



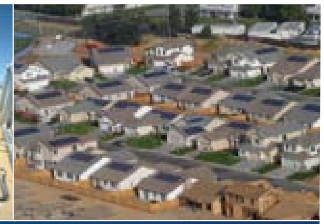

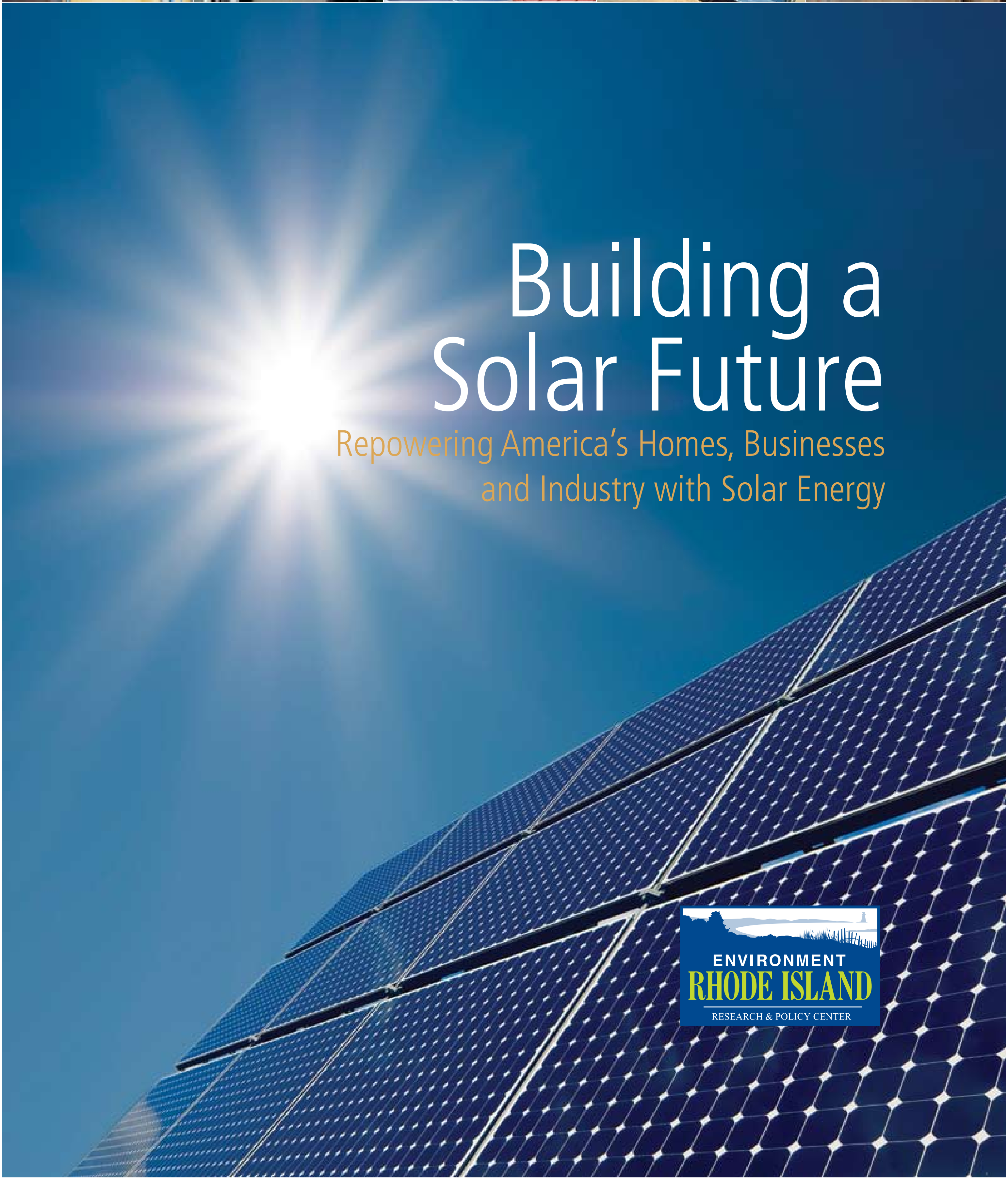

Building a Solar Future

Repowering America's Homes, Businesses and Industry with Solar Energy

ENVIRONMENT
RHODE ISLAND
RESEARCH & POLICY CENTER

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Executive Summary

America has virtually limitless potential to tap the energy of the sun. Solar energy is clean, safe, proven and available everywhere, and the price of many solar energy technologies is declining rapidly. By adopting solar energy on a broad scale, the nation can address our biggest energy challenges—our dependence on fossil fuels and the need to address global warming—while also boosting our economy.

America has the potential to obtain a large and increasing share of our energy from the sun. **In the near term, America should set the ambitious goal of obtaining 10 percent or more of our *total energy consumption** from the sun by 2030, using a wide variety of technologies and tools.** Achieving that target would result in the sun providing us with more energy than we currently produce at nuclear power plants, more than half as much as we currently consume in our cars and light trucks, or nearly half as much as we currently obtain from burning coal.

A comprehensive suite of public policy strategies can remove many of the common barriers to solar energy development and help to make this vision a reality.

There are many ways to take advantage of the sun's energy. Solar energy can be converted to electricity, or used for lighting, heating and cooling. It can replace the fossil fuels we burn at electric power plants, in factories, in our homes, and even in our cars. Solar energy technologies include:

- **Photovoltaics (PV) –** Photovoltaics directly convert solar radiation into electricity. PV can take the form of panels or be incorporated into building materials. PV is scalable, generates electricity anywhere the sun shines, including in cold climates, has no essential moving parts, uses virtually no water, and is one of the few power generation technologies well suited for use in urban areas.

* Note: This goal refers to total energy consumption from *all* sources in the United States, not just electricity consumption.

- **Concentrating solar power (CSP) –** CSP plants use mirrors to focus the sun's energy to harness heat that can be used directly or to generate electricity. Because heat is cheaper and easier to store than electricity, CSP plants with thermal storage can be designed to provide energy from the sun even at night. CSP plants have been reliably generating power in desert areas of the West for decades and are now experiencing a resurgence due in part to falling costs and increasing demand for utility-scale renewable electricity.

- **Solar water heaters –** Rooftop-mounted collectors capture solar energy as heat and produce hot water. Solar heat collectors can be extremely efficient; low-temperature heaters can capture up to 87 percent of the solar energy that reaches them. Solar water heaters can also be adapted for uses ranging from residential water heating to large-scale industrial use.

- **Solar space heating and cooling –** Collectors similar to those used for hot water can also be used to heat air in place of furnaces or boilers. These systems can contribute 50 percent or more of the energy needed to heat a building. Solar energy can even be used to cool buildings through the use of absorption chillers.

- **Passive solar design –** For centuries, skilled builders have designed homes and other buildings that take the best possible advantage of solar energy. "Passive" solar design can contribute to the overall efficiency of a building, reducing the need for energy for lighting, heating and cooling.

Solar energy can help power virtually every aspect of America's economy.

Solar Homes

- New homes can be built to maximize use of the sun's energy through passive solar design and the use of solar PV panels and water heating systems. Solar energy can be paired with advanced energy efficiency techniques to create zero net energy homes, which produce as much energy as they consume. Zero net energy homes have already been built in parts of the country, are possible in all climates, and often save money for consumers over time.

- Many existing homes can also incorporate solar technologies. Photovoltaic panels can be installed on the roofs of 35-40 percent of homes nationwide, and solar heat collectors on 50 percent of residential roofs.

Solar Businesses

- Commercial buildings—such as big-box stores, strip malls and office complexes—also have many opportunities to take advantage of solar energy. About 60 to 65 percent of commercial roof space nationwide is suitable for photovoltaics. Large-scale commercial photovoltaic and solar water heating installations are also cheaper per unit of energy than smaller residential installations.

- Many businesses present unique opportunities to tap solar energy:
    - Walmart's use of skylights in some its big box stores has cut

energy costs by 15 to 20 percent by reducing the need for electric lighting.

- Laundry facilities, hotels, hospitals and even baseball's Boston Red Sox have adopted solar water heating to reduce their consumption of natural gas for water heating.

Solar Factories

Manufacturing facilities consume vast amounts of energy to create heat, much of it at temperatures that could be supplied by solar water heating systems. Food processors, chemical companies and textile plants are among those that are good candidates for solar energy. For example, a Frito-Lay plant in California uses solar concentrators to provide heat for cooking snack foods. At full capacity, the system replaces as much natural gas as is used by 340 average American homes.

Solar Farming

Solar photovoltaics can provide a large share of the electricity needed to operate a farm and keep harvested crops cool, and are especially useful for pumping water, providing irrigation and meeting other needs in remote areas that aren't easily reached by the electric grid. Many farms could also take advantage of solar energy for heating greenhouses, ventilating barns or drying crops.

Solar in Transportation

- The development of plug-in vehicles—both plug-in hybrids and fully electric vehicles—will allow renewable energy to play a larger role in powering our transportation system. Toyota, for example, is developing solar charging stations for its Toyota Prius plug-in hybrid vehicle, due on the market in 2011. In addition, America's vast areas of highways and parking lots could house solar panels.

- New transportation technologies create new opportunities to use solar power. California's high-speed rail authority has committed to powering the state's new rail system with renewable energy, while major shipping companies are experimenting with the use of "solar sails" to reduce the environmental impact of shipping.

Solar Communities

- Government facilities such as offices, schools and wastewater treatment plants, as well as community institutions such as churches, are often excellent candidates for solar energy.

- New policy tools enable members of a community to work together to finance solar energy installations, enabling even individuals without suitable roofs to take part in expanding solar power.

- Housing developments in Europe and elsewhere have created neighborhood-wide solar district heating systems that reduce fossil fuel consumption for space heating and water heating by 25 percent or more.

Building the Solar Grid

- Concentrating solar power plants can replace coal and other fossil fuels for base load electricity generation.

- Since photovoltaics generate energy best when demand is highest—on hot, sunny summer days—they can reduce the effective peak demand that utilities have to meet, providing stability to the grid, reducing the need for expensive new power plants and transmission lines, and curbing air pollution.

- Photovoltaic cells and solar water heaters distributed on buildings around the country will reduce the amount of energy that needs to flow from central power plants or energy providers to consumers.

- Investing in forms of "smart grid" technologies can expand the amount of electricity the nation can generate from distributed solar power while maintaining reliable electricity supplies.

America can obtain a large share of its energy from the sun. But it will not happen on its own. Local, state and federal governments must implement public policies that remove the barriers currently impeding the spread of solar energy and adopt policies to make solar energy an important part of America's energy future.

- **Financial incentives**, such as grants, tax credits and feed-in tariffs help to compensate homeowners and businessowners for the benefits their investments in solar energy deliver to society and can create a robust early market for solar technologies, building the economies of scale needed to lower the price of solar energy. To create a stable market, financial incentives should be applied consistently over a long period of time, instead of as intermittent, on-again off-again programs.

- **Renewable electricity standards (RES)**, such as those now in place in 29 states, can ensure that utilities integrate solar into their energy profiles. Solar carve-outs, which require that a share of the RES be met with solar energy, can ensure a diversified mix of renewable resources and encourage the development of distributed renewable resources.

- **New financing tools** can help individuals and businesses absorb the large upfront costs of solar installations and begin reaping benefits immediately. Municipalities can use their power to borrow at low interest rates to finance residential solar installations, which can be paid back through assessments on property tax bills. Utility on-bill financing can achieve similar aims, while low-interest loans and loan guarantees can help reduce the payback time for solar energy investments by businesses.

- **Advanced building codes and standards** can ensure that builders take maximum advantage of passive solar heating and lighting in new buildings and create new opportunities for integrating solar energy into existing buildings. Solar-ready building standards guarantee that new homes are built with solar energy in mind, and can be broadened to require that solar energy be offered as an option on new homes. Some states and countries have gone so far as to require the use of solar energy (specifically, solar water heating systems) on new residential buildings.

- **Consistent rules to ensure access to solar energy** are needed to overcome bureaucratic barriers that can prevent individuals and businesses from using solar power. Solar access laws prevent homeowners' associations and municipalities from adopting rules that effectively ban the use of solar energy, while revisions to permitting rules and utility regulations can reduce the hassle and cost of installing solar energy and ensure that people are compensated fairly for the solar power they supply to the grid.

- **Public education and workforce development** efforts are critical to expanding the use of solar energy. Public education programs can help answer consumers' questions about solar energy and make it easier to "go solar." Workforce training can expand the number of workers with the skills needed to partake in the dramatic growth of America's solar energy market. Meanwhile, energy labeling requirements for buildings can ensure that the energy-saving value of passive and active solar energy systems is fully understood when properties change hands.

- **Investments in a solar grid** will be needed to fully tap America's solar energy potential. A well-designed "smart grid" can ensure that solar power is an asset to the electric grid, while limited investments in new transmission capacity can help to tap the nation's best solar resources.

- **Research and development programs** can help ease the integration of existing solar technologies, further develop emerging technologies with great promise for the future, and investigate new potential uses for solar energy.

Introduction

America's energy system is all-important to our economy, but it is so integrated into our daily lives that it has become all but invisible to most of us.

Few of us ever stop to marvel at the path that a drop of oil must take from a Saudi Arabian well to the gas tanks of our cars—the drilling technology that allows the crude oil to be pumped from deep beneath the earth, the pipelines that carry that oil to a port, the military power that keeps the shipping lanes open for the tankers to transport that oil halfway around the world to our shores, the giant refineries that convert the crude oil into gasoline, and the extensive distribution infrastructure that gets the gasoline into our tanks.

Similarly, few of us see the immense infrastructure that turns a lump of coal mined in Montana into the electricity that powers a computer in Alabama—the giant machines that mine the coal, the trains that carry it across the country, the massive power plants that convert it into electricity, the ubiquitous web of wires that transmit that electricity across great distances and through neighborhoods to our homes.

Even fewer of us see the environmental damage left behind by our consumption of fossil fuels. Some of that damage is invisible, such as the health-threatening pollutants that foul our air and infiltrate our lungs or the leaking underground oil storage tanks that slowly pollute drinking water. Sometimes the damage is inflicted far away from where most Americans live, appearing as the melting of Arctic ice due to global warming, or the filling in of a remote Appalachian hollow resulting from mountaintop mining. As people in America and worldwide have awakened to the environmental dangers posed by fossil fuels, we have built even more infrastructure to mitigate those dangers—from installing scrubbers on coal-fired power plants to training hazmat teams to clean up oil spills.

Over the course of more than a century, and with the investment of untold billions of dollars, America has built an energy system that does a masterful job of unlocking the energy stored in underground deposits of fossil fuels and transforming that energy into the heat, electricity and kinetic energy that power our economy. However, that same system does a poor job of taking advantage of the powerful renewable energy sources all around us—especially the sun.

Indeed, as America has built its economy around the expectation of continued access to cheap fossil fuels, we have turned our backs on centuries of received wisdom about how to use the sun's energy to our benefit. Once upon a time, skilled builders oriented homes to take maximum advantage of the sun and wind, installed awnings and deciduous trees to block the sun's rays in summer, and used light-colored building materials to reflect solar energy in hot climates. Today, many of these practices have been eschewed in the quest for mass-produced "cookie cutter" homes that are cheaper to build but more expensive to operate, solidifying our dependence on fossil fuels.

Cheap fossil fuels have also caused us to turn our backs on newer technologies to tap the power of the sun. Solar water heaters have been standard equipment on homes in some parts of the world for decades (and were common in parts of the U.S. in the early part of the last century), yet are rare in the United States today. For years, technologies such as solar photovoltaic panels and concentrating solar power plants have stood ready to play an important role in supplying us with energy, only to falter for lack of consistent government support of the kind enjoyed by the fossil fuel industry.

Today, America is experiencing the downsides of our dependence on fossil fuels as never before. The ominous specter of global warming, the continued pollution of our air and water that results from fossil fuel use, and worries about the cost and availability of fossil fuels in an era of growing worldwide demand—all of these are powerful reasons to look for alternatives. And never before have so many good alternatives been available.

Solar energy has the potential to dramatically reduce our use of fossil fuels in virtually every area of our economy. It is clean, safe, ubiquitous and flexible. It is also increasingly cost competitive with conventional sources of energy.

Taking advantage of America's limitless solar energy potential would deliver great rewards to the nation, but it won't be easy. It will take creativity to transform our energy system from one based on fossil fuels and centralization to one that efficiently reaps solar energy at the places where that energy is used. Realizing a "solar future" for America will require new habits of thinking, new policy tools, and, most of all, a roadmap of where we are headed.

The immense infrastructure that brings fossil fuels to our homes is a potential obstacle to that transformation, but it is also an inspiration. If America and the world can surmount the challenge of using a drop of oil from a desert half a world away to power a trip to the grocery store in Omaha, how much easier must it be to harness the heat and light that strikes our homes every day?

The time has come for America to embrace a vision of a clean energy future, with solar energy as a key contributor, and to lay the groundwork for that future by adopting smart public policies that can transform our economy and preserve our environment.

Why Solar? Why Now?

America urgently needs to reduce our consumption of fossil fuels to protect our environment and ensure our continued economic prosperity. Solar energy can replace many of the fossil fuels we currently use to power our homes, communities, farms, businesses, factories and cars.

America's Dependence on Fossil Fuels: Harming Our Environment and Threatening Our Future

The vast majority of the energy America uses each year, 84 percent of it, comes from fossil fuels.[1] Coal, oil and natural gas are inherently limited resources, requiring tremendous effort and expense to discover, extract, process and distribute. Fossil fuels represent one of the most important day-to-day expenses for American families and businesses—in 2006, the United States spent nearly 7 percent of its gross domestic product, or $921.2 billion, on fossil fuels for home, business and transportation use.[2] For every dollar that an American household spends each year, about 9 cents goes toward the purchase of energy, most of it for fossil fuels.[3]

Perhaps the greatest challenge posed by our dependence on fossil fuels is the damage those fuels do to our environment and our health. Fossil fuel combustion contributes to the formation of smog and soot, which damage the lungs and make the air in areas housing 186 million Americans unhealthy to breathe.[4] The burning of coal contributes to the formation of acid rain and contaminates our waterways with mercury, a neurotoxin that makes fish in many waterways unsafe to eat.

The toll of fossil fuel extraction on our environment is widespread and severe—from oil spills off our coast to the fragmenting of natural habitat for natural gas drilling. Coal mining in the 19th and 20th centuries fouled approximately 9,000 miles of rivers in Appalachia with acid mine drainage.[5] "Mountaintop removal" mining in many of these same areas threatens new environmental damage in the 21st century.

No issue, however, poses as great a long-term threat to our environment as global warming. Global warming is underway, and its impacts can already be felt in the United States and worldwide. Already, plants and animals are being forced northwards by rising temperatures, putting populations at risk.[6] In the oceans, rising temperatures and acidity are rapidly destroying coral reefs and threatening other ecosystems.[7]

Disturbing though these changes are, they are only a fraction of what will take place if we fail to rein in our emissions. In the few years since the Intergovernmental Panel on Climate Change issued its most recent report, global warming's harmful effects have already outpaced the scientists' worst predictions.[8] Worse yet, scientists report that we are approaching "tipping points" at which the effects of global warming will accelerate, and efforts at mitigation become more and more difficult.[9]

If global warming emissions continue unabated, global temperatures may increase by as much as 11.5° F and sea levels could rise 6.5 feet by the end of the century, causing massive flooding and displacement.[10] If global warming is allowed to take place on this scale, the consequences will likely include the extinction of as much as 70 percent of all species on earth, intense heat waves with temperatures reaching 120° F in large parts of the United states, and droughts across as much as a third of the globe.[11]

In 2008, our nation emitted more than 7 billion metric tons of global warming pollution, the vast majority of it resulting from the production and use of fossil fuels.[12] In order to preserve a reasonable chance of keeping the increase in global average temperatures below 2° C, emissions of global warming pollutants must peak soon and be cut by roughly half by mid-century. The United States, as the world's second-largest emitter of global warming pollution, and the country responsible for more of the global warming pollutants in the atmosphere than any other, must go farther and faster than the world as a whole.

Achieving these emission reductions will require us to use every resource available to us to decrease our use of fossil fuels. While energy efficiency will likely account for the first major steps we take towards averting a climate crisis, we will also need to replace existing dirty energy sources with new clean fuels. Solar energy—in the form of solar power plants, solar panels and collectors on our homes and businesses, and new buildings that take advantage of the sun's energy through their design—will be a critical tool for achieving this goal.

Solar Energy: A Powerful Solution

Solar energy technologies are a powerful solution to reduce the environmental damage caused by our dependence on fossil fuels.

Life-cycle analyses of solar photovoltaic (PV) systems show that they dramatically reduce emissions of global warming pollutants and smog- and soot-forming pollutants compared with fossil fuels, even when the emissions created in the manufacturing

The decision to install solar PV yields 26 to 27 years of true fossil fuel-free electricity.

of the PV systems are included. For some PV technologies, life-cycle emission reductions are as high as 89 to 98 percent.[13]

According to the U.S. Department of Energy, the "energy payback" time for a PV system—the amount of time it takes to save as much energy as was used to produce the system—ranges from three to four years and is decreasing over time. Assuming a system lifetime of 30 years, the decision to install PV yields 26 to 27 years of true fossil fuel-free electricity.[14]

Concentrating solar power plants also dramatically reduce fossil fuel use and emissions. According to one analysis, a concentrating solar power plant generates enough energy in its first five months in operation to "repay" the energy used to build the plant.[15]

Solar energy can dramatically reduce our use of fossil fuels and our emissions of global warming pollutants. There are many solar technologies that can play a role in America's energy system, and many ways to use those tools to help power our economy.

Building a Solar Future for America: The Tools

When most people think about solar energy, they think of solar panels sitting on rooftops, or, less frequently, mirrors spread out across the desert. While these technologies are important, they represent only part of the potential for solar energy to transform our energy system.

The sun is a ubiquitous and tremendously flexible source of energy. Solar energy can be converted directly into electricity, stored as heat for later conversion, or used in the forms—light and heat—in which it arrives. It can be captured centrally and then distributed to users, or collected right where it will be used. There are many technologies and tools that can be used to harness solar energy.

Photovoltaic Power

Photovoltaic (PV) cells use the sun's radiation to generate a direct flow of electricity. The two most common forms of PV are crystalline silicon PV—the traditional, self-contained PV panels most Americans envision when considering solar power—and "thin films," inexpensive sheets of material that can be used in panels or be spread across roofs and other architectural features. Crystalline silicon PV panels are frequently more expensive, but are more efficient at converting sunlight into electricity, and can be mounted on a roof or can stand alone on top of a pole or piece of machinery. Thin films, while less efficient, cost less and require less silicon to produce. They can also be integrated unobtrusively into buildings—rolled out across rooftops or walls as a barely visible sheet.

PV systems are easily transportable and installable, and can be used to generate electricity where it will be used, even at locations the electric grid doesn't reach.[16] PV is also modular, so installations can be scaled to the appropriate size for a given use.[17] PV's scalability allows it to be used for both large-scale power plants and to power handheld calculators, and it distinguishes PV from almost every other power generation technology—imagine, for instance, a coal-powered calculator, or a nuclear-powered roadside cell phone call-box.

PV has other advantages as well. PV

Solar photovoltaics help to power the Indian Pueblo Cultural Center in Albuquerque, New Mexico, one of many community buildings that can make good use of solar energy. Credit: Sandia National Laboratories

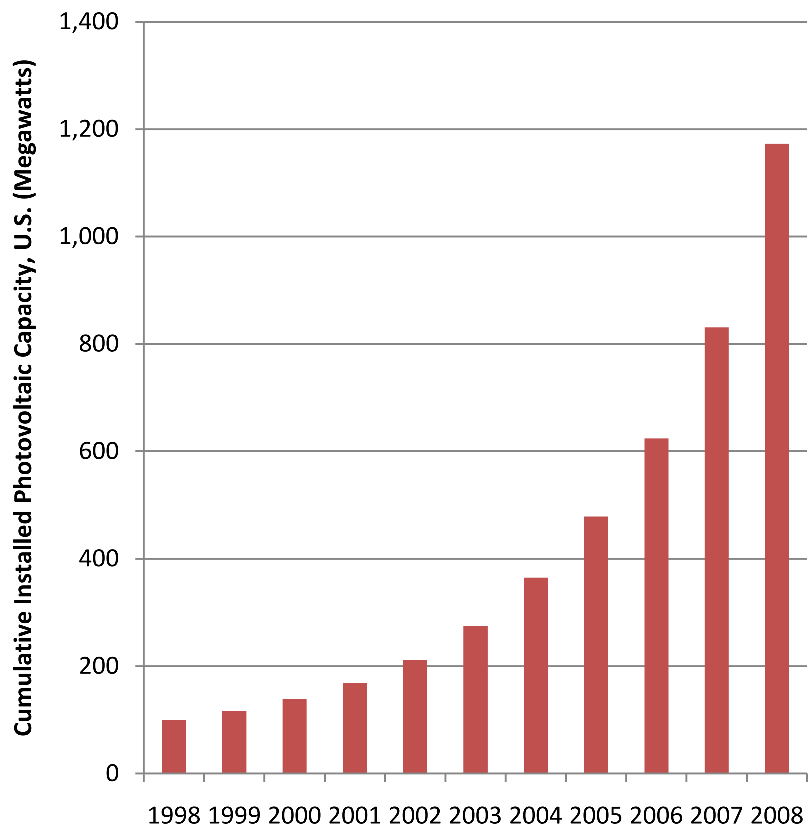
is one of the few power-generating technologies that is a good fit for urban areas—it produces no air pollution and can be installed on buildings, parking lots and other developed areas without interfering with human activities. As a result, there is no additional land required for siting a distributed PV system. PV systems, unlike steam generators, do not use water for anything other than routine cleaning of the panels, making them a good fit for areas with low water availability. And PV systems generate the greatest amount of electricity at the times when it is most needed, particularly hot, sunny summer days.

Photovoltaic installations are increasing rapidly in the United States. Between 1998 and 2008, the amount of installed PV capacity increased by a factor of more than 10, from 100 megawatts (MW) to 1,173 MW.[18] (See Figure 1.) But the potential for PV systems far outstrips the number installed today. America's residential and commercial rooftops, for example, could host as much as 712 gigawatts of solar panels (roughly 700 times the capacity of all solar installations today) if every inch of suitable rooftop were to be covered, enough to produce roughly a quarter of America's electricity using current technologies.[19] Central-station photovoltaic systems in sunny areas, PV systems along roads or over parking lots, and PV installations at factories could add to this total.

Concentrating Solar Power

Whereas PV technologies produce electricity only when the sun is shining on them, concentrating solar power (CSP) can provide a steady and uninterrupted

Figure 1. Installed Photovoltaic Capacity, United States[20]



stream of power by storing the sun's heat and using it to power a generator. These systems are particularly suitable for large power stations, but can also be deployed for smaller scale on-site generation.

All concentrating solar power technologies use mirrors to focus light on a receiver to heat a fluid. Once heat has been captured, it can be stored until it is needed, or it can be used immediately to power a steam generator or heat engine.

Large-scale concentrating solar plants can take several forms—either focusing heat on a single central tower, or on long pipes that carry heated fluid to a central collector. These technologies are versatile enough to use as a stand-alone power plant, as a preheating system for the water used in fossil-fuel plants, or in a hybrid configuration alongside existing fossil fuel generators.[21] CSP plants in California have been reliably producing power for decades, while at least six new plants have come on line since 2006. [22]

Concentrating solar can also be used on a smaller scale, with satellite dish-like mirrors focusing energy on a small receiver that contains a heat exchange engine. These systems have less storage capability, but are also more modular, requiring less access to vast open spaces.

Solar Water Heating

Solar water heating systems are among the simplest uses of sunlight for energy. In solar water heating systems, water (or a heat transfer fluid) is piped to the roof of a building, where it is heated by traveling through sunlight-absorbing pipes. Because

Solar "power towers" such as this one in California use arrays of mirrors to focus sunlight on a central receiver, and can incorporate thermal storage, which enables the plant to deliver electricity even at night. Credit: Sandia National Laboratory

capturing heat from sunlight is simple and efficient, solar water heating systems can absorb as much as 87 percent of the energy radiated at a given section of roof.[23] Solar water heating can be used for swimming pools, to replace conventional residential and commercial hot water heaters, and in larger-scale industrial settings.

A range of collector types is available for heating water with solar energy. The least expensive systems raise water temperatures only about 18° F above the ambient air temperature and are typically used to heat swimming pools.[24] A slightly more expensive collector can heat water to temperatures suitable for a home hot water system.[25] These collectors can function in all climates, and in warm climates they can be made less expensive by storing water on the roof near the collector. The most expensive collectors are designed for applications requiring extremely hot water, or for heating large volumes of water for commercial or industrial use. Solar water heating systems should have a conventional fuel backup to provide heat on cloudy days. Overall, solar collectors can typically provide for 50-80 percent of a building's water heating needs.[26]

Solar water heating has already become widely used in some countries. In Israel, for example, 90 percent of homes currently use solar water heating and Hawaii has recently adopted a standard requiring solar water heating on all new homes built in that state, though with some exceptions.[27]

Passive Solar Lighting and Heating

For most of human history, skilled builders designed buildings to take advantage of the sun for lighting and heating. That changed in the mid-20th century as builders began to rely on cheap energy to make up for deficiencies in a building's design. A renewed focus on energy conservation, however, has brought the practice of daylighting and passive solar heating back into the forefront of architectural thought.

In its simplest form, daylighting is the art of bringing a comfortable amount of light into living and work spaces during the day, without causing excessive glare or heat transfer through windows. Lighting designers can use windows, skylights, reflective surfaces, and exterior features that direct or diffuse light to illuminate rooms and decrease the need for artificial lighting.[28] A well daylit space will have comfortable levels of light in all different areas, throughout the day, and all year round. Daylighting can reduce total building energy costs by as much as one third.[29] Solar lighting systems can be augmented by electric lights that are controlled automatically by dimmer switches and that supplement sunlight when necessary. Advanced systems, meanwhile, can use fiber optic cables to deliver light from collectors on the roof to fixtures that also hold electric lights, automatically decreasing the amount of electricity used as appropriate.[30]

Passive solar heating, much like passive solar lighting, aims to admit solar energy to a building when it is needed, while keeping it out when it is not. South-facing windows that admit winter sunlight (usually positioned so as to be shaded during the summer), skylights, and air circulation features that move solar heat through the house all assist in reducing the need for active heating.[31] Passive solar features can also include sunspaces such as enclosed porches, which provide a pocket of warm air outside the building envelope. Thermal storage walls (dark-colored walls behind glass that can conduct heat to the interior) can store solar energy during the day and release it at night.[32]

Passive solar design techniques such as daylighting can create attractive living spaces while reducing electricity consumption. Credit: U.S. Department of Energy Solar Decathlon, reprinted under Creative Commons license

Active Solar Heating and Cooling

Solar heat can also be captured through active systems, either for heating residential and work spaces or for industrial purposes. The collectors used for these systems generally resemble those used for solar hot water heaters; either glazed plates (for most home space heating applications) or evacuated tubes (for commercial, industrial, or solar cooling applications) are used.[33] In some cases, solar space heating and water heating systems can be combined.

When used for home heating, active solar systems generally provide for 40-80 percent of a building's heating needs.[34]

While solar heating is fairly intuitive, it may be more surprising to learn that solar energy can also be used to cool buildings, even without being converted into electricity. In a solar cooling system, air is cycled through a dessicant material that pulls the humidity out of the air. That material is then baked dry by solar heat—captured just as in a solar heating system—allowing it to be reused. The dry air can then evaporate water from another source, such as an indoor fountain, which cools the air—just as the evaporation of sweat cools a human body. Such systems can save approximately 50 percent of the energy used to air condition a building.[35] They are also at their most effective on sunny days when the need for air conditioning is likely to be greatest.

Solar water heating systems, which are common in parts of the world, can provide 50 to 80 percent of a building's hot water needs. Credit: VELUX/ESTIF

A Solar Future for America

Solar energy can be integrated into virtually every part of American life—the homes we live in, the offices where we work, the farms and factories that produce the products we buy, and the schools where our children learn. With creativity and sound public policy, solar energy can make a major contribution to America's energy future.

Solar Homes

There are more than 128 million housing units in the United States, including more than 80 million single-family homes.[36] Virtually all of these homes consume fossil fuels for heating, lighting, air conditioning and other purposes, yet only a tiny fraction currently produce energy from the sun. Tapping America's full potential for powering our homes with the sun could dramatically reduce our dependence on fossil fuels and our emissions of global warming pollution while also creating thousands of installation jobs that can't be outsourced.

What a Solar Home Looks Like

Solar homes use the energy of the sun to avert the need to burn fossil fuels or tap electricity from the grid. New homes have the greatest potential to take advantage of solar energy, but solar technologies can also be integrated easily into many existing homes.

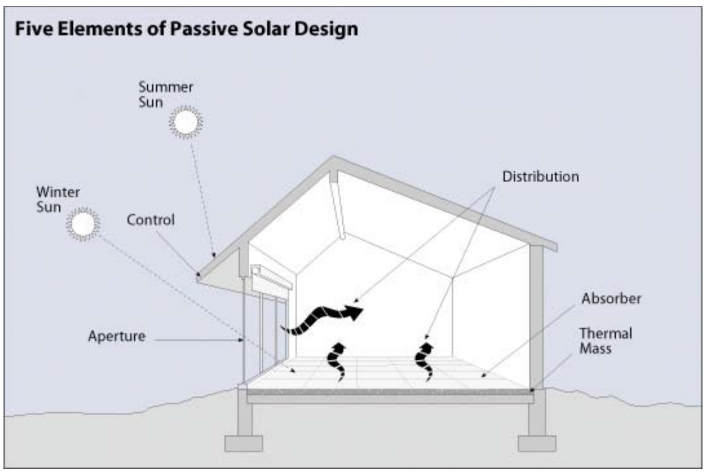
New Homes

New homes are the easiest places to take maximum advantage of the sun's energy. Solar energy can play an important role in the construction of "zero-energy homes," which produce as much energy as they use over the course of a year.

Most of the features that distinguish a "solar home" are subtle. Well-positioned windows and skylights decrease the amount of time that electric lighting is needed each day. Thoughtful building orientation and the proper use of shading elements—such as overhangs, awnings or deciduous trees—allow warming sunlight in during the winter while keeping it out during the summer. "Thermal mass" elements, such as stone walls or floors, can be used to store the sun's warmth during the day and release it at night. Replacing conventional wood-frame walls with thermal mass walls made of concrete, for example, could reduce whole-house energy consumption by 6 to 8 percent.[37]

Not only are many of these design elements energy savers, but many of them also add to the beauty and comfort of a new home.

Figure 2. Elements of a Passive Solar Home[38]



New homes also provide an opportunity to take full advantage of "active" solar energy technologies such as photovoltaics and solar water heating systems. Instead of having to retrofit a building's electricity or plumbing systems to accommodate solar energy, solar technologies can be built into new homes right from the start, and the home and surrounding vegetation can be deliberately designed to maximize the solar energy potential of the home.

Installing a solar water heater in a new home, for instance, can cost just half of what it would to install one in an existing home.[39] Photovoltaics, meanwhile, can be incorporated into building materials so that they require little technical expertise to install. In October 2009, Dow Chemical announced that it would be rolling out a line of solar shingles that it expects to generate $5 billion worth of revenue by 2015, and which will take less than half as long to install as conventional solar panels.[40] Other companies are developing similar products.

Home builders with standardized solar home designs can incorporate solar energy features less expensively than the owner of an existing home, and may be able to shave costs further by ordering solar components in volume and developing a trained workforce. California, for example, has seen the development of new residential subdivisions—amounting to hundreds of homes—that incorporate solar technologies either as an option or a standard feature.[41]

Residents of solar homes have generally been happy with their purchase. A 2006 survey of California solar home owners found that 92 percent would recommend the purchase of a solar home to a friend.[42] Builders of solar homes also benefit because solar homes sell faster than conventional homes.[43] When combined with advanced energy efficiency technologies, passive and active solar energy can dramatically reduce fossil fuel consumption in homes, while saving homeowners money. A study in the U.S. Southwest estimated that "zero-energy" homes could reduce net energy consumption by 60 percent or more. These homes would cost an added $15,000 to $20,000 for construction, but in all cases the homeowner would save more in energy bills than was spent on the energy-saving features.[44]

Nor do solar homes only work in the Southwest or other sunny regions of the United States. A Massachusetts state task force, for example, concluded that the energy savings of a zero-energy home in that cold-weather state more than compensate for the additional upfront cost. In fact, incorporating passive solar features can actually *reduce* some of the costs associated with building a new home by allowing for the installation of smaller, less expensive heating and air conditioning systems.[45]

Some building design experts are contemplating "Energy-Plus" building designs that make homes net energy producers. These homes are built using extremely airtight construction materials and techniques and use designs that take optimal advantage of sunlight. The international Passive House design standard, for example, saves up to 90 percent of the energy used in home space heating.[46] These buildings could be paired with active solar systems to be net sources of energy to their communities.

Existing Homes

Existing homes may not have been built to take advantage of the sun, but many are good candidates for incorporating solar energy.

Photovoltaic panels can be installed on almost any roof, but they are most effective on flat or lightly-sloped roofs facing the equator, which receive direct sunlight throughout most of the day. Current estimates suggest that 35-40 percent of residential buildings are suitable for photovoltaic panels.[47]

Solar water heaters typically decrease the amount of natural gas or electricity required for water heating by 50 to 80 percent.[48] A National Renewable Energy Laboratory study estimated that 50 percent of residential buildings nationwide could use solar water heating systems.[49] As with solar photovoltaic panels, solar water heating systems—in which a rooftop collector is used to pre-heat water for household use—can be installed in any climate, although different types of systems work better in different parts of the country. Solar water heating systems are smaller, technologically simpler, less expensive, and more efficient at capturing the energy at sunlight than solar PV panels. Installing a solar water heater in an existing home

Solar homes—such as those in this California development—are increasingly common and sell more rapidly than conventional homes. Credit: Sacramento Municipal Utility District costs about $6,000.[50] State and federal incentives can defray some of the cost of installing solar water heaters.

Solar Businesses

America's commercial buildings—its big-box stores, strip malls, hotels, office buildings, and the like—are just as dependent on fossil fuels as our nation's homes. Commercial buildings are responsible for nearly roughly 14 percent of the nation's energy consumption.[51] For certain types of businesses, fossil fuel expenditures can be a major business expense. A growing number of firms nationwide are coming to recognize that adopting solar energy makes good business sense, as well as good environmental sense.

What a Solar Business Looks Like

America's commercial sector is extraordinarily diverse, with businesses of many types ranging in size from mom-and-pop stores to giant office complexes. Different kinds of commercial buildings present different kinds of opportunities for using solar energy. Businesses that use a particularly large amount of energy for any one purpose have the potential to take advantage of the economies of scale described for homes in offsetting that need with solar energy.

- Big box stores are single-story buildings and use a great deal of electricity for indoor lighting during the daytime. By installing just one skylight per 1,000 square feet of store space and using dimmable indoor lights, Walmart has been able to save 15-20 percent of total building energy costs in many of its superstores.[52] In addition, Walmart has installed solar PV systems on 20 of its stores and plans to expand its production of solar electricity in the years to come.[53]

- Warehouses also use a great deal of energy on lighting, and can benefit from incorporating passive solar lighting features. Temperature-controlled warehouses can save energy by incorporating appropriate passive solar heating or cooling features.[54]

- Laundromats use a great deal of energy to heat both water for washers and air for dryers, and can use solar energy for both of these purposes. For example, the World's Largest Laundromat in Berwyn, Illinois, installed a solar water heating system designed to produce 2,400 gallons of hot water every day after natural gas prices spiked in 2001.[55] Other kinds of businesses and institutions with large laundry facilities, such as prisons and hotels, can use solar energy in a fashion similar to laundromats.

- Restaurants and other businesses that serve food to many customers can use solar water heating for their water heating needs. Baseball's Boston Red Sox, for example, installed solar water heaters on the roof of Fenway Park, reducing consumption of natural gas for water heating at the facility by more than one-third.[56]

- Businesses and institutions with large public meeting spaces or other open spaces can use 50 percent or more of their total energy on heating, and could use solar heating systems to offset their need for conventional heating.[57]

As with solar homes, newly built commercial buildings can be designed to incorporate passive and active solar features from the very beginning, reducing their cost. A 2007 assessment of several categories of "green buildings" (some of which incorporate passive or active solar energy systems), for example, found that there was no significant difference in the cost of building green versus non-green buildings.[58] A similar analysis of buildings meeting the Leadership in Energy and Environmental Design (LEED) standards found that buildings meeting the criteria of the lowest three tiers of the LEED program cost an additional 2 percent or less to build, while cutting energy consumption by 28 to 48 percent.[59]

Commercial buildings are much more likely than residential buildings to have flat roofs, meaning that many of them can play host to properly oriented photovoltaic panels or solar water heating systems. A report for the National Renewable Energy Laboratory estimated that 60-65 percent of commercial roof space nationwide would be suitable for PV panel installation.[60]

Many businesses have larger roofs, and use more energy, than residential energy customers. This makes it possible for them to take advantage of the significant economies of scale that come with purchasing and installing active solar installations of larger sizes. Large photovoltaic systems with between 500 and 750 kilowatts (kW) of capacity, for instance, cost about 30 percent less per Watt of capacity than small residential systems.[61] The high-efficiency heat collectors often used for commercial solar heating applications, meanwhile, can be installed in large numbers and coupled with mirrors to enhance their effectiveness. These measures can reduce the per-square-foot cost of these high-efficiency collectors to 50 percent or more below the average cost of residential units.[62]

One potential barrier is that commercial establishments are disproportionately likely to rent their buildings, creating potential "split incentive" problems, in which builders bear the cost of installing solar energy systems but tenants reap the benefits in reduced energy costs. Feed-in tariffs and third-party financing tools can help to surmount these obstacles. (See page 43.)

Workers install solar panels on the roof of the supervisor's office at Wayne National Forest in Ohio. Many office buildings can take advantage of solar energy. Credit: Alex Snyder, Wayne National Forest

Solar Factories

Historically, manufacturing facilities have been thought of as environmental polluters, not potential contributors to a green future. But America's manufacturing sector has a great deal to gain from a transition to cleaner sources of energy.

Manufacturing is extremely energy intensive. Food processing facilities, cement plants, steel mills and other industrial facilities use energy on a vast scale. They are responsible for roughly 28 percent of the global warming pollution emitted in the United States.[63] Reducing fossil fuel consumption in factories is not just a matter of environmental concern. American manufacturers face the challenge of international competition—reducing energy costs is just one way to remain competitive.

Solar energy cannot replace all the energy that is used by America's manufacturing sector, but it can make an important contribution to meeting the energy needs of many of America's factories.

What a Solar Factory Looks Like

America's manufacturers use energy for a wide array of purposes. Electricity is used to light shop floors and power machinery, fossil fuels are burned in boilers to create steam and process heat and to generate electricity. Solar energy can help to alleviate energy demand in several of these areas.

The creation of "process heat" uses more energy in America's manufacturing sector than any other single activity.[64] Melting iron in a mill or cooking cement in a kiln obviously requires process heat, but so does distilling ingredients in a pharmaceutical plant, pasteurizing milk in a food processing plant, or bleaching cloth at a textile mill.

Uses of process heat are classified by the temperatures required. Some processes take place at temperatures well above what can be achieved economically using solar energy, but many others take place at lower temperatures. About 30 percent of process heat is used at "low" temperatures—below the boiling point of water—and another 27 percent is used at "medium" temperatures—between 100 and 400° C.[65] Solar heat is most useful for processes occurring at less than 250° C.[66] In certain key industries—such as food, textiles, and paper—60 percent or more of process heat is needed at these temperatures.[67] Solar water heating is potentially

Audi installed a solar cooling system (above) at its training center in Ingolstadt, Germany. Credit: Solahart/ESTIF.

well-suited to several uses of industrial heat, including cleaning, drying, preheating of boiler water, and sterilization.[68]

Industrial plants that use large amounts of process heat at low and medium temperatures can potentially install large arrays of solar thermal collectors to provide that heat. Worldwide, approximately 90 solar process heat systems are currently in place, including several in the United States.[69] The largest solar process heat system in operation in the United States is located at a Frito-Lay factory in California. It uses a 5-acre field of solar concentrators to create steam, which is used to heat the oil used to cook the company's SunChips brand of snack foods.[70] At full capacity, the system can produce 14.7 billion BTU of energy per year, equivalent to the annual natural gas use of 340 average American homes.[71]

The industries with the most existing solar process heat plants are food, chemicals, transport and textiles.[72] The kinds of solar heat collectors used can vary with the temperatures needed, and with the scale of the application. Rooftop collectors similar to those used for residential hot water are appropriate for some industrial applications, while large-scale collector arrays similar to those used for concentrated solar power plants can serve large scale, high temperature uses. For fairly low temperature uses, process heat can actually be generated at the same time as electricity through the use of photovoltaic/thermal collector arrays, which capture the waste heat generated by sunlight striking photovoltaic panels.[73]

Solar process heat is just one of many opportunities to tap solar energy in industry. The Steinway & Sons piano factory in New York City, for example, recently installed the world's largest solar cooling system. During the summer, the system cools and dehumidifies the factory, preventing moisture from affecting the precision parts of the company's world-famous pianos, while during the winter the system helps heat the facility.[74]

Solar photovoltaics can be used to help meet the electricity needs of factories. Like commercial buildings, large factories are likely to have flat roofs and be exposed to sunlight. Installing photovoltaics on factories can reduce demand for electricity, provide power to drive motors and industrial machinery, and deliver electricity back into the grid during peak demand times on hot summer days.

Passive solar design can also reduce energy demand in factories. About 5 percent of the energy used in the manufacturing sector is actually used for lighting and climate control in workspaces.[75] Passive solar design elements such as daylighting can reduce the need for artificial light. Ford Motor Company's Rouge Center truck plant in Dearborn, Michigan, for example, was redesigned to incorporate daylighting of work areas, augmented by well-controlled electric lights.[76]

The use of solar energy in industry can avert the consumption of fossil fuels, while providing a hedge against volatile fossil fuel prices for energy-intensive industries. The vast amount of energy used in industry means that the potential for energy savings and emission reductions is large. A study by the International Energy Agency, for example, estimated that solar process heat could provide for roughly 4 percent of industrial heat demand, reducing consumption of fossil fuels.[77]

The expansion of solar energy use in industry faces unique hurdles, however. Solar process heat, for example, seems like a perfect fit for many industries that rely on hot water—industrial facilities are hungry for options to reduce energy costs and the technology to provide solar hot water is relatively cost-effective and technologically proven.

However, industrial facilities, like other businesses, are often driven by short-term economics, rather than the potential to generate energy savings over the long term. A mid-1990s review of cancelled solar process heat projects in the U.S. found that two projects were rejected by companies because they sought a three-year payback time, while the proposed projects delivered payback in 4.4 and 5.2 years, respectively.[78]

In addition, integrating solar water heating into an existing industrial plant can be technologically challenging—essentially requiring the re-engineering of key processes. Resolving those issues requires the existence of experts trained in integrating solar energy into industrial processes. Unfortunately, the solar process heat industry in the United States is relatively undeveloped. The European Union is working aggressively to develop markets for and expertise in the solar process heat sector, and the United States could follow suit.[79]

Solar on Farms

In the 1930s, the United States brought electricity to remote towns and dwellings across the country through rural electrification—one of the signature accomplishments of the New Deal. Access to cheap energy, however, has also resulted in many tasks that were once carried out using solar energy—such as crop drying—being shifted to fossil fuels.

Agriculture represents only a small portion (approximately 1 percent) of America's total energy consumption.[80] But, for individual farmers, fossil fuel costs can repre-

P-R Farms in California's San Joaquin Valley uses the electricity created from a photovoltaic system to power its cold storage and packing operations, resulting in a dramatic reduction in monthly energy bills. Credit: PowerLight sent a large share of their total expenses. Farmers spent $28.8 billion on energy in 2003, about 14 percent of their production expenses.[81]

The distributed, modular nature of solar energy makes it uniquely suitable to provide electric power and heat on farms and ranches around the country. Farms and ranches may need electricity for pumps and fences and on-site processing operations, space heating for barns and greenhouses, and hot water for cleaning at locations where running electric wires from the grid or frequently refilling fuel tanks can be inconvenient and expensive. Photovoltaic panels and solar heat collectors, which require minimal maintenance, no refueling, and no connection to a grid, can provide a simple and economical solution.

What a Solar Farm Looks Like

Solar energy is already commonly used on farms for remote applications. Photovoltaic panels, for instance, are often used for powering water pumps in remote pastures. These PV-powered pumping systems cost a total of $2,500 to purchase and install, and operate completely independent of the grid.[82] Solar electricity can also be used to power electric fences, irrigation systems, and building machinery. These remote solar systems, while small, can deliver outsized environmental benefits, since they often replace inefficient and highly polluting diesel generators.

There are, however, many other potential applications for solar energy on farms. Space heating and ventilation, for example, are important on many farms, providing winter heat for animal barns and greenhouses and keeping the air in animal enclosures free of dust, gases and odors. Farmers also use heat to dry crops—a traditional role for solar energy that is now sometimes performed by heat from fossil fuels. Passive solar heat can displace fossil fuels for some greenhouse and crop drying applications. Many greenhouses that derive growing light from the sun, but heat from gas or propane, could be replaced with buildings that rely on passive solar heating for much of their needs. These passive solar greenhouses are oriented to capture more direct sunlight from the south, and use thermal mass and insulation to store heat from the day through the night.[83] In warmer climates, crop drying can be performed in sheds with glazed south-facing walls that admit heat, requiring no active heating system.[84]

Active solar heating is most useful on farms for heating barns. Barns contain a large volume of air, and also need more ventilation than many large buildings, because of the dust and livestock emissions that quickly build up in them.[85] Solar heating systems can replace gas or propane heaters in barns, and can also be used to promote air circulation during the summer. Active heating systems can also be used for crop-drying applications, but are most cost-effective for this purpose when the solar collector provides heat both to a drying shed and other buildings, as needed.[86]

Farmers who need to clean barns or machinery use a significant amount of energy for heating water. Dairy farms in particular (which have both barns and milking machines to clean on a regular basis) need large energy inputs for water heating—as much as 40 percent of the farm's total energy use.[87] A solar water heater can replace half the fossil fuel used for water heating, preventing emissions and saving money.[88]

Some farms are adopting photovoltaics to provide electricity to keep harvested crops cool and to run equipment. As of early 2009, more than 50 California wineries had installed solar panels, with dozens more planning to follow suit, taking advantage of California's abundant sunlight to help power their operations.[89]

Solar in Transportation

The phrase "solar cars" brings to mind images of toy-store science projects and experimental, Batmobile-style vehicles. But any transportation vehicle—a car, truck, train or even boat—can be a "solar" vehicle, so long as it is capable of being powered by electricity, and that electricity comes from solar power.

America has many reasons to look for alternative sources of energy for its transportation system. The nation's dependence on petroleum has severe environmental, economic and national security implications. Shifting more of America's transportation system to operate on electricity would enable the nation to use a wider variety of fuels, including solar power and other forms of renewable energy.

America's transportation system also represents a powerful, if less obvious, set of opportunities for the utilization of solar power. The nation's transportation system takes up a tremendous amount of land. According to one estimate, approximately 43,000 square miles of land in the United States—an area roughly the size of Ohio—is covered by impervious surfaces, most of them roads and parking lots.[90] Most of this area is unshaded and has little current use other than for storing or transporting cars, meaning that it could easily be used for generating solar energy.

Solar garages, such as this one at Arizona State University, shade vehicles while providing power to the grid, and could someday be used to charge plug-in vehicles. Credit: Kevin Dooley, reprinted under Creative Commons license.

Finally, the hundreds of millions of cars on America's roads could someday help expand the use of renewable energy sources such as solar energy. Plug-in cars can allow for the short-term, distributed storage of electricity in vehicle batteries, providing a source of emergency power to smooth out the peaks and valleys of electricity supply and demand.

What Solar Transportation Looks Like

Small solar panels are increasingly common sights along highways across the United States, providing electricity for roadside signs, emergency call boxes and other roadside equipment without the need to operate generators or run wires to distant locations. States such as Oregon are going further by installing photovoltaic arrays designed to power all of the lights at a highway interchange.[91]

But these applications account for only a tiny portion of the energy used in powering the nation's transportation system, the vast majority of which goes toward moving vehicles. The introduction of "plug-in" vehicles—electric vehicles and plug-in hybrids—could enable solar power to make a meaningful contribution toward powering our transportation system.

Plug-in vehicles are similar to today's hybrid-electric vehicles, which store the energy captured by regenerative braking and use that energy to help power the vehicle. However, plug-in vehicles have larger batteries that can also store electricity drawn from the grid. In a plug-in hybrid, grid electricity augments energy from a fossil fuel-powered internal combustion engine. In an electric vehicle, there is no internal combustion engine at all; the

Oregon's "solar highway" project involves the installation of solar panels along roadsides in the state. Credit: Gary Weber, Oregon Department of Transportation photo/video services

vehicle is powered entirely by electricity drawn from the battery.

Plug-in vehicles are currently a rarity in the United States, but that could change within the next couple of years. Several major automakers are working to develop plug-in hybrids—General Motors' Chevrolet Volt is scheduled to enter the market in late 2010, and Toyota's Prius plug-in hybrid will be put out for testing in early 2010 with a full release in 2011.[92] Several other automakers are exploring plug-in technologies, including the potential for fully electric vehicles, with the Nissan Leaf all-electric vehicle to be introduced in late 2010.[93]

Plug-in vehicles make environmental sense virtually regardless of how the electricity that powers them is generated. Electric motors are inherently more energy efficient than internal combustion engines. Even with the very dirtiest electricity, electric cars are about equivalent to today's conventional cars in terms of global warming pollution. Powering plug-in vehicles with renewable energy, however, dramatically increases their environmental benefits.[94]

Plug-in vehicles also provide new opportunities for tapping solar energy and for integrating renewable energy into the electric grid. Almost all vehicles spend the majority of their day sitting still—often in exposed parking lots at a place of work. Solar powered charging stations in parking lots would enable drivers to charge their vehicles during the day, while also providing a source of shade to keep vehicles cool. Toyota is developing solar charging stations for plug-in vehicles in Japan, and several companies in the United States have built solar parking lots that feed clean energy into the grid.[95] Solar charging has the potential advantage of channeling the direct current produced by solar panels into a vehicle battery without the need to convert to alternating current—eliminating the loss of energy that occurs when DC power is converted to AC and vice versa. In any case, pairing the expansion of plug-in cars with solar power installations can give plug-in hybrid owners the option of charging up during the daytime without adding strain to the electric grid.

In addition to parking lots, highways provide another possible location for solar panels. Oregon is considering the expansion of its "solar highway" program and solar panels have been installed along roadsides in Europe for decades.[96]

Airports are also proving to be fertile ground for solar panel installations. Numerous airports across the country—including facilities in Denver, San Francisco and Austin—have installed solar arrays that provide a share of the power for airport operations.[97] Buffer land surrounding runways also provides large swaths of unshaded area that could be used to house solar panels.

While electric cars are in the early stages of deployment, parts of America's transportation system are already powered by electricity. Subway and light rail systems, along with many commuter rail lines and some intercity train lines, are powered by electricity. The recent expansion of light rail systems in cities such as Los Angeles, Salt Lake City, Phoenix and Denver promises to shift more travel away from gasoline-powered vehicles and toward electric transportation. In addition, the nation is beginning to invest in creation of a high-speed rail network that would likely be powered by electricity, and leading states are working to ensure that the electricity that powers the system is renewable. California's High Speed Rail Authority, for example, has committed to generating 100 percent of the power for the state's high-speed rail system from renewable energy and has evaluated the potential role of solar power in achieving that target.[98]

Solar energy can even help alleviate emissions from the global shipping industry. The shipping industry is estimated to have produced just over 3 percent of the world's global warming pollution in 2007.[99] A major Chinese shipping firm, for example, is experimenting with the use of "solar sails"—large arrays of photovoltaic panels—on some of its ships, while a small number of solar ferries already ply the waters of harbors around the world.[100]

Solar in Communities

"Going solar" has traditionally been an individual affair, with pioneering homeowners or businessowners deciding to install their own solar energy systems. The benefits of solar energy, however, can be even greater when entire communities work together to build solar energy systems.

Some forms of solar energy technology—such as neighborhood solar heating systems with seasonal heat storage—are only practical on the community level. Community involvement can also create new opportunities for individuals to adopt solar energy, even if their homes are poor candidates for solar panels. Meanwhile, many community buildings are good candidates for solar energy.

Moreover, broad adoption of solar energy in a community can create important economies of scale. The greater the local market for solar photovoltaics or hot water systems, the greater the base of expertise that can develop among the many individuals and businesses involved in the process—solar system installers, electricians, builders, banks, utilities, etc. In the many American cities, particularly on the East Coast, that face challenges in meeting electricity demand, intense development of solar power can help alleviate the need to build new power plants in densely packed urban areas or build expensive transmission lines to bring in power from elsewhere—saving money for ratepayers as a whole.

This solar thermal array, installed at Arnold Schwarzenegger Stadium in Graz, Austria, provides heat for the town's district heat system. Credit: SOLID/ESTIF

What a Solar Community Looks Like

Solar communities can take many forms. A few potential ways that solar energy can be integrated into communities are discussed below.

Solar District Heating

A "district heating" system is one in which steam or hot water from a central plant is piped to residential and commercial buildings in a city, neighborhood, industrial park or college campus. In other words, instead of each individual building having a furnace or boiler, all the buildings in a district heating system receive heat from one central power plant.

District heat has a long history in the United States. District heat systems were built in many American cities to provide a profitable use for the steam left over after generating electricity. New York City's system is the largest in the United States.[101] Denver, Los Angeles, Boston, Chicago and Kansas City are among the many other cities with downtown heating systems.[102] Nationwide, more than 300 universities and 120 hospitals also use district energy in the form of heat, cooling or both.[103]

Solar energy can help to power district energy systems. In Europe, several housing developments have been built with solar district heating systems. In these systems, rooftop solar collectors heat water, which is then piped to a central storage tank. The storage tank is typically designed with thick concrete walls and buried underground to retain heat for use in times of day when the sun is not shining or even, with the installation of seasonal storage, colder months of the year.[104] The solar district heating system in Friedrichshafen, Germany, which uses seasonal storage to supply heat and hot water to more than 500 apartments, covers approximately 25 percent of the neighborhoods' space heating and water heating energy needs; other solar district heating installations in Germany provide an even greater fraction of home heating or hot water.[105] Such systems are even viable in extremely cold climates. A 52-unit housing development in Alberta, Canada, will use solar energy to supply 90 percent or more of the complex's space heating and hot water needs.[106]

Solar district heating has gotten the greatest traction in Europe, but the largest such project is currently being built in the United States. The 900,000-square-foot Fletcher Business Park in western North Carolina will be heated and cooled by a solar district energy system.[107]

Solar energy collectors can also be used to augment steam production in existing district heat systems, reducing the need to burn fossil fuels.

Community-Owned Solar Energy Systems

Two of the biggest hurdles to the installation of household solar power systems are the upfront cost of the system and the lack of an appropriate rooftop. Homeowners who wish to "go solar" have another option for using solar power, however—to go in with their neighbors on a community-owned solar system.

Across the nation, recent years have brought a growing movement toward community-owned renewable energy. Renewable energy installations can be built by institutions controlled by local residents, such as municipal utilities, municipal governments or electric cooperatives. For example, in Colorado, an electric cooperative offers its customers the ability to lease a solar panel installed on the utility's property. The homeowner receives a credit on the monthly bill for the value of the solar power generated by his or her panel.[108] A similar program was recently launched in Utah.[109]

Some states are working to create new opportunities for community-based solar power. Colorado legislators have introduced a "solar gardens" bill that would enable individual homeowners to partner to build, and receive the benefits of, solar energy systems not located on their properties.[110] Massachusetts has adopted a "neighborhood net metering" policy in which groups of 10 or more individuals in a single town can share in the benefits of a solar power installation.[111]

Solar in Community Buildings

Community institutions—schools, churches, municipal buildings and the like—are among the largest and most visible buildings in any city or town. Many of these buildings also have unique characteristics that make them particularly well-suited to take advantage of solar energy. Consider schools, which are primarily occupied during daylight hours and devote one quarter of their total energy consumption to lighting.[112] Schools, therefore, provide an excellent opportunity to take advantage of daylighting, reducing electricity needs and creating a more pleasant learning environment. Most schools also have large amounts of available roof space, and could use rooftop solar collectors for much of their heating needs.

Other community institutions present similar opportunities:

- Churches and other large community spaces use as much as 60 percent of their energy for heat.[113] Solar heat collectors could provide much of this energy, particularly during daytime services. Church office buildings frequently have large, flat roofs.

- Libraries, museums, and other public buildings use significant amounts of energy on heat and lighting, and often have large flat roofs available for PV panels or solar heat collectors. Skylights and other passive design features can be used to daylight the top stories of these buildings.

- Wastewater treatment plants are also good candidates for solar energy, with large open spaces that can easily host solar panels to help meet the facilities' energy needs.

One advantage that churches, schools, and other public buildings have over homeowners in installing solar technologies is that they generally expect to remain in the same building for decades, which gives them greater certainty that they will receive the full lifetime benefit of any solar project. Additionally, schools, libraries, and government office buildings are owned and operated by the same local governments that are often responsible for extending credit and incentives to homeowners for solar projects. By taking advantage of their ability to issue municipal bonds at low interest rates, local governments can finance solar projects in a way that spreads the costs and benefits of solar improvements out over the same time frame.

President Obama and Vice-President Biden inspect solar panels on the roof of the Denver Museum of Nature & Science, one of many community buildings that can benefit from solar energy. Credit: White House, Pete Souza

The Benefits of Solar Communities

When many homeowners and institutions in a community "go solar," the benefits are often magnified.

For example, as a vigorous market for solar energy develops in a community, the demand for trained solar energy installers increases and the amount of experience gained by those installers grows. Installation costs can represent a large share of the total cost of a solar energy system and reducing those costs is a key step in making solar energy cost competitive. Research suggests that, as solar installers gain experience and "learn by doing," the cost of installations decline.[114] Moreover, this effect is *local*, meaning that the development of a vigorous solar market in a community or state can help bring costs down, creating a virtuous circle that makes solar energy accessible to a greater number of homeowners and businesses.

Installing large amounts of solar power in an area can also reduce peak demand for electricity in areas where the grid is strained—reducing the need to construct expensive new power plants or transmission lines. Because solar photovoltaics generate the most electricity at precisely the times when electricity demand is highest (hot, sunny summer days), they can play a major role in reducing peak demand on the electricity system. In New Jersey, for example, 10 megawatts (MW) of solar power capacity can be counted on to offset 4 to 7 MW of conventional peak generation, meaning that carefully located solar panels can dramatically reduce the need to run expensive "peaking" power plants, build new power plants, or expand transmission lines to serve peak demand.[115]

Solar Grid

Solar energy, as we have seen, can be captured in American homes and businesses—even entire communities—sharply decreasing fossil fuel consumption. These solar technologies are "distributed"– they are implemented at or near the places where energy is used. Distributed resources have many advantages over the current centralized system of generating and distributing electricity: they do not rely on the expansion of expensive long-distance transmission networks, they are more energy efficient, and, with proper integration, they can make a large contribution to the resiliency of the electric grid and reduce the need for expensive peaking power plants and transmission lines.

But our existing electric grid can also play a role in moving America toward a solar future. The grid enables us to move power from places where it is not being used to places where it is in demand, supplying electricity to our homes at times when the sun is not shining and delivering solar electricity to places where it is needed. The grid also enables us to take advantage of excellent solar resources that are far removed from any source of demand.

Centralized solar power facilities—such as photovoltaic farms and concentrating solar power plants—can augment or replace many fossil fuel resources in our electricity system, while investment in "smart grid" technologies can help America better tap the solar resources in our own backyards.

Utility-Scale Solar Resources

America's desert Southwest and other sunny areas of country possess some of the best solar resources in the world. The solar radiation striking just a small portion of the southwestern U.S. contains enough energy to power the entire nation. There

Parabolic trough concentrating solar power plants, such as this one in California, have the potential to generate large amounts of power in sunny areas of the Southwest and elsewhere. Credit: Gregory Kolb, Sandia National Laboratory are several ways to harness that resource.

Concentrating solar power (CSP) plants use mirrors to focus the sun's rays on a central collector fluid, with the captured heat used to generate electricity (or, less commonly, to provide heat for industrial processes or space heating). CSP plants have been providing reliable electricity in California for decades, and a new generation of plants is currently in operation, under construction, or in the early stages of approval. Six new CSP plants have begun operation in the United States since 2006, with many more—and larger—projects in the pipeline.[116] In California alone, developers have proposed more than 10 gigawatts of concentrating solar power projects—an amount roughly comparable to 1 percent of America's current electricity generating capacity.[117] Similar levels of solar development have been proposed in Arizona and Nevada.

The potential for CSP development is virtually limitless—CSP plants covering just 9 percent of the area of Nevada could power the entire country.[118] The most important limitations on the technology stem from its surroundings—specifically, the difficulty of finding adequate water supplies in desert areas, potential conflicts with sensitive desert ecosystems, and the challenge of transporting electricity long distances to population centers.

But while CSP has some disadvantages compared with distributed solar power, it also has some advantages. One major benefit of CSP is that the heated fluid produced by the system can be easily and cost-effectively stored (as opposed to electricity, which requires costly batteries for storage). CSP plants with thermal storage can deliver electricity even when the sun is not shining, enabling them to compete directly with "base load" sources of power such as coal and nuclear power, thereby expanding the share of electricity demand that can be satisfied by solar power.

Ultimately, the nation will need to take advantage of both distributed and central solar resources such as CSP to take a serious bite out of our dependence on fossil fuels. Careful location of CSP systems to minimize environmental impacts, the use of air-cooled systems that reduce water consumption, and limited investments in expanded transmission capacity can ensure that CSP delivers the maximum benefits to our environment.

In addition to stand-alone plants, CSP also has the potential to be used in conjunction with fossil fuel power plants. In Florida, a 75 megawatt CSP facility is being built as part of a "hybrid" power plant with an existing natural gas fired generator.[119] Pairing solar energy with conventional power generation can reduce fossil fuel consumption and global warming emissions while ensuring a steady and reliable source of electricity to the grid.

In addition to the potential for distributed use on rooftops, photovoltaic (PV) modules can also be used in "solar farms" to generate electricity for the grid. Large-scale PV installations can be built quickly to respond to emerging power needs, can be located optimally in areas with good solar resources, and use very little water, making them a perfect fit in arid regions of the nation. Moreover, installing PV in a single location, using standardized equipment on a large scale, can be less expensive than installing the same amount of capacity in bits and pieces on rooftops.

In 2009, the largest PV farm in the nation—a 25 megawatt facility consisting of more than 90,000 solar panels—came on line in Florida.[120] Another 6,000 megawatts of PV has been proposed for other large-scale projects across the country.[121]

Solar Power in a Smart Grid

The nation's electricity system was designed as a one-way street—a small number of large, central power plants generate electricity, which is then delivered to millions of homes and businesses. To keep the grid running reliably, generators must be turned off and on to ensure a perfect balance between the supply and demand at every second of the day.

The spread of solar photovoltaic power, however, will make the job of keeping the grid in balance more complicated. Instead of homes and businesses being electricity consumers, many will also be electricity producers, feeding power into the grid. In addition, solar energy is variable in ways that are both predictable (night versus day) and unpredictable (the passing of a stray cloud).

America has a long way to go before solar energy begins to have a meaningful impact on the grid. The nation can dramatically expand the amount of solar power in today's grid without reliability problems, and an even greater fraction can be provided if thoughtful steps are taken to integrate solar energy into the existing grid.[122] But maximizing the share of our electricity that comes from solar power will likely require changes in the way we produce and deliver electricity—as well as investments in a well-designed "smart grid." With creativity and investment, experts suggest that as much as 20 to 30 percent of our electricity could someday come from photovoltaics—greatly expanding the ability of solar energy to address the nation's energy needs.[123]

A well-designed "smart grid" is one that is much more sophisticated in managing electricity supply and demand than the current grid. It might include:

- Smart inverters—Technology to enable utilities to control the flow of power from solar PV inverters—the devices that transform DC power from solar panels to the AC power

Plug-in vehicles, such as these plug-in hybrids, can contribute to stabilizing the grid by providing electricity storage capacity. Energy storage is a key technology that can enable renewable sources of energy such as solar energy to play a larger role in America's energy future. Credit: Argonne National Laboratory used in the grid and in homes. Utilities could use these "smart inverters" to manage the flow of solar electricity into the grid to maximize grid stability.

- Smart controls—Homeowners could use smart controls to make the maximum use of solar electricity—for example, by heating hot water, running space heating or cooling equipment, or (someday) charging plug-in vehicles at times when solar panels are producing the maximum amount of electricity instead of, for example, the evening hours when solar panels do not produce electricity but demand for power remains high.

- Smart energy storage, including the installation and remote control of batteries to provide quick backup power during cloud passages and to store excess solar power produced during peak periods. There are many possible ways to incorporate energy storage into the grid, including the installation of batteries at various points in the grid and the use of batteries in plug-in vehicles.[124]

These investments in smart grid technologies have the potential to deliver large returns. A recent study by Navigant Consulting found that investment in a "PV Smart Grid" would deliver positive economic benefits, while improving the economics of investments in PV and dramatically increasing the amount of solar power that can be integrated into the grid.[125]

Mapping Out a Solar Vision

America's potential for solar energy development is virtually limitless. Solar energy can meet a wide variety of energy needs, it is available everywhere in the United States, and the prices of key solar technologies are declining—in some cases, rapidly.

The nation should set a course to maximize our use of solar energy, putting America on a path toward an energy system that relies primarily on clean, renewable sources of energy. A good place to start would be to ensure that at least 10 percent of all the energy used in America in 2030—and preferably more—comes from the sun. (See "Energy vs. Electricity: What Does the 10 Percent Target Mean?" page 38.)

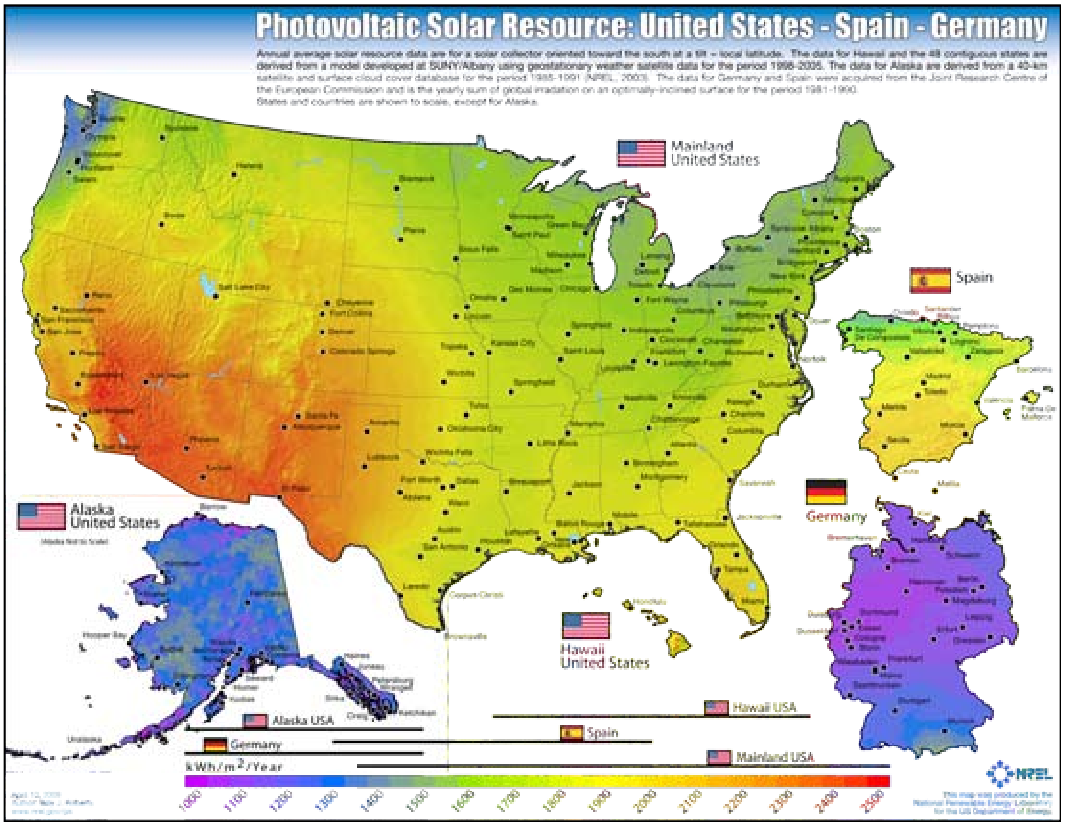
America's Solar Potential

The nation's potential for solar energy dwarfs our current consumption of energy, as well as projected energy use in the future.

Distributed solar PV – A 2004 study by Navigant Consulting estimated the technical capacity for PV on residential and commercial rooftops in 2010 at 712 gigawatts—roughly enough to supply about a quarter of America's electricity using current photovoltaic technologies.[127] Rooftops, however, aren't the only places where solar panels can be installed. Factory roofs, roadsides, parking lots, former industrial sites, airport buffer lands, wastewater treatment plants and other built-up areas could also play host to solar PV. Moreover, PV could be used "off the grid" to offset energy demand, as has increasingly been the case in recent years with the advent of solar powered streetlights, emergency call boxes, water pumps, etc.

Utility-scale solar—The American Southwest and other sunny areas of the country have almost endless potential to produce solar energy. Analysis by the National Renewable Energy Laboratory (NREL) has found that prime locations in the Southwest—those in proximity to transmission lines, on flat topography, and outside of environmentally sensitive areas—could host 11,000 gigawatts of con-

Figure 3. U.S. Photovoltaic Resource Map



America's solar resource compares favorably with the resource in two leading countries for solar energy development: Germany and Spain. Even the least sunny areas of the contiguous U.S. have solar resources on a par with Germany, while much of the southwestern U.S. has a better solar resource than Spain. Credit: National Renewable Energy Laboratory

centrating solar power plants, enough to produce six times more electricity than the entire nation consumes today.[128]

Solar water heating—Solar water heating presents the potential for great energy savings. A national analysis of technical potential by NREL estimated that the nation could avoid 0.5 quadrillion Btu of fossil fuel consumption (about 0.5 percent of America's current energy use), along with the consumption of large amounts of electricity, through wholesale adoption of solar water heating. As noted earlier, the International Energy Agency estimates that industrial solar process heat could displace 4 percent of industrial heat demand—reducing America's energy consumption by at least another 0.15 percent.

Passive solar and active solar heating, cooling and lighting—America's potential for passive solar energy—and for the development of "active" solar heating, cooling and lighting technologies—is difficult to quantify, but the technology clearly exists to build homes and commercial buildings that use dramatically less energy than conventional buildings.

Energy vs. Electricity: What Does the 10 Percent Target Mean?

Many targets for renewable energy development are set in terms of the percentage of our electricity supply that comes from renewable sources of power. State renewable electricity standards (RES) typically take this approach, with solar "carve outs" in RES policies sometimes setting goals for a percentage of electricity that will come from solar photovoltaics and/or concentrating solar power.

About 40 percent of America's total energy consumption is devoted to the generation of electricity.[126] But, as this report shows, solar energy can do much more than generate electricity—it can be used to improve the energy efficiency of our buildings and to substitute directly for fossil fuels such as natural gas and oil.

The target proposed in this report—getting 10 percent of America's *total energy* from the sun—is, therefore, broader and more ambitious than a target of obtaining 10, or even 20 percent of our *electricity* from solar power. While shifting a large share of our electricity production to solar power is an important component of maximizing America's solar energy potential, the nation must also take full advantage of the potential for solar energy to offset fossil fuel use through passive solar heating and lighting and to replace fossil fuels in our homes and businesses, as well as our transportation system. The target proposed in this report recognizes the broad range of ways that solar energy can power our economy and sets an ambitious goal for its future development.

A Near-Term Goal

America's solar potential is nearly limitless. But tapping that potential—and doing it on a timeline that will make a meaningful contribution to addressing global warming and fossil fuel dependence—will require a bold national commitment to rebuild our energy system around clean, renewable energy.

The project of rebuilding our energy system will take time. Our existing systems for extracting, processing and delivering energy from fossil fuels are more than a century in the making and the result of untold billions of dollars in investment. However, it is imperative that we begin the job of rebuilding our economy around renewable energy now, and commit to challenging short-term goals that will put us on the road to an America that is free from dependence on fossil fuels and the environmental damage those fuels cause.

A goal of obtaining 10 percent of America's energy from the sun by 2030 is just such a challenging target. We already have the technology to get most of the way there. But achieving that goal would also challenge the nation to develop new technologies, and to begin to undertake the type of systemic changes that will enable solar energy to play an even bigger role in decades to come.

Achieving a 10 percent goal for solar energy would result, in two decades' time, in the sun providing us with more energy than we currently produce at nuclear power plants, more than half as much as we currently consume in our cars and light trucks, or nearly half as much as we currently obtain from burning coal. Together with efforts to improve energy efficiency and develop other renewable energy sources, solar energy can play a major role in weaning the nation from polluting, dangerous, unstable and, in some cases, increasingly expensive forms of energy.

The first step to getting a large share of our nation's energy from solar energy is to reduce our use of energy overall through improved energy efficiency. A recent draft report by the National Academy of Sciences (NAS) found that the nation could cost-effectively reduce its overall energy consumption by 26 to 31 percent by 2030.[129] The NAS report includes some, but not all, passive solar technologies, as well as the introduction of plug-in hybrid vehicles, and estimates that, by taking full advantage of the nation's energy efficiency potential, energy consumption could be reduced to 82 to 88 quadrillion Btus (quads) by 2030, compared to a projected 118 quads.[130]

Under that scenario, obtaining 10 percent of our energy from the sun would require the nation to offset roughly 8.8 quads of energy consumption. Much of this energy can come from solar electricity generation—both photovoltaic and concentrating solar power. As noted above, the nation has enough solar energy potential to power our entire economy several times over. A scenario in which the nation obtains 20 percent of its projected electricity use in 2030 from solar energy (taking into account the energy savings resulting from the efficiency improvements in the NAS study) would offset approximately 6.4 quads of primary energy use at electric power plants.[131] (A team of researchers led by experts at the National Renewable Energy Laboratory is exploring the potential and implications of a 20 percent solar electricity scenario as this report goes to press.)

The remaining 2.4 quads could come from a variety of other sources. Taking advantage of the half the nation's potential

America has tremendous potential to capture energy from the sunlight that strikes rooftops and paved areas, such as this parking lot in San Diego. Credit: Envision Solar for solar water heating on homes and commercial buildings could reduce America's projected primary energy consumption in 2030 by a minimum of 0.3 quads. Tapping the potential for solar process heat in industry would provide additional savings.

Other measures that could increase the share of our nation's energy that comes from the sun include:

- Widespread deployment of technologies to further reduce energy consumption beyond the levels discussed in the NAS study, including widespread adoption of net zero-energy buildings and shifting of vehicle and airline trips to highly efficient modes such as public transportation and rail.

- Increased use of solar electricity generation, possibly through the development of energy storage.

- Installation of solar district heating and active solar space heating and cooling systems.

- Deployment of distributed solar energy systems in agriculture, for vehicle charging, and other applications.

Getting 10 percent of our energy from the sun will not be easy. It will take a dedicated and concerted effort starting now, as well as great creativity in developing public policies that can surmount the barriers to the rapid deployment of solar energy and ensure that the transition to a clean energy system happens both quickly and smoothly. If America can muster the creativity and will to achieve that goal, however, the benefits for the nation's environment, energy security and well-being would be dramatic.

Achieving a Solar America

Solar energy has a great deal going for it. It is enormously popular—polls consistently find that the vast majority of Americans back increased government support for solar energy, and that Americans prefer expansion of renewable energy technologies, including solar, over other approaches to addressing the nation's energy challenges.[132] Solar energy is available everywhere, can be used for many purposes, and the fuel is free.

But despite these advantages, achieving a solar future for America won't happen on its own.

Understanding the Barriers to a Solar America

Conventional wisdom holds that solar energy hasn't made serious inroads in the United States because it is too expensive. And to a certain extent that is true: "active" solar energy systems such as photovoltaics and solar water heating systems have historically been more expensive than conventional sources of energy—especially when the social costs of fossil fuel consumption, including air pollution, global warming and national security implications, are not factored in.

But cost is actually one of the less-important barriers to solar energy. There are a host of regulatory, legal, information and financing barriers—sometimes erected by

Solar energy can power communities across the nation, even in northern climates. The Drake Landing solar community in Okotoks, Alberta, Canada, just south of Calgary, relies on the sun for 90 percent of its space heating needs through the use of a solar district heating system with seasonal storage. Credit: Natural Resources Canada companies with an interest in preserving the status quo—that prevent solar energy from gaining more traction in the United States. These are barriers that can be surmounted by creative public policy.

The current cost barriers to solar energy are falling, in some cases rapidly. Between 1998 and 2008, the installed cost of photovoltaic systems declined by 31 percent, excluding the impacts of tax incentives and subsidies.[133] During 2009, prices declined even further, with the cost of PV modules falling by roughly 20 percent.[134] The cost of concentrating solar power has declined as well, from about 44 cents per kilowatt-hour for the first plant built in the 1980s to roughly 15 to 16 cents per kilowatt-hour today, and costs can be expected to continue falling.[135]

By 2015, the cost of retrofitting a home with solar panels is projected to drop to $4.80 per Watt (from $7.40 per Watt in 2007) and could fall to as low as $3.10 per Watt in that year if researchers meet the targets established by the Department of Energy's Solar America Initiative.[136]

At those prices, solar photovoltaics will achieve "grid parity"—a price equivalent with the lifetime cost of an equivalent amount of grid electricity—by the middle of this decade. (Indeed, in some states with high electricity prices and generous incentives for solar power, such as California, grid parity has already arrived.)[137]

If the price of solar energy becomes lower than that of conventional sources, one would think that the path would be clear for solar energy to take on a leading role in America's energy picture. Unfortunately, it's not that simple.

Solar energy faces a set of additional obstacles that must be overcome if America is to achieve the benefits of a solar future:

- **Knowledge barriers:** The most basic obstacle to the spread of solar technologies is lack of knowledge. Builders may not understand the benefits of passive solar techniques or how to implement them in construction. Consumers or businesses may be unaware of how to go about integrating solar energy into their buildings, or of how much energy and money solar technologies can save. All of these knowledge barriers hamper the deployment of solar energy.

- **Regulatory barriers:** In some places, installing solar panels on one's roof or in one's yard isn't just a challenge; it's against the law. Restrictive homeowners' association rules may prevent the installation of solar energy, or archaic zoning rules may limit homeowners' ability to install solar energy facilities on their properties.

- **Upfront costs:** One common reason that people do not invest in clean energy or energy efficiency technologies is that the costs occur immediately, while the benefits occur over the entire life of the system. In essence, buying a solar energy collector is like buying several decades of energy all at one time. Even if the overall cost is lower, it can be difficult for many families and businesses to spend so much at once.

- **Capital availability:** A related obstacle is the fact that some homeowners or businesses that wish to install solar energy systems may not be able to obtain the credit necessary to finance the installation. Banks, especially given the recent credit crunch, may be unwilling to lend to homeowners to finance the installation of a solar energy system. As a result, lower-income households, those with poor credit, and many small businesses miss out on the opportunity to install solar energy.

- **Payback times:** A solar energy system may pay for itself over time, but individuals and particularly businesses will be reluctant to invest in solar if the payback period is too long. Economic research suggests that only a small percentage of customers will use a technology that takes five or more years to pay back its costs.[138] For businesses, required payback times can be even shorter—a review of cancelled industrial solar process heat projects found that many companies required payback periods of three years or less for capital investments—a standard that the proposed projects barely failed to meet.[139]

- **Length of tenure:** Even homeowners or businesses that are willing to accept longer payback times may be unwilling to invest in solar due to concerns that they will move out of their current location before the solar system pays itself off, or that the remaining value of the system will not be received upon resale.

- **Split incentives:** When the owner of a building is different from the person who pays the utility bills, the owner has less incentive to install a solar energy system. Unless they can be confident that they will receive the benefits of their purchase, landlords will have little reason to consider solar technologies.

- **Failure to incorporate social benefits:** Owners of solar panels rarely receive checks in the mail for the benefits their investments deliver to society—reduced global warming impacts, reduced health care costs due to avoided pollution, enhanced national security, reduced need to invest in peaking electric plants and transmission wires, etc. Government and utility financial incentives can compensate for the failure to take into account the true costs and benefits of various energy technologies.

- **Risk:** When consumers draw power from the electric grid, they are sheltered from the financial risks posed by the failure of electric generating equipment. Even if ratepayers must pay to replace a failed power plant, the costs of doing so are spread among thousands or millions of customers. Owners of solar energy systems, however, bear the risk that the system will fail or be destroyed and need to be replaced (though these risks can be mitigated through warranties and insurance).

- **Utility barriers:** Traditionally regulated utilities, which are assured a return on investment for the investments they make in electricity generation and often benefit financially by selling more power to consumers, have financial incentives to resist the spread of customer-owned solar systems that reduce the demand for grid-supplied electricity. Utilities may create hassles for consumers or businesses seeking to connect their solar energy systems to the electric grid, or establish limits on the number or size of systems eligible for net metering, in which consumers are compensated for the energy they supply to the grid. Utilities seeking to build their own solar projects may run into barriers of a different sort: lack of access to the transmission capacity needed to carry their power to customers.

It is these hurdles, more than cost, that often impede the spread of solar power. After all, Americans have a strong recent track record of embracing exciting new green technologies—even those with higher upfront costs and uncertain payback. The experience with hybrid-electric vehicles—of which more than 1 million have been sold in the United States over the past decade—demonstrates the appeal of energy-saving technologies.[140] Now, thanks to early consumer demand, car manufacturers produce hybrids in a variety of styles and produce more of them, cutting the price differential between hybrids and conventional vehicles. This dynamic will enable hybrids to make even bigger inroads into the auto marketplace in the years ahead.

The big difference between solar energy and hybrid vehicles is that switching from a conventional car to a hybrid is relatively easy. Hybrids are sold at the same dealerships as traditional cars, are financed in the same way, use the same roads and can be parked in the same driveways. Adopting solar energy, on the other hand, is "disruptive"—it challenges our traditional relationship with energy. Homeowners transform from energy consumers to energy producers; businesses and homeowners make long-term investments in clean energy rather than buying electricity by the kilowatt-hour over time; and the electric grid becomes a two-way rather than one-way street.

Getting solar energy into America's homes and businesses isn't just about making solar energy cheaper, though that will help. It is about adapting our current ways of managing, delivering and financing energy to unlock the potential for solar energy that is already at our doorstep.

By using public policy to remove the "emergency brakes" that inhibit the deployment of solar energy and finding ways to step on the accelerator, America can make solar energy systems as common—or more common—on America's homes and businesses ten years from now than hybrid cars are on the road today.

Policies to Build a Solar America

The first step in achieving a solar vision for America is to take the many creative public policy tools that are already promoting the adoption of solar energy at the local, state and federal levels and implement them more broadly. The nation must also lay the groundwork for future large-scale adoption of solar energy in the decades to come.

Many public policies are making a real difference in speeding the diffusion of solar power. In California, for example, programs under the banner of the California Solar Initiative have resulted in the installation of 283 megawatts of solar PV since the beginning of 2007, more than doubling the amount of solar power installed in the state in less than three years.[141] New Jersey has achieved similar results, installing more than 60 megawatts of solar PV in 2008 and 2009.[142]

Among the many public policies that can contribute to the spread of solar energy are the following:

Spurring Demand through Financial Incentives

Financial incentives for solar power have several public policy purposes. First, they serve as a means for compensating consumers for the societal benefits of solar power. They also help to create a robust early market for solar technologies—a market strong enough to persuade companies to invest in the research, development and expanded manufacturing capacity needed to hasten the day when solar power will achieve cost parity with fossil fuels. Moreover, financial incentives for solar energy can balance the impact of the massive federal subsidies currently received by fossil fuel producers. Between 2002 and 2008, for example, the federal government lavished $72 billion in subsidies on the fossil fuel industry, compared with just $29 billion to renewable energy (with most of the renewable energy funds used to subsidize corn ethanol).[143]

California, New Jersey and other states have helped spur solar power installations through financial incentives. Financial incentives can come in several forms:

Cash incentives provide an upfront rebate to homeowners or businesses installing solar panels. California's Million Solar Roofs Initiative, for example, provides grants to homeowners who install solar systems, with the amount of the rebate declining over time to reflect the anticipated declining cost of solar power. There are various types of cash incentives including rebates paid upfront or over time, grants, or access to a renewable energy credit market.

Tax credits also encourage individuals and businesses to install solar energy. Current federal law allows individuals to receive a tax credit for 30 percent of the cost of installing a qualified solar PV or hot water system.[144] The federal government also provides a similar investment tax credit for businesses adopting solar energy.[145] As with cash incentives, the value of tax credits can be made to decline over time as solar energy becomes increasingly cost-effective.

Feed-in tariffs are special rates paid to owners of solar photovoltaic systems that supply electricity to the grid. The idea behind a feed-in tariff is to reduce the financial uncertainty facing would-be installers of solar panels by providing a long-term, guaranteed, incentivized rate for power supplied by a solar energy system to the grid. Feed-in tariffs have played a large role in the development of Germany's world-leading solar power industry, and have recently been adopted by Vermont and Washington state. The

Fair net metering policies can ensure that consumers receive the full benefits of their investments in solar energy. Credit: Kenn Kiser

Vermont law, for example, is designed to ensure that homeowners or businesses receive the same return on equity for their investment in solar as utilities would receive for their investments in power generation technology.[146]

Net metering policies enable consumers to receive fair compensation for the excess solar electricity they feed into the grid. Net metering typically compensates consumers at the retail or wholesale price of electricity rather than at an incentivized price. Not all net metering policies are created equal, however—some policies require consumers to forfeit accumulated credits on their electricity bills to the utilities at the end of the year, while other utilities and states set onerous limits on the size of solar energy systems that are eligible for net metering or on the share of a utility's overall electricity eligible for net metering. Consistent, fair and generous net metering policies can make it much more advantageous for homeowners and businesses to install solar energy systems.

Leveling the Playing Field for Solar

Solar energy provides a vast array of benefits to electricity consumers, the environment, and society at large. Public policies can ensure that solar energy is treated fairly in the marketplace.

Policies to **encourage utility deployment of distributed solar energy** can be designed to ensure that the unique value of solar energy is taken into account when utilities decide which energy resources to use. For example, California includes a "time-of-delivery adder" in assessing the value of projects proposed for compliance with the state's renewable electricity standard, ensuring that the added value of electricity delivered during periods of peak demand is factored into decision-making. The value of distributed solar energy in avoiding transmission line expenses and other benefits of solar could also be taken into account.

Putting a price on global warming pollution can ensure that decision-makers consider the environmental costs and benefits of the energy choices they make. A cap-and-trade system for global warming pollution, such as the one that has already passed the U.S. House of Representatives, would begin to incorporate the real cost of pollution from fossil fuel power plants into the price of energy, and would help promote the development of clean energy alternatives.

Ramping Up Solar with Renewable Electricity Standards

Renewable electricity standards (RES) are requirements that utilities in a given state obtain a certain percentage of their electricity from renewable sources of energy. Fourteen states have established **solar carve-outs** in their standards to ensure that the RES encourages the development of solar energy. RESs encourage utilities to build large-scale solar projects and to install distributed solar systems on homes and businesses. In addition, states such as New Jersey enable individuals or businesses who install solar energy systems to receive payments from utilities seeking to meet their renewable energy obligations, providing yet another financial incentive for the adoption of solar power.

Government purchasing requirements are similar to RESs in that they require government agencies to "lead by example" by getting a share of their energy from solar and other forms of renewable energy. For example, federal law requires the U.S. government to get at least 7.5 percent of its electricity from renewable power by 2013, dramatically reduce fossil fuel use in government facilities, and deploy solar water heating equipment if it is cost effective over the entire life cycle of the equipment.[147]

Overcoming Financing Barriers

Local state and federal governments are developing novel public policy tools to surmount barriers to the financing of solar energy projects. Among them:

Municipal financing—Eighteen states now allow municipalities to finance individuals' solar energy installations, recouping the costs through a special assessment on the property owner's tax bill.[148] This model—called property-assessed clean energy (PACE) financing—enables municipalities to use their ability to obtain financing at low interest rates to pay for the upfront cost of installing solar panels on homes and businesses. Property owners then pay back the costs over a period of 20 years on their property tax bills. If a property owner sells the property during that period, the charge to pay back the solar panel remains on the property tax bill for the new owner. The PACE system overcomes several barriers to the deployment of solar power: it absolves homeowners of the risk that they will move out before they receive the full benefits of the system, it provides low-interest financing, and it enables homeowners to begin seeing the benefits of their investment right away through lower utility bills. A similar model, called utility on-bill financing, offers home or business owners the opportunity to pay for their solar energy purchase through a small charge in their utility bill—the same place that they will see savings from decreased reliance on fossil fuels.

Community solar—As noted earlier, at least one electric cooperative has experimented with the idea of allowing customers to purchase a solar panel located on utility land, with the value of the energy produced by the panel credited to the consumer on his or her bill. Several states are considering expanding this model to allow groups of homeowners to finance and reap the benefits of solar power installations not located on their properties. This type of community solar program enables consumers who are unable to install solar energy on their own properties to participate in expanding the reach of clean energy. While promising and capable of filling a unique niche for those who can't go solar themselves, this program should not take the place of opportunities for customers to own their own solar systems.

Low-interest loans and loan guarantees reduce the pay-back time for solar energy installations. A PV array that will take 20 years to pay for itself can become immediately profitable if a homeowner can pay for it through a low-interest loan. The U.S. Department of Agriculture, for example, operates a loan guarantee program for agricultural adoption of renewable energy technologies. Similarly, federal **renewable energy bonds** enable

Government can help spur the development of a solar economy by taking the lead in installing solar energy systems on public buildings, such as this middle school in Missouri. Credit: Missouri Department of Natural Resources local and state government agencies to finance solar projects at very low interest rates.[149]

Implementing Advanced Building Codes and Standards

New buildings present the greatest opportunity to integrate solar energy in a cost-effective way while combining it with energy efficiency—a natural marriage. Building codes can be designed to encourage the use of solar energy technologies in a variety of ways.

Advanced building energy codes require a dramatic increase in the energy efficiency of new residential and commercial buildings. Ambitious building energy codes can play a particularly important role in encouraging the use of passive solar design techniques in new buildings, and in ensuring that designers take a "whole building" approach to integrating renewable energy technologies with energy efficiency to produce a new generation of buildings that is far less dependent on fossil fuels. The ultimate goal is to design **zero net energy buildings**, which produce as much energy as they use over the course of a year. Local and state governments can create incentive programs for the development of zero net energy buildings and commit to ratcheting up building energy codes over time to achieve that goal.

Similarly, **government green building requirements** can ensure that new public buildings, including schools and government offices, achieve maximum levels of energy efficiency and incorporate solar energy technologies. These requirements assure that government buildings go beyond the baseline requirements of building energy codes to deliver exceptional energy-saving performance.

Solar-ready home policies require that all new homes are designed to accommodate solar electricity or hot water. These policies make it easier and less expensive for homeowners to implement solar energy when it suits them. New Mexico, for example, adopted legislation in 2007 authorizing new construction standards that require the proper strength and orientation of roofs, wiring, and other provisions to allow the future integration of solar energy.[150] Similar policies could require homebuilders to offer solar as a standard option on new homes, just as they do choices of paint color or countertops.

Solar requirements—One way to encourage the deployment of solar energy on new buildings is simply to require it. Such a policy may seem extreme at first blush, but solar mandates are becoming increasingly common worldwide and are beginning to gain a foothold in the United States. Israel has required the use of solar water heaters since 1957 and Spain recently adopted a similar policy.[151] As of January 2010, Hawaii, where approximately one-quarter of all homes already have solar water heaters, will require the use of solar water heating in all new residential construction, with a few exceptions.[152]

Guaranteeing Access to Solar Energy

Restrictive and outdated rules by homeowners' associations, local governments and utilities can prevent willing homeowners and businesses from adopting solar energy. **Solar access laws** guarantee individuals the ability to develop solar energy on their properties, in part by establishing the ground rules regarding individuals' access to sunlight (i.e., what happens when a tree or neighboring structure blocks a solar panel), and in part by limiting the ability of homeowners' associations and local governments to restrict the installation of solar energy systems.

Solar energy installations can also run into permitting bottlenecks at the municipal level. **Permitting reforms** include reducing or eliminating permitting fees, reducing the length of time necessary for obtaining permits for solar installations, and standardizing permitting requirements between jurisdictions, as well as ensuring a well-trained and adequate number of city level inspectors and permitting officials.

Utility policies can also erect hurdles to solar development by allowing utilities to charge excessive "standby fees" for solar hookups, capping the amount of solar energy eligible for net metering or, in the most extreme cases, not offering net metering at all. **Fair net metering policies** allow for surplus solar power compensation where a solar system owner gets paid for surplus solar electricity generated over a year-long period, allow a wide range of solar projects to qualify for net metering, and eliminate unjustified restrictive caps on the percentage of load that can be met with solar energy systems under net metering. States without any net metering policies should also establish them.

Educating the Public and Training a Solar Workforce

Knowledge barriers are among the most fundamental impediments to the accelerated deployment of solar energy. Consumers need the tools to evaluate whether solar energy makes sense for them and good roadmaps for how to make the process of "going solar" as easy as possible. Builders, architects, electricians, plumbers and other professionals need to understand the potential benefits of solar energy and how to integrate it into their work.

Workforce training is critical to ensuring that America has the base of trained workers necessary to build a solar future. State and federal governments should create and expand job training programs for solar workers and should work with professional organizations and government research and development agencies to ensure that the latest knowledge about the most effective ways to harness solar energy is quickly disseminated to practitioners in the field.

Governments should also develop creative policies to encourage **domestic manufacturing of solar energy equipment**. As the United States builds up a substantial domestic market for solar energy, the nation should use that development to take leadership in the global solar energy market. Well-designed tax credits and other policies can ensure that a greater share of the clean energy jobs created by a large expansion of solar energy remains in the United States.

Consumers need far better tools to ascertain the energy efficiency of buildings and building designs. A consumer shopping for a new clothes washer, for example, can read the government-required EnergyGuide label to quickly determine the energy cost of that appliance over its expected lifetime compared with other models. **Building energy labeling** requirements would require a home energy audit to be conducted prior to sale to allow the purchaser of the building to determine its level of energy efficiency. Building energy labeling would increase the likelihood that individuals would recapture the value of their investments in passive solar technologies and solar panels on resale by ensuring that would-be purchasers understand the monetary savings that will result from those investments.

Public education programs can help the public to understand the benefits of solar energy and provide easy ways (such as 1-800 numbers or directions to a Web site) for consumers to start the process of "going solar." These programs should include targeted outreach to groups with specific information needs. Industrial plant managers in particular, who can potentially install some of the largest and most cost effective solar energy systems, are likely to avoid unfamiliar technologies when providing for critical energy needs.[153] Education efforts that familiarize these decision makers with the range of available solar options, and how those technologies can serve their needs, can lead to more use of solar energy for appropriate and beneficial purposes.

Building the Solar Grid

As noted earlier, **investments in a smart grid** are critical to unlock the full potential of distributed solar electricity. Investing the necessary resources in smart grid development is important, but definitions of "smart grid" vary and the nation can ill-afford to waste resources on technologies that are unnecessary or that do not move the nation toward a clean energy future. Smart grid investments should be channeled toward those technologies that can contribute to the expansion of solar power, including advanced inverters, improved communications, and deployment of electricity storage.

Similarly, efforts to build a smarter grid should be undertaken alongside clean energy development efforts in other fields, specifically the development and deployment of **plug-in vehicles**. Should plug-in vehicles prove to be a grid asset—as the potential for short-term energy storage in vehicle batteries suggests they may—policies should be put in place to ensure that plug-in vehicle owners receive fair compensation for the services they provide to the grid.

Finally, the nation should ensure that **adequate transmission capacity** exists to connect areas with strong solar energy potential to places where electricity is used. It is important, however, that the nation not *overbuild* transmission capacity and insist that new transmission lines are devoted to carrying renewable energy, not paving the way for additional fossil fuel-fired plants. New transmission lines should be run, wherever possible, along existing corridors, and should always be carefully sited to minimize environmental impacts.

Discovering New Solutions

Many solar energy technologies are ready to make an immediate contribution to the nation's energy challenges. Solar photovoltaics, residential and commercial solar water heating systems, and concentrating solar power plants are all proven technologies. **Research and development** programs can continue to hone and improve those technologies, increasing the efficiency of solar cells, helping to develop efficient new manufacturing techniques, and finding new ways to overcome barriers to the integration of large amounts of solar energy into our economy.

There are, however, several solar technologies that, while promising, require greater effort to develop. Technologies such as industrial solar process heat, solar district heating, active solar lighting, and solar cooling have the potential to deliver great benefits in energy savings and pollution reductions. These technologies would benefit from concerted and coordinated research efforts and development strategies.

Looking far down the road, researchers will also need to develop methods for recycling solar energy systems that have reached the end of their useful lives, reclaiming as many useful materials as possible and ensuring that solar systems are disposed of without harm to the environment.

Finally, as this paper shows, there are

nearly as many potential ways to take advantage of solar energy as the human mind can imagine. Not all of these ways will turn out to be practical, but any idea with a chance of making a meaningful contribution should be explored. In 2009, the U.S. provided funding for the Advanced Research Projects Agency-Energy (ARPA-E)—an agency specifically designed to explore experimental energy technologies with transformative potential. For example, one research project funded by the agency is exploring the potential to use living organisms to convert sunlight and carbon dioxide into transportation fuel.[154] Many—indeed, most—of the ideas studied by ARPA-E will never come to fruition. But redoubling America's commitment to basic energy research will not only increase the chances of discovering the next transformative solar energy technology, but will also increase the chances that that technology will be developed in the United States.

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