

This saving of electricity and avoidance of smog costs little. At the time of roof replacement, a new white roof costs little more than a dark one, but will last longer. Pavements can be cooled two different ways: retain asphalt as the binder, but use white aggregate that will show as the dark asphalt wears down to the light aggregate color, or "white top" with concrete, which is stronger and actually cheaper in the long run. In Los Angeles, trees shading a lawn actually save water because the trees, after a few years of watering, survive on natural ground water, whereas the cooler lawn requires less municipal water.

For Los Angeles, estimated annual savings are impressive—over half a billion dollars—from

1. Direct air-conditioning savings to the buildings with cooler roofs and shade trees: $100 million.
2. Indirect air-conditioning savings to all buildings because Los Angeles' temperature is $\leq 6°$F cooler: $70 million.
3. Health and lost work time saved because O_3 is reduced 12%: $360 million.

This 12% reduction in ozone is comparable with that achieved by switching to cleaner-burning gasoline, which costs drivers an extra $1 million daily. It is fivefold the reduction predicted for 10% electric cars. If we assume each one of a million electric cars costs an extra $5000 ($500/year for each car), then 10% electric cars will cost $500 million/year. These costs are expensive compared with the low costs for Cool Communities!

For a decade decision-makers in Los Angeles regarded Cool Communities as "too good to be true." This started changing about 1996 amid the following events and activities.

- Southern California Edison, the Los Angeles basin's largest utility, independently verified the LBNL analysis.
- EPA plans to add cool surfaces and shade trees to its list of ozone control measures acceptable for State Implementation Plans for the 114 urban areas that will soon be out of compliance with ozone standards. Accordingly, California South Coast Air Quality Management District has added cool roofs and shade trees to its list of control measures.
- South Coast Air Quality Management District has gone even farther. Since 1994 it has operated a "cap-and-trade" smog offset market called RECLAIM (REgional CLean Air Incentive Market) which trades offset credits at about $1000/tonne of NO_x (precursor or feedstock of smog). Now South Coast Air Quality Management District has accepted the concept of direct reduction of smog (O_3) by temperature as equivalent to a reduction in NO_x.

- U.S. standards for new building energy efficiency, such as ashrae series 90, are being updated to credit the solar reflective properties of the roof.

So after a decade with little attention paid to cool roofs and shade trees by the air quality community, the persistence of the Berkeley group has borne fruit; the Cool Communities Program is recognized as sound environmental science.

The national savings to be realized are great. Because roofs are replaced only every 10–20 years and trees take 10 years to mature, the full savings from Cool Communities will be delayed until $\sim$2015. But by then we may be able to eliminate heat islands throughout the United States, save air-conditioning costs of $4 billion/year, and avoid annual CO_2 emissions of 7 MtC. U.S.-wide health gains have not yet been modeled, but we do have some sad but significant statistics. When Chicago suffered 700 heat-related deaths in l995, it turned out that most of the fatalities were frail, elderly people who lived on the top floors of badly ventilated apartment buildings with nonfunctioning air conditioning (the power failed) and with dark roofs. Cooler buildings, under white roofs, in cooler communities will also protect the elderly and infirm during heat storms and thus prevent tragedies like the Chicago heat storm.

For more details, see our paper in *MIT Technology Review* (26), which is also available on the Web (http://EETD.LBL.gov/Heatisland).

What about heat islands and ozone outside the United States? To outmatch Los Angeles and Phoenix, there are of course scores of hot, polluted megacities abroad. One of my goals is to help them introduce the use of cool pavements, shade trees, and cool roofs, particularly cool tiles, to reduce smog. A first step could be for DoE/EPA to invite city planners from abroad to study at LBNL and to work for some months on "cool community" projects in the United States.

When I moved to Washington, DC, in l994, my new boss, DoE Assistant Secretary Christine Ervin, and I agreed that I would continue as national spokesman for Cool Communities and start collaborations with Los Angeles, EPA, National Aeronautics and Space Administration, ASHRAE, and the roofing industry. As I have already noted above, we have indeed set up these collaborations. EPA now has a Heat Island Reduction Project, and cosponsors Energy Star Roofs with DoE. We have even cultivated and sponsored a Cool Roof Rating Council, an industry group that will test, rate, and label cool roofs. But we still excite far less interest than the President's Million Solar Roofs initiative.

Solar Collectors on Hot Roofs—a Missed Opportunity

In 1997 the Administration, with the backing of the solar industry, introduced a "Million Solar Roofs" initiative to install solar systems (mainly domestic hot water and PVs) on buildings. To my great (but predicted) disappointment, it fails to address the most obvious "solar" option of switching roof color (an almost free measure at the time of the next roof replacement, which accordingly has little backing from manufacturers—cheap solutions are not popular).

Here is a brief comparison of cool roofs and PV for a 2000-ft^2 roof in Florida. Compared with a traditional roof, a cool roof will reduce daily air conditioning use by ∼10 kWh, worth about $1. (27–29). A typical PV installation is sized for 3–4 kW (peak) and, even if bought in quantity, costs $6–$8/W (peak), for a total of $20,000–$30,000. In area, the PV array covers only ∼10% of the roof, leaving plenty of space for the rest to be white. To simplify the economics, let us consider a smaller, 2-kW (peak) system installed on a traditional hot roof. It will supply ∼10 kWh each sunny day, all of which will go to offsetting the air- conditioning penalty for the hot roof. At $8/W (peak), the 2-kW (peak) system costs $16,000, whereas a new cool roof costs nothing extra. And a cool roof reduces ozone formation; a hot solar collector on a hot roof certainly does not. In other words it is dumb to put PV on a dark roof, and more generally it makes no economic sense to install any renewable-energy systems on an inefficient building.

PV is already economic for off-grid markets (i.e. not served by power companies) and should soon be cost-effective on-grid in Hawaii, which is blessed with sunshine and burdened with expensive, oil-fueled electricity. To delay greenhouse warming, we should accelerate PV development and deployment where it is cost effective. But elsewhere, PVs should be introduced on a level playing field, along with other renewable technologies that are already cost effective: cool roofs, wind power, domestic hot water, and transpired collectors (30).

1985–1989: CALIFORNIA PIONEERS ENERGY EFFICIENCY

National Association of Regulatory Utility Commissioners Energy Efficiency Task Force and California Collaborative

The National Association of Regulatory Utility Commissioners, chosen from all 50 states, saw the societal benefits of utility DSM programs, and they were aware of DSM's peril after the 1985 OPEC collapse. So they appointed my good friend and Chair of the National Association of Regulatory Utility Commissioners' Energy Conservation Committee, Nevada Public Service Commissioner Stephen Wiel (now at LBNL) to form a task force to recommend changes to utility profit rules to reward DSM investments. Wiel in turn invited the usual efficiency champions including Ralph Cavanagh of NRDC, Amory Lovins of Rocky Mountain Institute, Maine Commissioner David Moskovitz, and me.

Some utilities in the Pacific Northwest were already allowed to earn a 10% premium rate of return on efficiency investment, and at first this seemed like a natural recommendation. But I was concerned about basing rewards on the level of investment. Thus my work on cool roofs to reduce air-conditioning costs and smog showed that, when a roof needed replacing anyway, there was no significant investment needed to order the new roof in a cool color and to downsize the air conditioner. The cleverest measures to save energy are the ones that cost the least, but these are least likely to excite the profit motive of a utility, no matter how large a premium rate of return is allowed. Moskovitz and I easily convinced the group that a return-on-investment formula just favors large, dumb investments, whereas “shared savings” are economically efficient. This point of view would soon lead to the California Collaborative and to a Shared Savings program. Under Shared Savings, whenever a California utility saved a customer $1.00, it was permitted a tiny rate increase (less than 1%), allowing its stockholders to earn an extra $0.15 and leaving the customer quite content with $0.85 savings.

In l988 the task force wrote a historic statement (Box 2), adopted by Wiel and his committee and later endorsed by the National Association of Regulatory Utility Commissioners as a whole, calling for new profit rules, awarding the highest profits to those programs that cost the least.

Box 2: Statement of Position of the NARUC Energy Conservation Committee on Least-Cost Planning Profitability

A utility’s least-cost plan for customers should be its most profitable plan. However, due to the fact that incremental energy sales increase profits, traditional rate-of-return calculations generally provide substantially lower earnings to utilities for demand-side resources than for supply-side resources. For that reason, profit motive generally encourages utilities to invest in supply-side resources even when demand-side alternatives are clearly identified in its resources plan as being the least-cost resource.

The loss of profits to utilities from relying more upon demand-side resources is a serious impediment to the implementation of least-cost planning. This obstacle to least-cost planning should be addressed. There are identified mechanisms for offsetting the profit-erosion problem.

Therefore, it is the position of the Energy Conservation Committee that state commissions:

1) should require their utilities to engage in least-cost planning;
2) should consider the loss of earnings potential connected with the use of demand-side resources; and
3) should adopt appropriate mechanisms to compensate a utility for earnings lost through the successful implementation of demand-side programs which are a part of a least-cost plan and seek to make the least-cost plan a utility’s most profitable resource plan.

(Adopted unanimously by the Committee on Energy Conservation on July 26, 1988.)

This statement stimulated Collaborative Processes in California, New England, and some other states. The process brought together utilities, regulators, energy users, state agencies, environmental groups, and other stakeholders to draft detailed new profit rules. Under the auspices of the Conservation Law Foundation of New England, I testified in every state in New England, leading up to their Collaborative. Both California and New England Collaboratives took effect in 1990, and introduced Shared Savings. The same utilities that had championed growth as a manifest good now championed efficiency as even more profitable.

Parenthetically, I should point out here that Box 2 is dated July l988, the same year that the hot dry summer marked another historic energy-related development. This was the summer that the United States lost about 5% of its agriculture, as did Europe and China, and when recognition of the threat of global warming suddenly ignited, again bolstering the case for energy efficiency.

From 1990, the Shared Savings idea spread slowly across the United States, and DSM programs grew to about $3 billion/year. But the prospect of "restructuring," which would introduce competition between power companies, caused utilities to reduce these programs by 1996. Fortunately the California legislature, well aware of the value of energy efficiency, passed AB 1890 in l996, imposing a "wires charge" of 2.5%, i.e. a "wire charge" of 2.5% on all electricity sold within the state for the next 4 years. The wires charge yields $540 million/year to fund public benefits programs—$240 million for DSM (with a modern emphasis on market transformation), $60 million for public-benefit R&D, $110 million for a renewable-energy portfolio, and $130 million for low-income programs. I continue to serve (with a bad attendance record) on the Technical Advisory Committee for the California Board for Energy Efficiency.

Shared Savings was a great idea for regulated utilities. Many countries still have private utilities (or are privatizing them) and will continue to regulate them as natural, noncompeting monopolies. I plan to continue to recommend Shared Savings to help these countries promote greater efficiency.

Advising the California Legislature on Energy/Environmental Regulation

In 1989–1990, I had the pleasure of being invited to sell my legislative ideas from the inside. California Senator Herschel Rosenthal, Chair of the Legislature's Joint Committee on Energy Regulation and the Environment, sponsored Senate Concurrent Resolution-7, establishing an 18-month study of improving energy efficiency and air quality. Three academics or environmentalists were to collect facts and opinions and make recommendations. Dian Grueneich, a public-interest utilities lawyer and counsel for CIEE and I were chosen. Our third colleague later resigned when a conflict of interest arose.

We used interviews, questionnaires, workshops, and our own experience to draft 30 recommendations for a more efficient California. Joint Committee members merged most of them into half a dozen bills, all of which passed the Legislature. It was a rewarding and efficient way to enhance efficiency and air quality, and champions of these causes in other states might suggest the same approach (31).

Pacific Gas and Electric's ACT^2 Shows 50% Reduction in Energy Use

Another wonderful opportunity appeared in l989. At the kickoff hearing on the California Collaborative on July 20, both Amory Lovins and I claimed that it was cost effective to reduce most buildings' energy use by 50% and that California utilities should expand their DSM programs to capture this potential saving and earn 10%–20% of its value.

PG&E already had a strong efficiency program, but was now interested in testing its ability to maximize profits by halving the measured energy intensity of existing buildings and the projected intensity of new buildings built to barely satisfy, but seldom to beat, the Title-24 standard. Amory and Carl Weinberg, PG&E's Manager of R&D, proposed to the PG&E Board a \$10-million demonstration of super-efficient buildings. The Board approved the formation of ACT^2 and appointed a steering committee of Ralph Cavanagh, Amory, Carl, and me[5]. We retrofitted or redesigned seven sites (residential and commercial, existing and new). At six of the seven sites, we easily saved 50%. In the last site, we saved only 45% (28).

To me, the most interesting outcome was not the official one, which was that an alert, motivated design team can save 50% of the energy with a reasonable payback time, but was how hard it was to find any competent design team and any competent "third party" to do the measurement and verification. In both cases the first design team and the first "commissioning" team were not up to the task, and we had to fire them and restart the selection process. The real lesson learned is that we need to motivate and train many more architects and commissioning agents to design and deliver efficient buildings.

Amory Lovins frequently calls ACT^2 the first whole-building project to demonstrate that conservation supply curves bend down again if savings are big enough to downsize, simplify, or eliminate the HVAC equipment (23, 33). I have already discussed this issue in Box 1.

Unfortunately, by the time we finished the last ACT^2 site, planning for utility restructuring had swept away PG&E's interest in profitable Shared Savings projects. Sadly, PG&E has dismantled its highly experienced ACT^2 team.

1993: WATER FOR DEVELOPING COUNTRIES

In spring 1993, as usual I taught Physics 180—Efficient Use of Energy, which involves student projects. Derek Yegian, a graduate student who had served in the Peace Corps and was interested in improving drinking water in poor countries,

[5]The project was originally called A^2 for Amory and Art. I suspect that some senior PG&E officials thought that it would fail, and thus A^2 was a fine name. But it was a great success, and we changed the name to ACT^2 for "Advanced Consumer Technology Test for Maximum Energy Efficiency."

proposed solar thermal-water pasteurization. In the developing world, waterborne diseases such as cholera, typhoid fever, gastroenteritis, dysentery, and infectious hepatitis kill more than 400 children every *hour* and cause the loss of billions of hours of worker productivity each year. Municipal tap water is uncommon in many households, and two out of three people in the world must fetch water from outside their homes. Disinfecting water by boiling it over cookstoves stresses the biomass resource, deforests hillsides (leading to mud slides after storms), and increases the burden on those collecting the fuelwood, mostly women and children. Gathering wood occupies time that might be spent productively in other activities.

I hired Yegian at LBNL for the summer, and within a month, with the help of my Indian-born former graduate student and colleague at LBNL, Ashok Gadgil, Yegian greatly improved the design of existing solar pasteurizers and passed the plans on to Pax International, which provides them to developing countries. Yegian still had another 6 weeks to be creative.

Gadgil pointed out that in India and Southeast Asia water pollution is worst during the monsoon season when heavy rainfall washes raw sewage and other contaminants from the fields into the wells and surface water. And of course, there is little sun during the monsoon.

So we went on to show that we could use a 40-W ultraviolet germicidal lamp to purify 4 gal/min at a cost of a few cents per ton. In a modern city with a reliable water distribution system, one can purify with chlorine for $0.01/ton, but that doesn't help villages or slums in developing countries. Gadgil, Yegian, and others developed a prototype device called UV Waterworks (UVWW). One 40-W unit will supply a village of 1000, and there are $>$300,000 electrified villages in India alone. Each UVWW unit daily disinfects 10 tons of water. During each year of a 10- to 15-year life serving a typical developing-nation community of 1,000 people, each unit will prevent the death of one child and the stunted growth of 10 children. Under aggravated conditions like epidemics, health benefits will be much larger. Because women are primarily responsible for collecting fuel wood, fetching water, and bearing and caring for children, the UV disinfection system can greatly improve women's quality of life by reducing their workloads as well as the number of children they lose to waterborne diseases. Each UVWW unit will avoid daily foraging for firewood by more than 100 women and children.

Each unit also avoids the daily release of 0.8–2 tons of carbon equivalent from combustion of wood or other biomass that would have been used to boil the water. I summarize a paper by Gadgil et al (34). Biomass-fueled cook stoves average only 12% efficiency, so to boil 1 kg of water, they generate CO_2 with a carbon equivalent of 0.12 kg. But the cookstoves also generate many products of incomplete combustion of which CH_4, NO_x, and CO have high global warming potentials, adding an additional equivalent carbon burden of 0.08 kg of C. Even if the biomass is sustainably harvested (no CO_2), the minimum daily additional carbon emission from incomplete combustion for 1000 people to boil 10 tons of water is 0.8 tC each day. Adding nonsustainable CO_2 brings the figure up to 2.0 tC/day or 730 tC/year (equivalent to the carbon emission from 730 cars). We find it remarkable that a device costing only a few hundred dollars, with a service life of $\sim$10 years, has the lifetime potential of saving 2500–7500 tonnes of carbon. In terms of deforested hillside, the life-time mass of avoided firewood is equivalent to more than 10,000 tons! After I left Berkeley, Ashok Gadgil and LBNL found Elwyn Ewald, a retired expert of Third World health with 20 years of development experience, who licensed LBNL's UVWW patent rights, formed WaterHealth International [www.waterhealth.com], and has put it in production. In December 1998, 25 UVWW units were serving 10,000 villagers in the Philippines, and, by the end of the century, the number of users worldwide should grow to between 100,000 and 200,000.

In 1996, UVWW received *Discover Magazine's* award for best environmental invention for the year, and a *Popular Science* award as one of the top 100 inventions of the year.

1993: FROM BERKELEY PROFESSOR TO DEPARTMENT OF ENERGY ADVISOR

Department of Energy's Carnot Award for Energy Conservation

In 1993 I received the pleasant news that I was to be the second LBNL recipient of the Carnot Award. DoE's Office of Energy Efficiency and Renewable Energy had created this prize, named after Sadi Carnot, the great French scientist who, in 1824, calculated the maximum theoretical efficiency of an engine, now known as its Carnot efficiency. This analysis in turn led to the formulation of the Second Law of Thermodynamics. Sam Berman had been the first recipient in 1988, and I received mine in January 1994. It was for this award and talk that I prepared Table 1.

When Clinton and Gore took office in l992, Washington became a less hostile, even inviting city. Many of my friends who had played the role of loyal opposition to the previous administration now were the administration. Thus Jack Gibbons, director of the Office of Technology Assessment was appointed Science Advisor to the President and Director of Office of Science and Technology Policy, and he took my old friend Henry Kelly with him to the White House. I began to catch a case of Potomac fever.

On my January 1994 Carnot Prize trip, I met Christine Ervin, then DoE's Assistant Secretary for Energy Efficiency and Renewable Energy, and we discussed my coming to DoE as her science advisor. At the time, UC was offering a very attractive retirement plan, and I had a list of projects I wanted to start at DoE, so I readily accepted. In June 1994 Roz and I rented out our Berkeley hillside home and moved to Alexandria, VA.

National Science and Technology Council Construction and Building Subcommittee

In the Clinton administration, much interagency planning and coordination occurs in councils, like the National Security Council, International Trade Council, Council of Economic Advisors, and including the National Science and Technology Council. My friend Henry Kelly was now partly responsible for the National Science and Technology Council, and had suggested that it form a subcommittee on Construction and Building (C&B). He further suggested as cochairs Richard Wright, Director of the Buildings and Fire Research Laboratory at the National Institute of Standards and Technology, and me. We hit it off wonderfully, partly because Richard was pleased to do most of the work and to host our secretariat at the National Institute of Standards and Technology, staffed by his associate director, Dr. Andrew Fowell.

I learned that construction is one of our two largest industries—health is the other (then comes transportation and then food). Our annual construction investment is nearly $1 trillion. Two-thirds of construction goes into buildings, new or remodeled. The construction industry spends only 0.5% of its revenues on R&D, although the U.S. average is 3% (35). I also learned that construction, which employs only 6% of our workforce, pays 33% of workers' compensation, with insurance premiums ranging from 7% to 100% of payroll. For each new home, the cost of workers' compensation averages $5000. Construction workers die or are injured on the job at 2.5-times the rate for all other industrial sectors. The best U.S. construction companies are as safe as those in Europe or Japan, but many are 5-fold–10-fold worse. Safety training for U.S. workers is sadly lacking.

We crafted seven ambitious goals for constructed facilities, to be demonstrated and ready for general use by 2003. Five of these goals involved 50% reductions in delivery time; in cost for operation, maintenance, energy, and water; in occupant-related illnesses and injuries; in waste and pollution; and in construction workers' illnesses and injuries. To these we added a 50% gain in durability and flexibility and a 30% gain in productivity and comfort. The last will be hardest to achieve and hardest to measure.

We then invited industry leaders to several workshops to comment on the goals and set R&D priorities. To our surprise industry leaders supported the ideas and have adopted them as National Construction Goals.

I personally have been most interested in the issues of indoor environment and air quality and their relation to both occupant health and productivity. We have started a Workplace Productivity and Health project and are planning a more ambitious Healthy Buildings initiative.

The C&B Subcommittee has started several valuable industry-government partnerships, of which the best known is PATH (Partnership for Advancing Technology in Housing). These projects are discussed in reference 35.

Better Financing for Commercial-Building Retrofitting—Monitoring and Verification Protocols and Data

Building energy retrofit yields on average a 20% return on investment, but with modern controls, monitoring, and better "commissioning," experienced contractors can reliably get 30%–50% returns. Even a 20% return on investment beats the stock market, and building investments are less *risky* than the stock market. But the data demonstrating all of this are scattered (and often proprietary), so Wall Street is only beginning to understand that energy retrofits of buildings are low-risk profit centers.

While still in Berkeley, I had decided that we needed a comprehensive public-domain collection of retrofit data to convince bankers to lower their interest rates. As soon as I got to DoE, I met Greg Kats, who had similar interests. But Greg had a Stanford MBA and actually understood finance. He was also experienced in energy efficiency policy and had worked with Amory Lovins at the Rocky Mountain Institute before joining DoE. Greg and I teamed up and started talking to lenders, who advised us of an unexpected prerequisite—a common national monitoring and verification protocol.

In 1994 >$1 billion of retrofit was financed by utilities or by energy service companies under performance contracts. These may take different forms. The capital may be provided by the host building or by the energy service companies. In either case the energy service companies perform the work and are repaid out of measured savings. Note that all performance contracts require that host and contractor agree on a protocol to establish the value of each year's savings.

What troubled our financial advisors was that many different protocols were sprouting like weeds. New Jersey had one, as did individual utilities and the EPA. Furthermore, ASHRAE had a project to write a detailed engineering protocol, but that would take several years. Our Wall Street friends asked us to coordinate these individual protocols and provide a national protocol. So Greg and I invited all of the parties above plus many other stakeholders to collaborate and produce the l996 North American Energy Measurement and Verification Protocol (36).

Subsequently Greg, as Director of Finance for Energy Efficiency and Renewable Energy, has spent about half of his time, and I have devoted ~10% of mine, in managing and expanding the protocol to cover water conservation, indoor environmental quality, and industry. We have worked to get it adopted in many states, and internationally by Canada, Mexico, the European Community, and for projects of the World Bank and sister development banks. Hence we have renamed it International Performance M&V Protocol (IPMVP). The Federal Energy Management Program for federal buildings has also adopted it.

The IPMVP has been translated into Chinese, Japanese, Korean, Spanish, Portuguese, Russian, Ukrainian, and Polish and is being adopted and applied at different rates in each country. It is being translated into another four of five languages this year. We have been told that a pending $40-million World Bank efficiency loan to Ukraine would probably not occur without the IPMVP, which provides confidence in better and more consistent savings performance and allows reduced transaction costs through the standardization it provides.

The good news is that risk as perceived by financiers and hence the risk premium on the interest rate is indeed dropping. This must be partly owing to bankers' increasing familiarity with retrofit, and partly to the existence of IPMVP; we cannot apportion the credit. But when we were first organizing the IPMVP a few years ago, the average interest rate premium above 30-years on Treasury bonds was 4–7%, and now it has dropped to $\sim$2%, for a gain of 2–5 percentage points.[6] Our growing benefit/cost database should help to shave off a little more.

Emissions Trading Under International Performance Monitoring and Verification Protocol

As the only international consensus approach to measuring and verifying efficiency upgrades, the IPMVP is expected to serve as a technical basis for emissions trading programs domestically and internationally. Domestically, for example, EPA is planning on using the IPMVP as a basis for determining emissions credits allocation in state implementation plans for NO_x compliance. Internationally, the Intergovernmental Panel on Climate Change, multilateral development banks, and other institutions expect to use the IPMVP to determine CO_2 offsets and achieve consistency between countries in determining CO_2 reduction from efficiency investments as part of an international climate change trading programs.

Our next goal is to decrease the energy use of new buildings and beat the relatively lax code requirements. The most cost-effective opportunity to save energy is during the design phase of a building, and today many new buildings have beaten code by 25%–35%, with annual return of investment of 25%–35%. Greg and I plan to collect data and case histories and work with public and private builders to encourage them to make small additional investments to achieve rewarding net savings. We will do this in collaboration with EPA's Energy Star Buildings program.

1995–PRESENT: GLOBAL CONCERNS

Energy-Efficient, Low-Carbon Technologies—The Five-Lab Study

My most productive and stimulating collaborator at DoE turned out to be Joe Romm, who worked his way up through several different jobs while I've been in

[6]On a five-year loan, the five-year percentage cost of interest is about 2.5 $\times$ the annual interest rate. So, if the rate has dropped 4% (from 6% to 2%), the cost of the project has dropped 10%, which should significantly accelerate the rate of investment in retrofits. Of course the 2%–5% drop in interest rate does not apply to large successful energy service companies that have excellent credit ratings and low cost of capital.

Washington. Joe received a doctorate in physics from Massachusetts Institute of Technology in l987. He worked on national security issues until 1991 and with Amory Lovins at Rocky Mountain Institute until 1993. Amory recommended him to Hazel O'Leary, then Secretary of Energy, and her deputy, Bill White, who snapped him up as a special assistant. By 1995, Joe had become Principal Deputy to Christine Ervin, the Assistant Secretary for Energy Efficiency and Renewable Energy, who had hired me. (Christine resigned after Clinton's first term, and Joe went on to serve as Acting Assistant Secretary). Between 1992 and 1994, he also wrote an excellent book (37) and has now written a comprehensive sequel (38).

In the summer of 1996, $<$18 months before the United Nations conference on climate change, scheduled for Kyoto in November 1997, Joe, Christine, Eric Petersen[7] (now Director of Policy, Planning, and Budget for Energy Efficiency and Renewable Energy) and I began to talk quantitatively about CO_2 reduction. Among developed countries in 1996, discussion centered on returning to 1990 levels by 2010. In 1990 the United States emitted 1340 MtC from CO_2. For 2010, the Energy Information Agency's (EIA) "business as usual" CO_2 scenario projected 1740 MtC, so the analytic challenge was to estimate the cost (or gain) to save annually 400 MtC, which meant shaving 23% off the projected annual 1740 MtC in 2010, only 12 years away. This required increasing our CO_2 efficiency at an average annual rate of 2%. After the collapse of OPEC in late 1985, efficiency has been growing annually at a 1% rate, so adding 2% would raise the total rate to 3%. Most economists feared that this would be very expensive, and would threaten our economy.

In contrast, several engineering economic studies undertaken about 1990 (I had worked on two of them) found cost-effective carbon savings of 30%–50%, but they all had a 20- to 30-year time horizon, to allow for natural stock turnover (39). The 20- to 30-year implementation time is required by the long service life of energy-related products. Thus cars and appliances last 12 years; refrigerators, 16; airplanes and factories, 30; power plants, 40 years; buildings and urban sprawl, 100 years. These are very long times in the light of our self-imposed constraint of 2010.

There was one heartening empirical fact, which I had been pointing out for years. OPEC hit us with high prices from fall 1973 through fall 1985 (12 years), but during the first year or so confusion reigned over policy, so that new products did not really start adapting until late 1974, leaving us 11 years to respond to energy scarcity. The good news was that, between 1974 and 1985, auto fuel economy doubled (corresponding to an improvement of 7%/year). Many other products roughly doubled in efficiency; thus the average new refrigerator plotted in Figure 3 dropped its energy use to 58%. Space heating for new buildings dropped to 50%, corresponding to an efficiency gain of 100% or, again, 7%/year. Using overall data on energy vs GDP, I get a good fit to a rate of efficiency gain of 5% a year, averaged over all energy-consuming new products, for those energy-aware 11 years (40).

[7]Petersen died of cancer, Aug. 25, 1999.

Given all of these considerations, the four of us at DoE realized that we just did not know how fast and at what cost (or reward) we could “get to Kyoto.” We determined to find out quickly.

The expertise for a comprehensive low-energy, low-carbon study was mainly at DoE’s national laboratories. We also realized that a lab study (as opposed to a DoE study) would, once completed, avoid tedious “concurrency sign-offs” at DoE. Christine put up $500,000, and Joe picked five labs; Berkeley (Mark Levine) and Oak Ridge (Marilyn Brown) were coleaders, supported by Argonne, National Renewable Energy Lab, and Pacific Northwest National Lab (see 36a–41).

The efficiency analysis took shape by Christmas, but added up to only 230 MtC out of the 400 MtC required by 2010 to satisfy the Kyoto goal. But this efficiency gain would save billions of dollars annually (a net of $43 billion in 2010), and enough natural gas to fuel one-fourth to one-third of our coal-fired power plants. So to find the remaining 170 MtC we focused on electric power plant conversion and on the gas-fired generation of combined heat and power for industry and buildings. By summer we estimated that we could “get to Kyoto” by combining the efficiency gains with a $10 billion/year investment in low-carbon electric generation, saving ~200 MtC/year from each. (Lowering carbon per kilowatt hour also includes extending the service life of nuclear plants, and accelerated investment in renewable energy sources.) To stimulate $10 billion/year investment within the utility industry, we would need a carbon tax (or better, cap-and-trade permit price) of $25–$50/tC.

Note that the trading of carbon permits represents only an income transfer between companies, mainly within the utility and auto industries, and not a cost to society. Of course there is some real cost, for example to convert a power plant from coal to gas, or just to burn gas instead of coal, but the real cost is small compared with the transfer payments that induce the fuel switching. Our complete scenario (annual net efficiency savings less investment in lower carbon electric power) shows a tiny net economic gain of $38 billion out of a year 2010 projected economy of $10 trillion, or $<0.5\%$. We were happy to call this $(0 \pm 1)\%$ (41).

Zero cost or reward was welcome news at a time when the Administration’s planning for Kyoto was mainly bad news. As I mentioned before, most economists feared that to comply with Kyoto would seriously threaten our economy, and the administration gets advice from thousands of economists. Its response was to plan to be noncommittal at Kyoto. It would argue that CO_2 production by the already-developed countries (known as the Annex I countries) would soon be overwhelmed by CO_2 from the developing countries, so we could not afford to cut our CO_2 (and hurt our economy) unless they also agreed to reduce their CO_2 growth. (My problem with this argument is that EIA predicts that, as far ahead as 2020, 55% of CO_2 will still come from Annex I countries, and of course the CO_2 stored in the atmosphere over the last 100 years is overwhelmingly from our developed countries. So I can understand the feeling of the developing world that it is we who should take the first steps.)

So the bad news was that two of the leading champions of energy efficiency and greenhouse gas reduction were quitting government service. Tim Wirth, then Undersecretary of State for Global Affairs, and Eileen Clausen, Assistant Secretary for Oceans and International Environmental and Scientific Affairs, were both preparing to leave government to move to foundation-supported positions.

With Christine's blessing, Joe Romm led the charge to convince the Administration that we could afford to cooperate at Kyoto. He worked tirelessly to convinced Energy Secretary Federico Peña, colleagues at the Office of Management and Budget and other agencies, and friends on Capitol Hill. On October 10, l997, in a speech at a White House Conference on Global Climate Change, President Clinton said, "I'm convinced that the people in my Energy Department labs are absolutely right." And Vice-President Gore did go to Kyoto, asserted real U.S. leadership, and salvaged a squabbling, foundering conference.

Of course this victory was only partial, because the present Congress is not ready to adopt the Kyoto Protocol.

I do not want to imply that the Five-Lab study convinced many economists, because it has been criticized by skeptics as close as the EIA, an agency housed at DoE, but independent of DoE. In October 1998, EIA released a study requested by the U.S. House of Representatives Committee on Science (42) in which they detailed their concerns in Section 7.

These concerns point up the gap between macroeconomists and physical scientists. The former tend to model the economy "top-down" (i.e. from the top, downwards), using as levers mainly energy prices and taxes, with little attention to individual technologies. The latter work "bottom-up" with simple spread sheets and conservation supply curves, organized by individual technologies.

The macroeconomic models work well for conditions close to business as usual, but in my opinion they run into trouble if they stray far from business as usual, mainly because they keep the rate of efficiency improvement for new products unrealistically frozen at $\sim$1%/year. The engineering economists (at least those making a road map from here to Kyoto) envision a different world, far from business as usual. In this world, some combination of science, natural disasters, and business and political leadership is foreseen to have created a sense of urgency to delay the risk of global warming. In this "greener" world, industry, business, and government would naturally take an interventionist, perhaps even energy-intrusive stand, reminiscent of the OPEC-dominated years 1974–1985. Then, with steady domestic leadership rather than unexpected OPEC price spikes, I believe we can achieve the remarkable 5%/year rates of technical progress of those years, without the disruptions. So, in conclusion, we haven't convinced many economists, but the White House listens both to economists and technologists, and the Five-Lab study gave Clinton and Gore the Kyoto road map they needed.

Fortunately DoE has recognized the value of the Five-Lab team and has transformed it into a relatively permanent "Clean Energy Future" study group tasked to formulate policies to help the United States make progress along the Five-Lab road map.

Delaying the Threat of Climate Change

I conclude with a few personal observations on global warming/climate change. Before 1988, my first motivation for improving energy efficiency was to save money; second, I wanted to save resources (e.g. oil, gas, and forests) for future generations.

Then came the hot dry summer of 1988, when the threat of greenhouse warming burst onto the scene and into the headlines. This not only reenergized the energy efficiency community, whose prominence was waning and whose budgets had been flat since the collapse of OPEC in l985, but it also slightly changed my priorities from "1. Money, 2. Resources, 3. Pollution," to "1. Money, 2. Pollution, 3. Resources." Restated in environmental language, my concerns are switching from "running out of sources" to "running out of sinks." Thus my heightened interest, discussed above under the Five-Lab study, in combined heat and power, in gas-fired and biomass cofired electric generation, life extension of nuclear plants, and appropriate renewable-energy resources.

Before 1988 my goal was simple—invest in efficiency so as to save as much money as possible. But for CO_2 reduction I have a two-phase strategy:

1. For the next decade, until we understand more precisely the threat of climate change, I think that the only politically realistic policy for the Unites States will be to stabilize emissions at today's levels (or better, to try for 1990 levels).
2. By 2010, the risk of climate change should be better understood and accepted and the cost somewhat quantified, and worldwide we'll probably have to plan on further reducing CO_2/GDP well below the 1990 Kyoto target.

How difficult is Goal 1, to stabilize CO_2 emissions? I cannot resist one last small table (Table 2), which hearkens back to the discussion, for the United States, of the Five-Lab Study, but adds data on developing countries.

Table 2 shows projected annual growths (not today—1999—with Asia and Russia in economic crisis, but EIA's estimate for the 25-year average (1995–2020) for the United States, China, developing countries, and the whole world. The top three rows display the primary outputs: GDP, E, and CO_2; the next two rows are just the derived intensities E/GDP and CO_2/GDP.

If the United States (shown in column A) is to maintain economic growth yet stabilize CO_2 emissions, row 3 shows that we need to reduce CO_2 by only an extra 1.2%/year, on top of the present 0.7%/year shown on line 3a, for a total annual drop of CO_2/GDP of 1.9%/year. Technically this should be easy. In the preceding section (on the Five-Lab Study), I pointed out that, in the energy-anxious 11 years 1975–1985, new energy-related U.S. products improved their efficiency $\sim$5%/year. Energy and carbon showed almost identical growth rates, so if the external threat of OPEC moved us to gain 5%/year, broad internal recognition of the risk of climate change should be able to motivate us to accelerate from the present annual improvement of 0.7% to 1.9%.

TABLE 2 Projected annual percentage growth (1995–2020) of gross domestic product, primary energy, and CO_2 for the United States, China, developing countries[a], and the world.

Growth indicator	A. United States	B. China	C. Developing countries[a]	D. World
1 Gross domestic product, (GDP)	1.9	7.9	5.2	3.1
2 Primary energy (E)	1.0	4.2	3.8	2.3
3 CO_2	1.2	4.4	3.8	2.4
2a E/GDP	−0.9	−3.7	−1.4	−0.8
3a CO_2/GDP	−0.7	−3.5	−1.4	−0.7
2b E/GDP fit to new products during the "Efficiency Years" (1975–1985)[b] *Source: Rosenfeld, Bassett (40)	−5			−3[b]

[a]Developing countries are Asia (except Japan and Australia), Middle East, Africa, and South and Central America (except Mexico).

[b]Eastern Europe and the former Soviet Union did not respond to the OPEC price shock, so we exclude these countries from our world fit.

Source:DOE/EIA-0484(98)(43) *Intl En. Outlook's Report # is DOE/EIA-0484(98), and it is my autobio citation 43.

At the other extreme, consider the developing countries in column C, whose combined GDP is predicted to grow much faster than that of the United States. To maintain this growth but level off in CO_2, they must decrease their emissions and energy use by an additional annual 3.8%, on top of their present 1.4% (row 3b), for a total of 5.2%. This sounds difficult, except for two encouraging trends:

1. Developing countries have energy and carbon intensities roughly 2.4-fold higher than that of the industrialized countries, (see Figure 19 of reference 43), so the technical constraints will not soon be a problem. They could increase their intensities at the required 5.2% annually for 30 years before they reach the satisfactory intensities of Switzerland, France, Austria, or Greece today.
2. Regardless, the developing countries are still the minor part of the problem; despite their rapid growth, they will reach not reach 40% of the world's CO_2 emissions until 2005, or 50% till 2020. (Table A9 of reference 43). So after the industrial world starts to conserve CO_2, there is still a decade or so for this new urgency and the new technology it spawns to diffuse into the developing world.

Before we leave Table 2, I call attention to the China column (B). Chinese planners are committed to energy efficiency, not because of any great concern for CO_2, but simply because efficiency beats coal production as a stimulant to economic growth. This commitment has led to a remarkable gain in energy intensity, which is predicted to continue at an annual rate of 3.7%. My hope is that the rest of the developing world can achieve this goal.

CONCLUSION: FROM REVELATION THROUGH REVOLUTION

In conclusion, energy efficiency is an enduring challenge. Inefficient use of energy and hence waste of money and resources will merit our attention for the foreseeable future, and I believe the same can be said of the threat of climate change. Energy efficiency has been a rewarding discipline because it simultaneously saves money and protects the environment. I'm proud to be working in this field.

ACKNOWLEDGMENTS

As the reader will have observed, my greatest pleasure has been to work with leaders of energy efficiency for the last 25 years and to have been able to attract a few of the strongest to Lawrence Berkeley Lab. More friends than I have room to list have reviewed and improved this autobiography; I end with thanks to all of them.

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LITERATURE CITED

1. Fermi E, Orear J, Rosenfeld AH, Schluter RA. 1949. *Nuclear Physics*. Chicago: Univ. Chicago Press

1a. Rosenfeld AH. 1954. Production of charged pions from hydrogen and carbon. *Phys. Rev.* 96:130

1b. Rosenfeld AH. 1954. Production of pions in nucleon-nucleon collisions at cyclotron energies. *Phys. Rev.* 96:139

2. Carnahan W, Ford KW, Prosperetti A, Rochlin GI, Rosenfeld AH, et al. 1975. *Efficient Use of Energy: Part I. A Physics Perspective*, ed. SM Berman, SD Silverstein, *Part III. Energy Conservation and Window Systems. AIP Conf. Proc. No. 25*. College Park, MD: Am. Inst. Phys. Updated by Hafemeister D, Kelly K, Levi B. 1986. *AIP Conf. Proc. No. 135*

3. Dean E, Rosenfeld AH. 1977. Modeling natural energy flow in houses. In *Efficient Use of Energy in Buildings, A Report of the 1975 Berkeley Summer Study, LBL 4411, EEB 77-2,* ed. E Dean, AH Rosenfeld, Chapter 3. Berkeley, CA: Lawrence Berkeley Natl. Lab.

4. Goldstein DB, Rosenfeld AH. 1976. *Projecting an Energy-Efficient California. LBL 3274//EEB 76-1*. Berkeley, CA: Lawrence Berkeley Natl. Lab.

5. Goldstein DB, Rosenfeld AH. 1975. *Conservation and Peak Power—Cost and Demand. LBL4438//EEB 76-2*. Berkeley, CA: Lawrence Berkeley Natl. Lab. Reproduced in 1988. *NATO Adv. Sci. Inst. Ser.*, Vol.

149. Dordrecht, The Netherlands: Elsevier/Kluwer

6. Rosenfeld AH, Levine MD. 1981. *Accelerating the Building Sector's Sluggish Response to Rising Energy Prices*. Testimony before the Interior Appropr. Comm., US House Represent., Washington, DC, April 8, *LBL 12739, EEB 81-2*
7. Traynor GW, Anthon DW, Hollowell CD. 1982. Technique for determining pollutant emissions from a gas-fired range. *Atmos. Environ.* 16:2979–87
8. Budnitz RJ, Berk JV, Hollowell CD, Nazaroff WE, Nero AV, Rosenfeld AH. 1979. Human disease from radon exposures: the impact of energy conservation in residential buildings. *Energy Build.* 2:209–15
9. Nazaroff WW, Feustel H, Nero AV, Revzan KL, Grimsrud DT, et al. 1985. Radon transport into a detached one-story house with a basement. *Atmos. Environ.* 19:31–46
10. Nero AV, Schwehr MB, Nazaroff WW, Revzan KL. 1986. Distribution of airborne radon-222 concentrations in U.S. homes. *Science* 234:992–97
11. Nero AV. 1988. Controlling indoor air pollution. *Sci. Am.* 258(May):42–48
12. Price PN. 1997. Predictions and maps of county mean indoor radon concentrations in the mid-Atlantic states. *Health Phys.* 72:893–906
13. Goldstein DB, Rosenfeld AH. 1977. Facts and fact sheets on home appliances. In *Energy Extension Services, Proc. 1976 Berkeley Workshop*. Berkeley, CA: Lawrence Berkeley Natl. Lab.
14. Geller H, Goldstein DB. 1999. Equipment efficiency standards: mitigating global climate change at a profit. Geller-Goldstein Szilard Lecture. *Phys. Soc.* 28(2):1–5.
15. Berman S, Fisher AC, Hollander JM, Rosenfeld AH, Ross MH, et al. 1979. *American Council for an Energy-Efficient Economy: Manifesto*. Unpublished
16. Rosenfeld AH. 1981. Buildings section. In *A New Prosperity: Building a Sustainable Energy Future, the SERI Solar/Conservation Study*, ed. H Kelly, pp. 11–175. Andover, MA: Brick House
17. Geller H, Harris JP, Levine MD, Rosenfeld AH. 1987. The role of federal research and development in advancing energy efficiency: a $50 billion contribution to the US economy. *Annu. Rev. Energy* 12:357–95
18. Mills E. 1995. *From the Lab to the Marketplace. LBL Publ. 758*. Berkeley, CA: Lawrence Berkeley Natl.Lab. http://EETD.LBL.gov/CBS/Lab2Mkt/Lab2Mkt.html
19. Meier A, Rosenfeld AH, Wright J. 1982. Supply curves of conserved energy for California's residential sector. *Energy* 7(4):347–58
20. Meier A, Wright J, Rosenfeld AH. 1983. *Supplying Energy Through Greater Efficiency: The Potential for Energy Conservation in California's Residential Sector*. Berkeley: Univ. Calif. Press
21. Natl. Acad. Sci. 1991. Conservation supply curves for buildings. In *Policy Implications of Greenhouse Warming: Mitigation, Adaptation, and the Science*, Append. C, pp. 708–16. Washington, DC: Natl. Acad. Press. www.nap.edu/ readingroom, search for "warming"
22. Lovins AB, Lovins LH. 1991. Least-cost climatic stabilization. *Annu. Rev. Energy Environ.* 16:433–531
23. Von Weizaeker EU, Lovins AB, Lovins LH. 1997. *Factor Four: Doubling Wealth, Halving Resource Use*. London: Earthscan. Available in North America only from Rocky Mountain Inst. http://www.rmi.org
24. Modera MP, Dickerhoff D, Nilssen O, Duquette H, Geyselaers J. 1996. Residential field training: an aerosol-based technology for sealing ductwork. *Proc. ACEEE Summer Study* 1:169–75. *LBNL Rep. LBL-38 544*. Berkeley, CA: Lawrence Berkeley Natl. Lab.

25. Feustel H, Simionas R. 1996. *1995 Indoor Environment Program Annual Report*, p. 11. EEDT Div., *LBNL Rep. 38351*. Berkeley, CA: Lawrence Berkeley Natl. Lab.
26. Rosenfeld AH, Romm J, Akbari H, Lloyd A. 1997. Painting the town white—and green. *MIT Technol. Rev*. Feb/Mar: 54–59. http://www.EETD.LBL.gov/heatisland
27. Konopacki S, Parker D. 1998. Saving energy with reflective roofs. *Home Energy* 15(6):9
28. Parker D, Huang YJ, Konopacki SJ, Gartland LM, Sherwin JR, Gu L. 1998. Measured and simulated performance of reflective roofing systems in residential buildings. *ASHRAE Trans*. 108, Part 1. www.fsec.ucf.edu/∼bdac
29. Parker D, Durant S. 1998. *The Impact of PV on Energy-Efficient Housing*. FSEC-CR-1019-98. Cocoa, FL: Fla. Solar Energy Cent. See also www.fsec.ucf.edu, click on Million Solar Homes, PVRes
30. Kutcher CF. 1996. Transpired solar collector systems: a major advance in solar heating? *Energy Bus. Technol. Sourcebook. Proc. 19th World Energy Eng. Congr., Atlanta, GA*, Nov. 6–8, pp. 481–89. Atlanta: Assoc. Energy Eng.
31. Grueneich D, Rosenfeld AH, Modisette D. 1990. *Summary of Draft Recommendations for Legislative Action: Energy Efficiency as a Coordinated Environmental and Energy Strategy*. Submitted to Calif. Legis. Jt. Comm. Energy Regul. Environ., Sacramento, Sept. 12
32. Brohard G, Brown M, Cavanagh R, Lovins A, Rosenfeld A. l998. ACT2 Project: the final report. *Proc. 1998 Summer Study on Energy Efficiency in Buildings*, pp. 67–78. Washington, DC: Am. Counc. Energy-Effic. Econ.
33. Hawken P, Lovins AB, Lovins LH. 1999. *Natural Capitalism: Creating the Next Industrial Revolution*. New York: Little Brown. In Press
34. Gadgil A, Greene D, Rosenfeld AH. 1998. Energy-efficient drinking water disinfection for greenhouse gas mitigation. *Proc. 1998 Summer Study on Energy Efficiency in Buildings* 5:131–41. Washington, DC: Am. Counc. Energy-Effic. Econ.
35. Rosenfeld AH, Snell JE, Wright RN. 1999. *Construction and building—interagency program for technical advancement in construction and building*. Rep. Subcomm. Constr. Build., Comm. Technol., Natl. Sci. Technol. Counc. www.bfrl.nist.gov/info/cbtc/pubs.html
36. Bullock C, Kats G, Rosenfeld AH. 1996. *North American Energy Measurement and Verification Protocol. DOE/EE-0081*. Washington, DC: US Dep. Energy. www.IPMVP.org
37. Romm JJ. l994. *Lean and Clean Management—How to Increase Productivity by Reducing Pollution*. New York: Kodansha Am.
38. Romm J. 1999. *Cool Companies*. Covelo, CA: Island Press
39. Brown MA, Levine Md, Romm JP, Rosenfeld AH, Koomey JG. 1998. Engineering-economic studies of energy technologies to reduce greenhouse gas emissions: opportunities and challenges. *Annu. Rev. Energy Environ.* 23:287–385
40. Rosenfeld AH, Bassett D. 1999. *Annual energy efficiency improvement: 1% today, 5% from 1975–1985, what next?* Int'l Energy Agency Workshop Eng. Econ. Stud. Low-Carbon Technol., Washington, DC. ww.w.iea.org/workshop/engecon
41. Interlab. Work. Group. 1997. *Scenarios of U.S. Carbon Reductions: Potential Impacts of Energy Technologies by 2010 and Beyond. ORNL CON 444.* www.ornl.gov/ORNL/Energy_·Eff/labweb.htm
42. Energy Inf. Agency. 1998. *Impacts of the Kyoto Protocol on US Energy Markets and Economic Activity. SR/OIAF/98-03*. Washington, DC: US Dep. Energy
43. Energy Inf. Agency. 1998. *International Energy Outlook, 1998 with Projections through 2020. DOE/EIA-0484 (98)*. Washington, DC: US Dep. Energy

P 15 time, and the uncertainty of both have already stifled nuclear investment. Yet the capital markets
haven't yet understood an even greater risk: that nimbler competitors with lower and decreasing
costs could grab nuclear projects' revenues, so even if construction went as planned, the costly
nuclear electricity may not sell, let alone continue to sell for the decades required to repay and
reward nuclear investors. Whether or not the utility is traditionally regulated, customers can at
any time buy more efficient lights, motors, appliances, buildings, and industrial equipment if efficiency
looks cheaper than the kilowatt-hours they're offered. Customers can even mostly or
wholly abandon their costly suppliers and produce their own power, as many large users have
done. The market, long focused on which kind of central power plant produces the cheapest
kilowatt-hours, and content to assume ever-growing demand for electricity at any price, is only
starting to appreciate the bigger risk that no central plant can compete with the smaller, faster,
cheaper, more accessible options that customers increasingly prefer.
But regardless of market preferences, should governments encourage
***
How can power plants' carbon emissions be cost-effectively reduced?
Generating electricity causes two-fifths of U.S. and more than one-third of global fossilfueled
CO2 emissions, which in turn are about three-fourths of total CO2 emissions, excluding the
additional effects of other greenhouse gases. Nuclear power addresses only part of the electrical
fraction of fossil CO2 emissions—the fraction of chiefly coal-fired power generation that runs
fairly steadily, not at widely varying output, in grids large enough to accommodate nuclear units'
size (far too big for many smaller countries or rural users).74 Nuclear power's potential climate
solution is further restricted by its inherent slowness of deployment (in capacity or annual output
added per year), as confirmed by market data below. And its higher relative cost than nearly all
competitors, per unit of net CO2 displaced, means that every dollar invested in nuclear expansion
will worsen climate change by buying less solution per dollar.
*****The reason is simple:75 you can't spend the same dollar on two different things at the same time. (Economists call this "opportunity cost"—making any investment foregoes others.)

New nuclear power *costs far more* than its distributed competitors, so it *buys far less coal displacement* per dollar than the competing investments it stymies. Let's take this argument in two graphical steps built on the cost comparison in Fig. 1 above. One can quibble about many details the numbers, but their qualitative message is incontrovertible. As the Italian proverb says, *L'aritmetica non è un'opinione* (arithmetic is not an opinion).

***** pg 17
yardstick
of carbon displacement's effectiveness. A kilowatt-hour of nuclear power does displace nearly all the 0.9-plus kilograms of CO2 emitted by producing a kilowatt-hour from coal. But so
does a kilowatt-hour from wind, a kilowatt-hour from recovered-heat industrial cogeneration (ascribing
its carbon emissions to the process heat that was being produced anyway), or a kilowatthour
saved by end-use efficiency. And all of these three carbon-free resources cost at least onethird
less than nuclear power per kilowatt-hour, so they save more carbon per dollar.
Combined-cycle industrial cogeneration and building-scale cogeneration typically
**** pg 17
Combined-cycle industrial cogeneration and building-scale cogeneration typically burn natural
natural gas, which does emit carbon (though half as much as coal), so they displace somewhat
less net carbon than nuclear power could: around 0.7 kilograms of CO2 per kilowatt-hour.76
Even though cogeneration displaces less carbon than nuclear does per kilowatt-hour, it displaces
more carbon than nuclear does per dollar spent on delivered electricity, because it costs far less.
With a net delivered cost per kilowatt-hour approximately half of nuclear's, cogeneration delivers
twice as many kilowatt-hours per dollar, and therefore displaces around 1.4 kilograms of CO2
for the same cost as displacing 0.9 kilograms of CO2 with nuclear power.
**** p 18
Firmed windpower and cogeneration are 1.5 times
more cost-effective than nuclear at displacing carbon. So is efficiency at even an almost unheardof
7¢/kWh. Efficiency at normally observed costs beats nuclear by a wide margin—for example,
by about ten-fold for efficiency costing one cent per kWh.

*** New nuclear power is thus so costly that shifting a dollar of spending from nuclear to efficiency
protects the climate severalfold more than shifting a dollar of spending from coal to nuclear.
Indeed, under plausible assumptions, spending a dollar on new nuclear power *instead of* on

efficient use of electricity has a worse climate effect than spending that dollar on new coal
power!
*** p19
That is,
every dollar spent on new nuclear power will produce 1.4–11+ times less climate solution than
spending the same dollar on its cheaper competitors. For a power source merely to emit no carbon
isn't good enough; it must also produce the *least carbon per dollar,* and must do so *sooner*
than its competitors. That's because, if climate is a problem, then we must invest judiciously, not
indiscriminately, to buy the most solution per dollar and the most solution per year—best buys
first, not the more the merrier. Buying a costlier and slower solution, like new nuclear power,
will make the climate problem worse than it would have been if we'd bought cheaper, faster options
instead.
Whether *existing* nuclear plants have displaced and are displacing any carbon emissions,
as is often claimed,[77] depends on what assets would have been bought instead to generate the
***p21

The nuclear industry's central stated reason for omitting renewables, such as windpower
(which accounts for nearly half the recent growth in decentralized renewables' global capacity),
from its list of admissible competitors with nuclear power is that windpower isn't "24/7" or "reliable."
Unlike some important sources of distributed renewable power—such as small hydro,
geothermal, biofueled, and even much solar-thermal-electric[81] generation—that can be dispatched
whenever desired, windpower (and smaller but even faster-growing photovoltaics) do
produce varying output depending on the weather. Yet this variability, often assumed to pose a
fatal obstacle,[82] becomes far less important in a renewable energy supply system
using diverse technologies, because weather that's bad for one source is good for another: stormy weather is
generally good for windpower and hydro but bad for solar, while fine weather does the opposite.
Diversifying locations helps too, because weather varies over areas that are often smaller than
power grids. Technical reliability of single generating units is not the issue: modern wind turbines

are ~98–99% available, far better than any thermal plant. The issue is rather the *aggregate*
effect of some renewables' variability. As we'll now see, that effect is small.
***p22

'Not one of more than 200 international studies has found significant costs or technical barriers to reliably integrating large variable renewable supplies into the grid'.[89]

Some renewables' variability does require attention and proper engineering, but it's neither
a serious issue nor unique to renewables: the grid is already designed for the sudden and unexpected
loss of big blocks of capacity from transmission or central-plant outages.
from moment to moment as customers turn loads on and off; sudden variations, *e.g.* during the
ads in popular televised UK sporting events, can ramp demand so rapidly (due largely to large
water pumps when millions of toilets flush simultaneously, but euphemistically blamed on electric
kettles) that utilities are hard-pressed to maintain stable supplies. Demand often varies
widely from day to night and from summer to winter. Utility planners understand all this and design
for it. Yet there is no technical difference between variations in demand and in supply; they
are entirely fungible, and indeed onsite generation can be usefully considered a negative load.
Calm winds or cloudy skies last up to a few days in decent sites, but can be offset by complementary
renewables at the same sites or by any renewables at more distant sites.
***p24

Rather, a portfolio of many smaller
units is inherently *more* reliable than one large unit—both because it's unlikely that many units
will fail simultaneously,[96] and because 98–99% of U.S. power failures originate *in the grid*,
which distributed generation largely or wholly bypasses.
Research is increasingly showing that if we properly diversify renewable energy supplies
in type and location, forecast the weather (as hydropower and windpower operators now do), and
integrate renewables with existing demand- and supply-side resources on the grid, then renewables'
electrical supplies will be *more* reliable than current arrangements.

****
too real. Nuclear plants are capital-intensive and run best at constant power levels, so operators

go to great pains to avoid technical failures. These nonetheless occur occasionally, due to physical causes that tend to increase with age due to corrosion, fatigue, and other wear and tear. Some nuclear power failures are major and persistent: of the 132 U.S. nuclear units that were built and licensed to operate (52% of the original 253 orders), 21% were permanently shut down because of intractable reliability or cost issues (or in one case a meltdown), while a further 27% have suffered one or more forced outages of at least a year.[98] When the remaining 68 units work well, their output is indeed commendably steady and dependable, lately averaging ~90% capacity factor in the United States. However, even these relatively successful nuclear plants also present four unique reliability issues:

- Routine refueling, usually coordinated with scheduled major maintenance, shuts down the typical U.S. nuclear plant for 37 days every 17 months.[99]
- In both Europe and the United States, prolonged heat waves have shut down or derated multiple nuclear plants when their sources of cooling water got too hot.[100]
- A major accident or terrorist attack at any nuclear plant could cause most or all others in the same country or even in the world to be shut down, much as all 17 of Tokyo Electric Company's nuclear units were shut down for checks in 2002–04 for many months, and some units for several years after falsified safety data came to light. Natural disaster can also intervene: a 7-unit Tokyo Electric Power Company (TEPCO) nuclear complex, the largest in the world—outproduced only by the Itaipu and Three Gorges Dams, and supplying 6–7% of Japan's power—was indefinitely shut down by 2006 damage from an earthquake stronger than its supposedly impossible design basis, and remains down in spring 2008. Its output is being replaced by recommissioned and hastily finished oil-, gas-, and coal-fired plants; the operator's extra cost in FY2007 alone was ~$5.6 billion.[101]
- Unlike scheduled outages, many nuclear units can also fail simultaneously and without warning in regional blackouts, which necessarily and instantly shut down nuclear plants for safety. But nuclear physics then makes restart slow and delicate: certain neutronabsorbing fission products must decay before there are enough surplus neutrons for stable

operation. Thus at the start of the 14 August 2003 northeast North American blackout,
nine U.S. nuclear units totaling 7,851 MW were running perfectly at 100% output, but after
emergency shutdown, they took two weeks to restart fully. They achieved 0% output
on the first day after the midafternoon blackout, 0.3% the second day, 5.7% the third,
38.4% the fourth, 55.2% the fifth, and 66.8% the sixth. The average capacity loss was
97.5% for three days, 62.5% for five days, 59.4% for 7 days, and 53.2% for 12 days[102]—
hardly a reliable resource no matter how exemplary its normal operation. Canada's restart
was even rougher, with Toronto teetering for days on the brink of complete grid failure
despite desperate appeals to turn everything off. This nuclear-physics characteristic of
nuclear plants makes them "anti-peakers"—guaranteed unavailable when they're most
needed.
The grid is designed to cope, and does cope, with such massive and prolonged centralstation
outages, albeit with difficulty and at considerable cost for reserve margin, spinning reserve
(spare capacity—generally coal-fired—kept running and synchronized for instant use), and
replacement energy. The investments needed to manage central-thermal-plant intermittence (nuclear
or fossil-fueled) have already been made and paid for. It is therefore hard to understand
why the occasional and predictable becalming of wind farms or clouding of solar cells over a
much smaller time and space, offset by higher output from statistically complementary renewable
resources of other kinds or in other locations, is a problem.
****p26
so *any* country wishing
to use nuclear power must depend on one or more other countries for vital supplies.
****p28
One more dimension of energy and national security requires mention: proliferation. As President George W. Bush has rightly stated, the spread of nuclear weapons is the gravest threat to national security for the United States (and everyone else). Yet commercial nuclear power is the biggest driving force behind that proliferation, providing do-it-yourself bomb kits—nearly all the needed materials, skills, knowledge, and equipment—in innocent-looking civilian disguise, all concealed within a vast flow of civilian nuclear commerce. Acknowledging nuclear power's market failure would unmask and hence penalize proliferators by making the needed ingredients harder to get, more conspicuous to try to get, and politically costlier to be caught trying to get, thus revealing the motive for wanting them as unambiguously military. This would make proliferation
far more difficult, and easier to detect sooner by focusing scarce intelligence resources on needles, not haystacks.112
****P29

Nuclear power is promoted113 as “the only energy option available today that can provide large-scale electricity 24/7 at a competitive cost without emitting greenhouse gases.” Each part of this case, as we’ll see, is false, but two important parts—the implication that electricity supply must be “large-scale” and must come from constantly operating (“24/7”) generators—require deeper discussion, starting with unit size. As with the climate-protection claim, the truth is just the opposite.
****p29
show that micropower surpassed nuclear power in 2006 in total electricity production (each provides
one-sixth of the world’s power), surpassed nuclear generating capacity in 2002, and is
growing enormously faster. In 2005, global micropower provided one-fourth of the world’s new
electricity: it added 10–14· (without or with peaking and standby units) as much capacity and 3·
as much output as global nuclear added in the same year. In 2006, nuclear lost 0.2% or 0.75 GW
of net capacity as retirements exceeded new units, offset this loss by 2.2 GW of upratings for a
1.44-GW net gain, and raised its output 1.3% through the upratings plus higher capacity factors.
[115] Yet in 2006, micropower added 43.4 GW, or 57.7 GW including peaking and standby
units that can generally be made dispatchable (able to send out power reliably whenever desired).
During 2007, for which cogeneration data are not yet available, we estimate that distributed renewables
added another ~30 GW to achieve ~222 GW of total capacity[116] (60% as much as nuclear),
and they are expanding by ~15% a year[117] while nuclear power struggles to expand at all.
***p31
Fig. 6 (top): generating capacity of distributed electric generation worldwide and Fig. 7 (bottom): its electrical output; data are actual through 2006 or 2007 depending on data set, then industry-projected. Neither graph shows decentralized peaking nor standby generators, which have added large amounts of capacity since data collection began in 2000 (Fig. 8 below); also, some kinds of cogenerators in some countries are not yet included. By the end of 2006, micropower had 32% more capacity, and distributed renewables had more than half as much capacity, as nuclear power did, and together, both kinds of micropower generated 5.8% more electricity than nuclear power did.
*****p31*
Dismissed as unimportant, uneconomic, unreliable, and futuristic, micropower in 2005 provided from one-sixth to more than half of all electricity in a dozen industrial countries,118 including 53% in Denmark, 38% in Finland and Holland, ~31% in Russia, 20% in Germany, 17% in Japan and Poland, *vs.* ~6%119 in the United States, which still has many barriers to fair competition. 120
******p31

The word “baseload” is often misused to describe the power plants that big economies supposedly need. But in utility load-dispatch parlance, “baseload” doesn’t mean big, steadily operating, or dispatchable; it means plants that generate electricity at the lowest *operating* cost, so they’re dispatched whenever available, supplemented as needed by costlier-to-run plants. (Thus any renewable generator is run as a baseload resource because it has almost no operating cost. Its capital cost, which must be paid whether it runs or not, is irrelevant to this calculus.) As explained below, no sensible criterion requires a given power plant to be big nor to run steadily,

since many small plants, even variable ones, can add up to big and reliable supply—as they increasingly do in competitive power systems that allow them.
*****
For their first century of the electricity industry, power plants were costlier and less reliable than the grid, so it made sense to build bigger plants that backed each other up via the grid. But in the latest quarter-century, power plants have become cheaper and more reliable than the grid, so cheap and reliable power must now be made at or near customers. This can create many hidden economic benefits—not counted in the comparisons in this paper—that typically raise distributed resources' economic value by roughly a game-changing *tenfold*.121 Markets are starting
to recognize and capture these "distributed benefits," such as reduced financial risk from small and fast rather than big and slow increments of capacity, fuel-price hedging by renewables (which have no fuel and hence no fuel-price volatility), avoided grid costs and losses, and better avoidance and handling of faults on the grid. Utility planners are also starting to realize that, as the late Dr. Shimon Awerbuch showed at the International Energy Agency, a balanced portfolio of electrical sources should include a substantial fraction—typically tens of percent—of renewables,
even if they cost more, for the same reason and with the same mathematics that a financial portfolio should include riskless Treasuries even of they cost less: renewables' constant price improves the price/risk profile of the entire portfolio.

Moreover, negawatts, though less carefully measured, seem to add each year about as
much effective new "capacity" as micropower does worldwide.[122] Thus probably more than half
of the world's new electrical services now come from negawatts and micropower, while *all* central
plants—big thermal stations plus big hydro—provide probably less than half.[123] The electricity
revolution is already well underway and is rapidly accelerating.

enough to deal with urgent issues like climate change. For it to displace much coal-fired power would require an immensely larger nuclear industry:124 in perhaps the most ambitious vision, John Ritch, director-general of the World Nuclear Association, envisages125 a 20× nuclear expansion
by 2100, starting with more than 1,000 reactors in the next 25 years and 2,000 to 3,000 by 2050 (*vs.* ~440 today, most or all of which will have retired by about 2050). Yet during 2004–07, global nuclear installations averaged just 1.5 GW/y, or about one big plant's worth per year, including
upratings of older plants, while the world added ~135 GW/y of total generating capacity. Nuclear power had only a ~2% share of global growth in electric generating capacity, while windpower (13.7 GW/y) had 10%, all distributed renewables 17%, and all micropower 28% (probably rising to around one-third in 2007–08). These empirical data contradict the claim that nuclear is fast and big while its non-central-thermal-plant alternatives are small and slow. On the contrary, during 2004–07, micropower added ~14× more capacity (~20× in actual installations without upratings of old nuclear plants) and ~3× more electrical output than nuclear, and is pulling away. The nuclear industry projects that its gross additions (excluding retirements and upratings) will total 17 GW during the five years 2006–2010, but micropower is now adding 17 GW about every 15 weeks—17× faster.126
*****pg 34

'By spring 2008, global installed
windpower capacity had exceeded the United States' 100 GW of installed nuclear capacity.'
'In 2007, the United States added more wind
capacity than it had added coal capacity in the past five years combined.'

****p35
But robust growth in renewables continues to accelerate after, and in
many countries without, significant subsidies. Nearly all subsidies to renewables, where present, are far smaller than historic or current nuclear subsidies. And neither cogeneration nor efficient end-use receives or has received subsidies of any consequence almost anywhere. A simpler and more plausible explanation for distributed resources' competitive success against nuclear power, and other central stations, is thus that they have lower costs and financial risks, as discussed
***p36
Just in the two years ended April 2008, California utilities have saved more than 6 TWh, or nearly the annual output of a large nuclear unit. Of course every technology has its own hassles, obstacles, barriers, and hence risk of slow or no ultimate implementation at scale.
****p 37
What careful analysis does consistently show is that new nuclear is so costly and slow relative to its winning competitors that it will *retard* the provision of energy services.'
***p39
All China's new nuclear plants are commanded and funded by Beijing, while two-thirds of the new coal plants are "bootleg" units not authorized by Beijing. All are meant to meet burgeoning
electricity demand that negawatts will increasingly soften and distributed sources will meet. That demand growth is driven largely by construction of inefficient buildings and factories made from inefficiently produced materials; half the demand growth is due to largely wasted air conditioning and refrigeration. And since Beijing still holds many economic levers, it's easier to take a big bite out of demand than in the even more unruly U.S. economy, where most infrastructure
is already built. In principle, a fast-growing economy can reduce its intensity even faster than its service demands rise: even the severalfold-more-efficient United States did so in 2005–2006, *reducing* its absolute use of coal, oil, gas, and total energy. China's top priority on energy efficiency reflects its leaders' understanding that unless efficiency is the foundation of growth, supply-side investments will eat the capital budget and starve end-use investments.
On 24 January 2008, the European Union announced a climate strategy aiming
***p41
Negawatt program costs tend to decline with experience, as shown by evaluations for the three California investor-owned utilities161 and the aggregate of the 79 Pacific Northwest utilities evaluated by the Northwest Power Planning Council.162 California has generally mild climates, high building and appliance efficiency standards, and a long history of world-class demand-side management efforts, so other places lacking those attributes should tend to have bigger potential at lower costs.
****p42
168
Thus full U.S. deployment of just three winning competitors—recovered-waste-heat cogeneration (conservatively excluding all cogeneration that uses fresh fuel), windpower, and enduse efficiency—could provide ~13–15× nuclear power's current 19% share of U.S. electric generation, all without significant land-use, reliability, or other constraints, and with considerable gains in employment.
****p43
Renewables other than windpower, not yet counted, also have immense potential.170 Solar technologies aren't resource-limited nor even, in practice, area-limited. For example, on conservative
assumptions, just a 100×100-mile area of Nevada—less than one-fourth the nation's paved road and street area—containing 10%-efficient photovoltaics in half its area could annually produce as much electricity as the United States uses.171 In practice, of course, PVs would be building-integrated, rooftop-mounted, and built into parking-lot shades, alongside highways, etc. to avoid marginal land-use and to produce the power near the load,172 and PVs would be complemented
by other renewable sources (wind, geothermal, small hydro, etc.).173
****p43
to today's.174
All these options avoid paying a premium for nuclear power's siting, fuel, and manufacturing constraints; its proliferation, accident, terrorism,175 waste, and political risks; and its inherent unsuitability for the distributed service needs of billions of people in developing countries,

few of which even have an electric grid large enough to accommodate a modern nuclear plant.
For the two billion people with no electricity, and generally with no wires and no money, waiting
***p44
for the grid is too costly and too slow; efficient use and distributed renewables such as solar cells are the only practical, affordable, and prompt solutions. These are highly successful where deployed,
e.g. in Kenya, the world leader in installations per capita: nearly twice as many Kenyans "adopt solar power each year [as] make connections to the country's electric grid."176
Negawatts are an extraordinarily potent macroeconomic lever for global development, too, because saving electricity requires far less capital than expanding its conventional supply,177
and the power sector is the world's most capital-intensive, gobbling about one-fourth of global development capital.
***p44
Advocates often plead for "retaining the nuclear option" rather than "abandoning" or "closing off" new nuclear build. But "keeping the nuclear option open" doesn't mean benign neglect
or mere tolerance of free-market investments. Rather, it means, and has always meant, massive government intervention—ever-larger subsidies and other advantages to try to sustain or revive an industry dying of an incurable attack of market forces. Inevitably, such largesse comes at competitors' expense in funds, attention, markets, and—most precious—time. In the United States, that opportunity cost is now reaching a critical stage as the industry, still unable to attract private investors, desperately seeks ever-greater public funding.
Increasing market distortions
The simplest scorecard for a nuclear revival is how private investors vote
****p 44
Increasing market distortions
The simplest scorecard for a nuclear revival is how private investors vote with their dollars. Just distributed renewables (with no cogeneration or negawatts) attracted $56 billion of pri-
vate risk capital in 2006 and $71 billion in 2007,180 growing by tens of percent per year even in a soft economy. New nuclear power, as usual, got zero private risk capital from the market: it's bought only by central planners181 drawing ever more heavily on the public purse. Focusing its immense political power—most major countries' electricity policy has for decades been dominated
by nuclear interests—the nuclear industry is trying to stem its reverses and turn its fictitious revival into reality by shifting ever more of its costs from reluctant investors and customers to unwitting, inattentive, or powerless taxpayers, as recent U.S. history illustrates.182
Longstanding pre-2005 U.S. Federal nuclear subsidies totaling ~0.9–4.6¢/kWh183 have elicited no nuclear orders since 1973. In 2005, the Chairman of Dominion, an applicant for early nuclear site approval, told *The New York Times*, "We aren't going to build a nuclear plant anytime soon. Stanford & Poor's and Moody's would have a heart attack. And my chief financial officer would, too."184
****p 46
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***p48
well north of $100 billion.
One would expect the promoters of an allegedly robust and mature technology to risk more of their own assets on the veracity of their claims. These enterprises are certainly big

enough: the combined ~2004 revenues of the subsidized U.S. firms exceed the GDP of the world's 112 poorest nations, so if those firms were a country, they'd have the world's 13thbiggest economy.205 Yet without government handouts even bigger than the current astronomical levels, the U.S. nuclear revival continues to lack a key element: buyers. And of course such crony-capitalism interventions that shift risk and its cost from investors to taxpayers (or customers)
do not make those costs go away, but merely hide, delay, and reallocate them.206
It remains to be seen whether even these extraordinary market distortions will elicit
****p50

What, then, should a rational climate-protection policy do to abate emissions of fossilfuel-caused CO_2? The foregoing logic suggests that:

- much, indeed most, of the carbon displacement should come from end-use efficiency, because that's both profitable—cheaper than the energy it saves—and quick to deploy;
- end-use efficiency should save not just coal but also oil—especially in transportation,219 which in the United States in 2003 emitted 82% as much CO_2 as power generation: indeed, since power generation emits only two-fifths of U.S. and world CO_2,220
across-theboard
energy efficiency addresses 2.5 times as much CO_2 emission as an electricity-only
focus;
- supply-side carbon displacements should come from a diverse portfolio221 of short-leadtime, mass-producible, widely applicable, benign, readily sited resources that can be adopted by many actors without complex institutions or cumbersome procedures;
- the total portfolio of carbon displacements should be both *fast* in collective deployment (MW/y—or, more precisely, TWh/y per y) and *effective* (carbon displaced per dollar);
- a diversified portfolio needn't and shouldn't contain every possible option, any more than a financial portfolio should include obvious losers just because they're on the market; and
- intelligent investment should follow the order of *economic* priority—which is also the order of *environmental* priority—because not choosing the best buys first releases more carbon than would otherwise occur.

*****p51
This is not a new idea. As Keepin and Kats arrestingly put it in 1988,222 based on their reasonable
and now-conservative estimate that efficiency would save ~7× as much carbon per dollar as nuclear
power, "*every $100 invested in nuclear power would effectively release an additional tonne of carbon into the atmosphere.*" Thus, counting the opportunity cost of nuclear power *vs.* a reasonable
modern efficiency cost of 1¢/kWh, "the effective carbon intensity of nuclear power is nearly eight times *greater* than the direct carbon intensity of coal-fired power."
****p52

'But then thoughtful citizens must ask how can a credulous press continue to accept, report as fact, and promulgate
a vision so divergent from observed market realities?223
To be sure, some leading newspapers have described nuclear regulatory and construction complications, and a few have mentioned that financing may present challenges. Yet the broader story—an industry that is failing and unfinanceable despite wildly escalating subsidies, has been massively outpaced by competitors it doesn't even recognize, and is unable even in principle to deliver its claimed climate and security benefits—remains virtually untold.
Perhaps this article can stimulate journalists to sharpen their critical faculties, legislators to study evidence, and citizens to demand choices based on demonstrable facts. Sooner or later, truth will out. Sooner will do less harm to our climate, economy, and security.

Renewable Energy
Can Meet Mississippi's Needs

People have been presented only a false choice between conventional fossil fuels and nuclear power. Based on the work of governments, universities and other organizations in the United States, Europe and Japan, it is technically and economically feasible for a diverse mix of existing renewable technologies to completely meet Mississippi's electricity needs over the coming decades. The Gulf Coast states have vast renewable resources, which can be harnessed effectively and reliably. This can be done without producing carbon emissions, radioactive waste, or other significant pollution.

Mississippi continues to be reliant on polluting fossil fuels and nuclear power for its electricity generation. Electricity consumption in Mississippi totaled 46 million megawatt hours (MWh) in 2004. Of this total, 73.2% was produced using fossil fuels and 23.4% from nuclear power.[1] In order to avoid continued pollution, halt climate change, and increase energy independence, Mississippi and the other Gulf Coast states must tap into their renewable energy resources, including solar, wind, advanced hydropower, and geothermal energy.[2] While non-hydro renewables presently provide just 3.4% of electricity in the Mississippi, *it is technically and economically feasible for a diverse mix of existing renewable technologies to completely meet the state's electricity needs in the coming decades.*

Solar

According to a U.S. Department of Energy evaluation of solar energy potential, "Mississippi has a good, useful resource throughout the state."[3] A 2004 Energy Foundation report concluded that in the next two decades with current technology *solar photovoltaic panels (PV) could provide Mississippi with 27 million MWh per year - about 59% of Mississippi's annual electricity consumption*. This is a low estimate, as it uses a modest value for Mississippi's hours of sunshine and only includes the available residential and commercial roof space. Using the available space from parking lots, awnings, windows, highway medians, and industrial buildings would further increase the amount of potential electricity generated from solar in Mississippi. The overwhelming majority of solar panels can and would be built into existing buildings and infrastructure, and will not take up any additional land.

Wind

Mississippi also has useful wind resources, particularly offshore. A Stanford study on U.S. wind resources in 2003 found that the Gulf of Mexico has a potential bounty of coastal and offshore wind energy – much more so than previously believed.[4] Offshore wind typically has higher speeds and more regular patterns than wind over the land. To date, however, no complete mapping has been done of Mississippi's wind resources[5]. The few studies that have been done are dated and limited in scope.[6] Specifically, they are based on very few measurements taken with outdated techniques like measuring wind speed at 50 meters. Most wind turbines range from 60 to 80 meters where winds are stronger.[7]

According to the 2003 Stanford study, Mississippi has at least two significant offshore areas with class 4 and 5 winds respectively.[8] These classes of wind are typically rated by the Department of Energy as "good" and "excellent" for commercial production. *Two large wind installations in these areas each of 120 turbines would produce 1.4 million MWh annually – equal to the contribution from all of Mississippi's non-hydro renewables in 2004.[9] In other words, developing just these two wind sites would double renewable generation in the state. This is before any systematic mapping has been done. Given the wind sites in the Gulf Coast region near Louisiana, Texas, and Florida, it would not be unreasonable to expect Mississippi to have additional wind resources.*

Mississippi is also surrounded by states with significant offshore wind resources.[10] According to the Stanford study, Louisiana has several areas offshore with class 6 and 7 winds, and could be a large source of offshore wind power in the U.S.[11] Recently companies like Wind Energy Systems Technologies LLC (WEST) have proposed the installation of offshore wind turbines on abandoned oil and natural gas platforms in the state. The Florida panhandle also has offshore wind areas of mostly class 4 strength,[12] and Texas has an even larger coast with class 4, 5, 6, and 7 winds capable of commercial electricity production. In 2005, the Texas General Land Office announced the development of one of the first offshore wind projects in the U.S. just off of Galveston Island.

While the siting of wind turbines has been controversial in some communities, turbines are clean and safe, and have far fewer impacts than other forms of electricity generation. Improved turbine design has virtually eliminated turbine noise, while establishing siting considerations and limiting the number of turbines in one area has reduced concerns about visual effects. Bird and bat migration is being addressed through monitoring, warning signals, and site selection that takes their migratory patterns into account.[13] Much of Mississippi's wind is also offshore, meaning turbines would be five to fifty miles from shore – barely visible as specks on the horizon.

What about Variability and Intermittency?

One major concern often raised regarding solar and wind generated electricity is variability and intermittency. Although it is true that "the sun doesn't always shine and the wind doesn't always blow" - it is possible to harness these sources of energy in a way that substantially reduces these problems. Mississippi has a diverse renewable resource base, and the solar resources across the state could be balanced with the wind resources along the coast, advanced hydroelectric generation, and some types of sustainable biomass. Demand reductions through geothermal heat pumps and other forms of efficiency could also help these technologies meet the state's needs. Advanced hydro is already capable of producing baseload power, and offshore wind has similar potential. Peak solar energy production is particularly beneficial in Mississippi because it coincides with high energy demand for air conditioning during the summer.

A recent analysis by the International Energy Agency (IEA) - an intergovernmental body of twenty-six countries committed to advancing security of energy supply, economic growth, and environmental sustainability- *concluded that intermittency is not a technical barrier to renewable energy*. To deal with variability and intermittency, IEA recommends distributed generation, links across geographic areas, a diverse mix of technologies harnessing different resources, and the continued development of storage technologies. In the near term, single stage gas turbines could also be used to meet shortfalls in peak demand.

Significant advances along these lines have already been made. Presently, one of the best options for storage is hydroelectric pumped water. Hydroelectric pumped storage moves water from lower to higher reservoirs when extra electricity is being produced, and releases it when that energy is needed. These systems are well-established, low in cost, up to 80% efficient, and have an enormous capacity for storage. Mississippi currently operates no hydroelectric facilities, but has the potential to do so. Unfortunately, large conventional dams cause serious environmental damage. The Department of Energy estimates that advanced systems which minimize environmental impact can be applied at more than 80% of existing hydropower projects and all new projects.[14] A DOE resource assessment report found 19 existing impoundments in Mississippi suitable for 62.2 MW of pumped storage and 6 additional undeveloped sites with a potential storage capacity of 29.4 MW. Also, because energy is stored in times of excess generation, pumped storage systems do not compete with hydro generation.[15]

Geothermal

Geothermal heat pumps are systems that use the relatively constant temperature of the earth to heat and cool buildings, reducing the energy typically used for these purposes. These pumps can reduce a building's energy use by 30 to 60%.There are two principle types of geothermal heat pump systems – a vertical loop design and horizontal loop design. The vertical loop system is only a few feet wide, but extends deeper into the ground (350 ft average depth). The horizontal system only extends 12 to 18 ft. underground, but stretches much longer horizontally. The type and size of the system required depends on the amount of space available, as well as local geology and soil type.

The Department of Energy states that Mississippi has "resources that can be tapped for direct heat or for geothermal heat pumps."[16] Geothermal pumps save approximately a maximum of 1 kW per ton of capacity.[17] An average geothermal heat pump for a home has a capacity of about 3 tons,[18] and can be used to reduce the use of electricity for cooling and natural gas for heating. At Fort Polk Army Base in West Central Louisiana, where geothermal heat pumps were installed in 4,003 U.S. Army apartment housing units in 1996, electrical consumption was reduced by 26 million kWh, or 6,445kWh per apartment.[19] Geothermal pumps in commercial, industrial, and public buildings could result in even greater savings.

Other Forms of Efficiency

Efficiency is the cheapest and easiest way to reduce electricity use and facilitate the transition to renewable technologies. Efficiency also pays for itself many times over, as electric bill savings more than pay for the efficiency improvements. Examples include energy-efficient appliances, properly weatherizing buildings, and insulating hot water tanks and pipes. In 1993, the U.S. federal government's Office of Technology Assessment (OTA) estimated that the U.S. could reduce its electricity use 20-45% by adopting currently available efficiency technologies. Since the early 1990's when this analysis was performed, other efficiency measures - such as LED lights - have become commercially available, and thus the energy reductions possible through efficiency today are likely to be even greater. Electricity demand reduction through efficiency would further help Mississippi meet its electricity needs.

What about Cost?

Despite the perception that renewable technologies continue to be too expensive to consider, wind power at good sites in the U.S. is already significantly cheaper than power would be from new nuclear power plants.[20] Solar is still more expensive, but higher efficiency thin film panels and expanding manufacturing are expected to cause a significant drop in these prices.[21]

Moreover, conventional technologies such as coal and nuclear power have costs that are unaccounted for in our present economic models, such as carbon emissions, air pollution, land and water degradation from mining, the safety and security risks posed by commercial reactors, risks from nuclear weapons proliferation, and the dangerous legacy of radioactive waste. These costs should be accounted for in the price of these technologies before any price comparisons are made.

Also, over the last fifty years, federal support for nuclear power and fossil fuels has far surpassed support for renewable technologies, resulting in unequal technology development and commercialization. According to a report by the Renewable Energy Policy Project (REPP), from 1947 through 1999, direct federal government subsidies totaled $115.07 billion for nuclear power and $5.49 billion for wind and solar.[22] To make up for these problems, states around the U.S. now offer financial incentives for investing in renewable technologies.

For the documents referenced in this fact sheet, please see http://www.citizen.org/cmep/energy_enviro_nuclear/renewables/articles.cfm?ID=15584

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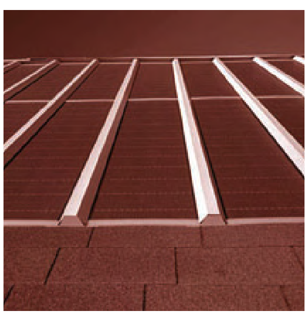
UTILITY SOLAR ASSESSMENT (USA) STUDY

REACHING TEN PERCENT SOLAR BY 2025



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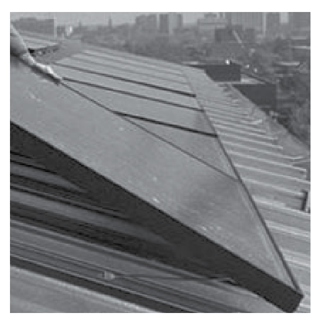

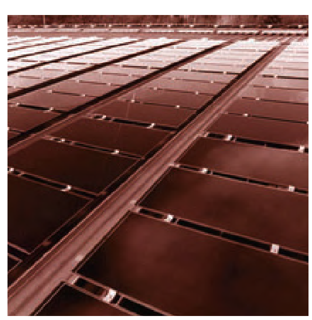

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UTILITY SOLAR ASSESSMENT (USA) STUDY
REACHING TEN PERCENT SOLAR BY 2025

JUNE 2008

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CONTENTS

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EXECUTIVE SUMMARY

Solar power has been expanding rapidly, growing an average of 40 percent per year since the beginning of this decade. In the past five years, global solar installations have expanded more than fourfold from approximately 600 megawatts (MW) in 2003 to nearly 3000 MW (the equivalent of three conventional power plants) in 2008.

Many industry analysts and experts believe that solar offers the promise of contributing a significant percentage of America's and the world's energy needs moving forward. How much could it reasonably contribute? Today, solar still represents a minuscule amount of U.S. energy supply—less than one tenth of one percent of total electricity generation. What would it take to dramatically increase this number to make solar a significant portion of electricity use, transforming the way U.S. utilities think about solar in the process?

Our research indicates that the solar contribution could be quite considerable, realistically reaching 10 percent of total U.S. electricity generation by 2025 by deploying a combination of solar photovoltaics (PV) and concentrating solar power (CSP).

Historically, utilities have played a marginal role in the direct growth of solar power. This is due to a number of reasons, from a utility mindset not originally aligned with distributed resources to the very real issue of solar as an expensive and intermittent energy source. But things are beginning to change. Public resistance remains high against nuclear power and increasingly high against coal. Since 2006, some 60 new coal plants in the U.S. have been cancelled, blocked, or delayed, and dozens more are being challenged in 20 states. Some states such as Kansas are considering moratoriums against new coal-fired generation—and this is even before nationwide mandatory carbon caps. California utilities are prohibited from buying new coal-fired power from out of state. In this new world, solar can help deliver the reliability that utilities need.

As conventional electricity sources such as coal, natural gas, and nuclear become increasingly expensive and solar technologies continue their inexorable price decline,

U.S. Solar Installed Capacity (CSP and PV)—Getting to 10 Percent

Year	Cumulative Capacity CSP + PV (MW)	Total Annual Generation Combined PV and CSP (MWh)	Total Projected Annual U.S. Electricity Generation/ Demand, All Sources (MWh)	CSP and PV Share of Total U.S. Electricity Generation
2007	1,284	2,513,665	4,119,235,230	0.06%
2010	3,027	5,849,916	4,219,402,150	0.14%
2015	15,184	29,385,504	4,397,329,160	0.67%
2020	69,260	133,345,983	4,608,068,490	2.89%
2025	255,646	485,723,159	4,858,105,640	10.00%

Source: Clean Edge, 2008

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the promise of a solar future beckons. Already, solar power can compete in regions with high electricity rates and with favorable incentives. It can compete effectively today for peak power production, in grid-constrained territories, and for applications that are off the grid.

Indeed, solar offers a number of significant benefits to utilities struggling with the complex issues of today's energy landscape. These benefits include:

Projected U.S. Solar Installations as a Percent of Total Electricity Generation—Recent Studies

Program/Report	Target Date	Cumulative MW Installed	Total Electricity Generation	% of Total Electricity Generation
SHINE (with ASAP)	2025	282 GW	520,646 GWh	10.7%
2004 SEIA PV Roadmap	2030	200 GW	360,000 GWh	7% of total generation and "50% of new U.S. generation" by 2030
A Solar Grand Plan: Scientific American	2020 & 2050	84 GW by 2020 (PV & CSP) 3,000 GW by 2050 (PV & CSP)	NA	69% of U.S. electricity and 35% of total energy by 2050

- Solar can offer a price hedge against volatile and increasing costs for fossil-fuel resources like coal and natural gas. Once installed, solar provides stable fixed prices to utilities and users.
- Solar is becoming a cost-effective peak generation resource.
- Within a decade, solar power will be cost-competitive in most regions of the U.S. on a kilowatt-hour (Kwh) basis.
- Compared to coal, nuclear, and gas-fired power plants, solar has no fuel costs, low maintenance costs, and will provide credits, rather than costs, in a carbon-regulated world.
- Solar PV is a widely available resource, suited to most locales around the nation.
- Solar PV can ease congestion in regions where energy demands have stressed the grid.

Comparative Power Costs for Utility Deployment

Energy Type	Coal	Natural Gas Combined Cycle	Geothermal	Wind	Concentrating Solar Power (CSP)	Nuclear	Solar PV
Capital Costs per 1000 MW (U.S. 2007 Average)	$1 billion - $3 billion	$1 billion - $2 billion	$1.2 billion - $2 billion	$1.5 billion - $2 billion	$3 billion - $4 billion	$3 billion - $7 billion	$5 billion - $7 billion
Fuel Costs	Yes	Yes	No	No	No	Yes	No
Subject to C02 Regulations	Yes	Yes	No	No	No	No	No

Source: Clean Edge, 2008

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Comparing Crystalline Silicon with Thin-Film/ Low-Price, Bulk-Purchase Crystalline - PV Price Reduction 2007-2025

Year	Crystalline Silicon PV - Average Price per Peak Watt Installed	Crystalline Silicon PV - Range kWh Cost	Thin-Film and Low-Price, Bulk-Purchase Crystalline PV - Average Price per Peak Watt Installed	Thin-Film and Low-Price, Bulk-Purchase Crystalline - Range kWh Cost
2007	$7.00	19¢—32¢	$5.50	15¢—25¢
2008	$6.50	17¢—30¢	$5.10	14¢—23¢
2009	$6.03	16¢—28¢	$4.74	13¢—22¢
2010	$5.59	15¢—26¢	$4.39	12¢—20¢
2011	$5.19	14¢—24¢	$4.08	11¢—19¢
2012	$4.82	14¢—24¢	$3.78	10¢—17¢
2013	$4.47	12¢—20¢	$3.51	9¢—16¢
2014	$4.15	11¢—19¢	$3.26	9¢—15¢
2015	$3.85	10¢—18¢	$3.02	8¢—14¢
2016	$3.57	10¢—16¢	$2.81	8¢—13¢
2017	$3.31	9¢—15¢	$2.60	7¢—12¢
2018	$3.08	8¢—14¢	$2.42	6¢—11¢
2019	$2.85	8¢—13¢	$2.24	6¢—10¢
2020	$2.65	7¢—12¢	$2.08	6¢—10¢
2021	$2.46	7¢—11¢	$1.93	5¢—9¢
2022	$2.28	6¢—10¢	$1.79	5¢—8¢
2023	$2.12	6¢—10¢	$1.66	4¢—8¢
2024	$1.96	5¢—9¢	$1.54	4¢—7¢
2025	$1.82	5¢—8¢	$1.43	4¢—7¢

- Utilities can use solar to meet state, and potentially national, Renewable Portfolio Standard (RPS) requirements.

- Solar is a domestically available, carbon-free energy source.

This report, the Utility Solar Assessment (U.S.A) Study, provides a robust roadmap for electric utilities to accelerate the growth of solar energy. Our research incorporates the latest technology, market, and policy breakthroughs, and interviews with more than 30 key industry players and experts, to show how a coordinated effort among regulators, the solar industry, and utilities can enable solar to reach 10 percent of U.S. electricity generation by 2025.

We aren't alone in this assessment. The Solar Electric Industries Association (SEIA) trade group, in its Solar PV Roadmap issued in 2004, stated that solar could provide 50% of new U.S. generation by 2030, a projected 7 percent of total electricity at that time. In our 2005 report, SHINE, we highlighted a plan that would enable the U.S. to get ten percent of its electricity from PV sources alone by 2025 via a concerted effort by the federal government to encourage increased investment in and deployment of solar power. Some people have gone even further. In their widely cited *Scientific American* article, "A Solar Grand Plan" published in January 2008, authors Ken Zweibel, James Mason, and Vasilis Fthenakis outline how the U.S. could get 69% of its electricity from solar by 2050.

Getting to Cost Parity

Capital costs for conventional energy sources are, in many cases, not dissimilar to the capital costs for solar PV. As solar prices decline and the capital costs for coal, natural gas, and nuclear plants increase, we are reaching a crossover point. Solar also has a

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number of additional advantages when comparing it with a comprehensive view of the expense of conventional resources, including no "fuel" costs, low operating and maintenance costs, zero on-site emissions, and broad public approval.

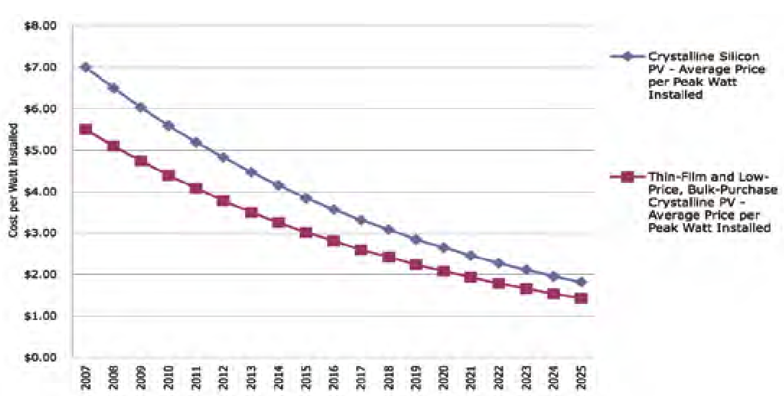
Equally important, we project that solar PV will reach cost parity with conventional retail electricity pricing, on a straight kWh rate basis, throughout much of the U.S. by around 2015.

We project that the cost for crystalline silicon PV systems will drop from an average of $7 peak watt (19-32 cents kWh) today to approximately $3.00 (8-14 cents kWh) a decade from now. Thin-film PV systems and low-price, bulk-purchased crystalline PV systems are projected to drop from around $5.50 per peak watt today (15-25 cents kWh) to $3.00 peak watt in 2015 (8-14 cents kWh) and less than $1.50 peak watt (4-7 cents kWh) in 2025. In our utility-scale concentrating solar power (CSP) calculations we show an average price of $3.50 per watt (around 18 cents per kWh) in 2007 declining to around $1 peak watt (approximately 5 cents per kWh) in 2025.

Recent industry developments, particularly large-scale solar deployment plans announced by major utilities, support the price projections outlined in this report. As utilities and others scale up their solar efforts, they are reaching economies of scale unlike anything we've seen in the past. Southern California Edison's recently announced 250 MW rooftop installation program is the perfect case in point. SCE could reach the $3.50 peak watt installed price as early as 2010. This supports the case that such price points are achievable and that some players may even get there sooner.

It is also possible that one or more disruptive players could enter the market at a scale and price points as early as 2010 that could achieve solar cost parity even sooner. While this report doesn't specifically map this more accelerated scenario, utilities and policy makers should keep a watch out for even more favorable solar cost comparisons

Comparing Crystalline Silicon with Thin-Film/Low-Price, Bulk-Purchase Crystaline PV Price Reduction 2007-2025



Source: Clean Edge, 2008

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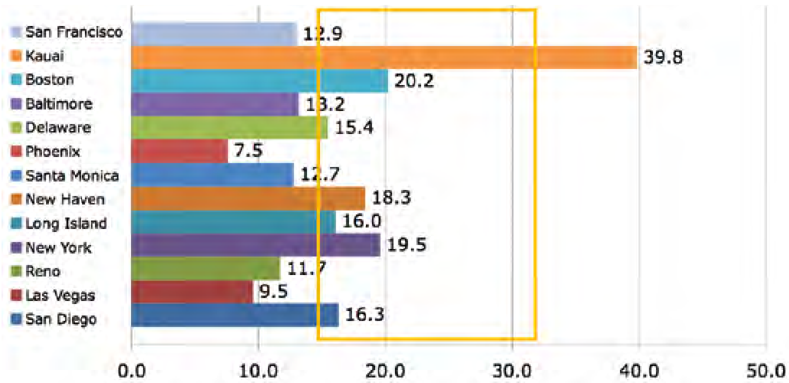
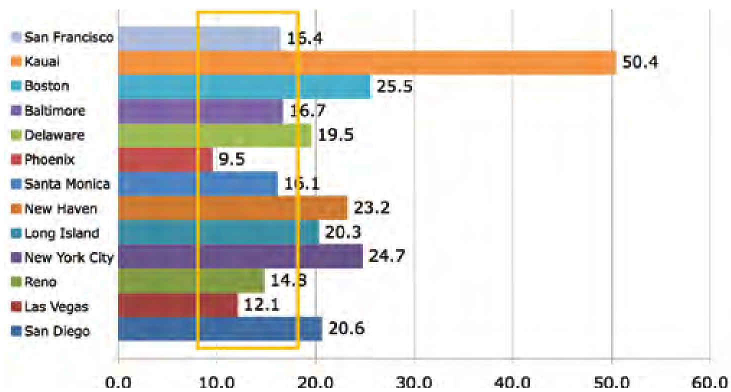
Comparing U.S. Average U.S. Retail Electricity Rates with PV, 2007 (Cents/kWh)



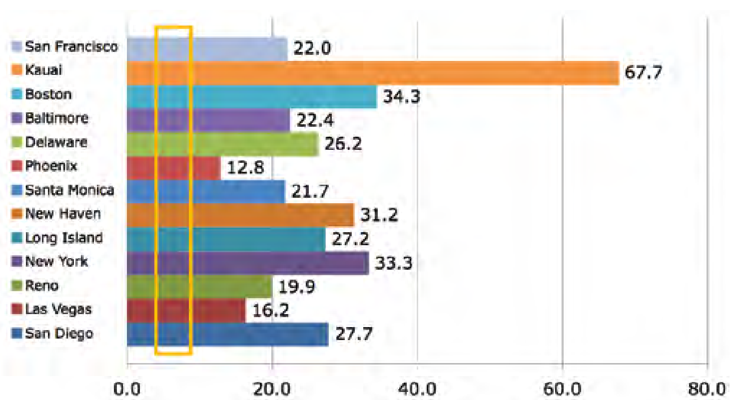
Source: Clean Edge, 2008

Comparing U.S. Average U.S. Retail Electricity Rates with PV, 2015 (Cents/kWh)



Source: Clean Edge, 2008

Comparing U.S. Average U.S. Retail Electricity Rates with PV, 2025 (Cents/kWh)



Source: Clean Edge, 2008

than discussed by this report.

In short, whether the market follows the trajectory mapped in this report, or a disruptive player forces an even more aggressive scenario, solar cost parity is within the planning horizon of most every utility in the U.S.

Based on projected trends in declining costs of solar and increasing retail electricity rates, the following tables show how solar PV—beginning to reach cost competitiveness in just a few U.S. regional markets today—will be cheaper than standard grid power in most U.S. markets by 2025.

What Investment is Required to Reach 10 Percent Solar?

The investment required to reach 10 percent solar in the U.S. by 2025 won't be inexpensive. But the investement is definitely within the range of what utilities and other energy consumers would have to pay for more traditional and polluting sources such as coal- and natural-gas-fired plants, and we believe, considerably less than the price tag for a similar amount of nuclear power or coal power (in a carbon-regulated environment).

Our figures show that the investment will be between $400 billion and $500 billion to install the required PV and an additional $50 billion to $60 billion to install the required CSP to reach the 10

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percent target. That's a total projected price tag of between $450 billion and $560 billion between now and 2025, an average of $26 billion to $33 billion per year.

It's important to note that these are not investments in R&D, but in actual deployment of these technologies. In other words, they represent procurement and installation capital costs paid for by utilities, businesses, residences, governments, and others installing solar systems. In this scenario, solar would represent more than half of all new generating capacity installed in the nation by 2025.

To put the projected investment in perspective, the Edison Electric Institute estimates that the U.S. electric utility industry spent more than $70 billion on new power plants and new transmission and distribution investments in 2007 alone. Conservatively assuming similar expenditures between now and 2025 (and most experts believe those annual costs will increase), we're talking about a total investment of more than $1.2 trillion—roughly double to triple our projected investment for solar in the U.S.

Given the appropriate tools and incentives, we believe utilities and their ratepayers could cover a significant portion of the solar investments required to reach the 10 percent target, with the balance picked up by governments (through installations of systems on their own facilities), direct purchasers/installers of solar power, and others.

Nexus Point: Solar and Utilities

In our research, we set out to answer a range of questions, including:

Glossary of Terms

Balance of System: Refers to components of a PV system beyond the cells themselves, including inverters, interconnection devices to the grid, two-way meters, and racking systems.

Baseload: The minimum level of demand on an electrical supply system over 24 hours.

CSP: Utility-scale concentrating solar power—large solar facilities which use mirrors or lenses to concentrate solar energy to heat fluids to power turbines to make electricity. Also called high-temperature solar thermal, CSP requires long days of direct sunlight without clouds and is best suited for desert locations.

Feed-In Laws: Allow solar customers to sell excess power that they have generated back into the grid.

Net Metering: Allows for measuring the difference between the electricity supplied by a utility and the electricity generated by a customer-generator, which is fed back to the utility over the applicable billing period. The meter is allowed to register the flow of electricity in both directions, and only the net amount is billed (or credited) each month.

Peaker Plant: A power plant that can be more easily turned on and off in order to accommodate periods of high demand, such as hot summer afternoon days when there is widespread use of air conditioners.

Peak Watt: The number of watts output when a solar panel is illuminated under standard test conditions.

PV: Solar photovoltaics—direct generation of electricity from sunlight by using solar cells packaged in photovoltaic modules. PV modules can be placed on rooftops or adjacent to buildings for distributed power, or organized into arrays for large-scale deployment in solar "farms" or solar "parks."

Renewable Portfolio Standards: Requires that all energy marketers have to have a certain percentage of renewables in their electricity mix.

System Benefit Charges (Public Benefit Funds): Like telephone and airline fees that support building and upgrading the entire network, SBC are fees placed on electricity companies or customers to fund renewable energy projects with public money.

Time-of-Use Rates: Real-time pricing reflects demand. When demand is greatest (usually between noon and 6 p.m.), pricing is the highest.

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- What factors have led to utilities' decisions to implement—or not implement—supportive solar policies and programs?
- What are the major barriers deterring utilities from deploying solar power today?
- What are leading examples of utilities implementing solar into their service areas, both inside and outside the U.S?
- What business models are working most effectively for a range of utilities?
- How is solar being used to offset peak-load issues and what is the role of distributed solar in the utility peak-load management toolkit?
- What's needed in the areas of technology, policy, and finance to accelerate solar growth by utilities?
- What significant new business opportunities exist for solar manufacturers, developers, and system integrators that can serve the utility markets?
- How much solar is likely to be deployed by utilities in the U.S. under a business-as-usual scenario versus a system that aggressively embraces and incentivizes solar opportunities?
- What would an aggressive and effective solar strategy look like with significantly different price signals—e.g., low solar prices and higher natural gas and coal prices?

Unquestionably, utilities have a critical and central role to play in the adoption of solar power. While some industry experts we interviewed felt that solar could continue on its current path without active utility involvement, most concluded that the utility sector's active participation will be required to bring solar "to scale." To do this, the solar industry, utilities, policymakers, and others will need to work together to make the wide-scale deployment of solar power a reality. As one industry insider explained: "To really scale [solar] it's all about utilities."

Increased Momentum for Utility Deployment of Solar Options

In earlier Solar Catalyst Group reports, we discussed the need for utility involvement and started to look at the regulatory frameworks that might make this possible. It was, admittedly, premature. Five years ago, very few solar industry professionals, utilities, or regulators, were talking openly about significant use of solar by utilities. Today, different strategies of how utilities could deploy a range of solar options, from distributed photovoltaics to large-scale concentrating solar power, are gaining significant interest.

In the past year alone, we've seen a sea change in the ways utilities and others are

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viewing the solar opportunity. Among these developments are:

- Dozens of major utilities—including FPL (Florida), PG&E (California), Austin Energy (Texas), and Duke Energy (North Carolina, Ohio, Indiana, and Kentucky)—have embraced solar. Although their plans are still evolving, the mere fact that they are taking action represents a significant departure from business as usual.

- In 2007, the use of silicon by the world's solar companies exceeded silicon use by the semiconductor industry for the first time. This historic shift, from solar companies surviving off the scraps of the chip industry at the beginning of the decade to now being the principal user of raw silicon material, initially led to significant silicon supply disruptions for solar PV manufacturing. The price of processed silicon feedstock increased dramatically as manufacturers struggled to keep up with demand. Now, supply and demand are coming back into balance and prices are beginning to decrease.

- Thin-film players such as First Solar are delivering non-silicon solar cells at promised lower prices, with some installed systems now at $5 per peak watt (including modules, balance of system, and installation costs). Other thin-film players such as Miasolé and Nanosolar are vying to similarly deliver low-cost, non-silicon alternatives and raising hundreds of millions of dollars from investors toward that end.

- After more than two decades of relative inactivity, utility-scale concentrating solar power (CSP) is back stronger than ever, with a range of investors, technology companies, and utilities looking at how to harness the solar irradiance in deserts around the world. In 2007, more than 70 MW of new CSP was installed worldwide, and hundreds of additional megawatts are under development.

- Google has set an ambitious goal of making renewables less expensive than coal-fired power generation. One of its key initiatives in achieving this goal: the development of cost-effective, next-generation CSP.

Given this momentum at the local, regional, national, and global levels, and the inevitability of a price on carbon in the U.S. in coming years, utilities have reached a unique moment to figure out how to cross the chasm toward rapid scale-up of solar technologies as a key grid-tied energy source.

The Road from Here

Meaningful contributions from solar will require decisive and aggressive action on the part of all parties:

- Regulators will need to remove the regulatory and technical roadblocks and create a stable and consistent environment.

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Key Solar Stakeholders and Actions

Solar Companies	Utilities	Regulators
Bring installed solar systems costs to $3 per peak watt by 2018	Take advantage of the unique value of solar for peak generation	Decouple revenue from power consumption
Improve silicon cell efficiency and performance	Better serve customers in grid-constrained areas and "at the edge"	Give utilities the ability to 'rate-base' solar
Develop new low-silicon and non-silicon alternatives such as thin film and nanotechnologies	Implement solar as part of demand response systems and build-out of the smart grid	Establish open standards for production, time of use, interconnection, net metering, and smart grid technologies
Streamline installations and make solar a truly plug-and-play technology	Use solar as a price hedge against fuel cost increases and potential carbon costs	Institute a national RPS with a solar carve-out
Ramp up concentrating solutions—including CSP and potentially CPV—for central generation and to drive down costs	Adapt to the new power market with new business models	Create a federal carbon cap-and-trade system
Work with utilities and regulators to develop open standards for net interconnect, two-way flow of electrons, etc.	Harness the power of the desert	Pass a long-term extension of investment and production tax credits for solar and other renewables—and extend them to utilities
	Help train the next wave of workers	

- Utilities will need to fully integrate solar into their long-term business plans and encourage consumers to participate.
- Solar manufacturers will need to make the technology more cost-effective and substantially increase production.

The preceeding table briefly summarizes the actions, detailed throughout the report, required from the three most critical stakeholder groups.

This report outlines the major actions required by each of the key stakeholders to realize the goal of 10 percent solar by 2025. We discuss what it will take to put these strategies into practice, and we demonstrate how utilities have much to gain by being pro-active players in accelerating the growth and deployment of the solar energy market.

For the first time in history, a confluence of forces is coming together—solar technology developments, conventional energy price increases, aging transmission and distribution infrastructure, climate concerns, security issues, and others—that bring the dramatic worldwide growth of solar increasingly to center stage. In this rapidly changing energy landscape, the 10 percent goal is truly within reach.

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About the U.S.A Study

Clean Edge, Inc., a research and publishing firm focused on clean technologies, was engaged by Co-op America on behalf of its Solar Catalyst Program to prepare the U.S.A study. As background, this report builds on earlier work done by Clean Edge and Co-op America. Earlier reports in the series include the Solar High-Impact National Energy (SHINE) Project (2005); the Solar Opportunity Assessment Report (2003) and Bringing Solar To Scale: A Proposal to Enhance California's Energy, Environmental, and Economic Security (2002).

Report Methodology:

For the U.S.A Study, Clean Edge employed a comprehensive research methodology which included external interviews and primary and secondary research. We applied:

- Proprietary Clean Edge data—Solar PV market size, cost and pricing data, growth projections, and other key market data
- Expert interviews—Interviewees represented a range of interests including utilities, government agencies, financial institutions, and the solar industry
- Online research of companies and utilities, third-party data, etc.

Interview participants included:

- Jill Cliburn, Electric SUN (Analyst)
- Dan Kammen, UC Berkeley (Analyst)
- Paul Maycock, Editor, PV News (Analyst)
- Chris Robertson, Electric SUN (Analyst)
- Virinder Singh, Energy Consultant (Analyst)
- Travis Bradford, Co-founder of Prometheus Institute (Association)
- Mike Eckhart, American Council on Renewable Energy (ACORE) (Association)
- Julia Hamm, Solar Electric Power Association (Association)
- JP Ross, Vote Solar (Association)
- John White, CEERT (Association)
- David Hawkins, CAISO (Government)
- Sarah Kurtz , NREL (Government)
- Art Rosenfeld, California Energy Commissioner (Government)
- Peter West, Energy Trust of Oregon (Government)
- Julie Blunden, SunPower (Industry & Finance)
- Peter Corsell, GridPoint (Industry & Finance)
- Ron Kenedi, Sharp Solar Energy Solutions Group (Industry & Finance)
- Vinod Khosla, Khosla Ventures (Industry & Finance)
- Erika Morgan, CitizenRE (Industry & Finance)
- Jigar Shah, SunEdison (Industry & Finance)
- Scott Sklar, Stella Group (Industry & Finance)
- Tom Starrs, PPM Energy (Industry & Finance)
- Stuart Valentine, Progressive Asset Management (Industry & Finance)
- Andrew Wilson, Intel Corp. (Industry & Finance)
- Herb Hayden, Pinnacle West (Utility)
- Karl Knapp, City of Palo Alto (Utility)
- Hal LaFlash, Pacific Gas & Electric (Utility)
- Pamela Lesh, Portland General Electric (Utility)
- John McCawley, Excelon-PECO (Utility)
- Ron Miller, Xcel Energy (Utility)
- David Mohler, VP and Chief Technology Officer, Duke Energy (Utility)
- Greg Nelson, PNM (Utility)

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KEY INTERVIEW FINDINGS

In just the past year, a number of utilities and solar companies have announced aggressive programs to deploy large-scale solar power projects, including Southern California Edison's plan to install 250 MW of distributed solar PV, Duke Energy's stated goal of investing $100 million in rooftop solar, and Pacific Gas & Electric's announcements to invest in thousands of MW of concentrating solar power in California's deserts. While these players are still in the vanguard, a number of other utilities are looking to join them in building up and deploying solar resources. Our research indicates that while it will take a concerted effort among a range of stakeholders to reach 10 percent solar electrification in the U.S. by 2025, it's not outside the realm of possibility.

To better understand both the opportunities and challenges facing the solar industry, regulators, and utilities in reaching the 10 percent target, below are 12 brief summaries (and supporting quotes) of key findings from our research process. These represent the view of some of the brightest minds tracking and evaluating the solar opportunity as it relates to utilities and broader markets. More extensive discussions of each of these findings are found throughout this report and provide the building blocks for our analysis.

Solar in the News

Solar increasingly is the domain of multi-billion-dollar financial and corporate institutions. Below is a sampling of early-2008 headlines that demonstrate how big solar has become, and hints at where it is heading.

- *eSolar Raises $130 Million for Pre-Fabricated Utility-Scale Solar Thermal Power Plants*
- *PGE Announces Landmark Deal for up to 900 MW of Solar Thermal Energy*
- *Sharp Announces Plan to build 1000 MW Thin-Film Plant in Japan*
- *Duke Energy to Invest $100M in Roof-Top Solar*
- *Solar Cell Production Jumps 50 Percent in 2007*
- *Morgan Stanley Launches $200 Million Solar Development Fund*
- *Southern California Edison Launches Nation's Largest Solar Panel Installation Program—Up to 250 MW*
- *OptiSolar Sets Sights on World's Largest Solar Farm*
- *Abengoa to Build 280MW Concentrating Solar Power Plant in Arizona*
- *SunPower Signs 3GW Polysilicon Supply Contract with Chinese Company*

1. Solar resources are ubiquitous. One of the key findings of the interview process is a rather simple conclusion: the sun shines everywhere. Solar PV, unlike many other renewable (and non-renewable) technologies, can be deployed just about anywhere. It's not bound to specific regions. The best evidence of this: among nations, the world's largest producer of solar power is cool, often-cloudy Germany.

"Almost everyone (anywhere in the country) can use solar PV as part of their options—which is not true of hydro, or wind, or geothermal, or wave. Think of it this way: if Washington State can have a robust solar program, then anyone can."

2. Solar can provide utilities with a peak-power hedge. Solar can help utilities mitigate against high-cost peak power. In many regions of the U.S., the peak demand times for electricity, particularly hot summer afternoons, coincides closely, although not identically, with the output from solar PV and CSP.

"Solar is great way to offset peak load issues—a way for utilities to hedge against needing to buy peak power."

"We need to think about solar more creatively with regard to peak—paired with wind, around power plants, etc. Look at where the grid is constrained and put solar PV there."

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3. Environment and carbon are becoming central drivers. The utility landscape is changing. To compete in the future, utilities are realizing that they need to adapt to emerging environmental and carbon regulations—and reinvent their businesses in the process. A pending price on carbon, which many experts see coming at the regional level in the next year or two, and nationally with five years, will have a significant impact on the bottom lines of utilities.

"If you go back 100 years and look at the social compact with the utilities—the original idea was that utilities got a monopoly in exchange for providing cheap, reliable, and ubiquitous electricity. But, these things were achieved at a cost: pollution and inefficiency. We are now asking them to add clean and efficient to the list of requirements."

"In a carbon-constrained environment the relative cost will come down dramatically for PV. CSP will drop below Nat Gas levelized pricing within ten years."

4. Solar power will soon reach price parity with conventional sources. Solar needs to scale up and come down in price to be of interest to more utility players. Utilities themselves can play a role in this process, but the solar industry needs to better deliver on its low-cost promise. A number of solar manufacturers and system integrators are working on this, and recent announcements point to solar reaching price parity with a range of conventional energy sources sometime in the next 3-7 years.

"The price point that's going to make a real difference is getting solar installed on the order of $3 per peak watt. We need to get to that level to see the pricing work. At $3 per peak watt you're definitely competitive with a natural-gas peaker plant."

"The cost of solar is coming down and pretty rapidly right now. And while the cost of PV is coming down, the cost of [fossil fueled] central stations is increasing. So pretty soon we'll be at a place where the costs intersect, where solar will be competitive with new coal and nuclear."

5. Utility participation is critical to solar success. A majority of survey respondents believe that utilities are in the best position to accelerate the growth of solar—and that without their participation the industry is doomed to the margins. In their view, a robust solar future is impossible without active utility involvement. This conclusion underlies the foundation for this report: that utility involvement is integral, not ancillary, to growing a mainstream and thriving solar industry in the United States.

"I think anyone that doesn't understand the centrality of utilities to solar generation is out to lunch. They are regulated monopolies. You don't

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want to disintermediate the customer and the utility. Sure, you can get Costco and Whole Foods to put solar on their rooftops—but you'll only get to 1-2 percent penetration. To really scale it's all about utilities. (The solar industry) needs to work with the utilities to make this work."

"Going around the utilities isn't going to scale—it won't make a dent."

6. Smart grid deployment is imperative. The deployment of the smart grid–the integration of information technology into the electric grid in a way that allows more control by both utilities and customers over how and when energy is generated, stored, and used–is essential to the rapid scale-up of solar. But utilities need to understand how the smart grid and solar fit into their development plans and have the regulatory support and tools to deliver new products and services. The smart grid will also be essential to the mass deployment of other renewable sources, such as wind, and for broad-based efficiency and conservation efforts.

"Electric utilities in general don't have a clear pathway to understanding how they make money in the next generation grid—in the same way that AT&T fought the telephone deregulation of 90's, utilities don't have appreciation for next-generation grid value for customers—and more importantly, for themselves—smart meters, demand side, storage. They can't see how it's good for the company, so they fight."

7. Distributed solar PV offers utilities unique advantages. Distributed assets can provide a range of advantages to utilities, including cost reductions and savings around centralized generation and transmission and distribution. Utilities are just now awakening to these opportunities.

"The cost of distributed solar PV is actually less than the cost of marginal generation, transmission and distribution. Most utilities just haven't figured that out yet."

"Everything about solar [distributed] has to do with transmission and distribution—we should NOT be looking at cost of generation—and yet that's what everybody looks at."

"Capital costs for large fossil fuel facilities are very expensive. But solar can be done in small chunks. This can help manage capital investments."

8. The solar industry needs to cooperate with utilities. Solar companies and other stakeholders need to work with utilities, not oppose or blame them for past missteps or mistakes. Solar advocates need to move beyond confrontational approaches of the past, and toward building solutions for all stakeholders.

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"This is a time when we [industry] need to be collaborative with utilities."

9. Standards must be implemented. Standards (around net metering, distributed generation assets, feed-in tariffs, and other elements) are critical to the future growth of solar. These standards, like those that have enabled the growth of the Internet, need to be "open" rather than proprietary, and supported by utilities, industry, and regulators. Without standards, distributed energy sources and the smart grid will not succeed.

"The smart grid [with open standards] is like the Internet—it opens up a world of new business plans and opportunities for the utility."

10. It's not just PV, but also CSP. Much of the attention has been on solar PV (because it's distributed and deployable just about anywhere), but concentrating solar power offers significant opportunity in desert and outlying regions.

"Two years ago, everybody thought CSP was a joke—now it's getting really serious attention."

"Long-term, CSP offers a promising solution for centralized solar."

11. Utilities need to be able to integrate solar expenditures into their rate base—and to be able to take a full life-cycle cost approach. Utilities are used to spending a lot on infrastructure—so the cost of solar doesn't necessarily scare them off. They just need regulatory approval to recover their expenditures. They also need to be able to compare the full life cycle of a solar installation to building new capacity for coal, natural gas, or nuclear generation. Solar power's zero fuel cost and very low maintenance expense helps its full life cycle costs compare favorably.

"To a utility $2 billion is not a lot of money—it's just one plant. Money isn't the issue, capturing the benefit of the investment is!"

"From a distributed perspective, we want to give the utility the ability to put solar on the roof, own it, and rate-base it."

"It all comes down to capacity and economic use of that capacity... instead of building a $2 billion coal plant I want to put $2 billion into smart grid, clean distributed generation, and storage—and then make the 'negawatts' and clean distributed generation count by ratepayers."

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12. Utilities have a unique relationship with customers. Utilities are in a unique position to serve customers with solar solutions. For example, they already have customers' trust and they touch them on a daily basis.

"People have a relationship with their utility—and recognize that they are reliable and safe. The lights are almost always on. They're out in the rain repairing stuff. So those are the people who can sell solar to the next market. They are so well known. It takes a long time and a lot of money to build a reputation like that."

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WITHIN REACH: TEN PERCENT SOLAR

As conventional electricity sources such as coal, natural gas, and nuclear become increasingly expensive and solar technologies continue their inexorable price decline, the promise of a solar future beckons. For the first time in modern history, the price of solar-generated electricity is within striking distance of conventional energy sources for a wide range of applications. Already, solar power can compete in regions with high electricity rates and with favorable incentives. It can compete effectively for peak power production, in grid-constrained territories, and for applications that are off the grid.

As the below demonstrates, capital costs for conventional energy sources are, in many cases, not dissimilar to the capital costs for solar PV. As solar prices decline, and the capital costs for coal, natural gas, and nuclear plants increase, we are reaching a crossover point. And it's not just about capital costs. As we point out in the Getting To Cost Parity section, solar has a number of additional advantages when comparing it with conventional resources, including no "fuel" costs, low operating and maintenance costs, and zero on-site emissions. Equally important, we project that solar will reach cost parity with conventional electricity pricing, throughout much of the U.S., sometime by around 2015.

Our research also shows that a transition from increasingly expensive, carbon-intensive electricity generation sources toward carbon-free energy sources is well under way in the U.S. Coal, which represented 67 percent of electricity generation in 1949, declined to less than 49 percent in 2007. Petroleum, which represented 14.2 percent of U.S. electricity generation in 1949, declined to around 1 percent in 2007. Natural gas, the cleanest of the fossil-fuel technologies, has remained relatively constant at around 20 percent of U.S. electricity generation between 1949 and 2007.

Carbon-free sources have, to date, been primarily the domain of nuclear power and hydroelectric, representing approximately 20 percent and 6 percent of total electricity generation respectively in 2007. But now, wind power and solar power are projected

Costs for New Plants

The table below shows the average estimated costs to build power plants fueled by different energy sources. Whereas coal, nuclear, and geothermal plants are able to provide baseload power, solar and wind are variable resources. Solar can compete with higher peak-power rates or as a distributed resource where it competes not only with generation but also transmission and distribution costs. Solar, with storage, can also contribute to baseload power needs. It is also important to note that solar, wind, and geothermal do not have "fuel" costs, since they get their power from the sun, wind, and the Earth's heat—free of charge.

Comparative Power Costs for Utility Deployment

Energy Type	Coal	Natural Gas Combined Cycle	Geothermal	Wind	Concentrating Solar Power (CSP)	Nuclear	Solar PV
Capital Costs per 1000 MW (U.S. 2007 Average)	\$1 billion - \$3 billion	\$1 billion - \$2 billion	\$1.2 billion - \$2 billion	\$1.5 billion - \$2 billion	\$3 billion - \$4 billion	\$3 billion -\$7 billion	\$5 billion - \$7 billion
Fuel Costs	Yes	Yes	No	No	No	Yes	No
Subject to C02 Regulations	Yes	Yes	No	No	No	No	No

Source: Clean Edge, 2008

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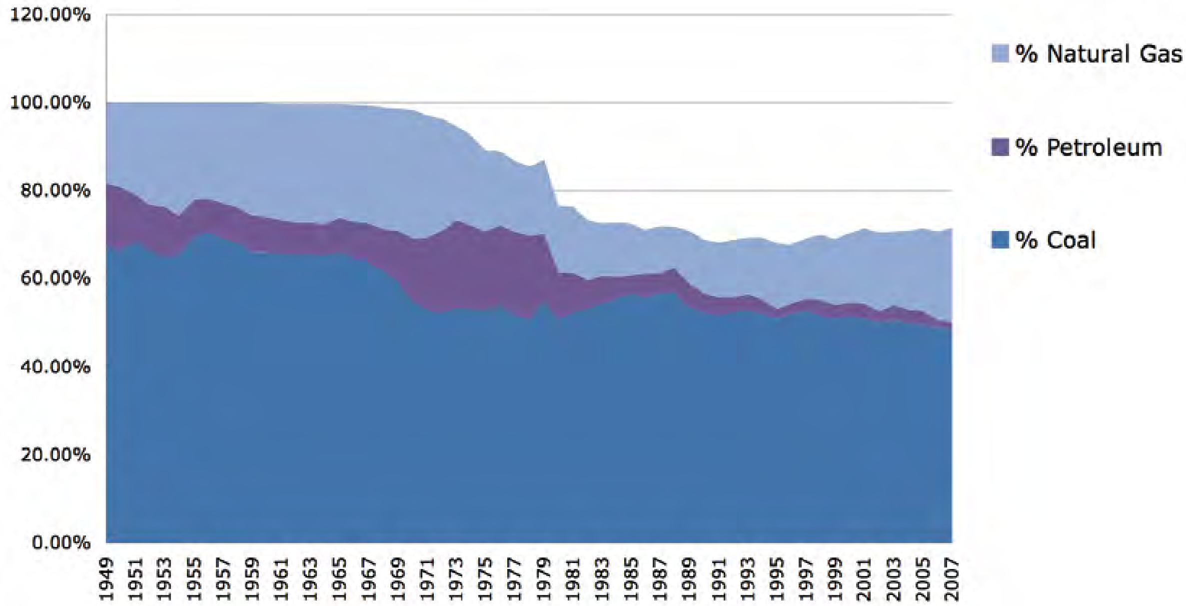
Fossil Fuels as a % of Total U.S. Electricity Generation 1949-2007



Annual Energy Outlook 2008, EIA, December 2007

to have an increasing impact on total U.S. electricity generation. Over the next two to three decades, we see these safe, non-polluting, carbon-free energy sources, along with conservation, efficiency, and smart-grid technologies, taking center stage in the U.S.

According to a DOE report issued in May 2008, wind power, which currently provides approximately 1 percent of total U.S. electricity generation, could provide up to 20 percent of U.S. electricity needs by 2030. The report, entitled 20% Wind Energy by 2030: Increasing Wind Energy's Contribution to U.S. Electricity Supply, examined ways that the four biggest barriers to such a massive scale-up of wind power—transmission, siting, manufacturing, and technology—can be overcome. Wind is currently providing significant levels of electricity generation already in Denmark (approx. 20 percent), Spain (10 percent), and Germany (7 percent). (The report is available at www.20percentwind.org).

We believe a similar trend will take place in the conversion of sunlight into electricity. While the U.S. currently gets less than one tenth of one percent of its electricity from solar power, our research shows that solar offers the opportunity to provide a significant portion of the nation's electricity supply for both distributed and centralized generation by 2025—up to ten percent from a combination of solar PV and CSP. As storage and smart grid technologies evolve, we see the potential for solar to provide an even larger percentage of U.S electricity needs.

We aren't alone in this assessment. SEIA, in its Solar PV Roadmap issued in 2004,

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Projected U.S. Solar Installations as a Percent of Total Electricity Generation—Recent Studies

Program/Report	Target Date	Cumulative MW Installed	Total Electricity Generation	% Of total Electricity Generation
SHINE (with ASAP)	2025	282 GW	520,646 GWh	10.7%
2004 SEIA PV Roadmap	2030	200 GW	360,000 GWh	7% of total generation and "50% of new U.S. generation" by 2030
A Solar Grand Plan: Scientific American	2020 & 2050	84 GW by 2020 (PV & CSP) 3,000 GW by 2050 (PV & CSP)	NA	69% of U.S.'s electricity and 35% of total energy by 2050

Source: Clean Edge, 2008

stated that solar could provide "50% of new U.S. generation" by 2030, a projected 7 percent of total electricity at that time. In our earlier report, SHINE, we highlighted a plan that would enable the U.S. to get ten percent of its electricity from PV sources alone by 2025 via a concerted effort by the Federal government to encourage increased investment in and deployment of solar power. Some people have gone even further. In their widely cited Scientific American article, "A Solar Grand Plan" published in January 2008, authors Ken Zweibel, James Mason, and Vasilis Fthenakis outline how the U.S. could get 69% of its electricity from solar by 2050.

What is the pathway for solar to reach 10 percent of total U.S. electricity generation by 2025? To reach reliable figures we've looked at a number of variables. For example, we:

- Assessed the total projected electricity generation needs for the U.S., on an annual basis, between now and 2025 using 2008 EIA projections.
- Calculated likely reductions in projected generation requirements by applying energy efficiency measures outlined in the Energy Independence and Security Act of 2007.
- Examined historic growth rates for solar PV and applied aggressive, though achievable, growth rates for PV installations in the U.S. through 2025. In this calculation, we applied a compounded annual growth rate (CAGR) of 33 percent for solar PV between 2007 and 2025. At the end of this nearly two-decade period we find solar PV contributing 8 percent of total U.S. electricity generation.
- Analyzed current and planned CSP projects in the U.S. and calculated an accelerated, but within reason, projection for growth through 2025. By applying a 28 percent compound annual growth rate (CAGR) from 2007 through 2025, we find CSP accounting for 2 percent of total U.S. electricity.

While both solar PV and CSP, as noted above, would require aggressive growth rates to reach the goal of ten percent by 2025, such growth isn't without precedent.

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U.S. Solar Installed Capacity (CSP and PV)—Getting to 10 Percent

Year	Cumulative Capacity CSP + PV (MW)	Total Annual Generation Combined PV and CSP (MWh)	Total Projected Annual U.S. Electricity Generation/Demand, All Sources (MWh)	CSP and PV Share of Total U.S. Electricity Generation
2007	1,284	2,513,665	4,119,235,230	0.06%
2010	3,027	5,849,916	4,219,402,150	0.14%
2015	15,184	29,385,504	4,397,329,160	0.67%
2020	69,260	133,345,983	4,608,068,490	2.89%
2025	255,646	485,723,159	4,858,105,640	10.00%

Source: Clean Edge, 2008

Solar Photovoltaics (PV)

The solar PV industry has been expanding by more than 40 percent annually since the beginning of the decade, and many analysts believe that it can continue to expand forward at similar rates.

While such growth rates are not sustainable indefinitely, previous technologies have demonstrated that such growth can be achieved over a 20-year period. The personal computer industry, for example, experienced a CAGR of 38 percent from 1980 through 2000, according to the Computer Industry Almanac. In the clean-energy sector, the U.S. wind power industry has demonstrated a CAGR of 22 percent between 1990 and 2007. The cell phone industry, Internet, and other high-tech industries have sustained similar growth rates for sustained periods.

We believe that the solar PV industry (which is built on many of the same semiconductor platforms and breakthroughs as the computer and chip industry), could support double-digit growth rates for the timeframes we're outlining in this report.

In 2007, there were more than 230 MW of solar PV installed in the U.S. As noted above, we applied double-digit growth rates between 2007 and 2025 (on average a 33 percent CAGR). In this scenario, we get to 613 MW installed in 2010; 3066 MW in 2015; 13,746 MW installed in 2020; and nearly 50,000 MW in 2025.

While these are aggressive growth rates, we believe they are achievable. For example, the 2015 projection of 3,066 MW of solar installed in the U.S. is roughly equivalent to the total amount of solar PV installed globally through 2007.

The 13,746 MW installation projection for 2020 would represent approximately a third of total projected global installations in that year. By 2025, solar PV would have to reach 49,467 MW to provide 8 percent of projected electricity needs. While this goal is the most aggressive and would require a significant scale-up in global manufacturing to meet such demand, it is not outside the realm of possibility. Indeed, considering

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U.S. Photovoltaic Installations, Generation (Current and Projected)

Year	Annual PV Installation (MW)	U.S. Cumulative Solar PV Installed (MW)	Annual PV Electricity Production at Capacity (MWh)	PV Share of Total U.S. Electricity Generation
2007	233	865	1,591,865	0.04%
2010	613	2,244	4,127,316	0.10%
2015	3,066	11,154	20,518,510	0.47%
2020	13,746	52,789	97,110,018	2.11%
2025	49,467	212,814	391,492,253	8.06%

historic growth rates and the potential impact of the U.S. policy and utility programs outlined in this report, such a figure is within reach.

Utility-Scale Concentrating Solar Power (CSP)

Through 2025, we project CSP expanding by approximately 28 percent per year on average in the U.S. At this growth rate, we would see growth going from 64 MW installed in 2007 to more than 6,000 MW in 2025. Our projections show a total cumulative installed CSP base of 4,000 MW in 2015, the same amount that the Western Governors' Association has targeted for development in the American Southwest by that year. To put this number in perspective, the U.S. installed more than 5,000 MW of wind in 2007. In total, the Western Governors' Association projects that there are more than 200,000 MW (200 GW) of potential CSP generation capacity in the U.S. West. Our report shows that we'd need to develop around 40 GW of this capacity to reach 2 percent of U.S. total generation in 2025.

The Current Scale-Up

The numbers outlined in this report are aggressive, but a closer look at planned solar PV manufacturing plants and CSP projects shows just how quickly the industry is working to meet the global (and U.S.) demand for solar power.

Company	Location; Size of Proposed Project; Technology	Target Completion Date
BrightSource	Various Locations, California; Up to five projects for PG&E totaling 900 MW; Solar Thermal Power Plants	First plant to be brought online in 2011
FPL Energy	Kern Country, California; 250 MW; Solar Thermal Power Plant	2011
REC	Singapore; 1,500 MW; Silicon PV Manufacturing Facility	2012
Sharp	Sakai, Japan;1,000 MW;Thin-Film Silicon Manufacturing Facility	Initial Capacity of 480 MW by March, 2010
SolarWorld	Hillsboro, Oregon;500 MW; Silicon PV Manufacturing Facility	Initial start up in 2009/2010

What Investment is Required to Reach 10 Percent Solar?

The investment to reach 10 percent solar in the U.S. by 2025 won't be inexpensive. But it's also within the range of what utilities and other energy consumers would have to pay for more traditional and polluting sources such as coal- and natural-gas-fired plants, and we believe, considerably less than the price tag for a similar amount of

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U.S. Concentrated Solar Power Installations, Generation (Current and Projected)

Year	Annual CSP Installation (MW)	U.S. Cumulative CSP Installed (MW)	Annual CSP Electricity Production at Capacity (MWh)	CSP Share of Total U.S. Electricity Generation
2007	64	419	921,800	0.02%
2010	168	783	1,722,600	0.04%
2015	1,194	4,030	8,866,994	0.20%
2020	3,467	16,471	36,235,965	0.79%
2025	6,613	42,832	94,230,906	1.94%

nuclear power or coal power (in a carbon-regulated environment).

Our figures show that the investment will be between $400 billion and $500 billion to install the required PV and between $50 billion and $60 billion to install the required CSP to reach the 10 percent target. That's a total projected investment of between $450 billion and $560 billion between now and 2025, an average of $26 billion to $33 billion per year. It's important to note that these are not investments in R&D, but in actual deployment of these technologies. In other words, they represent procurement and installation capital costs paid for by utilities, businesses, residences, governments, and others installing solar systems. In this scenario, solar would represent more than half of all new generating capacity installed in the nation by 2025.

To put the projected $450 billion–$560 billion investment in perspective, the Edison Electric Institute estimates that the U.S. electric utility industry spent more than $70 billion on new power plants and new transmission and distribution investments in 2007 alone. Assuming similar expenditures between now and 2025, we're talking about a total investment of more than $1.2 trillion—roughly double to triple our projected investment for solar in the U.S. Globally, some analysts estimate that investments by power companies, for generation and transmission and distribution (T&D), will total approximately $11 trillion between now and 2030.

The tables below show some of the projections for our calculations. For the high-range solar PV cost estimate we used a conservative starting price of $7 per peak watt installed and for the more aggressive, low-range solar PV cost estimate we started at $5.50 per peak watt. The $7 peak watt price in 2007 represents systems based on traditional crystalline silicon PV technologies, whereas the $5.50 peak watt system pricing represents thin-film and bulk-purchased crystalline solutions.

As we highlight in the "Technology Pathways: Getting to Cost Parity" section of this report, many of today's large-scale solar PV installations are already being installed at the lower-end price of around $5.50 per peak watt and these thin-film and low-cost silicon solutions are projected to decline to an average $3.50 peak watt by 2013 and

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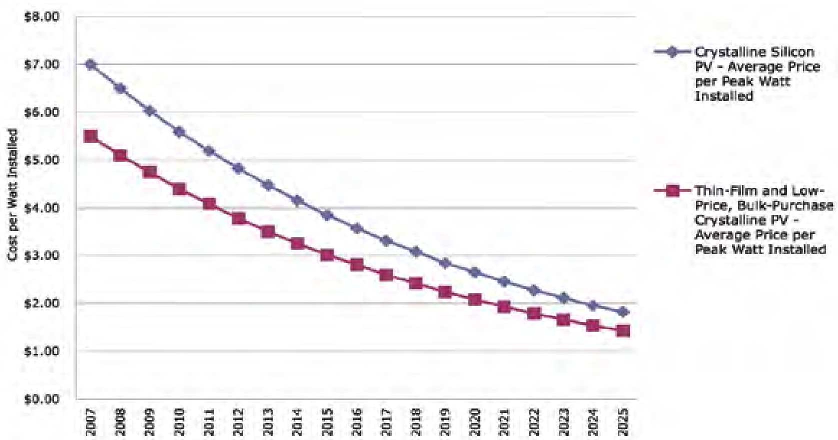
Comparing Crystalline Silicon with Thin-Film/Low-Price, Bulk-Purchase Crystaline PV Price Reduction 2007-2025



Source: Clean Edge, 2008

approximately a $1.50 peak watt by 2025. In our CSP calculations we show an average price of $3.50 per watt (around 18 cents per kWh) in 2007 declining to around $1 peak watt (approximately 5 cents per kWh) in 2025. The first table is based on cost reduction projections from third parties such as NREL, whereas the second table is based on an 18 percent reduction for every doubling of U.S. CSP installations.

The price projections outlined in this report are supported by recent developments. The reason: As utilities and others scale up their solar efforts they can reach economies of scale unlike anything we've seen in the past—not only around bulk module purchase agreements, but balance of system components and installation costs.

Southern California Edison's recently announced 250 MW rooftop installation program is the perfect case in point. They could reach the $3.50 peak watt installed price a few years earlier than our average predictions (see side bar below). This supports the case that such price points are achievable and that some players may even get there sooner.

Southern California Edison Targeting $3.50 Solar Systems

Southern California Edison, which was responsible for enabling the first wave of CSP in the nation more than two decades ago, is now looking to initiate the nation's largest utility-based rooftop solar PV program. Below are program details and highlights:

Total Planned Capacity: 250 MW

Cost: $875 Million

Estimated Cost/Peak Watt Installed: Average $3.50 peak watt

Timeline: 5 years (an average 1 MW a week) starting August 2008 on commercial roofs in San Bernardino and Riverside counties, the nation's fastest growing urban region

Size: 65 Million Square Feet of Commercial Rooftop (1128 football fields)

Transmission: Installations will be connected directly to the nearest neighborhood circuit, eliminating the need to build new transmission lines

Peak Demand: Solar units produce the most power when customer usage is at its highest

Source: Southern California Edison and Clean Edge, 2008

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In addition, the following tables show how much PV and how much CSP would have to be installed annually to meet the 10 percent solar target by 2025. In the table below, we show the cost with a starting price of $7 peak watt. In the second table, we show a starting price of $5.50, the average price to install low-cost thin-film solutions and competitively prices crystalline silicon systems in 2007.

In both cases, we apply a price reduction curve of approximately 18 percent for every doubling of projected global PV manufacturing output.

As noted above, the investment required to install solar PV and CSP is not dissimilar to what it would cost to install conventional gas, coal, and nuclear sources, with the added benefit of zero energy costs (the sun is provided free of charge), zero emissions at the point of power generation, and a resource that can be deployed in just about any

U.S. PV Growth Through 2025—Total Install Cost ($7/watt starting point)

Year	U.S. Solar PV Annual Market Size (MW)	Average Price per Peak Watt (U.S.)	Cost to install (U.S.)
2007	233	$7.00	$1.63 billion
2008	322	$6.50	$2.09 billion
2009	444	$6.03	$2.68 billion
2010	613	$5.59	$3.43 billion
2011	845	$5.19	$4.39 billion
2012	1,167	$4.82	$5.62 billion
2013	1,610	$4.47	$7.20 billion
2014	2,222	$4.15	$9.21 billion
2015	3,066	$3.85	$11.80 billion
2016	4,170	$3.57	$14.89 billion
2017	5,671	$3.31	$18.79 billion
2018	7,713	$3.08	$23.72 billion
2019	10,335	$2.85	$29.49 billion
2020	13,746	$2.65	$36.40 billion
2021	17,869	$2.46	$43.91 billion
2022	23,230	$2.28	$52.97 billion
2023	30,199	$2.12	$63.90 billion
2024	39,259	$1.96	$77.09 billion
2025	49,467	$1.82	$90.13 billion
		Total	**$499.34 billion**

Assumes an average starting price of $7 peak watt in 2007 (for average-priced crystalline silicon based modules), the total cost to install enough solar PV between 2007 and 2025 to reach 8 percent of total U.S. electricity generation would total $499 billion. Assumes 18% price reduction per doubling of global annual market size.

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U.S. PV Growth Through 2025—Total Install Cost ($5.50/watt starting point)

Year	U.S. Solar PV Annual Market Size (MW)	Average Price per Peak Watt (U.S.)	Cost to install (U.S.)
2007	233	$5.50	$1.28 billion
2008	322	$5.10	$1.64 billion
2009	444	$4.74	$2.10 billion
2010	613	$4.39	$2.69 billion
2011	845	$4.08	$3.45 billion
2012	1,167	$3.78	$4.41 billion
2013	1,610	$3.51	$5.65 billion
2014	2,222	$3.26	$7.24 billion
2015	3,066	$3.02	$9.27 billion
2016	4,170	$2.81	$11.7 billion
2017	5,671	$2.60	$14.77 billion
2018	7,713	$2.42	$18.64 billion
2019	10,335	$2.24	$23.17 billion
2020	13,746	$2.08	$28.60 billion
2021	17,869	$1.93	$34.50 billion
2022	23,230	$1.79	$41.62 billion
2023	30,199	$1.66	$50.21 billion
2024	39,259	$1.54	$60.57 billion
2025	49,467	$1.43	$70.82 billion
		Total	**$392.34 billion**

Assumes an average starting price of $5.50 peak watt in 2007 (for thin-film and low-cost, bulk-purchased crystalline silicon based systems), the total cost to install enough solar PV between 2007 and 2025 to reach 8 percent of total U.S. electricity generation would total $392 billion. Assumes 18% price reduction per doubling of global annual market size.

location in the U.S.

While solar prices decline, conventional sources are likely to rise considerably, making solar a more attractive option as utilities look to expand their energy generation assets and make the grid more reliable. According to Cambridge Energy Research Associates (CERA), conventional U.S. power plant costs have risen more than 130 percent between 2000 and the end of 2007, and were up 27 percent between October 2006 and October 2007. CERA, owned by IHS Inc, established the Power Capital Costs Index (PCCI), which uses 2000 costs to set a base for the index of 100 points. According to the firm, the index was at 231 at the end of the third quarter of 2007, meaning a $1 billion plant built in 2000 cost $2.31 billion to build in late 2007 with the same materials and specifications. And this is before cap-and-trade or other regulations put a price on

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U.S. CSP Growth Through 2025—Total Install Cost (Based on Third-Party Projected Cost Reductions)

Year	U.S. Solar PV Annual Market Size (MW)	Average Price per Peak Watt (U.S.)	Cost to install (U.S.)
2007	64	3.50	$ .22 billion
2008	83	3.24	$ .27 billion
2009	112	3.00	$ .34 billion
2010	168	2.78	$ .47 billion
2011	253	2.57	$ .65 billion
2012	379	2.38	$ .90 billion
2013	569	2.21	$ 1.25 billion
2014	853	2.04	$ 1.74 billion
2015	1,194	1.89	$ 2.26 billion
2016	1,672	1.75	$ 2.93 billion
2017	2,006	1.62	$ 3.25 billion
2018	2,407	1.50	$ 3.62 billion
2019	2,889	1.39	$ 4.02 billion
2020	3,467	1.29	$ 4.47 billion
2021	3,987	1.19	$ 4.76 billion
2022	4,584	1.10	$ 5.06 billion
2023	5,272	1.02	$ 5.39 billion
2024	5,905	0.95	$ 5.59 billion
2025	6,613	0.88	$ 5.80 billion
		Total	**$53.00 billion**

fossil fuels that could potentially increase their price.

To supply the amount of electricity generation (ten percent of total electricity consumption in 2025) outlined in our projections would require hundreds of billions of dollars in new coal, nuclear, and natural gas power-plant investments. As we point out in the “Technology Pathways: Getting to Cost Parity” section, solar is becoming increasingly competitive against these technologies, and in some cases is already price competitive. And as we seek to deploy cleaner, less volatile sources of energy—solar remains a very attractive option.

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U.S. CSP - Using 18% Reduction Rate Per Doubling of Annual Installation

Year	U.S. Solar PV Annual Market Size (MW)	Average Price per Peak Watt (U.S.)	Cost to install (U.S.)
2007	64	$3.50	$.22 Billion
2008	83	$3.28	$.27 Billion
2009	112	$3.08	$.34 Billion
2010	168	$2.88	$.48 Billion
2011	253	$2.70	$.68 Billion
2012	379	$2.53	$.96 Billion
2013	569	$2.37	$1.34 Billion
2014	853	$2.23	$1.89 Billion
2015	1,194	$2.09	$2.49 Billion
2016	1,672	$1.96	$3.26 Billion
2017	2,006	$1.83	$3.67 Billion
2018	2,407	$1.72	$4.13 Billion
2019	2,889	$1.61	$4.65 Billion
2020	3,467	$1.51	$5.23 Billion
2021	3,987	$1.41	$5.63 Billion
2022	4,584	$1.33	$6.07 Billion
2023	5,272	$1.24	$6.55 Billion
2024	5,905	$1.17	$6.87 Billion
2025	6,613	$1.09	$7.22 billion
		Total	**$62.04 billion**

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CHALLENGES AND ROADBLOCKS

Making solar more widely accessible and affordable requires no more and no less than the participation, cooperation, and coordination of the usual players involved in electricity generation—from legislators to regulators to contractors to financial institutions. But the key players, we believe, are the nation's energy utilities, ranging from huge investor-owned companies to small rural cooperatives, all of which are potentially large buyers, developers, and sellers of solar power.

On balance, despite some significant gains in the past 12 to 18 months, U.S. electric utilities have been reticent to deploy solar technologies, despite the many potential advantages it offers them. Even worse than inaction, many utilities have historically set up roadblocks—in the form of uncooperative positions toward net metering and interconnect standards—making it difficult for both business and residential customers to cost-effectively deploy solar. A number of utilities have also lobbied against pro-solar policies and initiatives. In short, some view solar as a problem rather than an opportunity.

But those attitudes are changing, and we believe those changes can be accelerated. For many utilities, solar PV represents a distributed energy resource that can reduce the need to build large, costly, polluting and publicly opposed fossil-fuel power plants and can ease congestion in regions where energy demands have stressed the grid. One thing is clear, however. For solar technology producers and developers to achieve the economies of scale (from mass production and implementation) necessary to make solar prices competitive on a wide scale, and to do it quickly, will required the sustained support, investment, and cooperation of utilities.

The challenges and roadblocks that the solar industry has faced from utilities and their regulators are many are varied. Understanding these technological, political, regulatory, cultural, and even psychological. Below are the top six challenges based on our interviews with industry players.

1. Utilities see themselves first and foremost as 'protectors of reliability.'

Risk aversion has been a cultural trait of the utility industry for decades, and it's not unwarranted—utilities are legally charged with the responsibility of keeping the lights on, at the lowest possible cost. That tends to reinforce decisions and strategies that favor tried-and-true, 'we've done it this way for decades' models of electric generation. And those models have traditionally been biased toward large, centralized fossil fuel or nuclear-powered generating plants.

But change is in the air. Going forward, it is going to be increasingly difficult—and costly—to build new coal and nuclear plants. Public resistance remains high against nuclear power and increasingly high against coal. Since 2006, some 60 new coal plants

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in the U.S. have been cancelled, blocked, or delayed, and dozens more are being challenged in 20 states. Some states such as Kansas are considering moratoriums against new coal-fired generation—and this is even before nationwide mandatory carbon caps, which we believe will be mandated next year and take effect early in the next decade. California utilities are prohibited from buying new coal-fired power from out of state. In this new world, solar can help deliver the reliability that utilities need.

We map out detailed strategies for solar's cost-effectiveness in the section titled "Technology Pathways: Getting to Cost Parity." Perceptions about the reliability of distributed solar PV technology are changing as the industry grows, its players mature, and major solar installations prove reliable for major utilities and their customers around the world. And CSP, where feasible, gives utilities a path to solar that fits with their traditional centralized generation model, as evidenced by the recent adoption of CSP among major California utilities.

2. The power grid is outdated and in disrepair—making solar integration difficult today.

Today's grid, antiquated and fragile in most parts of the country, presents a significant barrier to the incorporation of solar and other distributed energy sources. Originally designed to accommodate large centralized power stations generating the traditional "one-way flow" of electrons to substations and customers, the grid is often ill-prepared to accommodate electricity produced by local sources such as on rooftops. Solar's intermittent nature, with less electricity generated on cloudy days and none after sunset, is another attribute that's incompatible with a grid designed primarily for baseload power. This equation, of course, changes when deploying batteries or other storage options.

Since utilities will have to update the grid anyway, doing so with an eye toward integration of solar (plus energy efficiency, wind power and other renewables) makes a lot of sense. "Utilities will begin to embrace distributed solar as they invest in the smart grid—in things like informatics, telemetrics, and analytics," said one interviewee. "The great thing about the smart grid is that it's modular. You can add it in pieces, district by district. If you don't have a smart grid—you can't really leverage distributed solar."

3. Most utilities aren't organizationally structured to exploit or understand the value of solar.

The traditional management chart inside utilities can stack the cards against solar. At many utilities, for example there is no one responsible for evaluating the business case for solar. As one former utility executive put it, "Utilities are organized around centralized plants and distribution lines, so is this [distributed solar] something that the central plant guys deal with, or the poles and wires guys, or customer service?" For utilities with well-worn processes and with a preference for the status quo, it typically

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takes an internal champion to enact change, and many utilities lack that person.

Another part of the issue: utility management is usually heavily weighted toward mechanical engineers, who pride themselves on reliability and whose vision of solar is stuck in the 1970s, when solar was far less reliable and was championed by back-to-the-earth types. Even today, we heard that some utility traditionalists flat out don't like the "new solar people."

Of course, many in the solar industry, and in organizations advocating and lobbying for it, don't trust the utilities, either. "Many people in solar are suspicious of the motives of utilities, and often with good reason," said one industry advocate. "Utilities' actions have often been more about keeping control over solar and marginalizing it than about bringing the technology to its maximum potential." In one situation, a residential solar system in New York state was kept offline by a major Northeast utility, which had sent "letters of denial" on 11 occasions rebuking the solar system owner's request for interconnection.

4. Cost is still an issue

There is still a widespread perception that solar is not cost competitive with conventional fossil fuel or nuclear generation, or with other clean-energy sources, primarily wind power. While solar PV makes sense in remote locations without access to grid transmission lines, it's still challenged by cost in many other applications. One utility executive summed it up tersely: "Expense is the number-one reason not to implement solar."

There is validity to this perception. But as we detail in the "Technology Pathways: Getting to Cost Parity" section, things are changing rapidly. Solar will be cost competitive in nearly every area of the country within the planning time horizon of most utilities.

As a general rule, solar costs are declining while the costs of traditional centralized generation are going up. And when you add in the cost to not only build new fossil-fuel generation facilities, but also to build out transmission and distribution systems, distributed solar PV in particular can make sense even today. The challenge, in many cases, is to get utilities' perceptions—and their budgetary models—to catch up with new realities.

5. Absence of technical standards for integrating solar

Standards drive every industry, and a lack of standards can severely impede innovation and growth. At present, solar interconnection, reliability, and other critical standards either don't exist at all or exist as a hodgepodge of different standards, hindering utility solar planning for and implementation. To reach the target of 10 percent of U.S. generation by 2025, the industry needs to look and act more like the telephone industry, with much more consistent "plug and play" standards across the country. Imagine the Internet without standards and protocols: It wouldn't have flourished. The same is true for solar.

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"There are no national standards with enforcement for power reliability and quality" for solar, lamented one industry insider. "The utility industry is one of the few where the customer absorbs all the risk of power quality, surges and the like. The system we have [dates back to] a time when quality and reliability weren't the main issues—you were just lucky to have electricity. It's only in the last 20 years that we've become a digital country."

In sum, the barriers to the large-scale development and deployment of solar by utilities are not trivial. However, some are quickly becoming concerns of the past as costs of solar fall, costs for everything else rises, and, with the coming carbon regulation, more and more people inside and outside of utilities realize that better analytical tools for evaluating the true benefits of solar are needed. And as we discuss throughout this report, such challenges can be transformed into major opportunities with the right combinations of shifts in technology, policy, and business models.

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TECHNOLOGY PATHWAYS: GETTING TO COST PARITY

Solar PV and CSP are becoming increasingly attractive resources in today's electricity environment, where coal and natural gas prices are skyrocketing, grid infrastructure is crumbling, and carbon policies are beginning to dramatically alter the energy landscape. For example, although solar PV is currently two to three times the cost of retail electricity rates in most of the U.S., it is beginning to compete in high-cost regions like Hawaii, New York, and Southern California.

As a semiconductor-based technology, solar PV is ripe for continued downward pricing and efficiency improvements—much like the computer chip, its semiconductor brethren. We foresee PV prices falling from today's 15-32 cents per kWh to a projected 7-15 cents per kWh within a decade and around 4-8 cents per kWh by 2025. By 2015,

Comparing Crystalline Silicon with Thin-Film/Low-Price, Bulk-Purchase Crystalline - PV Price Reduction 2007-2025

Year	Crystalline Silicon PV - Average Price per Peak Watt Installed	Crystalline Silicon PV - Range kWh Cost	Thin-Film and Low-Price, Bulk-Purchase Crystalline PV - Average Price per Peak Watt Installed	Thin-Film and Low-Price, Bulk-Purchase Crystalline - Range kWh Cost
2007	$7.00	19¢-32¢	$5.50	15¢-25¢
2008	$6.50	17¢-30¢	$5.10	14¢-23¢
2009	$6.03	16¢-28¢	$4.74	13¢-22¢
2010	$5.59	15¢-26¢	$4.39	12¢-20¢
2011	$5.19	14¢-24¢	$4.08	11¢-19¢
2012	$4.82	14¢-24¢	$3.78	10¢-17¢
2013	$4.47	12¢-20¢	$3.51	9¢-16¢
2014	$4.15	11¢-19¢	$3.26	9¢-15¢
2015	$3.85	10¢-18¢	$3.02	8¢-14¢
2016	$3.57	10¢-16¢	$2.81	8¢-13¢
2017	$3.31	9¢-15¢	$2.60	7¢-12¢
2018	$3.08	8¢-14¢	$2.42	6¢-11¢
2019	$2.85	8¢-13¢	$2.24	6¢-10¢
2020	$2.65	7¢-12¢	$2.08	6¢-10¢
2021	$2.46	7¢-11¢	$1.93	5¢-9¢
2022	$2.28	6¢-10¢	$1.79	5¢-8¢
2023	$2.12	6¢-10¢	$1.66	4¢-8¢
2024	$1.96	5¢-9¢	$1.54	4¢-7¢
2025	$1.82	5¢-8¢	$1.43	4¢-7¢

Source: Clean Edge, 2008

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we see solar reaching cost parity with conventional energy sources in many markets in the U.S., given expected cost increases in fossil-fuel-based electricity. CSP, ideal principally for desert locations, has the ability to decrease from around 18 cents per kWh today to as little as 5 cents per kWh by 2025.

The solar industry hasn't been standing still in working to achieve cost and price reductions. In 2003, solar PV represented just 620 MW of total installations worldwide. By 2007, that number had quadrupled to nearly 3,000 MW. Clean Edge and other analyst projections put the global market for solar PV at around 8,000 MW—12,000 MW in terms of annual installations, and 15,000 MW—25,000 MW in terms of overall annual manufacturing capacity sometime between 2010 and 2012.

At these rates, solar PV is expanding globally by approximatley 40 percent annually. CSP has been a comparatively late starter, with very little new development throughout the 1990s and the first half of this decade. But CSP is now on the rise, with thousands of megawatts on the drawing boards and under development in the U.S., Spain, and elsewhere.

And pushing solar to cost parity at a potentially even faster pace, there are continuous technology and efficiency improvements going on across the solar spectrum. These include advances in thin-film solar PV technologies, CSP advances, more efficient, less costly crystalline silicon-based semiconductor materials for PV, along with advances in balance of system components and installation cost reductions.

Investors seem to agree that the solar value chain is ripe for advancements, with venture capitalists pouring hundreds of millions of dollars into advancing these technologies, and the public markets rewarding a range of solar companies. In 2005, solar companies represented three of the top performing technology IPOs of the year (Q-Cells of Germany, SunPower of the U.S., and Suntech Power of China). The following chart shows the annual investments of U.S. venture capitalists in solar companies. Solar now represents the largest clean-energy sector in terms of venture activity in the U.S., exceeding $1 billion in 2007.

U.S. Venture Capital Investments in Solar Power Companies

Year	Total Venture Investments (U.S.$ Millions)
2001	16
2002	46
2003	58
2004	78
2005	155
2006	305
2007	1,068

Source: New Energy Finance with supporting data from Nth Power and Clean Edge
NOTE: VC figures are for development and initial commercialization of technologies, products and services, and do not include private investments in public equity (PIPE) or expansion capital deals.

These investments serve a critical role in helping solar to reach the Holy Grail: price parity with fossil fuel power.

The Scale-up of Solar PV

The granddaddy of solar is crystalline-based photovoltaic technology, which has experienced incremental improvements in efficiency (the percent of sunlight falling onto a

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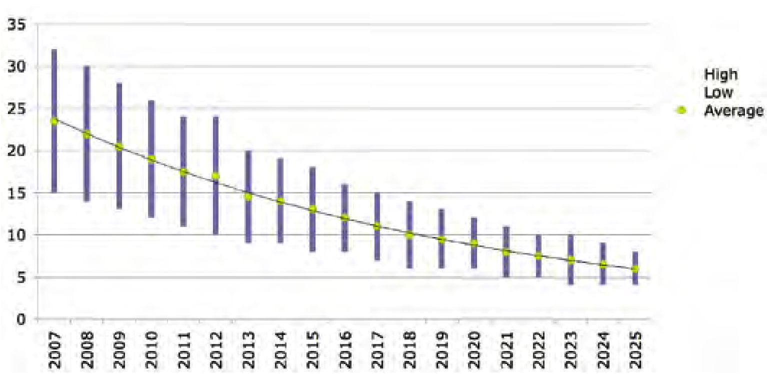
solar cell that is converted into electricity), while costs have dropped dramatically from approximately $30 per peak watt in 1980 to around $7 peak watt today. Polysilicon, the same feedstock used in the global chip and semiconductor industry, remains the dominant source material for PV cells, used in more than 90 percent of solar modules currently manufactured, according to the Solar Energy Industries Association.

Although solar PV has grown considerably in recent years, silicon supply constraints have been a problem. In an historic tipping point in 2006, solar surpassed semiconductors as the largest user of silicon. This caught silicon manufacturers by surprise and resulted in a temporary increase in solar PV pricing worldwide as demand outstripped supply. However, investments in silicon manufacturing plants designed for PV are expected to ease the supply pressure and reduce prices over the next year or so.

Another major trend impacting costs is the growth of thin-film PV. First Solar, a thin-film leader, is currently shipping PV modules that are being installed for around $5.50 peak watt, considerably less than the cost of conventional PV. The company already is sold out for the next five years, amounting to $6 billion and 3,000 MW worth of PV at an average price of $2 per peak watt, when the PV leaves the factory. At that price, total installation costs could drop to $4 a peak watt.

The following chart shows Clean Edge projections, on a kWh basis, for both crystalline and thin-film PV solutions. As global manufacturing increases, and utilities and others increase installations in the U.S., we see prices dropping from 15-32 cents kWh today to around 4-8 cents kWh in 2025, making solar cost-competitive with conventional generation in virtually every part of the United States.

U.S. Crystaline and Thin-Film PV Price Range 2007-2025 (Cents/kWh)



Source: Clean Edge, 2008

Sharp Solar, one of the world's top PV manufacturers, is also aiming its guns at thin film. Once an unabashed crystalline silicon leader, Sharp ceded the top manufacturing spot in 2007 to Germany's Q-Cells because of Sharp's inability to line up enough silicon feedstock. The company is aiming to bring online a 1,000 MW thin-film production line before the end of the decade. According to industry insiders, we could see up to six such thin-film plants from the company in coming years.

Other alternatives to polysilicon include nanotechnology-enabled solar cells. Because of their ability to replace or reduce the need for expensive silicon, thin-film

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The Next Wave: Thin-Film, Nano, and Concentrating PV Technologies

Amorphous Silicon is the most developed of the thin film technologies. However, it is less energy efficient (11 percent versus around 15 to 22 percent for polysilicon), so therefore requires more area to generate the same amount of energy. Efficiency is a concern when space is constrained (on residential rooftops, for example). However, in a solar farm or solar park where space is not at a premium, lower overall expense can be more important.

CIGS (Copper indium gallium selenide) solar cells do not require silicon, but are similarly less efficient than polysilicon. CIGS cells' manufacturing costs promise to be lower than PV as they can be printed directly onto glass sheets and other substrates. Nanosolar, Miasolé, Heliovolt are among the leading CIGS companies working on expanding production.

Cadmium Telluride (CdTe) cells are less expensive than silicon but not as energy efficient. Several companies including First Solar and Q-Cells are developing the technology. NREL currently holds the world-record conversion efficiency for CdTe of 16.5%. CdTe and CIGS, compared to silicon, have some additional concerns in terms of the availability and toxicity of some of these rare earth metals.

Nanotechnologies include inorganic semiconductor nanocrystals, self-assembling nanostructures, and dye-sensitized nanometer-scale crystals. Not yet in production today, nanotechnologies that can be printed through a roll-to-roll manufacturing processes have the potential to substantially reduce the cost of PV.

Concentrating PV basically concentrates the light of the sun onto silicon and other cell materials, at ratios of 2X all the way up to around 1000X. In effect, these companies can reduce the amount of silicon or other materials required for solar power, by the amount of concentration achieved. Companies such as SolFocus, Solaria, Soliant Energy, Energy Innovations and others are working to bring the technology to commercialization.

and nanotechnologies promise to be easier and cheaper to mass- produce over time. Manufacturing techniques include printing, sputtering, or stamping solar cells on substrates and integrating them into a wide variety of materials including roofing material and flexible panels. Large players, including Applied Materials, Sharp, and BP, are manufacturing thin-film cells, and several startups in the U.S. and China are building thin-film manufacturing plants.

In addition to these many technology advances, we're also seeing the general scale-up of manufacturing. For example, Renewable Energy Corp. of Norway recently announced it will build a solar manufacturing plant capable of producing 1,500 MW of solar panels in Singapore, which will equal three quarters of the entire world production in 2006. A 2004 report from the U.S. Energy Department's National Renewable Energy Lab theorized that large-scale manufacturing plants like this could cut the cost of PV modules down to $1 per peak watt. Another industry expert expects that by 2010, the cost of crystalline PV modules will shrink to $1.50 per watt, and $1 per watt for thin-film. These projections refer to estimated industry costs, not wholesale or retail module pricing.

Mass production in China is expected to further lower the cost of producing PV. "On

Module vs. Installed Prices

Solar prices typically are quoted in either wholesale module prices or installed prices, usually in terms of price per peak watt. Wholesale prices refer to the price per watt of a PV module purchased from the manufacturer. Installed prices refer to the full price of an entire solar PV system, once it is installed in a business or residence.

Unfortunately, many solar energy discussions refer to wholesale and installed prices interchangeably, thereby confusing analysis.

In this report, we typically refer to installed system prices (unless otherwise noted).

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PV Efficiency—How High Can It Go?

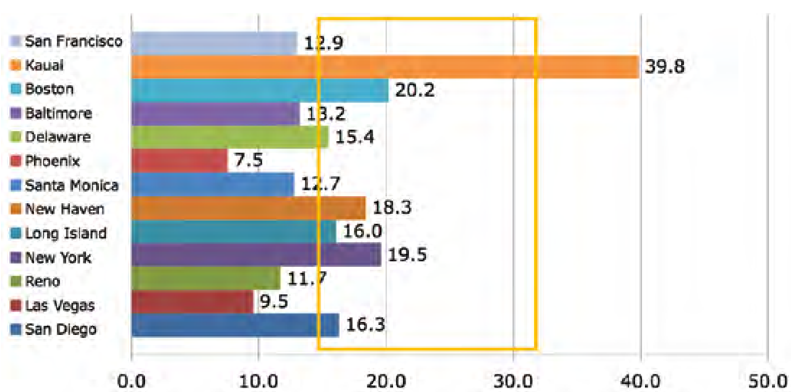
Looming on the horizon is a research and development project with substantial public and private backing that could throw current cost and performance measurements into disarray. The very-high-efficiency solar cells (VHESC) consortium, funded by the U.S. military with participants including the University of Delaware, MIT, DuPont, and BP Solar, has a stated goal to increase the efficiency of converting sunlight into energy from approximately 17 percent today to near 50 percent. The research is still in its infancy, but prototype cells have surpassed 40 percent efficiency. Doubling or tripling the efficiency of PV cells would have significant implications, especially for powering electronic devices such as computers and for applications where space is at a premium (such as rooftops). Such breakthroughs on a commercial scale, however, may be many years away.

the crystalline side lots of investment and scaling of manufacturing will bring down costs—[there will be] a staggering amount in China, and their ability to drive down costs [is well known]…" said one of our industry respondents.

Solar PV: Gaining a Competitive Price Advantage

Solar PV today is still approximately two to three times the cost of most retail electricity rates (before subsidies) in the U.S. With average retail electricity rates of 8-12 cents per kWh in the U.S.—solar PV must still drop by as much as 70 percent from today's average prices of 15-32 cents per kWh.

Comparing U.S. Average U.S. Retail Electricity Rates with PV, 2007 (Cents/kWh)



The above table shows the current cost for retail electricity in select U.S. cities compared with the high and low cost range for installing solar PV. In 2007 solar was competitive in just a few markets without subsidies, such as the Hawaiian island of Kauai.
Source: Clean Edge, 2008

But a closer look at the numbers shows that in some cases distributed solar PV—solar placed on rooftops or adjacent to buildings/users—can compete even at today's prices. In high-priced energy markets like Hawaii and Southern California, where retail rates can easily exceed 20 cents per kWh, solar PV may already be competitive with minimal or no subsidies.

In markets with strong subsidies and incentives, like California, New Jersey, and New York, solar PV can also be competitive through creative financing structures. A number of companies, such as SunEdison and MMA Renewable Ventures, have taken advantage of this and are offering customers competitive power purchase agreements (PPAs). In these cases, the systems integrator/financier takes care of system procurement, installation, and financing. Instead of selling the system itself to the customer, they sell the system's energy output. In many cases, these companies are able to offer electricity for the same price or less than prevailing

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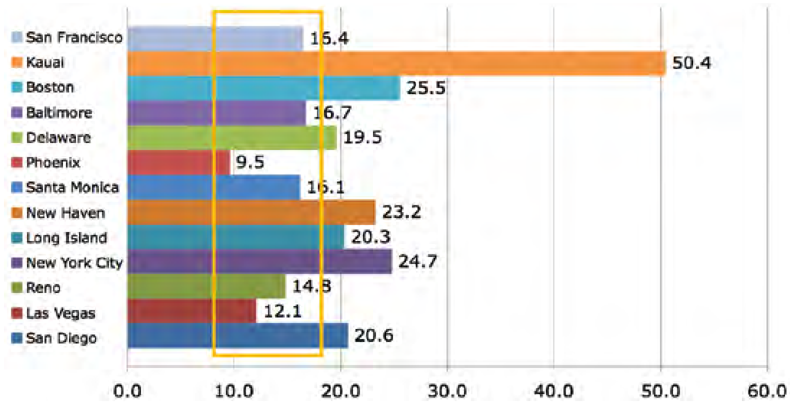
utility rates. As an added bonus, since they know the future costs of sunlight (i.e. zero), customers may be able to lock in pricing, over a specific contract period, usually ten years. That allows customers certainty over energy prices, immune from the vagaries of fuel price fluctuations.

Comparing U.S. Average U.S. Retail Electricity Rates with PV, 2015 (Cents/kWh)

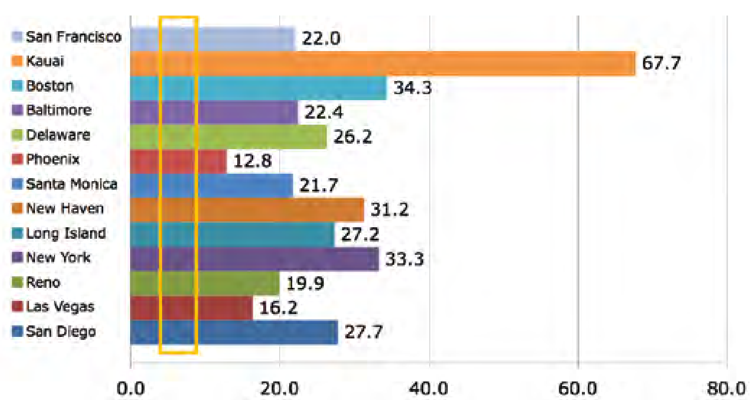


The above table shows projected cost for retail electricity in select U.S. cities in 2015 compared with the high and low cost range for installing solar PV. By 2015 Clean Edge projects that solar will be increasingly price competitive with retail electricity rates. Source: Clean Edge, 2008

Major utilities are now getting into the act of low-priced solar. As noted earlier, Southern California Edison launched its own program in early 2008 which aims to install 250 MW of solar in its territory over the coming years. The projected price to install these systems on commercial, industrial, and residential rooftops: around $3.50 a peak watt. SCE can hit such a competitive price because of economies of scale in procurement, installations, and integration, and the ability to eliminate costly middlemen. Other utilities are likely to follow suit.

But even with such innovative installation and pricing schemes gaining popularity, solar PV is still too high to compete on a price-only basis without subsidies in nearly all U.S. markets today. Our research shows that PV must reach approximately $3 per peak watt or less (equivalent to around 8-14 cents per kWh) to be competitive in most U.S. retail markets. Based on current growth rates and average pricing, however, we see the industry reaching that price in a decade or less—by around 2015. And it's important to note that the industry may reach this crossover point even sooner, should conventional electricity rates in the U.S. rise and PV prices decline faster than expected.

Comparing U.S. Average U.S. Retail Electricity Rates with PV, 2025 (Cents/kWh)



The above table shows projected cost for retail electricity in select U.S. cities in 2025 compared with the high and low cost range for installing solar PV. By 2025 Clean Edge projects that solar will be price competitive with retail electricity rates in every market in the U.S. Source: Clean Edge, 2008

By 2025, we believe that solar PV will be competitive against retail electricity rates in most regions of the U.S. And that's with applying a very conservative increase in retail electricity rates—just 3 percent per year. That's considerably less than the average rate

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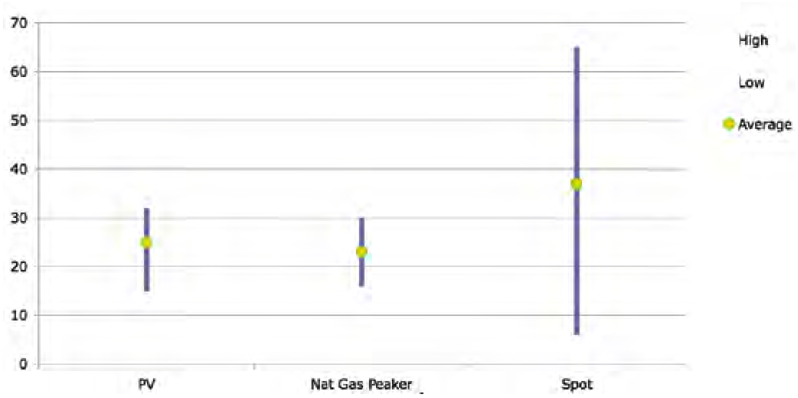
increases most consumers have been seeing over the past few years. With continued spikes in energy costs, the advent of carbon pricing schemes in the U.S., and other drivers, prices may change even more dramatically (as noted in the Within Reach: 10 Percent Solar section).

Peak Generation Opportunity

Another area where solar PV can be cost competitive today is for peak power generation—the times of day when utilities need the highest level of power output to meet demand, usually requiring them to fire up their least-efficient, most-costly generators. Solar PV at 18-32 cents per kWh, and CSP between 14-23 cents per kWh today, already compete favorably with a number of other peak-power solutions. As the table below shows, natural gas "peaker" plants cost between 8 and 30 cents per kWh, and spot energy can cost between 6 and 65 cents per kWh. At these prices, solar is already competitive.

Current Cost of Electricity - Electricity Source (Cents/kWh)



Source: Clean Edge, 2008

CSP: Desert Power

Whereas PV will be used primarily for distributed resources (and increasingly for centralized, as utility-scale solar farms are built), CSP is optimized for centralized plants located in desert regions. CSP systems use reflective materials such as mirrors to focus the sun's rays to heat a fluid (usually oil or water) to high temperatures that creates steam to drive a turbine to produce electricity. CSP technologies include several variations, such as parabolic troughs, dish systems combined with Stirling engines, central towers, and other hybrid technologies. Some of the key players in this sector include Ausra, BrightSource, and Solel. These firms have contracted with major California utilities to supply hundreds of megawatts of CSP at grid-competitive rates, from plants in the Mojave and other Southwestern deserts, in the coming decade.

CSP requires consistent, direct sunlight, but is extremely efficient and theoretically cheaper than PV. Up until 2006, the U.S. actually had more megawatts of CSP installed than PV. As noted elsewhere in this report, we believe that CSP prices could drop considerably in the next two decades as the technologies are scaled up and deployed more widely. Price ranges for electricity produced from CSP plants today (as shown in the chart on left) show that it is already approaching grid-parity in some regions.

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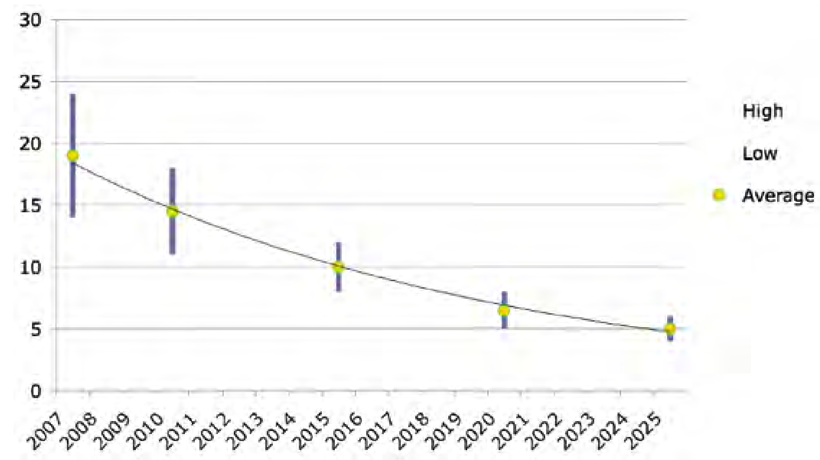
Moving Forward

The cost for solar power is becoming increasingly competitive with conventional energy sources. As solar prices drop due to economies of scale and the absence of fuel costs (there's no charge to tap the sun), and conventional prices rise because of increases in capital, fuel, and operational costs, the divide between solar and other energy sources will shrink and ultimately be erased. We predict a point in the not-too-distant future in which solar can be deployed more cheaply, more reliably, and more cleanly than fossil-fuel-based energy. Achieving this will require some technology and systems breakthroughs, but many of the technologies are already here. The solar technology landscape is changing rapidly, offering utilities opportunities for innovation and dramatic cost improvements.

CSP Price Ranges 2007-2025 (Cents/kWh)



Source: Clean Edge, 2008

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UTILITY PATHWAYS: SOLAR AS A SOLUTION

In the Challenges and Roadblocks section, we discussed the top technical, regulatory, and cultural barriers against widespread adoption of solar by utilities. But out of these many challenges come a range of opportunities. We've developed seven key pathways for utilities. They are:

1. Take advantage of the unique value of solar for peak generation
2. Better serve customers in grid-constrained areas and "at the edge"
3. Implement solar as part of demand response systems and build-out of the smart grid
4. Use solar as a price hedge against fuel cost increases and potential carbon costs
5. Adapt to the new power market with new business models
6. Harness the power of the desert
7. Help train the next wave of workers

1. Take Advantage of the Unique Value of Solar for Peak Generation

Solar is discounted by some utilities because its cost is mistakenly compared to base-load energy costs. Instead, solar, in most cases, should be directly compared with the cost of power during daylight hours that encompasses much of the peak demand.

Solar has value beyond its basic kilowatt-hour cost because solar power is generated during daylight hours and is most productive at times of day that coincide with utilities' peak demand period, particularly in the energy-intensive summer months. Solar plants that utilize tracking systems and storage can maximize power generation to address late afternoon peaks.

Solar can replace the least energy-efficient (and most expensive) "peaker" plants that are brought online to meet peak demand. Power from natural gas peaker plants can cost up to 15-30 cents per kWh. And energy bought on the "spot" market by utilities desperate for power can cost even more). Since distributed solar PV and CSP typically cost between 15-25 cents per kWh, they can be cost-effective replacements.

The advantages go beyond cost. Old fossil fuel-powered peaker facilities are more costly to maintain and emit more greenhouse gases, which are likely to become even more expensive in the future as expected U.S. carbon-cap legislation takes effect. The cost of solar relative to these peak demand costs is competitive in many markets today.

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As one analyst said, "If [utilities] would see all the [full] value of solar, it could be done without subsidies."

Solar's contribution to meeting peak-load demands also can be critical in helping utilities defer capital investments in central fossil-fueled generation capacity. Instead of adding multibillion-dollar generating plants that typically are underutilized during off-peak hours (generating costs but not revenue), solar energy delivers only when it is most needed. "The economic value of solar is really in the timing (relative to peak loads) and the resulting capital issue (that it can helps prevent or defer peak investments)," said one expert, echoing the comments of many. The value is in the peak power, not just the kilowatt-hours."

As outlined in the "Getting to Cost Parity" section, coal and natural gas power plants require upfront investments of $1 billion to $2 billion or more (nuclear plants require at approximately two to three times that, assuming they can be licensed in the first place), as well as operational fuel costs. Such plants typically are not cost-effective unless they are able to produce several hundred megawatts. And these costs are projected to continue to rise. Solar plants, on the other hand, can be built to the exact scale needed to meet demand, with additional modules added as needed.

2. Better Serve Customers in Grid-Constrained Areas and "At the Edge"

Distributed solar PV can be a cost-effective complement to existing generation in areas of the grid where power generation capacity has difficulty meeting peak demand and where consumption is expected to increase. Solar is able to fill demand with lower capital and per-kWh costs than many competing energy options. Meeting increased demand at great distances from existing generation plants with fossil fuel-based resources requires costly investment in additional downstream power plants, or significantly upgrading the transmission infrastructure to accommodate expanding centralized resources.

Utilities looking to reduce their transmission and distribution (T&D) costs and increase grid stability can benefit by increasing the percentage of distributed solar PV in their energy mix. Some utilities have not included the cost of T&D in their planning for expansion, particularly to power new housing developments and office parks at the fast-growing outer edges of "exurbia." "T&D to a suburb has been very reactive," said one industry observer.

The strain on the existing transmission lines and need for power increasingly further from central plants is forcing them to reconsider. Greater power demands at points far from centralized resources over increasingly overtaxed transmission lines are putting pressure on the grid. Distributed solar plants can be installed closer to the demand location, and to the scale needed, at a lower cost than increasing centralized produc-

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tion and/or upgrading transmission lines, which are multimillion dollar investments.

"This is what a disruptive technology does—it exploits the inefficiencies of the old system," said one expert. "Usually it's not a choice between the two; it's a marginal decision about what we do next. The grid is getting more and more expensive to maintain, and what solar lets us do is reduce that maintenance investment, by offsetting investments in line extensions. Everything about [distributed] solar has to do with transmission and distribution; we should not be looking only at the cost of generation, and yet that's what everybody looks at."

Regarding T&D planning, one utility official said, "We're really in the infant stages on that. We had traditionally thought we couldn't even plan our service territory T&D more than five years out. Now we're looking further out, like 20 years, and seeing that solar might help us defer, or not do, some T&D, or do smaller substations."

For regions where costly transmission lines are near maximum utilization, distributed solar can be economically preferable to major grid overhaul, explained one expert. "In cases where the utility is grid- or transmission-constrained, and the next choice is to upgrade the grid, if they could compare and contrast distributed solar in their budget, it would make sense."

Distributed solar generation capacity can also increase the flexibility and redundancy of the grid, thus improving reliability. It can alleviate bottlenecks on the grid that drive up costs for customers and facilitate competitive electricity markets that will ultimately lower prices.

However, utility ownership of distributed solar requires a seismic shift in the way utilities think about the ownership, management, and distribution of power. The "comfort zone" has been to manage centralized power plants or purchase large amounts of energy from a centralized third-party source. Utilities can introduce technology for managing distributed resources to meet this challenge; we discuss this pathway further in the Adapt to the New Power Market section below.

3. Implement Solar as Part of Demand Response Systems and Build-Out of the Smart Grid

Part of utilities' reluctance to embrace distributed solar is the inability of the aging power grid to respond to variable or intermittent power. But rather than continue to use this as an excuse for eschewing solar, utilities should join in a national effort to add intelligence to the grid and metering systems.

Smart meters, which provide two-way communications between customers and the grid, are a requisite for assessing hourly changes in power consumption and production. With smart meters in place at grid-tied solar locations, utilities can better manage the aggregated power, which can enable them to defer adding capacity and reduce

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supply shortfalls. Customers who are billed by time of use pricing will better track their energy consumption and will decrease their consumption of peak power.

According to one solar industry executive, “Electric utilities in general don’t have a clear pathway to understanding how they make money in the next generation grid—in the same way that AT&T fought the telephone deregulation of the ’80s, utilities don’t have appreciation for next-generation grid value for customers—and more importantly, for themselves—smart meters, demand-side management and storage. They can’t see how it’s good for the company, so they fight.”

Advances in information technology and the Internet have spawned a new generation of intelligent devices that have revolutionized communications and created a multitude of operating efficiencies. Utilities need to apply these same principles to power generation and transmission. Smart grid technology, which connects meters and transformers with central management facilities, can harnesses distributed solar to cut transmission costs and dynamically respond to changes in demand. The deployment of these technologies will give utilities unparalleled control over their resource so that they can access the least costly power when it is needed.

Several interviewees envisioned an intelligent grid system that would create an “open market” enabling solar customers to monetize the value of their system by selling excess power at optimal prices. Pricing for power could be based on time of use and the location-specific value of that power on the grid—and include any green and carbon-reducing attributes. “The real opportunity is allowing my meter to interact with the utility so I can make money,” said one industry expert. “Right now, I can zero out my bill, but I cannot make money. This now makes it an under-incentive to invest.”

While relying on distributed resources including solar and energy efficiency adds to the complexity of resource management, having more power sources in more locations can reinforce the integrity of the grid. Distributed power increases the flexibility and redundancy of the grid, and improves reliability because the failure of one generation facility will have less overall impact. This should be factored into the cost of acquiring power generation.

Using solar and intelligent grid technologies to eliminate failure points can also prevent costly blackouts. The blackout of August 2003 that decimated the Eastern U.S. cost between $7 to $10 billion, according to ICF Consulting and the Electricity Consumers Research Council. Solar power that can be controlled independently can minimize the losses of failed centralized generation. Locating solar plants adjacent to substations—where utilities often have right-of-ways and additional industrial land—can make the substation more cost effective.

Utilities are caught between increasing demand for peak power and an unfriendly environment against building new coal and nuclear power plants—which aren’t best suited

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for meeting peak power in the first place, since they can't be dialed up or down very far. One option for avoiding new centralized plants and increasing the performance of the grid is to focus on demand response. The North American Energy Standards Board and regional groups are creating guidelines for integrating distributed resources into demand response systems, which will simplify the addition of solar into the mix.

By curtailing the use of non-essential power during a demand surge or increasing rates and tapping into distributed customer-owned power, utilities can more quickly react to prevent outages and reduce their costs. Solar can contribute to utilities' demand curtailment services because peak solar energy production coincides with peak demand as noted above, and customers who have installed solar often have the smart metering equipment that is needed to control the power resources.

Distributed solar can also be aggregated and made available to utilities on demand. Project Opportunity Notice in New York State has created several projects that demonstrate how solar power can provide peaking capacity to specific areas of the grid. Utilities can work with commercial and residential customers to acquire distributed solar power as part of their demand response planning.

4. Use solar as a price hedge against fuel cost increases and potential carbon costs

As we detail throughout this report, fuel costs for coal and natural gas-fired generation are on the rise, in some cases dramatically, and most energy experts expect those trends to continue. They are also increasingly volatile, posing significant planning challenges to both utilities and regulators. Solar power, with its fuel cost of zero, can provide a key stability hedge in this volatile environment.

That advantage will take on increased significance when carbon caps, as expected, take effect in the U.S. in the next five years if not sooner. We won't speculate here about the potential price of carbon credits, but a power generation portfolio with solar power will pay increasing financial dividends in an economy with mandated carbon constraints.

5. Adapt to the New Power Market with New Business Models

Solar PV's rapid annual growth rates have been fueled in part by power customers—from homeowners to small and large businesses to government agencies—who appreciate the flexibility of owning (or leasing) part of their power generation and the security of protecting against future price increases. Customers and third-party developers own the overwhelming majority of the solar PV installed in the U.S. today—utilities own only a fraction of the 500 MW of solar PV systems currently installed nationwide.

That situation underlies much of the utility industry's traditionally less-than-enthusiastic, and sometimes contentious, relationship to distributed solar energy. Ownership of power generation beyond utilities reduces utilities' total revenue potential from traditional

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customers. Each kWh of power created at a residence or commercial rooftop is one less kWh needed from a utility, which could make it more difficult to request rate increases and maintain profit levels. Utilities must adapt to this new competition and customer relationship by creating new business models and forming new collaborations.

Across the country, commercially-owned PV installations are rising in popularity and growing in size. SunPower's PowerLight unit, for example, now has a contract with Wal-Mart to build solar electric power systems totaling 4.6 MW on seven facilities in California. Google has installed what was the nation's largest commercially-owned solar array when it went live in 2007—1.6 MW at its Mountain View, Calif., headquarters. Google plans on building 50 MW of solar by 2012. Utilities need to track these and similar developments as part of their overall demand projections, and to form partnerships to acquire the excess power of such installations.

Utilities also face increasing competition from third-party companies that own solar plants located on the premises of commercial and residential customers and sell the power or rent the panels to the customer at a fixed rate. Customers pay a deposit that is smaller than the usual upfront cost and commit to a long-term PPA that provides additional savings as electricity prices rise. Companies such as SunEdison, MMA Renewable Ventures, EI Solutions, and SunRun Generation guarantee the amount of power generated from the system and pay the difference if the solar power is less than expected. They also handle all aspects of installation, operation financing, and maintenance and get the benefit of receiving state and federal rebates.

Such third-party arrangements often include creative, innovative business and financing models—something that regulated utilities have rarely embraced. SunPower signed a contract with Hewlett-Packard to install a 1 MW PV system and perform system maintenance for 15 years at an HP facility in San Diego. HP will buy back the solar power at a reduced, locked-in rate. The system will be financed and owned by General Electric, which allows HP to take advantage of the environmental and financial benefits of solar with no upfront capital costs.

While these third parties originally targeted larger projects with commercial or industrial or university customers, some entrepreneurs are targeting residential systems. SolarCity in Foster City, Calif., is going the lease route, providing solar as a service as one option for its residential customers. With its SolarLease, the company obtains the necessary permits and installs and maintains (and owns) the system, all for one monthly fee, over a 15-year contract. In April 2008, SolarCity began offering a no-downpayment option to homeowners in California, and planned to make that option available in Oregon and Arizona later in the year.

Utilities can similarly capture some of the potential revenue from rooftop solar by owning the equipment, selling the power to the property owners, and sending the ex-

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cess energy to the grid. While this scenario represents a significant change in the way utilities operate, this model provides an opportunity for utilities to maintain revenue levels and keep their existing relationship with customers, leveraging their existing billing, customer service, and other operations. Furthermore, as utilities gain experience in installing and maintaining PV, they could develop new services that compete with the solar maintenance organizations that are growing in popularity.

That is starting to happen. Partnerships with third parties or other utilities that share the cost of solar plants enable utilities to participate in solar with minimal investment. Nevada Power, for example, is partnering with the Las Vegas Valley Water District and SunPower to build six facilities that will generate a total of 3.1 MW. The Distributed Solar Array project, as the effort is called, will cost $22.6 million to complete and will generate 5.3 million kWh during its first year of operation.

Utilities also are banding together to jointly own solar resources and share development costs. A trio of utilities in Arizona has joined with a California power producer and private companies to build a 250 MW CSP plant. Group members sign a long-term PPA for the installation that is more cost-efficient because of the economy of scale of pooling demand.

This model could be broadened to groups of homes and businesses that are able to pool their resources and reduce utilities' per-kWh cost of monitoring and maintaining distributed resources. However, some jurisdictions place limits on the size of systems that qualify for rebates, and rules that prevent utilities from being eligible for federal tax credits available to third parties or customers would have to be modified. Aggregating power from many smaller installations also brings substantial technical challenges, including maintenance and grid management.

Several experts also envision utilities becoming directly involved in their customers' solar installations as another way to broaden customer relationships and better understand the distributed power opportunity. Utilities can generate additional revenue by developing service plans and financing options for solar.

Utilities can complement solar with wind power to get a more continual energy source, since wind resources tend to be stronger at night and solar's during the day. Puget Sound Energy in Washington State installed 450 KW of solar PV adjacent to the utility's Wild Horse wind power facility near Seattle.

In short, utilities should look to these new solar market players as both potential collaborators and examples of new business models that can be emulated.

Utilities' ownership of the relationship with power customers could be substantially diminished if they do not actively participate in customer adoption of PV. If utilities get involved in promoting solar, installation, and maintenance, they could grow their revenue opportunities instead of ceding them to new players.

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6. Harness the Power of the Desert

The greatest opportunity for cost effectively implementing solar power on a grand scale in the U.S. is in the Mojave, Sonora, and other great deserts of the Southwest. Along with conventional PV, concentrating photovoltaic (CPV) and CSP have potential to make significant contributions to utilities' energy contributions, if current technical challenges of distribution and storage can be overcome. Once proven, these technologies could become attractive options for diversifying energy and meeting renewable portfolio standards.

The potential output from concentrating solar electricity in the Southwest U.S. is more than triple the current installation of all forms of solar worldwide, according to a 2007 study from the American Solar Energy Society. With appropriate federal and state policy support, 4 gigawatts (4,000 MW) of additional CSP plants could be deployed in the Southwest by 2015, and a much greater amount by 2025. The CSP Global Marketing Initiative, for example, anticipates a 5 GW increase in CSP by 2014, while the Western Governors Association's Clean and Diversified Energy Initiative, comprising 19 states, has plans to install up to 8 GW of solar by 2015, roughly half from PV and half from solar thermal. This would represent 13.3 percent of the estimated new electricity generation for those participating states.

Others believe that the potential for CSP and CPV could be much greater. In their Solar Grand Plan report in *Scientific American*, authors Zweibel, Mason and Fthenakis projected that up to 69 percent of U.S. electricity, and 35 percent of U.S. total energy, could come from desert regions by 2050. This ambitious scheme calls for 30,000 square miles of CPV and 16,000 square miles of CSP. Although ambitious, the plan clearly highlights the massive potential of southwestern deserts' solar resources.

While PV is effective in many areas and climates of the world, concentrating solar technologies have considerable limitations in less-than-optimal sunlight conditions. Both CSP and CPV perform at productive levels only in areas that have direct sunlight and few clouds for most of the year.

Other limitations to CSP include:

- CSP plants can require a large supply of water—obviously not ideal given desert locations.
- Ideal CSP sites are often located in remote regions, far from the utility grid.
- Natural gas systems can be required to provide back-up power to CSP facilities.
- The process for obtaining the necessary licenses and permits to develop CSP plants can be slow and expensive.

These challenges could slow CSP's adoption in the short term.

City Loans for Solar—A New Concept

The upfront capital cost for residential solar systems, typically over $15,000, can be prohibitive for most homeowners. But a growing number of federal, state, and municipal tax credits and rebates are making solar more accessible.

In a unique program, the city of Berkeley, Calif., is trying to make solar more accessible with a plan that would pay the upfront cost of the system, with homeowners repaying the cost over 20 years through additional tax payments. The Berkeley City Council preliminarily approved the plan in November 2007, and shortly thereafter the mayor of San Francisco offered a similar loan program for building owners across the Bay. Will other cities follow suit?

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Lost in Transmission

Transmission lines near desirable CSP locations are often inadequate to handle the capacity—or are non-existent. The current financing model for new transmission lines discourages the participation of all but the largest utilities, as new facilities are required to pay for most of the costs of new transmission lines up front.

Creating new transmission lines and generation facilities simultaneously falls into the classic chicken-and-egg conundrum. Currently power plant developers are responsible for most of the upfront cost of building the transmission trunk lines to the grid, a capital-intensive proposition that can prohibit the participation of smaller renewable power developers. It can be difficult for utilities to receive financing for transmission projects to support generation that's yet to be built, and likewise new generating facilities won't receive funding without accompanying transmission lines. Of course, this issue also applies to traditional centralized power plants such as coal and nuclear; one proposed nuclear station in Florida includes an estimated $2 billion price tag for new transmission lines.

The California Independent System Operator Corporation in October 2007 approved changes to transmission financing requirements that could pave the way for improved federal regulations. Under the new system, as individual generation projects are built and connected to the grid, each generator would pay its pro-rated share of the annual Transmission Revenue Requirement (TRR) payments required by the Federal Energy Regulatory Commission. Instead of paying upfront, the costs increase as power generation capacity goes online.

This financing arrangement would continue until the entire capacity of the project is filled, at which time the remaining TRR for the transmission facility would be supported by the project developers. This will make it easier for solar power developers to participate alongside utilities in the expansion of the transmission lines necessary to reach remote areas of power generation.

Until the wave of current CSP projects (currently exceeding 3,000 MW in the U.S.) provides quantifiable benefits and reliable performance, utilities will likely be slow to adopt concentrating solar. But there are encouraging developments. The designers of the recently installed Nevada Solar One CSP plant are addressing some of CSP's limitations with a design that is more efficient in holding temperatures than the original SEGS plants, and requires a natural gas backup equal to just 2 percent of the power output, far less than previous systems.

Several experts interviewed for this report believe older, more proven trough technology will be a more widely accepted CSP technology because it is viewed by risk-averse utilities as a stable, simple technology. As one interviewee said, "Mirrors are easy, tubes are easy, and steam turbines are easy." Said another 30-year utility veteran, "Trough (technology) is proven; it works." The biggest maintenance challenge for the technology that reflects the rays of the sun is how to economically keep the mirrors clean.

7. Help Train the Next Wave of Workers

Utilities need to work with solar companies, community colleges, NGOs, and other key stakeholders to help provide job training for the coming demand for solar and energy efficiency jobs. Having enough people for these jobs is one of the key success factors for the growth of solar. In addition to the investment in the utilities' own business future, this pathway will also pay off in positive community relations, from providing both job training and actual jobs. Some utilities such as PG&E and Southern California Edison offer both online and in-person workshops for training in solar technology.

As part of this pathway, utilities should reach out to and work with grass-roots groups

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advocating "green jobs" for members of low-income communities, such as Sustainable South Bronx in New York City and the Ella Baker Center for Human Rights in Oakland, California. Such efforts are awaiting significant federal support via the Green Jobs provision of the 2007 energy bill, which Congress passed but has not yet allocated funding.

There are many potential routes for utilities to take to dramatically increase their development and use of both PV and CSP solar resources. But we believe that these seven pathways are the most realistic and carry the greatest potential for solar to reach our threshold of 10 percent of U.S. generation by 2025. With the right mix of innovation, changes of mindset, and technology improvements, we believe it is possible.

Utilities, however, do not exist in a vacuum—virtually every move they make requires approval, or at least oversight, from government regulators and in some cases, legislators. The pathways for regulators are the focus of our next section.

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REGULATORY PATHWAYS: CHANGING THE RULES

Utilities operate in a highly regulated industry, which means that government—federal, state, and local—has a critical role to play if solar is to reach 10 percent by 2025. Indeed, this goal cannot be reached without policy makers removing roadblocks and increasing incentives. In the current regulatory framework, the natural evolution of solar energy's steady growth and gradually reducing prices is insufficient to transform it from a niche resource into a mainstream technology that becomes a pillar of the electricity mix.

Public policy provides both the carrots and sticks that prompt utilities to add solar to their portfolios. Through legislation, they develop the financial incentives that can justify investing in solar power plants, or through renewable portfolio standards, they can require (either indirectly or through carve-outs) the inclusion of solar as a percentage of their power generation. Regulations control the technical standards that so far have hindered integrating solar, as well as the rules and licensing requirements for the power industry.

Congress has established corporate tax credits for utilities and third-party power producers of solar energy; expansion of these incentives would likely result in increased investment from utilities. Similarly, federal tax credits for residential and commercial solar purchases made through the end of 2007 have spurred installations, but such tax credits are currently unavailable to utilities for distributed solar projects.

The Federal Energy Regulatory Commission sets the rules for transmission requirements and permitting of power generation for utilities. States have their own rules for transmission and interconnecting solar resources with the grid, forcing utilities that do business across state lines to grapple with multiple regulations.

State utility commissions control the electricity rates that can be used to finance expanded solar investments as well as the grid interconnection standards, while environmental agencies oversee siting and permitting. These rules and regulations vary by state and even within utility service territory, which can impede solar development because of the higher cost of compliance with multiple rules. The agencies' ability to create consistent statewide and interstate regulations can simplify and reduce the cost of developing and deploying solar power.

Municipal rules for interconnections or permitting can also vary from city to city, hindering investments in solar for utilities who want to serve multiple regions. The glut of local-government paperwork and technical hurdles as well as the economic uncertainty from temporary incentives has dampened utility enthusiasm for solar. Local regulators and policy makers could play a significant role merely by showing interest in solar, as evidenced by the Berkeley, California, City Council's municipal loan program for residential solar installations as discussed in the Utility Pathways section. As one utility executive said, "If (local) commissioners got fired up about solar, that is more powerful than anything else."

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These and other issues need to be addressed to enable utilities to implement solar power effectively and efficiently. Below we highlight the six major steps that regulators and policy makers can take to help enable the growth of the U.S. solar industry, and to give power producers and utilities the tools necessary to greatly expand their use of solar resources. They are:

1. Decouple revenue from power consumption
2. Give utilities the ability to 'rate-base' solar
3. Establish open standards for production, time of use, interconnection, and smart grid technologies
4. Institute a national RPS with a solar carve out
5. Create a federal carbon cap-and-trade system
6. Pass a long-term extension of investment and production tax credits for solar and other renewables—and extend them to utilities

1. Decouple Revenue from Power Consumption

State regulators can make solar much more attractive to utilities by changing the system by which they earn profits and set rates. In most states utilities earn more when their customers consume more energy, so it is in their best interest not to encourage customers to "go solar" because it reduces their revenue. Tying profits to total power sold also discourages utilities from promoting energy efficiency.

Decoupling earnings from revenues enables utilities to increase their profitability while encouraging customers to become energy efficient or install solar power. Decoupling is among the most important policy matters that legislators and regulators need to adopt; it should become the standard for all states as a mechanism of promoting energy efficiency and solar adoption.

As one utility interviewee said, in working through the difficult discussions with regulators on investments, capacity, and rates, why deal with the hassle and loss of margin on something small and unknown like distributed solar—when "on the contrary, if I just go and make this single-cycle turbine investment, it's a known result and a known return on investment."

2. Give Utilities the Ability to 'Rate-Base' Solar

Decoupling, as big a change as it would be for many utilities, will not be enough. Utilities need to be able to "rate-base" solar—that is, be able to recoup their investments in distributed solar PV by including those costs in customer rate calculations. That's currently not the case in most areas. Utilities currently make money by generating power, but only for large-scale central facilities. Regulators need to give utilities the

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tools to make money from distributed generation sources like solar PV—as well as from investments in efficiency and the smart grid. That will require a major paradigm shift for many public utility commissions. But it's a necessary step, and one that will help many utilities get over solar's price hurdles.

"To a utility $2 billion is not a lot of money—it's one plant," said one utility director. "Money isn't the issue, capturing the benefit of the investment is. We're not seeing much yet [from regulators] in the way of decoupling. Utilities need to be able to make money by investing in efficiency. If you want us to have a clean, efficient grid, let us make money doing it."

One solar industry executive uses the mnemonic DRR to express what's needed—Decoupling, Rate-Basing, and Rate Design. Solar and efficiency investments must be spread across the rate base to avoid inequities in rate design. Otherwise, utilities run the risk of having non-solar customers effectively subsidize those with solar, by charging higher rates to make up for what they perceive as revenue shortfalls from customers with solar installations paying zero to the utility. "If you don't do [decoupling and rate-basing], rate design will piss off customers," said the executive. "When collecting less [from solar users] due to net metering, they have to collect more for everybody else. But if fixed costs are collected on a per-bill basis, they don't have this issue."

In the design of all aspects of DRR, regulators must make provisions to ensure that low-income customers are helped, not hurt, by the regulatory changes. There are a number of ways to accomplish this goal, such as offering lower rates for low-income customers, providing direct subsidy programs, and offering low-income customers free energy-efficiency audits and upgrades to keep their bills low. Protecting low-income customers is essential from both a social and economic justice perspective, and will help utilities create alliances with consumer and community groups so that they support rather than protest changes.

3. Establish Open Standards for Production, Time of Use, Interconnection, and Smart Grid Technologies

National net-metering and time-of-use pricing rules would promote conservation and bring solar's value to the fore. Net metering enables solar power users to deduct excess energy sent to the grid at premium rates from their utility bills. Time-of-use pricing shows consumers how much they are paying for the use of electricity at different times throughout the day and night, which would encourage energy efficiency and distribute demand more evenly.

Lack of consistent and open interconnection standards between states has resulted in a patchwork of regulations that has discouraged the adoption of solar because of the technical challenges in connecting solar to the grid. National standards for interconnections would reduce the cost and time involved in integrating solar and

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would help guarantee a more level playing field for distributed generation of solar power. A unified and open standard would benefit installers and utilities by removing uncertainty and enabling consistent services and products to be offered across state lines. Utility executives considering major investments in smart grid technology say they don't want to get locked in to a proprietary standard that could hinder, or add to the expense of, further improvements down the line.

Municipalities should enact solar-friendly building codes to eliminate barriers to installing solar PV in residential or commercially zoned areas. These codes would fast-track the permitting process for buildings that integrate solar. Cities such as San Francisco have begun requiring solar power to be part of new commercial construction.

4. Institute a National Renewable Portfolio Standard with a Solar Carve-Out

At the federal level, a national RPS can be a significant spur to solar deployment from utilities. We recommend a national RPS that would mandate solar development, via a solar carve-out, by utilities in states with good solar resources. Some of those states currently lack a state RPS, such as "Sunshine State" Florida.

The state RPS experience has been telling. State RPS's and tax incentives for solar have been the prime motivators for utilities to become involved in solar projects. The states with the largest adoption of solar—California, New Jersey, New York, Colorado, and Arizona—have all seen greatly accelerated demand after an RPS or incentives were put into place. Not surprisingly, these states ranked as the top five in PV installations in 2006. (For a list of state by state RPS's, see the Database of State Incentives for Renewables and Efficiency at www.dsireusa.org.) "Where an RPS is in place, an operator (independent from the utility) makes it possible for the utility to benefit without having to get directly involved" in solar construction, said one utility executive.

Most utilities that have embraced solar thus far have done so out of necessity: renewable portfolio standards (RPS) in the states where they operate require them to purchase a percentage of solar and wind energy. Since many large utilities sell power in more than one state, a national RPS would spark demand and provide utilities with a consistent target across all of their regions of operation. In December 2007, the Senate rejected a bill that include a national RPS that would have required investor-owned utilities to purchase a mere 2.75 percent of power from renewable sources by 2010 and 15 percent by 2020. Many climate advocates feel that the RPS needs to be at least 20 percent by 2020. It is imperative that the next Congress pass a national RPS with aggressive targets.

5. Create a Federal Carbon Cap-and-Trade System

A nationally mandated carbon cap-and-trade system (or carbon tax, which seems less likely politically) would help solar and other renewables move faster toward cost

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parity with fossil-fuel and nuclear power generation. But it needs to happen soon—and preferably with 100% allocation. The prospect of establishing a federal carbon legislation has prompted some utilities to hold off on solar and other investments, including efficiency. Utilities are "realizing that something is coming, and that solar has to be considered in their area," but they are delaying solar investments because of the uncertainty and lack of a clear business model, said one industry observer.

Assessing the comparative impacts on solar of the many current and potential cap-and-trade schemes before the U.S. Congress is beyond the scope of this report. But the basic concept of establishing a price for carbon emissions in the U.S. will be a critical financial motivator for large-scale solar development. It will especially spur utilities to reconsider investments in the most carbon-intensive of all energy sources, coal, and look to alternatives like solar (both PV and CSP) to supply future power needs.

6. Pass a Long-Term Extension of Investment and Production Tax Credits for Solar and other Renewables—and Extend Them to Utilities

Consumers and utilities alike will invest in solar with greater frequency when the tax benefits are consistent and reliable over several years. While countries such as Germany and Japan have seen an explosion in solar because of government initiatives and long-term, stable tax benefits, the U.S. federal government has been an unfortunate example of unpredictable, on-again off-again policy incentives. As this report went to press, Congress had still not passed extensions of investment and production tax credits for clean energy that will expire at the end of 2008. And even if they are passed, there's a likely possibility that they will be stopgap extensions for just one year. A long term (10-year) federal tax credit would not only motivate manufacturers to build more solar panels (making it cheaper for consumers), but it would also further legitimize the technology.

Congress missed an opportunity to significantly boost investments solar when it did not renew solar investment tax credits as part of the energy legislation that was signed into law in December 2007. The commercial and residential solar tax credits should be renewed and extended for a minimum of five years to give purchasers security to invest in solar. These credits should be extended to utilities as well, since they would be able to invest in solar on a much larger scale than individual consumers of energy. If Congress deemed it necessary to continue the generous tax incentives for the oil and gas industries to find new sources of energy, then surely investing in renewable energy is worthy of similar incentives. The on-again, off-again history of production tax credits in the U.S. has been particularly devastating to the wind power industry, resulting in a roller-coaster of boom and bust cycles that plague industry players, investors, and clean energy advocates.

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Production tax credits have proven to be the most effective policy instruments to encourage investments in solar. Production-based incentives such as feed-in tariffs have driven the world-leading adoption of solar in Germany, Spain and Japan. Feed-in laws, which enable business and homeowners to sell excess energy back to the grid at beneficial rates and have been crucial abroad, yielding the following results:

- Spain reached 76MW of grid connected by 2006, and sales of PV more than doubled in 2007.
- Germany, with the most generous feed-in program in the world, is already generating more than 11 percent of its electricity from renewables, and 3 percent of the total energy mix is from solar. Somewhat amazingly, given its northern location with fewer hours of sunlight than most U.S. areas, Germany generates roughly half of the world's PV power via more than 300,000 solar installations. Approximately 250,000 Germans are now employed by the renewable energy industry.
- Japan has set and met specific goals for residential solar through a generous feed-in program and by reimbursing homeowners for a percentage of the cost of the system.

Production credits also reflect the value of solar in meeting energy needs more than cost of system-based credits. A bill currently under consideration in the Michigan legislature would mandate feed-in rates equivalent to that of Germany and could be used as a model for a national initiative. Washington State has already passed feed-in tariffs, and so has Ontario, Canada. Similar feed-in tariff bills are under consideration in Minnesota, Illinois, and Rhode Island. Most industry insiders feel that a national feed-in tariff is unlikely in the U.S., given recent congressional difficulties in passing extensions to the much less aggressive investment tax credits for solar and other renewables.

In February 2008, the California PUC approved a significant, though limited, feed-in tariff for solar in the Golden State. Small-scale solar systems of 1.5 MW or less, operated by customers of PG&E and SCE under long-term contracts of 5 to 15 years, are eligible to receive payments of 8 to 31 cents per kWh; most will average about 15 cents. The program carries a total cap of about 105 MW for PG&E and about 125 MW for SCE. Those two utilities and five others are also eligible for a separate feed-in tariff only for solar arrays located at public water and wastewater facilities. That program has a statewide cap of 250 MW. California's program is a positive step, but its intricate rules and limitations point up the challenge of getting beyond incremental improvements. Regulators and legislators need to think much bigger and adopt even more aggressive policies in order to achieve a nationwide goal of 10 percent solar.

State and local governments can also spur solar sales through property tax incentives including exemptions, exclusions and credits that exclude the added value of a solar

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States in the Lead

Following is a summary of select incentives and other policies promoting solar in states producing the most solar power, listed in order of the states with the greatest solar output.

California

- The "Million Solar Roofs" program (2006) requires that solar be an option for buyers of all new construction, expands the ceiling on net metering, and directs municipalities to create solar rebate programs.
- The California Solar Initiative (CSI) dedicates $3.2 billion over ten years to create 3,000 MW of solar power by 2017. CSI is focuses on distributed installations and awards incentives based on the projected output of the system.
- A feed-in tariff approved in early 2008 allows payment of 8 to 31 cents per kilowatt-hour to customers of utilities PG&E and SCE with PV systems of 1.5 MW or less.

New Jersey

- Has been proactively encouraging solar investment through an RPS and strong support from the state's Board of Public Utilities.
- RPS requires that 2.12 percent of energy come from solar power by 2021. Customer rebates are available for the capital costs of their system and a renewable energy credit program.
- Net metering and interconnection policies are among the strongest of any state.

  A law passed in August 2007 prevents homeowners associations from blocking solar panel installations on certain types of properties.

New York

- Second state to adopt uniform interconnection standards for distributed generation systems up to 2 MW.
- New York offers a state sales tax exemption (passed in 2005) for residential solar heating and energy equipment, and a property tax exemption for the additional value of a property due to installing solar or other renewable power resources.

Arizona

- Solar-friendly RPS requires 15 percent of the state's energy needs from renewable energy, of which 30 percent must come from distributed generation.

Colorado

- Colorado was first to bring an RPS to the voting public, which passed it in 2004.
- Solar set-aside requires that 0.4 percent of the state's power comes from solar energy by 2015.

system from tax assessment. Another method is through personal income tax credits for the cost of solar purchases, which are now available in 32 states.

In sum, more than in most industries, the strategies and decisions of electric utilities are inextricably entwined with public policies established by legislators and implemented by regulators. Whether carrots or sticks, the policies and regulatory changes recommended above are critical to achieving the ambitious goals for U.S. solar expansion that we map out in this report. Regulators and policymakers share with the utilities a large share of responsibility to make it happen.

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THE ROAD FROM HERE

In this report we've highlighted the biggest opportunities and challenges facing the widespread adoption of solar by utilities; reviewed the history of utilities' growing involvement in solar; and highlighted the key pathways that major stakeholders need to take for the U.S. to achieve 10 percent of its electricity mix from solar by 2025. These pathways include:

- The solar industry bringing down costs and scaling up manufacturing
- Utilities putting a value on solar assets and embedding them into their strategic planning
- Regulators giving utilities the tools to rate-base and recover their investments in solar

Below is a table that highlights the key activities that we've outlined in this report, and which, based on our research, we believe will go a long way in enabling the growth of a robust solar industry in the U.S.—thereby creating jobs, reducing our nation's dependence on polluting and volatile supplies of fossil fuels, and ensuring economic competitiveness.

Key Solar Stakeholders and Actions

Solar Companies	Utilities	Regulators
Bring installed solar systems costs to $3 per peak watt by 2018	Take advantage of the unique value of solar for peak generation	Decouple revenue from power consumption
Improve silicon cell efficiency and performance	Better serve customers in grid-constrained areas and "at the edge"	Give utilities the ability to 'rate-base' solar
Develop new low-silicon and non-silicon alternatives such as thin film and nanotechnologies	Implement solar as part of demand response systems and build-out of the smart grid	Establish open standards for production, time of use, interconnection, net metering, and smart grid technologies
Streamline installations and make solar a truly plug-and-play technology	Use solar as a price hedge against fuel cost increases and potential carbon costs	Institute a national RPS with a solar carve-out
Ramp up concentrating solutions—including CSP and potentially CPV—for central generation and to drive down costs	Adapt to the new power market with new business models	Create a federal carbon cap-and-trade system
Work with utilities and regulators to develop open standards for net interconnect, two-way flow of electrons, etc.	Harness the power of the desert	Pass a long-term extension of investment and production tax credits for solar and other renewables—and extend them to utilities
	Help train the next wave of workers	

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Game Changers

In addition to actions outlined in this report, in which solar PV and CSP "scale" through a range of stakeholder actions, we believe there are a number of potential game changers that could disrupt the system and accelerate the growth of solar, potentially even more dramatically. There are three that we think are particularly worth noting:

- ### PHEVs and All-Electric Vehicles Take Charge

A large number of respondents to our survey spoke about the advent of a distributed smart grid in which plug-in hybrid electric vehicles (PHEVs) and all-electric vehicles could be used to store and feed energy into the grid on demand—freeing up bottlenecks and reducing the need to build new, expensive, and polluting centralized conventional power plants. In this scenario, there would be hundreds of thousands of storage and back-up systems around the country. Since vehicles typically aren't in use more than 90 percent of the time, they could provide the perfect "vehicle" for storing electricity (in their battery packs), then sell this energy back to the grid at times when it most needed, such as evening hours after commuters return home. Vehicles' power might come from rooftop solar carports at work, from residential solar PV systems, or from centralized PV or CSP power plants.

In other words, PHEVs could charge during the day (if the vehicle is parked at home or at work), with that power used to reduce the household's demand during the peak (most expensive) hours. Taking it further, an arrangement with the utility could allow that power to be dispatchable by the utility through communications and electrical protocols within a vehicle-to-grid (V2G) system. Such systems already are being considered. In January 2008, General Motors convened executives from 50 U.S. utilities for a two-day "vehicle electrification workshop," at which participants shared the challenges and opportunities for creating a V2G system that would be, among other things, compatible from region to region.

Pioneering Texas utility Austin Energy is playing a leading role in Plug-In Partners, a national campaign to help drive this vision. Another leader, Central Vermont Public Service, is driving this vision through their "plug 'n go" campaign, installing charging stations in town that will eventually allow the utility to also tap the stored energy in cars to address peak power needs.

Imagine a hot summer day in California. As people drive home to turn on their air conditioners and TVs and ovens to cook their dinners—thereby taxing the grid—they add one simple thing to their nightly ritual. As they park their PHEV in the garage—they plug it into the grid to help ease the power demands and constraints on a sweltering California day.

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This vision would require the advent of a truly smart "two-way" grid (outlined earlier in the report) as well as a dramatic increase in PHEVs and all-electric vehicles, few of which are on the road today. But it's not outside the realm of possibility. In fact, with quite a few organizations and innovators working on this solution—we think it's more a matter of when then if. The big question is: Are we looking at five, 10, 15 or more years?

- **A Manhattan Project/Apollo Mission/New Deal for Clean Energy Becomes a Reality**

Influential New York Times columnist Thomas Friedman likes to say that "green is the new red, white and blue." In the book *The Clean Tech Revolution* [written by this report's principal authors, Ron Pernick and Clint Wilder] we make the case that U.S. economic competitiveness and relevance lies in tapping the growth potential for clean energy, efficiency, and other clean technologies. Who else better to enable the growth of the clean-tech revolution than the country that brought the world the airplane, the automobile, the computer chip, and the Internet?

But America can't rest on its laurels. The U.S. federal government, in many respects, has been missing in action for the past quarter century, ceding clean-technology control and leadership to states and to other nations.

But what if there were a Manhattan Project, Apollo Mission, or New Deal for clean energy? If national leaders were to make the research, development, and deployment of clean energy and the build-out of clean-tech infrastructure the centerpiece U.S. economic competitiveness, energy independence, and job creation, renewable energy, including solar, could shift into hyper-drive. Such a program would likely include a mix of tax credits, a federal RPS, R&D support, carbon cap-and-trade, and other features—backed up with hundreds of billions in research and capital investment.

Clean Edge and Co-op America previously envisioned a Manhattan Project for solar in our 2005 SHINE report.

Such a concerted federal effort, which would inspire a generation of entrepreneurs, scientists, educators, financiers, and others, would change the national and global energy landscape.

Germany, which has been promoting the growth of its renewable energy industry at the national level, has seen significant results in its efforts—and provides a strong example. Renewable energy jobs in Germany equaled 250,000 in 2007, nearly double the number of clean-energy jobs just three years earlier. According to government figures, as many as 400,000 people could be employed in the renewable energy industry in Germany by 2020. Germany, not a particularly

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sunny country, is the world's largest market for solar PV and now has the largest solar PV manufacturing company (Q-Cells) in the world.

Imagine what might happen if the U.S. pursued a plan of its own.

- **Large-Scale Energy Storage Breakthroughs Reshape the Grid**

To get beyond the ten percent number for solar will require significant breakthroughs in both central and distributed storage options. As noted above, distributed energy storage systems (such as those in electric vehicles) could be tapped for a next-generation grid that exploits the solar resource. And residential and commercial customers could install batteries for short-term evening use on peak summer days, or longer term storage for use through shorter, sometimes cloudier winter days.

But what about energy storage for large-scale solar plants? Research continues on a host of advances that could make centralized solar more economical for utilities. Possible utility-scale storage options include pumped hydro (water pumped above a hydro electric plant, or water left available above the dam because the solar energy was available); compressed air storage (in underground caverns); heat storage (underground steam storage, molten salt or hot water; high-speed flywheels; and large-scale batteries to store electrons from both solar and wind generation sources. Later this year, Xcel Energy and partners including NREL will begin testing an 80-ton, one-megawatt battery pack (20 batteries of 50 KW each) that stores power from a wind farm. When fully charged, the battery could power 500 homes for more than seven hours. If successful, that type of storage could also be used for solar, another energy source in which Xcel has significant investments.

Breakthroughs in any of these technologies, either in feasibility or cost or both, would dramatically change the game. They would help transform the current perception of solar, held by many key principals at utilities, as primarily a provider of peak power on hot summer days. And peak demand doesn't always coincide exactly with solar's top output. One utility executive says peak demand in his region occurs one to two hours after peak PV production. While solar can still be helpful in this scenario, storage would erase any of the disadvantages caused by differences between peak solar production and peak utility demand. So large-scale- or distributed-storage could help significantly. As one expert put it, "Storage is the holy grail. Anyone who solves this will earn enormous returns. Utilities should look into R&D here."

These game changers would certainly assist in the rapid growth of the solar industry, but as we mention above, they are not a requirement for getting to the 10 percent vision.

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A Goal Within Reach

Dramatic change is never easy. But we strongly believe, based on our assessment of industry dynamics and the many interviews conducted for this report, that today's grand vision—10 percent of U.S. electricity from solar by 2025—is not a pipe dream. Challenges exist, but the pathways we have mapped out for utilities, regulators, policymakers, and technologists are sensible and realistic. Most importantly, cost parity for solar is within the planning horizon of most every utility in the U.S.

Grand visions for solar power are not new. Since the 1970s, solar industry advocates have waxed enthusiastic about the technology's potential to supply a significant portion of the nation's electricity needs. But for myriad reasons, the reality of solar power in the U.S. has fallen far short of that vision.

We believe, based on the research in this report and the industry trends we see unfolding every day, that the context of solar power in the United States is changing rapidly. Technology and efficiency are improving, costs are falling, costs of traditional power sources including natural gas, coal and nuclear are skyrocketing, and utilities that have long ignored or even opposed solar on a large scale are changing their tune.

From now to 2025 and beyond, solar (both PV and CSP) presents dramatic new, cost-effective opportunities for utilities struggling with the challenges of increased fuel and construction costs for fossil fuel and nuclear plants, RPS mandates, public and political opposition to coal, demands for grid modernization, and the strong likelihood of nationwide carbon caps in the next 12 to 18 months.

Admittedly, the price tag to get to 10 percent solar—$450 billion to $560 billion—isn't small. But utilities are used to spending billions of dollars in capital investments for generation assets and transmission and distribution—as long as they have the incentives and tools to get there. Indeed, the financial requirements outlined in this report aren't for R&D, they would go toward the direct installation of solar PV systems on rooftops, carports, and adjacent to buildings and to large-scale PV and CSP systems. They would equate to actual energy production, a combined cumulative installation of 250 GW of solar power.

To put the $450 billion to $560 billion price tag in perspective: the Edison Electric Institute estimates that the U.S. electric utility industry spent more than $70 billion on new power plants and new transmission and distribution investments in 2007 alone. As we point out earlier in the report, the estimated solar price tag would represent approximately a half to a third of utility investments between now and 2025, if similar spending patterns occur.

Venture capitalists, government labs, corporations, and others have been building out the next-gen solar opportunity—with big players like Sharp, Applied Materials, and GE competing against relative newcomers like Suntech Power, SunPower, and Q-Cells,

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who themselves are working to stay ahead of smaller startups like Miasolé, Nanosolar, and SolFocus. These companies are delivering advanced, scaleable technologies that will enable the next wave of energy innovation.

Our research indicates that the goal of 10 percent solar by 2025 is absolutely within reach. We recommend that all the players covered in this report—utilities, industry players, regulators, and policymakers—start on these courses of action with a strong sense of urgency. In the context of U.S. energy independence, economic innovation, job creation, and climate change—there is no time to lose.

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APPENDIX A: SOLAR AND UTILITIES: A BRIEF HISTORY

The solar industry has a rich and deep history. Most people point to Bell Labs' work and the first conversion of sunlight to electricity via a PV cell in 1954 as the birth of the modern solar era. But modern solar roots date back even further to two of the great scientific minds of the 20th century: Nikola Tesla issued a patent for a "radiant energy" apparatus in 1901 and Albert Einstein published a paper on the "photoelectric effect" in 1905. (See Appendix B for comprehensive solar history timeline.)

To a large extent, the early history of solar PV (outside of non-terrestrial applications for satellites and the space program) has been written by residential and commercial energy customers purchasing and maintaining their own systems (or more recently acquiring solar energy through "green power" providers). Utilities, to date, have played a limited role in the maturation of solar PV, at least in the United States.

In the early 1970s, a few residential properties were the first to rely on solar power. The federal government largely stayed on the sidelines until later in the decade, when President Jimmy Carter created a research center for solar energy and instituted the first federal tax credits (and placed solar cells on the roof of the White House).

Throughout the 1980s the federal government showed almost no interest in solar, as symbolized by President Ronald Reagan removing the solar panels from the White House. According to the Renewable Energy Policy Project, solar received the equivalent of 3 percent ($4.4 billion) of the subsidies given to the nuclear industry ($145.4 billion) from 1947-99.

The first large-scale purchase of solar power by a utility was by Southern California Edison, which started receiving power from the Solar Electric Generating Stations (SEGS) concentrating solar thermal plants in the mid 1980s. (These plants are still online and providing some 350 MW of generating capacity). In the early 1990s, the Energy Policy Act of 1992 restored the 10 percent federal investment tax credit for using solar in power production, and utilities such as California-based Pacific Gas & Electric began to dabble in purchasing PV systems.

Until the early 21st century, most utilities continued to rely almost exclusively on fossil fuels and nuclear energy for power. This is understandable given the lack of state and local legislation promoting renewables and the cost disparity between abundant and inexpensive fossil fuels and newfangled but costly solar.

However, since the beginning of the decade, a number of utilities have begun deploying solar more aggressively. In recent years more than two dozen states have established renewable portfolio standards that require utilities to purchase clean energy, several of which include solar carve-outs. Utilities have begun buying equipment and purchasing solar energy through power purchase agreements from concentrating solar plants

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Table: Solar Grows Up—The Increasing Size of PV Installations

Back as early as 2000, a 200 kW solar PV system was considered large. But that's changing, as Google's 1.6 MW system at its "Googleplex" corporate headquarters has gone online and as Wal-Mart proceeds with plans for large PV arrays on the roofs of 22 stores and distribution centers in California and Hawaii. Below is a table showing some of the larger solar PV rooftop and ground-mounted systems sprouting up around the globe.

Installation	Capacity	Installation Type	Location
Shenzhen International Floral Exhibition Buildings	1 MW	Built-in PV	Shenzhen, China
Alvarado Water Treatment Plant	1.1 MW	Rooftop	San Diego, California
Sierra Nevada Brewing	1.4 MW	Rooftop	Chico, California
Google	1.6 MW	Rooftop	Mountain View, California
Fort Carson	2 MW	Ground Mounted	Fort Carson, Colorado
Hall's Warehouse Corporation (SunEdison)	2 MW	Rooftop	South Plainfield, New Jersey
Springerville Generating Station	4.6 MW	Ground Mounted	Tucson, Arizona
Sharp Plant, Kaneyama	5.2 MW	Built-in PV	Kameyama, Japan
Alamosa Photvoltaic Solar Plant (SunEdison)	8.2 MW	Ground Mounted	San Luis Valley Alamosa, Colorado
Serpa PV Power Plant	11 MW	Ground Mounted	Serpa, Portugal
Nellis Airforce Base	14 MW	Ground Mounted	N. Las Vegas, Nevada
Solarpark "Waldpolenz"	14.7 MW	Ground Mounted	Brandis, Germany
Solarpark Beneixama	20 MW	Ground Mounted	Alicante, Spain
Hoya de Los Vincentes	23 MW	Ground Mounted	Murcia, Spain

Source: Clean Edge research including review of company press releases and public web sites.

as well as large PV farms and distributed PV installations. Utilities are also getting involved because of improvements in the technology—spurred by an unprecedented investment in venture funding and other private and public financing—as well as in their efforts to address grid congestion and other utility constraints.

But despite the recent surge in interest, solar remains a negligible portion of utilities' energy mix. Net solar power generation in the U.S. from utility-scale facilities is currently around 500 MW of capacity—half the size of an average nuclear, natural gas, or coal-fired power plant. Even more humbling, the U.S. has less than 20% of the installed PV capacity of global solar leader Germany, a country one quarter its size and with considerably less sunshine than many parts of the U.S.

The granddaddy of CSP, the SEGS plants near Barstow, Calif., helped prove to utilities that CSP can be a reliable and durable energy source. SEGS' parabolic trough performance—operating nearly 100 percent of the time during peak hours—has encouraged development of next-generation concentrating technologies. Operating since the mid 1980s and completing its ninth and final station in 1989, the SEGS units provide more than 350 MW of solar power generation. Originally developed by the now defunct Luz International, the plants are now owned and operated by FPL Energy and Carlyle Riverstone.

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For nearly two decades there was no new solar CSP development in the U.S. But over the past two years, CSP has been the major catalyst of a new chapter in utilities' embrace of solar power. Emerging CSP technology developers like Ausra, BrightSource, and Solel have applied for CSP projects totaling more than 24,000 megawatts in the Southern California desert, and California's big utilities have shown major interest. For example, PG&E has agreed to purchase 900 MW from a series of BrightSource plants.

FPL Energy, the Florida utility's development arm, is aiming to augment its leadership in wind power with major solar efforts. FPL said in 2007 it will spend $1.5 billion over seven years to built solar plants in California and Florida, mainly CSP. And CSP is also one of the three technologies targeted by Google's RE<C initiative to make renewable energy cheaper than coal. It's too early to say what Google's impact might be, but any push to significantly reduce solar costs could greatly expand utilities' participation beyond the wave of early leaders currently embracing the energy source.

Leading the Charge

Thanks to aggressive measures by the state's public utilities commission, as well as supportive political leadership, utilities in California have been setting the pace in solar adoption by building centralized installations and by offering rebates to customers who install distributed solar power. A brief look at California's top utilities and their solar activities to date:

Sacramento Municipal Utility District (SMUD)

SMUD has been a leader in solar energy for more than 20 years. SMUD has installed about 10 megawatts of solar power in its service territory on residential, commercial, and government buildings and in larger, utility-scale arrays. Ten megawatts of electricity is enough to power about 9,000 average-size single-family homes in the Sacramento region.

SMUD commissioned its first solar project, a 1-MW photovoltaic electricity generating facility, in 1984. SMUD encourages residential consumers through the SolarSmart Homes program that matches approved PV installers with interested consumers, resulting in more than 2,500 solar homes to date. SMUD also provides financing for certain energy efficiency measures for commercial, industrial, agricultural, and multifamily customers.

PG&E

California's largest electric utility built the first utility-owned distributed power system in 1993, with its grid supported PV system in Kerman, California. In 2007, PG&E began offering rebates to residential and commercial customers who purchase solar systems. The utility is aggressively adding renewable electric power resources to its supply and is on target to exceed 20 percent

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under contract or delivered by 2010. PG&E now has contracts to provide 18 percent of its future energy supply from renewable sources.

In 2007, PG&E announced plans to double its existing commitments to buy renewable solar thermal electric power, adding 1,000 MW of new supply to its portfolio over the next five years. This commitment builds on the company's previously announced plans with Solel and BrightSource to purchase more than 1,000 MW of solar thermal power. The additional commitment will be enough to power more than 750,000 homes.

Southern California Edison (SCE)

SCE has used solar energy as part of its generation portfolio since the 1980s as a buyer of electricity generated by the SEGS units in the Mojave Desert. But perhaps its biggest step came in March 2008, when SCE said it will invest $875 million to deploy up to 250 MW of PV modules on 65 million square feet of roofs of Southern California commercial buildings over the next five years.

SCE's renewable portfolio currently has the ability to deliver more than 2,700 megawatts of electricity, 354 MW of it from solar via the SEGS project. The utility has signed new power purchase agreements (PPAs) with Stirling Energy Systems to establish large CSP plant complexes in Southern California. SCE and San Diego Gas & Electric have pledged to buy a combined minimum of 800 MW annually from Stirling. SCE also has a one-megawatt PPA with California Sunrise for a PV plant.

San Diego Gas & Electric

SDG&E is considering spending $1.5 billion to encourage distributed solar power as an alternative to building a controversial 150-mile power line, some of it through environmentally sensitive areas. Beyond that, SDG&E hasn't made as many commitments in solar as its fellow Golden State utilities, but that could change soon. In March 2008, the utility said it was soliciting bids from clean energy suppliers including solar to help it meet California's 20 percent RPS mandate by 2010.

Some leading utilities in solar elsewhere in the U.S.:

FPL Group

FPL Group, Inc., one of the country's leading generators of renewable electric power, announced a $2.4 billion investment program in 2007 aimed at increasing U.S. solar thermal energy output, increasing efficiency, and reducing carbon dioxide emissions that contribute to global warming.

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FPL Group, and its subsidiaries Florida Power & Light and FPL Energy, will invest up to $1.5 billion in new solar thermal generating facilities in Florida and California over the next seven years, starting with a project at Florida Power & Light; up to $500 million by FPL to create a smart network that will provide its 4.5 million customers with enhanced energy management capabilities; and at least $400 million over five years in a new FPL Energy consumer education program and new consumer generation and energy-efficiency products.

Xcel Energy

Xcel is one of the best examples of how RPS mandates can spur a utility toward clean-energy leadership. Xcel, though already a leading developer of wind power at the time, lobbied heavily against Colorado's 2004 ballot initiative for an RPS of 20 percent by 2020. But in the three years since voters passed the measure, Xcel has become aggressive in solar. In January 2008, Xcel issued RFPs for a total of 25 MW of solar in its service area, which would bring it one-fourth of the way to Colorado's RPS solar carve-out mandate of 100 MW.

Xcel is also working with third-party solar developer SunEdison in a partnership that exemplifies the new types of business models utilities could, and may need to, embrace to achieve our 10 percent by 2025 vision. SunEdison financed, constructed and will maintain an 8.22 MW PV array in Alamosa, Colo., one of the largest in the U.S. Xcel purchases the solar-generated electricity and the renewable energy credits from the facility.

Xcel is also embarking on installing the first city-wide smart-grid system in the nation, in Boulder, Colo. In May 2008, it engaged smart grid technology leader GridPoint to provide a variety of control and monitoring systems, including one that allows plug-and-play integration of residential and small commercial PV systems.

Public Service Electric and Gas Company (PSE&G)

New Jersey's largest utility recently received approval from state regulators to offer $105 million in loans to help finance the installation of solar systems on homes, businesses, and municipal buildings throughout its service area. (Initially the program will be available only to non-residential customers, as PSE&G needs approval from the N.J. Department of Banking and Insurance to provide direct loans to residential customers.) The program will support the development of 30 MW of solar power, designed to fulfill about 50 percent of the RPS requirements in PSE&G's service area in 2009-2010.

Under the program, PSE&G will provide loans to developers or customers to cover approximately 40-60 percent of the cost of a solar installation project, depending on the projected output of the solar energy system and the cost of the system. Remaining costs will be funded by the owner of the solar installation. The program addresses one of the biggest hurdles facing homeowners and businesses who want to cut their electric bills by installing solar panels: the huge upfront costs.

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Tucson Electric Power (TEP)

A subsidiary of UniSource Energy, TEP currently has 4.6MW of solar PV at the Springerville Generating Station Solar System in northeastern Arizona, installed by Global Solar Energy. This site generates approximately 7,800 MWh annually.

An additional 742 MWh are produced by local systems and community installations sponsored by TEP's SunShare program.

Both TEP and Xcel are part of a multi-state consortium of Southwestern energy service providers issuing a request for proposal (RFP) for a utility-scale CSP plant. The plant would be owned by a third party, with consortium members each signing long-term PPAs. It is expected to produce 250 MW and be located in either Arizona or Nevada. When completed, it would be the largest solar power plant in either state. Other participants are Arizona Electric Power Cooperative, Arizona Public Service, Southern California Public Power Authority, and Salt River Project.

In short, utilities can look to pioneers like these to find examples how utilities are adopting solar power. One could make the case that the U.S. solar industry would not be where it is today without these utilities' participation. But overall, the historical growth of utilities' embrace of solar has been incremental, not transformative. That will have to change for the U.S. to reach the goal of 10 percent solar generation by 2025.

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APPENDIX B: SOLAR ELECTRICITY HISTORICAL TIMELINE

(Utility-Related Items in Gray)

!901 Nikola Tesla receives the patent U.S.685957, "Apparatus for the Utilization of Radiant Energy", and U.S.685958, "Method of Utilizing of Radiant Energy".

1905 Albert Einstein publishes his paper on the photoelectric effect (along with a paper on his theory of relativity).

1918 Jan Czochralski, a Polish scientist, produces a method to grow single-crystal silicon.

1950s Bell Labs produces solar cells for use in the space program. The work of Bell Labs represents the birth of the modern era of the solar PV industry.

1955 Western Electric licenses commercial solar cell technologies. Hoffman Electronics-Semiconductor Division creates a 2% efficient commercial solar cell for $1,785/ Watt.

1956 William Cherry, U.S. Signal Corps Laboratories, approaches RCA Labs' Paul Rappaport and Joseph Loferski about developing photovoltaic cells for proposed orbiting Earth satellites.

1958 Hoffman Electronics achieves 9% efficient photovoltaic cells.

1959 The National Aeronautics and Space Administration (NASA) uses solar modules to power the Vanguard 1 satellite. This was a perfect solution to the power needs of space exploration, as solar modules are lightweight, durable, and require little-to-no maintenance. Sunlight is also in constant abundance in space.

1960 Hoffman Electronics achieves 14% efficient photovoltaic cells.

1963 Japan installs the largest array of the time, a 242-watt, photovoltaic array on a lighthouse.

1970s Dr. Elliot Berman, with help from Exxon Corporation, designs a significantly less costly solar cell, bringing price down from $100 a watt to $20 a watt. Solar cells begin to power navigation warning lights and horns on many offshore gas and oil rigs, lighthouses, railroad crossings and for off-grid residential applications.

1977 Total global PV manufacturing production exceeds 500 kilowatts.

The U.S. Department of Energy launches the Solar Energy Research Institute "National Renewable Energy Laboratory", a federal facility dedicated to harnessing power from the sun.

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1978 The Public Utility Regulatory Policies Act (PURPA) mandates the purchase of electricity from solar producers determined to be qualifying facilities (QFs) that meet specified technical standards for energy source and efficiency.

A 15-percent federal energy tax credit is added to an existing 10-percent investment tax credit, providing incentive for capital investment in solar thermal generation facilities for independent power producers.

1982 The first, photovoltaic megawatt-scale power station goes on-line in Hisperia, California. It has a 1-megawatt capacity system, developed by ARCO Solar, with modules on 108 dual-axis trackers.

Worldwide photovoltaic production exceeds 9.3 megawatts.

1983 Worldwide photovoltaic production exceeds 21.3 megawatts, with sales of more than $250 million.

ARCO Solar dedicates a 6-megawatt photovoltaic substation in central California. The 120-acre, unmanned facility supplies the Pacific Gas & Electric Company's utility grid with enough power for 2,000-2,500 homes.

The first in a series of Solar Electric Generating Stations (SEGS) plants, generating 13.8 megawatts, is installed, with output sold to Southern California Edison Company. SEGS I uses solar trough technology to produce steam in a conventional steam turbine generator. Natural gas is used as a supplementary fuel for up to 25 percent of the heat input.

1984 The Sacramento Municipal Utility District commissions its first 1-megawatt photovoltaic electricity generating facility.

1985 20% energy conversion efficient silicon cells are created by the Centre for Photovoltaic Engineering at the University of New South Wales.

1986 ARCO Solar releases the G-4000—the world's first commercial thin-film solar module.

The world's largest solar thermal facility is commissioned in Kramer Junction, California. This is the first of 9 SEGS solar thermal installations produced by Luz International.

1989 Federal regulations that govern the size of solar power plants are modified to increase maximum plant size to 80 megawatts from 30 megawatts. The larger size allows SEGS VIII and IX to improve the economics of the power block, controls and auxiliary equipment, and to lower operating and maintenance costs.

1991 Luz International goes bankrupt while building its tenth SEGS plant. SEGS I through IX remain in operation totaling 354 MW.

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1992 University of South Florida develops a 15.9% efficient thin-film photovoltaic cell made of cadmium telluride, breaking the 15% barrier for the first time for this technology.

A 7.5-kilowatt dish prototype system using an advanced stretched-membrane concentrator, through a joint venture of Sandia National Laboratories and Cummins Power Generation is installed in Abilene, Texas.

The Energy Policy Act restores the 10-percent federal investment tax credit for independent power producers using solar technologies.

1993 Pacific Gas & Electric installs a 500-kilowatt "distributed power" PV system in Kerman, California.

The National Renewable Energy Laboratory (NREL) completes construction of its Solar Energy Research Facility; it will be recognized as the most energy-efficient of all U.S. government buildings in the world.

1994 Solar global cumulative installed capacity reaches 500MW.

NREL develops a solar cell—made from gallium indium phosphide and gallium arsenide—that becomes the first one to exceed 30% conversion efficiency.

The first solar dish generator to use a free-piston Stirling engine is hooked up to a utility grid.

NREL develops a solar cell made of gallium indium phosphide and gallium arsenide; it's the first one of its kind to exceed 30% conversion efficiency.

1996 Solar Two, a test 10MW solar concentrator is installed in Barstow, California.

1998 Solar global cumulative installed capacity reaches 1 GW.

1999 Spectrolab, Inc. and the National Renewable Energy Laboratory develop a photovoltaic solar cell that converts 32.3 percent of the sunlight that hits it into electricity.

Researchers at NREL develop a record-breaking prototype thin film solar cell that measures 18.8% efficient, topping the previous record for its type by more than 1%.

Cumulative installed photovoltaic capacity reaches 1000 MW worldwide.

2000 In Perrysburg, Ohio First Solar establishes the largest photovoltaic manufacturing plant with capacity to produce 1000 MW of panels annually.

2001 Solar global cumulative installed Capacity reaches 2 GW.

PowerLight Corporation (now SunPower) installs the largest rooftop solar power system in the United States—a 1.18 megawatt system—at the Santa Rita Jail in Dublin,

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California.

2002 President George W. Bush installs 'building-integrated photovoltaics' or BI-PV solar electric generators at the White House .

2003 Solar global cumulative installed Capacity reaches 3 GW.

2004 Solar global cumulative installed capacity reaches 4 GW.

California Governor Arnold Schwarzenegger proposes the Solar Roofs Initiative for one million solar roofs in California by 2017.

Colorado voters pass Amendment 37, the first state renewable energy portfolio standard approved by voters through a ballot initiative. The initiative requires the state's largest utilities to obtain 3 percent of their electricity from renewable energy resources by 2007 (with 4 percent of that coming from a solar carve-out) and 10 percent by 2015. It also establishes a standard net metering system for homeowners and ranchers.

2005 Polysilicon use in photovoltaics exceeds all other polysilicon use for the first time.

New solar cell breaks the "40 Percent Efficient" sunlight-to-electricity barrier

2006 Solar global cumulative installed capacity reaches 8 GW.

California Public Utilities Commission approved the California Solar Initiative (CSI), a $2.8 billion program that provides incentives toward solar development for the next 11 years.

Solar market reaches more than 2 GW of solar cell manufacturing output; $15 billion in revenues and $264 million in venture capital investment.

Colorado utility Xcel Energy begins its solar rebate program. Originally opponents of the state's solar initiative, the utility now offers funding for solar energy systems to be rebated at $2 per watt for residential systems up to 10 kilowatts (kW).

2007 Solar global cumulative installed capacity reaches 10 GW.

SolarWorld AG Announces it will build 500 MW solar manufacturing plant in Hillsboro, Oregon—largest in U.S.

Acciona completes 64 MW solar thermal plant in Nevada. It is the largest solar plant to be built in the world in the last 16 years. This project is representative of the rebirth of CSP in Spain and the U.S.

Google's 1.6 MW solar panel project begins operation—largest corporate solar installation to date.

More than 24,000 MW in solar thermal projects applied for under BLM land in Southeast California desert.

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California Public Utilities Commission approves the California Solar Initiative (CSI), a comprehensive $2.8 billion program that provides incentives toward solar development over 11 years. Originally limited to customers of the state's investor-owned utilities, the CSI is expanded in August 2006, as a result of Senate Bill 1, to encompass municipal utility territories as well. Municipal utilities are required to offer incentives beginning in 2008 (nearly $800 million); many already offer PV rebates.

California utility PG&E announces it will buy an additional 1,000 megawatts of solar thermal power over the next five years.

Florida utility FPL announces it will spend $1.5 billion over the next seven years to build solar power plants in California and Florida. That includes a 300-megawatt solar power station using technology developed by Ausra, a Silicon Valley start-up.

2008 PG&E signs the largest solar PPA in history for 900 MW (enough to power half a million homes) from five CSP plants to be built and operated by BrightSource in the Mojave Desert. The deal follows previous agreements by PG&E to buy more than 700 MW of solar CSP from providers Ausra and Solel.

The Sacramento Municipal Utility District announces its largest solar homes deal—$8.9 million in incentives and rebates for 1,487 residences built by Woodside Homes near Rancho Cordova, Calif. It will bring the number of homes powered by solar under SMUD's SolarSmart program to 4,000.

New Jersey's largest utility, PSE&G, receives approval from state regulators to offer $105 million in loans to help finance the installation of solar systems on homes, businesses and municipal buildings.

Duke Energy announces $100 million investment in rooftop solar on commercial buildings and signs a PPA with SunEdison to purchase the electricity from a 16 MW solar PV system in North Carolina.

Southern California Edison announces a planned $875 million program to install 250 MW of solar PV on commercial rooftops over the next five years.

Sources: Clean Edge Research, Solarbuzz, EERE, Wikipedia, Renewable Energy World, and the books From Space to Earth: The Story of Solar Electricity by John Perlin and Solar Revolution by Travis Bradford.

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Nuclear bomb

Nuclear energy, the sequel, is opening to raves by everybody from John McCain to a Greenpeace co-founder. Don't be fooled. It's the "Ishtar" of power generation.

By Joseph Romm

June 2, 2008 | No nuclear power plants have been ordered in this country for three decades. Once touted as "too cheap to meter," nuclear power simply became "too costly to matter," as the Economist put it back in May 2001.

Yet growing concern over greenhouse gas emissions from fossil fuel plants has created a surge of new interest in nuclear. Wired magazine just proclaimed "Go nuclear" on its cover. Environmentalists like Stewart Brand and James Lovelock have begun embracing nukes as a core climate solution. And GOP presidential nominee John McCain, who has called for building hundreds of new nuclear plants in this country, recently announced he won't bother showing up to vote on his friend Joe Lieberman's climate bill because of insufficient subsidies (read "pork") for nuclear power.

What do they know that scores of utility executives and the Economist don't? Nothing, actually. Nuclear power still has so many problems that unless the federal government shovels tens of billions of dollars more in subsidies to the industry, and then shoves it down the throat of U.S. utilities and the public with mandates, it is unlikely to see a significant renaissance in this country. Nor is nuclear power likely to make up even 10 percent of the solution to the climate problem globally.

Why? In a word, cost. Many other technologies can deliver more low-carbon power at far less cost. As a 2003 MIT study, "The Future of Nuclear Energy," concluded: "The prospects for nuclear energy as an option are limited" by many "unresolved problems," of which "high relative cost" is only one. Others include environment, safety and health issues, nuclear proliferation concerns, and the challenge of long-term waste management.

Since new nuclear power now costs more than double what the MIT report assumed -- three times what the Economist called "too costly to matter" -- let me focus solely on the unresolved problem of cost. While safety, proliferation and waste issues get most of the publicity, nuclear plants have become so expensive that cost overwhelms the other problems.

Already nuclear energy, the sequel, is a source of major confusion in the popular press. Consider this recent interview between Newsweek's Fareed Zakaria and Patrick Moore, one of the co-founders of Greenpeace, who is now a strong advocate for nuclear power. Zakaria asks, "A number of analyses say that nuclear power isn't cost competitive, and that without government subsidies, there's no real market for it." Moore replies:

That's simply not true. Where the massive government subsidies are is in wind and solar ... I know that the cost of production of electricity among the 104 nuclear plants operating in the United States is 1.68 cents per kilowatt-hour. That's not including the capital costs, but the cost of production of electricity from nuclear is very low, and competitive with dirty coal. Gas costs three times as much as nuclear, at least. Wind costs five times as much, and solar costs 10 times as much.

In short: That's absurd. Nuclear power, a mature industry providing 20 percent of U.S. power, has received some $100 billion in U.S. subsidies -- more than three times the subsidies of wind and solar, even though they are both emerging industries. And how can one possibly ignore the capital costs of arguably the most capital-intensive form of energy? Moore's statement is like saying "My house is incredibly cheap to live in, if I don't include the mortgage."

Furthermore, after capital costs, wind power and solar power are pretty much free -- nobody charges for the breeze and the sun. Operation is also cheap, compared with nukes, which run on expensive uranium and must be monitored minute by minute so they don't melt down. Moore is talking about old nuclear plants, which have been paid off. But the price of new nuclear power has risen faster than any other form of power, as a detailed study of coal, gas, wind and nuclear power capital costs by Cambridge Energy Research Associates concluded.

In fact, from 2000 through October 2007, nuclear power plant construction costs -- mainly materials, labor and engineering -- have gone up 185 percent! That means a nuclear power plant that would have cost $4 billion to build in 2000 would have cost more than $11 billion to build last October.

You know an industry is starting to price itself out of business when one of its trade magazines, Nuclear Engineering International, headlines a recent article "How Much? For Some Utilities, the Capital Costs of a New Nuclear Power Plant Are Prohibitive."

As the article related, in 2005, the U.S. Energy Information Administration projected about $2,000 per kilowatt for a nuclear plant's "overnight capital costs" -- the industry's rosy-eyed terminology for the cost of the plant if it could be built overnight, absent interest and financing costs, and assuming no construction cost overruns. At the time, Marvin Fertel, the chief nuclear officer at the Nuclear Energy Institute (NEI), told the Senate that the assumptions made on new nuclear plant construction were "unrealistically high and inflated."

But by mid-2007, a Keystone report, funded in part by the nuclear industry and NEI, estimated overnight costs at $3,000 per kilowatt, which, with interest, equals $3,600 to $4,000 per kilowatt. The report notes, "The power isn't cheap: 8.3 to 11.1 cents per kilowatt hour." That's not cheap, when you consider that in December 2007, retail prices in this country averaged 8.9 cents per kilowatt-hour.

Mid-2007 had already become the good old days for affordable nuclear power. Jim Harding, who was on the Keystone Center panel and was responsible for its economic analysis, e-mailed me in May that his current "reasonable estimate for levelized cost range ... is 12 to 17 cents per kilowatt hour lifetime, and 1.7 times that number [20 to 29 cents per kilowatt-hour] in first year of commercial operation."

At the end of August 2007, American Electric Power CEO Michael Morris said that because of construction delays and high costs, the company wasn't planning to build any new nuclear plants. Also, builders would have to queue for certain parts and face "realistic" costs of about $4,000 a kilowatt. "I'm not convinced we'll see a new nuclear station before probably the 2020 timeline," Morris said.

So much for being a near-term, cost-effective solution to our climate problem. But if $4,000 per kilowatt was starting to price nuclear out of the marketplace, imagine what prices 50 percent to 100 percent higher will do.

In October 2007, Florida Power and Light (FPL), "a leader in nuclear power generation," presented its detailed cost estimate for new nukes to the Florida Public Service Commission. It concluded that two units totaling 2,200 megawatts would cost from $5,500 to $8,100 per kilowatt -- $12 billion to $18 billion total!

Lew Hay, chairman and CEO of FPL, said, "If our cost estimates are even close to being right, the cost of a two-unit plant will be on the order of magnitude of $13 to $14 billion. That's bigger than the total market capitalization of many companies in the U.S. utility industry and 50 percent or more of the market capitalization of all companies in our industry with the exception of Exelon." This, he said, "is a huge bet for any CEO to take to his or her board."

In January, MidAmerican Nuclear Energy Co. said prices were so high it was ending its pursuit of a nuclear power plant in Payette County, Idaho, after spending $13 million researching its economic feasibility. Company president Bill Fehrman said, "Consumers expect reasonably priced energy, and the company's due diligence process has led to the conclusion that it does not make economic sense to pursue the project at this time."

MidAmerican is owned by famed investor Warren Buffett. When Buffett pulls the plug on a potential investment after spending $13 million analyzing the deal, that should give everyone pause.

How expensive have nuclear plants become? So expensive that Duke Power has been refusing to reveal cost estimates for a nuclear plant for the Carolinas, saying it would reveal trade secrets. I kid you not. The Charlotte News & Observer reported in April, "'If Duke is requested to disclose the cost today, it will undermine the company's ability to get the lowest cost for its customers,' said Duke attorney Lawrence Somers. 'In light of the testimony today, the public advocacy groups want the cost of this plant to go up.'"

Yes, those annoying public advocacy groups want to know the cost to the public of the plants before supporting them. The company actually testified that if everyone knew the plant's cost, that would "give tactical advantage to vendors and contractors during sensitive negotiations." What Duke seems to be saying is that if suppliers knew just how incredibly expensive the plant is, they would want a bigger piece of the pie. Such is the state of our free-market energy economy today.

Amazingly, North Carolina regulators agreed with Duke that the estimated cost is a "trade secret" under state law. South Carolina's consumer advocate, C. Dukes Scott, took a stance that was once called common sense in this country: "If you want the ratepayers to pay for something, are you going to tell them it's none of their business?"

In fact, back in February, Duke Energy CEO Jim Rogers told state regulators the plant would cost $6 billion to $8 billion, but a mere two months later said that estimate was "dated and inaccurate." Scott wondered, "If the cost wasn't confidential in February, how is it confidential in April?"

Let's take a look at one more example. Earlier this year, Progress Energy informed state regulators that the twin 1,100-megawatt plants it intends to build in Florida would cost $14 billion, which "triples estimates the utility offered little more than a year ago." That would be more than $6,400 a kilowatt. But wait, that's not all. As reported by the St. Petersburg Times, "The utility said its 200 mile, 10-county transmission project will cost $3-billion more." If we factor that cost in, the price would be $7,700 a kilowatt.

Amazingly, the utility won't even stand behind the exorbitant tripled cost for the plant. In its filing with state regulators, Progress Energy warned that its new $17 billion estimate for its planned nuclear facility is "nonbinding" and "subject to change over time."

And it gets even better (by I which I mean, worse) for Florida ratepayers. Florida passed a law that allows utilities to recoup some costs while a nuclear plant is under construction. How much? About $9 a month starting as early as next year! Yes, the lucky customers of Progress Energy get to each pay more than $100 a year for years and years and years before they even get one kilowatt-hour from these plants.

This would seem to be the exact opposite of the old claim for the nuclear industry, "Too cheap to meter." Now it's so expensive the company raises your rates before the power even gets to the meter!

How the renewable industry would love to charge people before they built their plants. Even without that benefit, Jigar Shah, chief strategy officer of SunEdison, explained to me that he could guarantee delivery to Florida of more kilowatt-hours of power with solar photovoltaics -- including energy storage so the power was not intermittent -- for less money than the nuke plants cost.

Many other forms of carbon-free power are already cheaper than nuclear today, including wind power, concentrated solar thermal power and, of course, the cheapest of all, energy efficiency. Over the past three decades, California efficiency programs have cut total electricity demand by about 40,000 gigawatt hours for an average 2 to 3 cents per kilowatt-hour. A May presentation of modeling results by the California Public Utilities Commission shows that it could more than double those savings by 2020.

If California's effort were reproduced nationwide, efficiency would deliver 130 gigawatts by 2020, which is more than enough energy savings to avoid the need to build any new power plants through 2020 (and beyond). And that means any new renewable plants built could displace existing fossil fuel plants and begin to reduce U.S. carbon dioxide emissions from the utility sector.

A May report by the Bush Energy Department concluded that Americans could get 300 gigawatts of wind by 2030 at a cost of 6 to 8.5 cents per kilowatt-hour, including the cost of transmission to access existing power lines. And the cost of integrating the variable wind power into the U.S. grid would be under 0.5 cents per kilowatt-hour. (Wind turbines provide energy on average 35 percent of the time. Nukes average 90 percent availability. That means it takes 300 gigawatts of wind capacity to deliver as much electricity as about 120 gigawatts of nuclear.)

Finally we have the reemergence of concentrated solar thermal power (also known as concentrated solar power, or CSP). Utilities in the Southwest are already contracting for power at 14 to 15 cents per kilowatt-hour. The modeling for the California Public Utilities Commission puts solar thermal at around 13 cents per kilowatt-hour. Because CSP has large cost-reduction opportunities from economies of scale and the manufacturing learning curve, the modeling foresees the possibility that CSP costs could drop an additional 20 percent by 2020. And those prices include six hours of storage capacity, which allows CSP to follow the electric load, and that is even better than nuclear power, which is constant around the clock.

All of these sources of electricity are considerably cheaper than the electricity that would be generated by new nuclear plants, which the commission estimates costs more than 15 cents per kilowatt-hour before transmission and delivery costs. This entire discussion doesn't even consider the issue of uranium supply, whose price has risen sharply in recent years. A big shift toward nuclear power would no doubt further increase prices. If, as many advocates want, we ultimately go toward reprocessing of spent fuel, that would add an additional 1.5 to 3 cents per kilowatt-hour to the cost of nuclear power.

Sen. McCain keeps saying, "If France can produce 80 percent of its electricity with nuclear power, why can't we?" Wrong question, Senator. The right question is: Why would we? Energy efficiency and renewables are the key to affordable, carbon-free electricity. They should be a focus of national energy and climate policy. Not nukes.

Visit *Climate Progress* to read "The Self-Limiting Future of Nuclear Power," Joseph Romm's extended analysis of nuclear energy. The report will available June 2 at 10 a.m. ET.

SCIENTIFIC AMERICAN

Scientific American Magazine - December 16, 2007

A Solar Grand Plan

By 2050 solar power could end U.S. dependence on foreign oil and slash greenhouse gas emissions

By Ken Zweibel, James Mason and Vasilis Fthenakis

High prices for gasoline and home heating oil are here to stay. The U.S. is at war in the Middle East at least in part to protect its foreign oil interests. And as China, India and other nations rapidly increase their demand for fossil fuels, future fighting over energy looms large. In the meantime, power plants that burn coal, oil and natural gas, as well as vehicles everywhere, continue to pour millions of tons of pollutants and greenhouse gases into the atmosphere annually, threatening the planet.

Well-meaning scientists, engineers, economists and politicians have proposed various steps that could slightly reduce fossil-fuel use and emissions. These steps are not enough. The U.S. needs a bold plan to free itself from fossil fuels. Our analysis convinces us that a massive switch to solar power is the logical answer.

Solar energy's potential is off the chart. The energy in sunlight striking the earth for 40 minutes is equivalent to global energy consumption for a year. The U.S. is lucky to be endowed with a vast resource; at least 250,000 square miles of land in the Southwest alone are suitable for constructing solar power plants, and that land receives more than 4,500 quadrillion British thermal units (Btu) of solar radiation a year. Converting only 2.5 percent of that radiation into electricity would match the nation's total energy consumption in 2006.

To convert the country to solar power, huge tracts of land would have to be covered with photovoltaic panels and solar heating troughs. A direct-current (DC) transmission backbone would also have to be erected to send that energy efficiently across the nation.

The technology is ready. On the following pages we present a grand plan that could provide 69 percent of the U.S.'s electricity and 35 percent of its total energy (which includes transportation) with solar power by 2050. We project that this energy could be sold to consumers at rates equivalent to today's rates for conventional power sources, about five cents per kilowatt-hour (kWh). If wind, biomass and geothermal sources were also developed, renewable energy could provide 100 percent of the nation's electricity and 90 percent of its energy by 2100.

The federal government would have to invest more than $400 billion over the next 40 years to complete the 2050 plan. That investment is substantial, but the payoff is greater. Solar plants consume little or no fuel, saving billions of dollars year after year. The infrastructure would displace 300 large coal-fired power plants and 300 more large natural gas plants and all the fuels they consume. The plan would effectively eliminate all imported oil, fundamentally cutting U.S. trade deficits and easing political tension in the Middle East and elsewhere. Because solar technologies are almost pollution-free, the plan would also reduce greenhouse gas emissions from power plants by 1.7 billion tons a year, and another 1.9 billion tons from gasoline vehicles would be displaced by plug-in hybrids refueled by the solar power grid. In 2050 U.S. carbon dioxide emissions would be 62 percent below 2005 levels, putting a major brake on global warming.

Photovoltaic Farms

In the past few years the cost to produce photovoltaic cells and modules has dropped significantly, opening the way for large-scale deployment. Various cell types exist, but the least expensive modules today are thin films made of cadmium telluride. To provide electricity at six cents per kWh by 2020, cadmium telluride modules would have to convert electricity with 14 percent efficiency, and systems would have to be installed at $1.20 per watt of capacity. Current modules have 10 percent efficiency and an installed system cost of about $4 per watt. Progress is clearly needed, but the technology is advancing quickly; commercial efficiencies have risen from 9 to 10 percent in the past 12 months. It is worth noting, too, that as modules improve, rooftop photovoltaics will become more cost-competitive for homeowners, reducing daytime electricity demand.

In our plan, by 2050 photovoltaic technology would provide almost 3,000 gigawatts (GW), or billions of watts, of power. Some 30,000 square miles of photovoltaic arrays would have to be erected. Although this area may sound enormous, installations already in place indicate that the land required for each gigawatt-hour of solar energy produced in the Southwest is less than that needed for a coal-powered plant when factoring in land for coal mining. Studies by the National Renewable Energy Laboratory in Golden, Colo., show that more than enough land in the Southwest is available without requiring use of environmentally sensitive areas, population centers or difficult terrain. Jack Lavelle, a spokesperson for Arizona's Department of Water Conservation, has noted that more than 80 percent of his state's land is not privately owned and that Arizona is very interested in developing its solar potential. The benign nature of photovoltaic plants (including no water consumption) should keep environmental concerns to a minimum.

The main progress required, then, is to raise module efficiency to 14 percent. Although the efficiencies of commercial modules will never reach those of solar cells in the laboratory, cadmium telluride cells at the National Renewable Energy Laboratory are now up to 16.5 percent and rising. At least one manufacturer, First Solar in Perrysburg, Ohio, increased module efficiency from 6 to 10 percent from 2005 to 2007 and is reaching for 11.5 percent by 2010.

Pressurized Caverns

The great limiting factor of solar power, of course, is that it generates little electricity when skies are cloudy and none at night. Excess power must therefore be produced during sunny hours and stored for use during dark hours. Most energy storage systems such as batteries are expensive or inefficient.

Compressed-air energy storage has emerged as a successful alternative. Electricity from photovoltaic plants compresses air and pumps it into vacant underground caverns, abandoned mines, aquifers and depleted natural gas wells. The pressurized air is released on demand to turn a turbine that generates electricity, aided by burning small amounts of natural gas. Compressed-air energy storage plants have been operating reliably in Huntorf, Germany, since 1978 and in McIntosh, Ala., since 1991. The turbines burn only 40 percent of the natural gas they would if they were fueled by natural gas alone, and better heat recovery technology would lower that figure to 30 percent.

Studies by the Electric Power Research Institute in Palo Alto, Calif., indicate that the cost of compressed-air energy storage today is about half that of lead-acid batteries. The research indicates that these facilities would add three or four cents per kWh to photovoltaic generation, bringing the total 2020 cost to eight or nine cents per kWh.

Electricity from photovoltaic farms in the Southwest would be sent over high-voltage DC transmission lines to compressed-air storage facilities throughout the country, where turbines would generate electricity year-round. The key is to find adequate sites. Mapping by the natural gas industry and the Electric Power Research Institute shows that suitable geologic formations exist in 75 percent of the country, often close to metropolitan areas. Indeed, a compressed-air energy storage system would look similar to the U.S. natural gas storage system. The industry stores eight trillion cubic feet of gas in 400 underground reservoirs. By 2050 our plan would require 535 billion cubic feet of storage, with air pressurized at 1,100 pounds per square inch. Although development will be a challenge, plenty of reservoirs are available, and it would be reasonable for the natural gas industry to invest in such a network.

Hot Salt

Another technology that would supply perhaps one fifth of the solar energy in our vision is known as concentrated solar power. In this design, long, metallic mirrors focus sunlight onto a pipe filled with fluid, heating the fluid like a huge magnifying glass might. The hot fluid runs through a heat exchanger, producing steam that turns a turbine.

For energy storage, the pipes run into a large, insulated tank filled with molten salt, which retains heat efficiently. Heat is extracted at night, creating steam. The molten salt does slowly cool, however, so the energy stored must be tapped within a day.

Nine concentrated solar power plants with a total capacity of 354 megawatts (MW) have been generating electricity reliably for years in the U.S. A new 64-MW plant in Nevada came online in March 2007. These plants, however, do not have heat storage. The first commercial installation to incorporate it—a 50-MW plant with seven hours of molten salt storage—is being constructed in Spain, and others are being designed around the world. For our plan, 16 hours of storage would be needed so that electricity could be generated 24 hours a day.

Existing plants prove that concentrated solar power is practical, but costs must decrease. Economies of scale and continued research would help. In 2006 a report by the Solar Task Force of the Western Governors' Association concluded that concentrated solar power could provide electricity at 10 cents per kWh or less by 2015 if 4 GW of plants were constructed. Finding ways to boost the temperature of heat exchanger fluids would raise operating efficiency, too. Engineers are also investigating how to use molten salt itself as the heat-transfer fluid, reducing heat losses as well as capital costs. Salt is corrosive, however, so more resilient piping systems are needed.

Concentrated solar power and photovoltaics represent two different technology paths. Neither is fully developed, so our plan brings them both to large-scale deployment by 2020, giving them time to mature. Various combinations of solar technologies might also evolve to meet demand economically. As installations expand, engineers and accountants can evaluate the pros and cons, and investors may decide to support one technology more than another.

Direct Current, Too

The geography of solar power is obviously different from the nation's current supply scheme. Today coal, oil, natural gas and nuclear power plants dot the landscape, built relatively close to where power is needed. Most of the country's solar generation would stand in the Southwest. The existing system of alternating-current (AC) power lines is not robust enough to carry power from these centers to consumers everywhere and would lose too much energy over long hauls. A new high-voltage, direct-current (HVDC) power transmission backbone would have to be built.

Studies by Oak Ridge National Laboratory indicate that long-distance HVDC lines lose far less energy than AC lines do over equivalent spans. The backbone would radiate from the Southwest toward the nation's borders. The lines would terminate at converter stations where the power would be switched to AC and sent along existing regional transmission lines that supply customers.

The AC system is also simply out of capacity, leading to noted shortages in California and other regions; DC lines are cheaper to build and require less land area than equivalent AC lines. About 500 miles of HVDC lines operate in the U.S. today and have proved reliable and efficient. No major technical advances seem to be needed, but more experience would help refine operations. The Southwest Power Pool of Texas is designing an integrated system of DC and AC transmission to enable development of 10 GW of wind power in western Texas. And TransCanada, Inc., is proposing 2,200 miles of HVDC lines to carry wind energy from Montana and Wyoming south to Las Vegas and beyond.

Stage One: Present to 2020

We have given considerable thought to how the solar grand plan can be deployed. We foresee two distinct stages. The first, from now until 2020, must make solar competitive at the mass-production level. This stage will require the government to guarantee 30-year loans, agree to purchase power and provide price-support subsidies. The annual aid package would rise steadily from 2011 to 2020. At that time, the solar technologies would compete on their own merits. The cumulative subsidy would total $420 billion (we will explain later how to pay this bill).

About 84 GW of photovoltaics and concentrated solar power plants would be built by 2020. In parallel, the DC transmission system would be laid. It would expand via existing rights-of-way along interstate highway corridors, minimizing land-acquisition and regulatory hurdles. This backbone would reach major markets in Phoenix, Las Vegas, Los Angeles and San Diego to the west and San Antonio, Dallas, Houston, New Orleans, Birmingham, Ala., Tampa, Fla., and Atlanta to the east.

Building 1.5 GW of photovoltaics and 1.5 GW of concentrated solar power annually in the first five years would stimulate many manufacturers to scale up. In the next five years, annual construction would rise to 5 GW apiece, helping firms optimize production lines. As a result, solar electricity would fall toward six cents per kWh. This implementation schedule is realistic; more than 5 GW of nuclear power plants were built in the U.S. each year from 1972 to 1987. What is more, solar systems can be manufactured and installed at much faster rates than conventional power plants because of their straightforward design and relative lack of environmental and safety complications.

Stage Two: 2020 to 2050

It is paramount that major market incentives remain in effect through 2020, to set the stage for self-sustained growth thereafter. In extending our model to 2050, we have been conservative. We do not include any technological or cost improvements beyond 2020. We also assume that energy demand will grow nationally by 1 percent a year. In this scenario, by 2050 solar power plants will supply 69 percent of U.S. electricity and 35 percent of total U.S. energy. This quantity includes enough to supply all the electricity consumed by 344 million plug-in hybrid vehicles, which would displace their gasoline counterparts, key to reducing dependence on foreign oil and to mitigating greenhouse gas emissions. Some three million new domestic jobs—notably in manufacturing solar components—would be created, which is several times the number of U.S. jobs that would be lost in the then dwindling fossil-fuel industries.

The huge reduction in imported oil would lower trade balance payments by $300 billion a year, assuming a crude oil price of $60 a barrel (average prices were higher in 2007). Once solar power plants are installed, they must be maintained and repaired, but the price of sunlight is forever free, duplicating those fuel savings year after year. Moreover, the solar investment would enhance national energy security, reduce financial burdens on the military, and greatly decrease the societal costs of pollution and global warming, from human health problems to the ruining of coastlines and farmlands.

Ironically, the solar grand plan would lower energy consumption. Even with 1 percent annual growth in demand, the 100 quadrillion Btu consumed in 2006 would fall to 93 quadrillion Btu by 2050. This unusual offset arises because a good deal of energy is consumed to extract and process fossil fuels, and more is wasted in burning them and controlling their emissions.

To meet the 2050 projection, 46,000 square miles of land would be needed for photovoltaic and concentrated solar power installations. That area is large, and yet it covers just 19 percent of the suitable Southwest land. Most of that land is barren; there is no competing use value. And the land will not be polluted. We have assumed that only 10 percent of the solar capacity in 2050 will come from distributed photovoltaic installations—those on rooftops or commercial lots throughout the country. But as prices drop, these applications could play a bigger role.

2050 and Beyond
Although it is not possible to project with any exactitude 50 or more years into the future, as an exercise to demonstrate the full potential of solar energy we constructed a scenario for 2100. By that time, based on our plan, total energy demand (including transportation) is projected to be 140 quadrillion Btu, with seven times today's electric generating capacity.

To be conservative, again, we estimated how much solar plant capacity would be needed under the historical worst-case solar radiation conditions for the Southwest, which occurred during the winter of 1982–1983 and in 1992 and 1993 following the Mount Pinatubo eruption, according to National Solar Radiation Data Base records from 1961 to 2005. And again, we did not assume any further technological and cost improvements beyond 2020, even though it is nearly certain that in 80 years ongoing research would improve solar efficiency, cost and storage.

Under these assumptions, U.S. energy demand could be fulfilled with the following capacities: 2.9 terawatts (TW) of photovoltaic power going directly to the grid and another 7.5 TW dedicated to compressed-air storage; 2.3 TW of concentrated solar power plants; and 1.3 TW of distributed photovoltaic installations. Supply would be rounded out with 1 TW of wind farms, 0.2 TW of geothermal power plants and 0.25 TW of biomass-based production for fuels. The model includes 0.5 TW of geothermal heat pumps for direct building heating and cooling. The solar systems would require 165,000 square miles of land, still less than the suitable available area in the Southwest.

In 2100 this renewable portfolio could generate 100 percent of all U.S. electricity and more than 90 percent of total U.S. energy. In the spring and summer, the solar infrastructure would produce enough hydrogen to meet more than 90 percent of all transportation fuel demand and would replace the small natural gas supply used to aid compressed-air turbines. Adding 48 billion gallons of biofuel would cover the rest of transportation energy. Energy-related carbon dioxide emissions would be reduced 92 percent below 2005 levels.

Who Pays?
Our model is not an austerity plan, because it includes a 1 percent annual increase in demand, which would sustain lifestyles similar to those today with expected efficiency improvements in energy generation and use. Perhaps the biggest question is how to pay for a $420-billion overhaul of the nation's energy infrastructure. One of the most common ideas is a carbon tax. The International Energy Agency suggests that a carbon tax of $40 to $90 per ton of coal will be required to induce electricity generators to adopt carbon capture and storage systems to reduce carbon dioxide emissions. This tax is equivalent to raising the price of electricity by one to two cents per kWh. But our plan is less expensive. The $420 billion could be generated with a carbon tax of 0.5 cent per kWh. Given that electricity today generally sells for six to 10 cents per kWh, adding 0.5 cent per kWh seems reasonable.

Congress could establish the financial incentives by adopting a national renewable energy plan. Consider the U.S. Farm Price Support program, which has been justified in terms of national security. A solar price support program would secure the nation's energy future, vital to the country's long-term health. Subsidies would be gradually deployed from 2011 to 2020. With a standard 30-year payoff interval, the subsidies would end from 2041 to 2050. The HVDC transmission companies would not have to be subsidized, because they would finance construction of lines and converter stations just as they now finance AC lines, earning revenues by delivering electricity.

Although $420 billion is substantial, the annual expense would be less than the current U.S. Farm Price Support program. It is also less than the tax subsidies that have been levied to build the country's high-speed telecommunications infrastructure over the past 35 years. And it frees the U.S. from policy and budget issues driven by international energy conflicts.

Without subsidies, the solar grand plan is impossible. Other countries have reached similar conclusions: Japan is already building a large, subsidized solar infrastructure, and Germany has embarked on a nationwide program. Although the investment is high, it is important to remember that the energy source, sunlight, is free. There are no annual fuel or pollution-control costs like those for coal, oil or nuclear power, and only a slight cost for natural gas in compressed-air systems, although hydrogen or biofuels could displace that, too. When fuel savings are factored in, the cost of solar would be a bargain in coming decades. But we cannot wait until then to begin scaling up.

Critics have raised other concerns, such as whether material constraints could stifle large-scale installation. With rapid deployment, temporary shortages are possible. But several types of cells exist that use different material combinations. Better processing and recycling are also reducing the amount of materials that cells require. And in the long term, old solar cells can largely be recycled into new solar cells, changing our energy supply picture from depletable fuels to recyclable materials.

The greatest obstacle to implementing a renewable U.S. energy system is not technology or money, however. It is the lack of public awareness that solar power is a practical alternative—and one that can fuel transportation as well. Forward-looking thinkers should try to inspire U.S. citizens, and their political and scientific leaders, about solar power's incredible potential. Once Americans realize that potential, we believe the desire for energy self-sufficiency and the need to reduce carbon dioxide emissions will prompt them to adopt a national solar plan.