On the Rise

Solar Thermal Power and the Fight Against Global Warming

ENVIRONMENT AMERICA
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Environment America
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Table of Contents

Executive Summary

Global warming is real, is happening now, and is largely caused by human activities. To prevent the worst impacts of global warming, the United States must take action to reduce global warming pollution quickly and dramatically. Electricity generation accounts for more than a third of America's emissions of global warming pollution. Preventing catastrophic global warming, therefore, will require the United States to shift away from highly polluting sources of power, such as coal-fired power plants, and toward clean, renewable energy.

Concentrating solar power (CSP) technologies—which use the sun's heat to generate electricity—can make a large contribution toward reducing global warming pollution in the United States, and do so quickly and at a reasonable cost. CSP can also reduce other environmental impacts of electric power production, while sparking economic development and creating jobs.

The United States has limited time to transition away from dirty energy sources and toward clean, renewable energy.

- The latest climate science tells us that the United States and the world must reduce emissions of global warming pollutants quickly and dramatically to prevent the most catastrophic impacts of global warming.
    - Should global average temperatures to increase by more than 2° Celsius, scientists warn that dangerous impacts from global warming will become inevitable, including

A row of parabolic trough solar collectors in a 150 MW parabolic trough solar thermal array in California. (Credit: Gregory Kolb, Sandia National Laboratories) flooding of coastal cities, the loss of large numbers of plant and animal species, and increases in extreme weather, wildfire and drought.

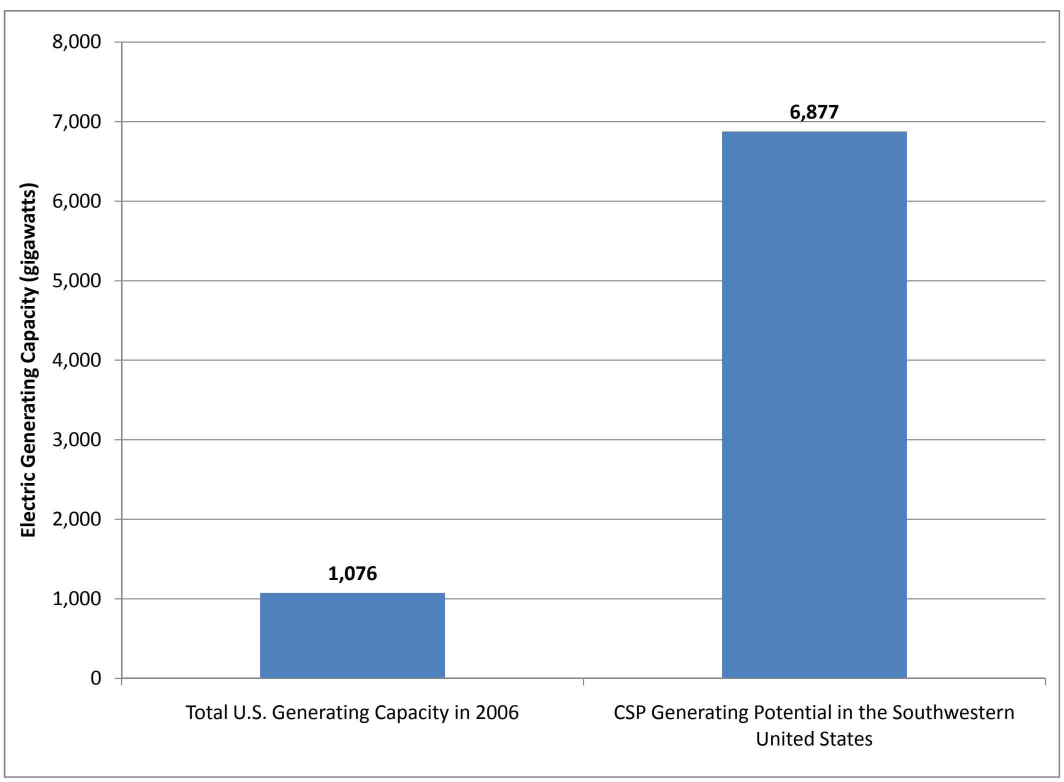
- To have a reasonable chance of preventing a 2° C increase in global average temperatures, the world must keep the concentration of global warming pollution in the atmosphere below 450 parts per million.[1]

- The United States must, at minimum, reduce its greenhouse gas emissions by 15-20 percent from 2000 levels by 2020, and by 80 percent by 2050 to prevent catastrophic impacts from global warming. Other nations must act aggressively as well.

- America's electric power plants produce more carbon dioxide (the leading global warming pollutant) than the *entire economy* of any nation in the world other than China.

- Even if America uses energy efficiency improvements to prevent future growth in electricity consumption, the nation will still need to expand its renewable generating capacity dramatically. Reducing carbon dioxide emissions from power plants to 20 percent below 2000 levels by 2020, for example, would require the U.S. to generate 15 to 24 percent of its electricity from new renewable sources—or between 158 GW and 257 GW of new renewable energy by 2020. The need for clean energy will further accelerate in future decades as the United States

Figure ES-1. CSP Potential in the United States[2]



seeks to meet increasingly stringent targets for emission reductions.

Concentrating solar power is ready to reduce global warming pollution, and can begin doing so right away.

- America has immense potential to generate power from the sun. The National Renewable Energy Laboratory has identified the potential for nearly 7,000 gigawatts (GW) of solar thermal power generation on lands in the southwestern United States—more than six times current U.S. electric generating capacity. Other sunny areas of the United States, such as the mountain West, the Great Plains and Florida, can also generate power from solar thermal energy.

- Solar thermal power plants covering a 100-mile-square area of the Southwest—equivalent to 9 percent the size of Nevada—could generate enough electricity to power the entire nation.

- Building just 80 GW of CSP capacity—a target that is achievable by 2030 with sufficient public policy support—would produce enough electricity to power approximately 25 million homes and reduce carbon dioxide emissions from U.S. electric power plants by 6.6 percent compared to year 2000 levels. Solar thermal power can make even greater contributions in the years to come—precisely the time when the nation must achieve deep cuts in global warming pollution.

- CSP plants are increasingly cost-competitive with other power generation technologies that do not produce carbon dioxide. The cost of energy from solar thermal power plants is estimated to be approximately 14 to 16 cents/kWh—competitive in cost with theoretical coal-fired power plants that capture and store their carbon dioxide emissions and with new nuclear power plants.

- CSP development has accelerated dramatically since the beginning of 2007. More than 2,800 MW of solar thermal projects are in some phase of development nationwide and could be completed by 2012.

CSP benefits the environment and America's economy.

- CSP power is clean. Its only necessary emission, water vapor, is harmless. By developing CSP, America can avoid the need for coal-fired power plants—which emit health-threatening mercury, particulate matter, and smog-forming pollutants and consume large quantities of water—and nuclear power plants, which consume large amounts of water and produce radioactive waste.

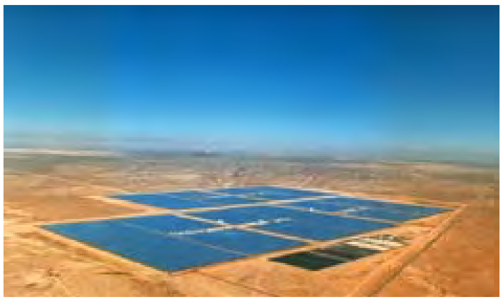
- CSP can play a leading role in the electric power system. Unlike intermittent forms of renewable energy, CSP plants with thermal energy storage can deliver power when it is needed to serve demand. CSP plants can be designed to provide either peak or baseload power, enabling them to address a variety of needs within the electric grid.

- Solar thermal plants create permanent jobs for local economies. Construction of 80 GW of CSP power has the potential to generate between 75,000 and 140,000 permanent, green jobs for Americans.

- CSP and other forms of renewable energy reduce demand for natural gas, thereby reducing prices. Installing

4 GW of CSP in California could save Californians between $60 million and $240 million per year in the cost of natural gas.

- America's vast potential for CSP could one day produce renewable electricity to be used in vehicles—thereby reducing the nation's dependence on oil.



An aerial view of the parabolic trough arrays at Kramer Junction, California. The five facilities have a combined production capacity of 150 MW. (Credit: Gregory Kolb, Sandia National Laboratories)

Strong public policies can increase the use of CSP in the United States. Priority actions include:

- Enacting a **national Renewable Electricity Standard (RES)** that requires 25 percent of all U.S. electricity to come from renewable resources—and a certain percentage from solar power technologies—by 2025. States should also enact RES policies or expand their existing RES targets.

- Expanding and extending the **Renewable Electricity Investment Tax Credit** can give CSP project developers the financial certainty they need to move forward.

- **Enacting caps on global warming pollution** at both the national and state levels, which will encourage the development of clean, low-carbon energy sources like concentrating solar power and encourage the retirement of America's dirtiest electric power plants. Money raised by auctioning allowances under a cap-and-trade system should help support renewable energy development and reduce the cost of the program to consumers.

- Creating **feed-in tariffs** for renewable energy sources, which provide financial rewards to generators who feed renewable energy into the power grid. Widely used in Europe, feed-in tariffs aim to move renewable energy to non-subsidized cost competition with conventional energy, creating fair markets between new and traditional electricity sources.

- **Providing access to transmission for CSP,** in particular through western regional policy agreements and initiatives, can ensure that solar power can be delivered to power consumers. New transmission lines should be built to renewable resource areas before they are built to traditional power generators and be sited and designed to minimize environmental impacts. The federal government should also fund existing research and development on a high-voltage direct current transmission backbone.

- Creating an annual $3 billion **fund for research, development, and deployment** of renewable energy for 2009, which can ensure that CSP and other renewable energy technologies are available to meet America's energy and climate challenges. The fund should be renewed for the next 10 years, committing $30 billion over the next decade. These dollars should come from shifting funds away from coal, oil, gas and nuclear power subsidies.

Introduction

America is at an energy crossroad. Energy is a mainstay of America's stability and growth: our economy requires energy to power everything from transportation to lighting to refrigeration. But while energy is essential, our energy choices are driving global warming, threatening our environment, and jeopardizing our economy.

Fortunately, America has access to vast reserves of clean, renewable energy that can meet our energy needs and address the challenges of global warming. Of the many clean energy technologies available to America, utility-scale solar thermal technologies—also known as concentrating solar power (CSP)—are among the most promising.

Concentrating solar power uses the sun's heat to generate electricity. Concentrating solar power has the potential to harness vast solar resources—and do so quickly and at decreasing costs. Because its power source is both renewable and free, solar thermal power buffers consumers from price volatility. The technology America needs to take advantage of that resource has continued to evolve over time and is now ready to play a leading role in addressing the challenge of global warming.

Solar thermal energy is one of many tools that will play a role in reducing the United States' dependence on polluting energy sources. The technology, know-how, and capacity for rapid CSP deployment exist in the United States today. Strong state and national policies can help Americans capture the many benefits that solar thermal power provides—and deliver a powerful solution for meeting the United States' pressing energy needs.

Global Warming and the Urgent Need for Renewable Energy

The Dangers of Global Warming

Global warming is real, is happening now, and is mainly caused by human activities—especially the burning of fossil fuels. The planet has already warmed by 0.7° C from pre-industrial levels, and global temperatures will increase an additional 0.2° C in the next two decades as a result of pollutants that have already been emitted into our atmosphere.[3]

Global warming has already triggered a range of impacts in America and around the globe:

- Glaciers are retreating worldwide and the annual extent of Arctic sea ice has declined by 2.7 percent per decade since 1978.[4] NASA scientists recently found a 23 percent decrease in the extent of Arctic sea ice between winter 2005 and winter 2007.[5]

- Sea level has risen with the melting of glacial ice and the expansion of the ocean as it warms. Average sea level has risen 6.7 inches in the past century.[6]

- Spring events—such as leaf unfolding, egg laying and bird migration—are occurring earlier in the year. Numerous species of plants and animals appear to be moving toward the poles in response to rising temperatures.[7]

- Storms may be getting more intense. The fraction of rainfall occurring in heavy precipitation events has increased.[8] Hurricanes appear to have become more powerful and more destructive over the last three decades, a phenomenon that some researchers link to increasing global temperatures.[9]

As the world continues to warm, the impacts of global warming will become increasingly severe. Scientists warn that if global average temperatures increase by 2° Celsius or more above pre-industrial levels, the likelihood of serious and irreversible impacts increases dramatically. These impacts include:

- The collapse of unique ecosystems such as the Amazon rainforest.[10]

- Increasingly high risk of extinction of

20 to 30 percent of the world's species (as opposed to smaller species losses with less extreme global warming).[11]

- Increased risk of coastal flooding from sea-level rise—threatening major population centers and important ecological resources in the United States and abroad.[12]

- Accelerated slow-down of the Atlantic thermohaline circulation, which could have large and difficult-to-predict impacts on climate.[13]

- Near-complete melting of the Greenland ice sheet, which would raise sea level by 23 feet over the course of millennia (and possibly much faster), and possible melting of the West Antarctic ice sheet, which would increase sea level by 5 to 16 feet.[14]

- More intense rainfall events, longer summer dry spells (increasing the risk of drought and wildfire), and more intense hurricanes.[15]

- Greater risk of crossing "tipping points" that would accelerate climate change, such as the release of methane from melting permafrost and conversion of ecosystems from net carbon sinks to net carbon sources.[16]

In order to preserve a reasonable chance of keeping the increase in global average temperatures below 2° Celsius, the world must keep the concentration of global warming pollution in the atmosphere below 450 parts per million (ppm), carbon dioxide equivalent.

The Intergovernmental Panel on Climate Change reports that, to stabilize the concentration of global warming pollutants at between 445 and 490 ppm, global emissions must peak no later than 2015 and decline by 50 to 85 percent below 2000 levels by 2050.[17] The United States, as the world's largest emitter of global warming pollution, must go farther and faster than the world as a whole.

America must, at minimum, halt increases in its global warming emissions immediately, cutting them to 15-20 percent below year 2000 levels by 2020 and to 80 percent below year 2000 levels by 2050. Other countries must do their share as well.

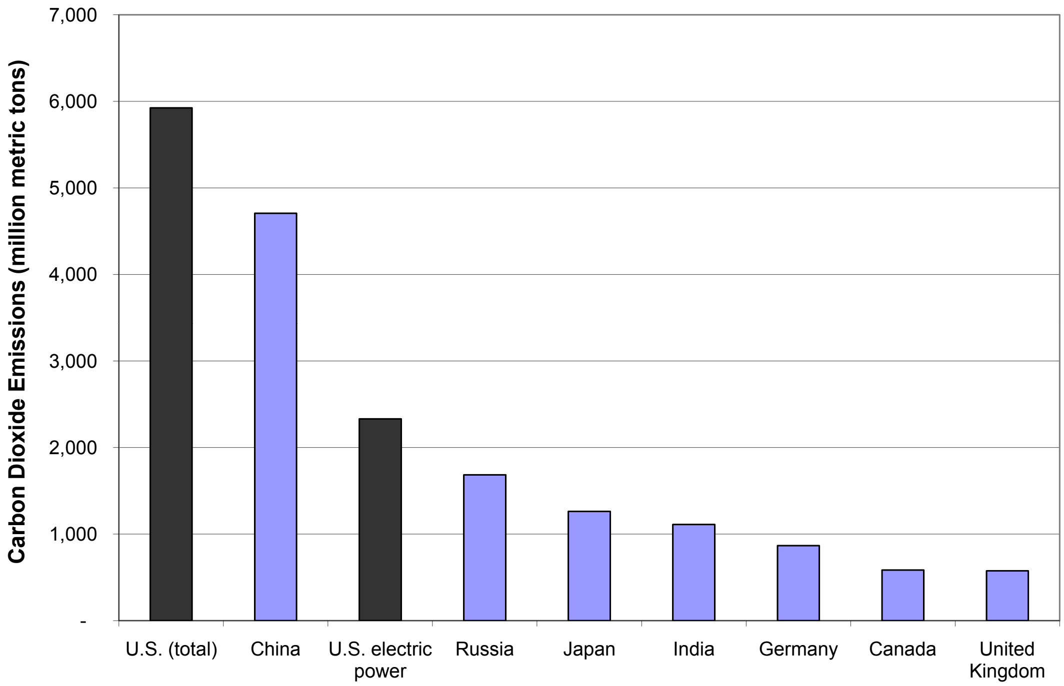
The Role of Renewable Electricity in Addressing Global Warming

America will need to expand its production of clean, renewable energy if it is to achieve the emission reductions that science tells us are necessary to stave off the worst impacts of global warming.

Electric generators are America's largest source of carbon dioxide, the leading global warming pollutant. Electric power plants were responsible for nearly 40 percent of America's carbon dioxide emissions in 2006 and more than a third of the nation's total emissions of global warming pollutants.[18] Indeed, America's power plants produce more carbon dioxide than the entire economy of any other nation in the world besides China.[19] (See Figure 1.) The vast majority of the carbon dioxide produced by power plants comes from coal-fired electricity generation.

The U.S. Department of Energy projects that, under business-as-usual conditions, America will consume 30 percent more electricity in 2030 than the nation did in 2005, and that power plants will produce 23 percent more carbon dioxide pollution.[21] Should that scenario come to pass, it will be virtually impossible for the United States and the world to avoid the worst impacts of global warming.

Figure 1. Carbon Dioxide Emissions from U.S. Electric Power Plants and Other Nations, 2004[20]



The first step is for the United States to use energy more efficiently. But even if energy efficiency is used to offset all projected growth in electricity demand, the nation will still need to develop large amounts of clean energy to meet its emission reduction goals. Based on recent projections from the U.S. Energy Information Administration, reducing carbon dioxide emissions from electric power plants by 20 percent by 2020 would require new renewable energy sources to produce between 15 percent and 24 percent of the nation's electricity, depending on the type of power generation that is replaced.[22] Reducing carbon dioxide emissions by 40 percent by 2030 would require between 28 percent and 43 percent new renewable energy.

Assuming an average capacity factor for renewable electricity generators of 40 percent, these targets translate to between 158 GW and 257 GW of new renewable energy by 2020 and between 302 and 466 GW by 2030.[23] If electricity consumption continues to increase, the amount of clean energy America must develop to hit its emission targets will be even higher.

Other studies confirm the scope of the challenge. A recent study by the American Solar Energy Society (ASES) estimates that renewable energy sources such as wind, solar, geothermal and biomass energy will need to constitute approximately half of America's electric grid by 2030 in order to keep the nation on track to achieve its long-term global warming emission targets—even if the nation simultaneously works to improve energy efficiency.[24]

The result is that America must develop hundreds of gigawatts of renewable energy capacity within the next few decades to address the challenge of global warming. But, while the challenge is daunting, there is also good news: America is developing renewable energy at a faster pace than ever before. The amount of wind power installed in the United States has nearly doubled since the end of 2005.[25] And the installation of solar photovoltaic panels in the United States increased by approximately 83 percent in 2007.[26]

While the growth of wind power and solar photovoltaics has captured headlines and broad public attention, another renewable energy boom—using a technology unfamiliar to many Americans—is beginning to take place in the deserts of the American Southwest and other locations with strong, consistent sunlight around the world. Concentrating solar power provides another powerful tool the United States can use to reduce our contribution to global warming and address the nation's energy challenges.

What Is Concentrating Solar Power?

In the direct sunlight of the southwestern United States, concentrating solar power (CSP) plants are harnessing the thermal power of the sun. The concept behind CSP is familiar: just as a magnifying glass focuses the sun's hot rays to ignite a scrap of paper, CSP focuses and collects the thermal energy of sunlight. But CSP creates far more heat than a magnifying glass, concentrating sunlight up to 10,000 times its initial intensity.[27]

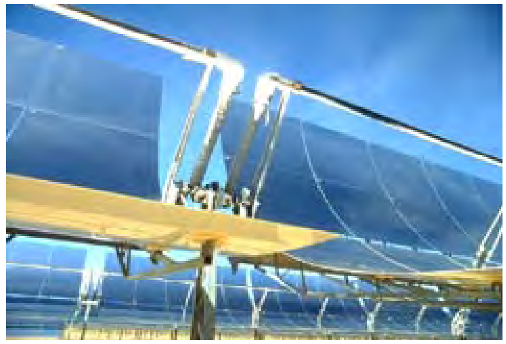
CSP differs fundamentally from the type of solar power most familiar to Americans: photovoltaics. While solar photovoltaic systems, such as rooftop solar panels, convert light directly into electricity, CSP systems concentrate and capture the sun's heat. In typical CSP plants, mirrors angle sunbeams to heat a liquid (typically water, oil or molten salts) to about 400° Celsius. This extreme heat is used to generate steam to drive large, conventional turbines or to power Stirling heat engines. Unlike electricity, which is currently costly and difficult to store, heat can be stored easily and relatively cost-effectively, making CSP a unique solar technology that can provide electricity even during cloudy weather and after sunset.

History of Solar Thermal Power

Since the 1980s, countries from Spain to the United States have been aware of the potential of concentrating solar power. In the wake of the energy crisis of the 1970s, governments and industry invested in research and development for a spectrum of renewable energy sources.

Nine Solar Electric Generating Stations (SEGS) were built in the southwestern U.S. from the mid-1980s to 1990. The plants, all of which continue to operate, range in size from 14 to 80 megawatts (MW), with a total capacity of 354 MW.[28] While the early CSP plants have produced power reliably for decades, early CSP technology, like all new technologies, was expensive. During the 1990s, low fossil fuel prices combined with the loss of enabling state and federal incentives, caused interest in CSP technology to dry up.

Recent concerns about energy security and global warming have attracted new investment, spurred new innovations that have reduced costs, improved the efficiency of CSP systems, and led utilities and policymakers throughout the world to once again focus on CSP as an option for addressing the world's energy challenges.



Solar collectors superheat thermal transfer fluid in the parabolic trough array at Kramer Junction. (Credit: Gregory Kolb, Sandia National Laboratories)

Types of Concentrating Solar Power Technology

Current CSP plants use four main design models.

Parabolic Troughs

Parabolic troughs are the form of CSP with the longest track record of delivering utility-scale power. In parabolic trough systems, special mirrors shaped as linear parabolas reflect the sun's rays toward an absorption tube suspended at the center of the trough's arc. The concentrated sunlight heats fluid inside the tube, generally a synthetic oil. The superheated fluid then travels to a collecting unit, where it heats water and generates steam to power turbines. The troughs are typically arrayed

Table 1. Parabolic Trough Power Plants in the United States[29]

Plant Name	Location	Year Operational	Net Capacity (MWe)
SEGS I	Daggett, CA	1985	14
SEGS II	Daggett, CA	1986	30
SEGS III	Kramer Junction, CA	1987	30
SEGS IV	Kramer Junction, CA	1987	30
SEGS V	Kramer Junction, CA	1988	30
SEGS VI	Kramer Junction, CA	1989	30
SEGS VII	Kramer Junction, CA	1989	30
SEGS VIII	Kramer Junction, CA	1990	80
SEGS IX	Kramer Junction, CA	1991	80
APS Saguaro	Tucson, AZ	2006	1
Nevada Solar One	Boulder City, NV	2007	64

on a north-south axis and track the sun throughout the day.

Parabolic troughs are effective at collecting sunlight, but have been hampered by relatively high costs. Typically, the fluids used to transfer heat from the troughs to the collecting unit cannot operate in excess of 400° Celsius (which limits plant efficiency and raises costs). Because the trough's absorption tube must remain fixed in relation to its mirrors, transfer fluid has to flow through flexible joints that shift throughout the day—joints that are expensive and require maintenance. Special curved mirrors are also expensive, and, because of their shape, hard to clean.

Recent technological advances, however, are making parabolic troughs more efficient and cost-effective. New plants such as Nevada Solar One, a 64MW facility that went on line in July 2007, have demonstrated increased efficiency at turning solar energy into electricity. Further, new trough designs are in development to eliminate ball-joints and increase the system's thermal capacity.[30] Engineers in Europe and the United States are experimenting with molten salts for use in higher-efficiency transfer fluids and heat storage systems, and with directly generating steam inside the absorption tubes, thereby reducing costs.[31] Several CSP developers are further working to increase the durability and minimize the costs of parabolic trough mirrors.[32] In addition, proposals are moving forward for new parabolic trough plants, including a 550 MW plant in California and a 280 MW facility in Arizona.[33]

Concentrating Dish/Stirling Engines

Shaped like a satellite dish, parabolic dish receivers work on a principle similar to the parabolic trough: curved mirrors bounce sunlight to a central collecting location. But instead of a long absorption tube, parabolic dishes focus light rays on a single area, suspended above the bowl of mirrors. Because of the high light concentration, temperatures at the focal point reach upward of 750° Celsius.[34] This heats a thermal fluid, which in turn powers a small steam or Stirling engine (located at the dish's focal point) to generate electricity.

While relatively efficient (with demonstrated peak solar to net AC electric conversion of over 30 percent), parabolic dishes have in the past been considered most useful as independent, off-grid units, particularly in remote and developing areas, or coupled with larger power plants.[35] This is because an individual dish is a self-sufficient unit: all the mirrors track as a unit, and the system generates electricity at the same site as its mirrors. The dishes are therefore modular and can be installed in places where there is not room for vast fields of mirrors. Since electricity is generated in the dish unit rather than at a central location, however, the dishes also have limited storage ability.

This parabolic dish collector in Shenandoah, Georgia, reflects sunlight to drive a Stirling heat engine, located on the arm above the dish. (Credit: Thomas Mancini, McDonnell Douglas/Sandia National Laboratories)

The central receiver of the Solar Two SEGS plant in Daggett, California, glows with sunlight reflected by its circular array of heliostats. (Credit: Joe Florez, Sandia National Laboratories)

Construction of several new, high-capacity parabolic dish plants is planned for the coming years. In 2005, Stirling Energy Systems announced two contracts with utilities in southern California for 800-1,750 MW of parabolic dishes.[36]

Central Receivers

Central receivers (or "power towers") also use mirrors to focus sunlight to a focal spot—in this case, a tower. But instead of using a dish to harvest solar power, central receivers rely on a stationary tower and nearly flat, tracking mirrors (heliostats) arrayed around the tower. Each heliostat in the array is free-standing, and is able to independently track the sun. Inside the receiving tower, a heat transfer fluid (usually water or molten salt) absorbs the sun's thermal energy and is used to generate steam for a turbine.

Because so much sunlight is concentrated in a small area, the tower fluid becomes superheated, reaching 650° Celsius. These higher temperatures help to reduce the cost of thermal storage. Also, the heliostats used in central receivers are nearly flat, rather than curved, reducing their manufacturing cost. These features combine to give central receivers the potential to be produced inexpensively.[37]

Demonstration central receiver plants have been built around the world, beginning in 1981 with a 0.5 MW test plant in Spain. Since then, countries including France, Italy, Japan, Russia and the United States have also constructed pilot central receiver plants, ranging from 1 to 10 MW.[38] The Solar One/Solar Two test facility was operational in Barstow, CA, between 1982-1988 and 1996-1999 (Solar Two involved a molten salts thermal storage retrofit on the Solar One plant). The facilities generated 10 MW of power and demonstrated increasing rates of generation and storage efficiency. Most recently, in March 2007, an 11 MW central receiver plant went on line to deliver power to the city of Seville, Spain—the first commercial power tower system in the world. Developers have filed an application to build a series of power tower systems, with a total of 400 MW of capacity, in southern California, with completion planned for 2012.[39]

Linear Fresnel Reflectors

Linear Fresnel reflectors (LFRs) use long rows of nearly flat, rotating mirrors to reflect light at absorbers elevated above the plane of the mirrors. Different absorbers use either a thermal transfer fluid or directly generate steam to power turbines.

While not as efficient as parabolic dishes and troughs or central receivers, LFRs offer many potential cost and structural advantages.[40] Like central receivers, their mirrors are made of standard glass in large, flat sheets—which require fewer steel supports than parabolic troughs and can be cheaply mass-produced. The mirrors' flat shape renders them more resistant to wind damage and makes them easier to clean.[41] LFRs' fixed absorbers also do not have moving joints, which simplifies fabrication and avoids the cost and maintenance challenges presented by joints in parabolic trough arrays.[42]

In the past, shadows caused inefficiencies in LFR arrays since all the mirrors in an array had to aim at a single absorber. A common solution was to increase the distance between the mirror rows—but this took up more surface area, decreasing the land efficiency of the system. The compact linear Fresnel reflector (CLFR) addresses this problem by adding multiple absorbers spaced at intervals above the mirrors. Because the mirrors must no longer be aimed at the same point, neighboring mirrors can be angled in opposite directions, minimizing shadows and allowing mirror rows to be placed closer together.[43]

Demonstration LFR arrays have been built in Australia, Spain and Belgium. Developers have applied for permits to build a 177 MW commercial-scale CLFR plant in California.[44]

Thermal Storage

The ability to store energy cost-effectively—and to deliver electricity when it is needed—represents one of the greatest advantages of CSP. Storing electricity is costly and often inefficient, requiring either expensive batteries or the conversion of electricity to another form of energy (using flywheels, pumped hydroelectric storage, or compressed air storage). By contrast, the ability to store heat energy created from concentrated sunlight enables CSP plants to store energy produced when the sun is shining and deliver it when it is needed by consumers.

Heated fluid produced by CSP plants can either travel directly to a boiler and generate steam to drive turbines, or it can travel to a storage unit. The storage unit serves as, essentially, a large Thermos: a structure that will store heat for later use.

Storage units typically employ one of three methods: "sensible" storage (liquids or solids), "latent" storage (phase-changing materials), or thermochemical storage.[45] Among other characteristics, an ideal thermal storage medium possesses high density, high heat transfer capacity, mechanical and chemical stability, and low cost.[46] Molten salts and concrete blocks (both "sensible" storage tools) in particular provide many of these qualities and are the subject of deepening scientific research.[47] Molten salts have been used in several recently constructed solar thermal plants.

Regardless of its form, thermal storage is key for the maturing of CSP technology as an electricity source because it addresses a fundamental challenge in renewable energy: intermittence. Many renewable energy sources, such as wind or solar power, produce electricity intermittently, or only when conditions are right. Further, the electricity they produce is difficult to store: the energy can be stored in batteries or other means, but these technologies are relatively costly and are not currently scaled to service utility-sized needs. As a result, there are theoretical limits to the share of wind and photovoltaic power that can be used while maintaining a reliably functioning electric grid. America is still a long way from reaching those limits and has vast potential to add power from intermittent renewable energy sources. But CSP with thermal storage provides the potential to deliver "dispatchable" renewable power today.

Thermal storage can also improve the economics of CSP plants—reducing the cost of producing power and increasing the value of that power to the electric grid. CSP plants without thermal storage generate power only when the sun is shining. To take full advantage of that power, CSP plant developers must install turbines that are sized to match the peak energy production of the solar field. With thermal storage, however, plant developers can use smaller, less expensive turbines that produce consistent power more of the time.

Most current CSP technologies have the potential to provide at least six hours of thermal storage—enough to help meet electricity needs during the evening hours, when electricity consumption is high but the sun is not shining. While not all new or proposed CSP plants include thermal storage, several new plants with extended storage are either under construction or in the planning stages. In Spain, two 50-MW parabolic trough plants are under construction that will employ six-hour thermal storage.[48] Also in Spain, the 15 MW Solar Tres central receiver plant will incorporate 15-hour thermal storage, using technology demonstrated at the Solar Two central receiver plant in California.[49] Abengoa Solar's proposed 280 MW parabolic trough plant in Arizona will also incorporate thermal energy storage.[50]

Engineers are working to further extend the length of time that utility-CSP plants can generate power, with the U.S. Department of Energy setting a goal of developing technology to provide 12 to 17 hours of thermal storage by 2020 and of reducing the cost of thermal energy storage.[51]

America's Vast Potential for Concentrating Solar Power

Concentrating solar power presents a unique opportunity for the United States. Vast solar resources exist on our lands, with the potential to provide more electricity than can be produced by all of America's current power plants. Tapping even a small portion of that potential can help America achieve meaningful reductions in global warming pollution in the near term.

An enormous and untapped energy resource lies, not buried in earth, but out in the open areas of the Southwest deserts. Largely concentrated in Arizona, southern California, southern Colorado, Nevada, New Mexico, and southern Utah, these lands hold the potential for nearly 7,000 GW of CSP power generation—over six times the nation's current electricity generating capacity.[53] This figure is very conservatively based on lands with high solar capacity that remain after ruling out lands that are incompatible with commercial development, have slopes greater than 1 percent, or comprise less than 10 contiguous square kilometers.[54]

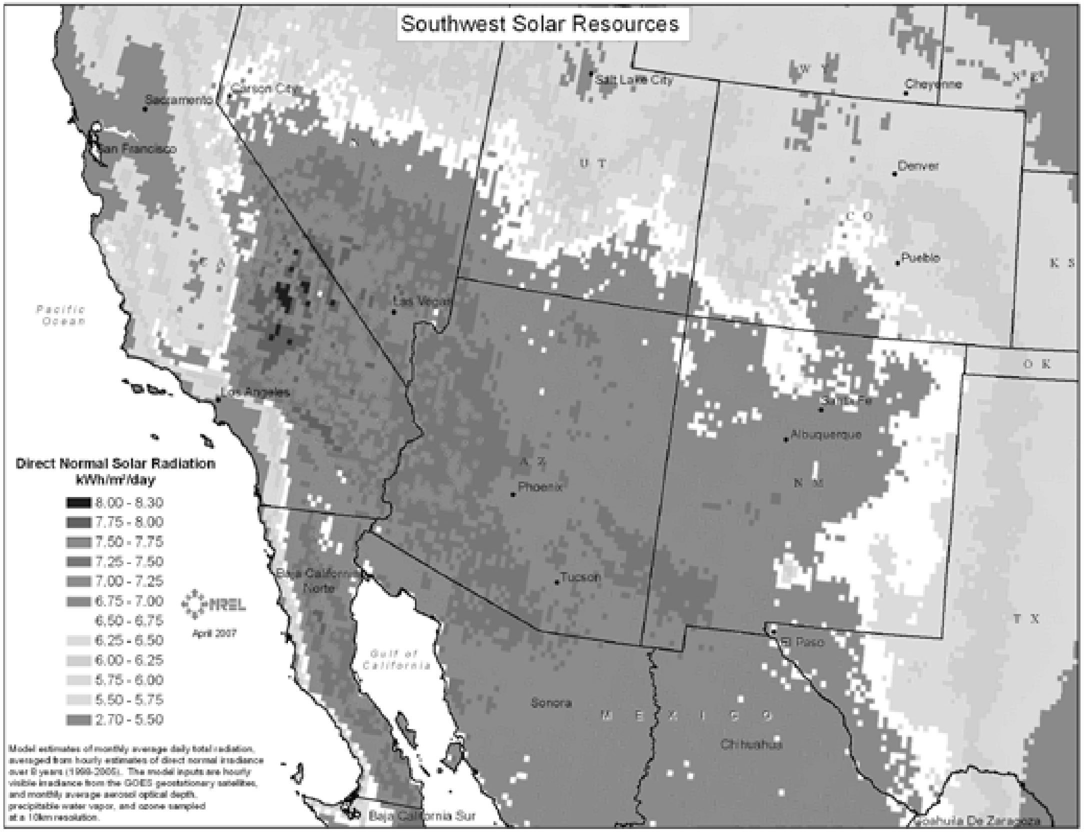
While the American Southwest has among the best solar thermal resources in the world, other parts of the United States, including much of the West, may also be able to take advantage of concentrating solar power, particularly since it has the

Table 2. CSP Potential in Southwest States[55]

State	High-Resource Available Area (mi^2)	Solar Capacity Potential* (MW)
Arizona	19,300	2,467,700
New Mexico	15,200	1,940,000
California	6,900	877,200
Nevada	5,600	715,400
Utah	3,600	456,100
Colorado	2,100	271,900
Texas	1,200	148,700

*Assumes that CSP power plants require about 5 acres of land area per megawatt of installed capacity. Solar generation can be estimated by assuming an average annual solar capacity factor of 25% to 50%, depending on the degree of thermal storage used for a plant.

Figure 2. Concentration of Solar Resources in the Southwestern United States[52]



potential to generate power when it is both most valuable and in highest demand—on hot, sunny summer days when air conditioning demand is high.

Tapping just one fifth of the southwestern United States' solar thermal potential would generate 100 percent of the electricity Americans are predicted to demand in 2030.[56] Indeed, America's current electricity demand could be satisfied with solar thermal power plants on a 100-mile-square area of the desert Southwest—an area equal to 9 percent the size of Nevada.[57]

America's ability to take advantage of CSP is not limited by the size of the resource, but rather by the availability of technologies capable of harvesting it at reasonable cost. As discussed elsewhere in this report, technological advances are

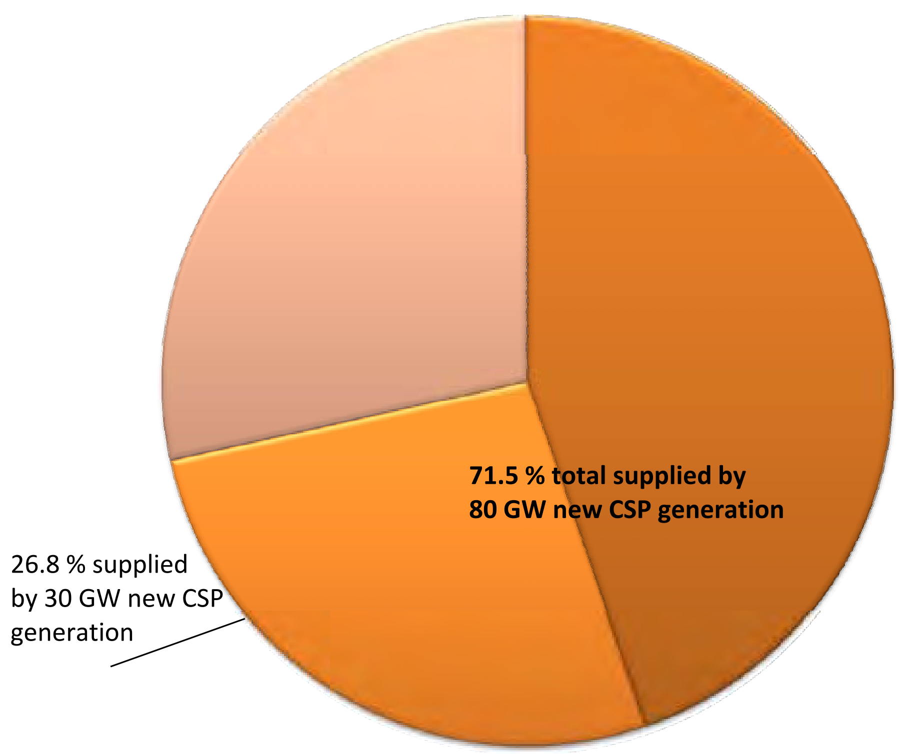
A parabolic dish receiver taps the solar resources of Southern California. (Credit: Thomas Mancini, Sandia National Laboratories) bringing down the cost of CSP technologies and producers are beginning to ramp up their ability to produce components of CSP systems.

A 2007 study by the American Solar Energy Society estimated that 30 GW-80 GW of solar thermal capacity could be installed in the Southwest by 2030 with strong and consistent public policy support.[58] Developing even this level of CSP—a fraction of the nation's ultimate solar thermal potential—would make a rapid and meaningful contribution to the nation's efforts to reduce global warming pollution.

The construction of 80 GW of CSP capacity would provide enough electricity to power more than 25 million homes—or a large portion of the Southwest.[59] Indeed, achieving 30 to 80 GW of CSP production could supply 27 to 72 percent of the electricity used in Arizona, California, Nevada, and New Mexico combined.[60] Additionally, 80 GW of CSP would produce 42 percent of the electricity the U.S. would need to meet a 25 percent national renewable electricity standard.

As noted above, America will need to develop hundreds of gigawatts of new renewable energy from a variety of sources—including wind, geothermal, solar photovoltaic, and biomass energy—to meaningfully address the threat posed by global warming. The development of 80 GW of solar thermal power by 2030 would make an important contribution to expanding America's supplies of clean energy, but it would merely scratch the

Figure 3. 30-80 GW CSP Generation as a Percent of Total Electricity Demand in Arizona, California, Nevada and New Mexico in 2006



surface on America's vast potential for concentrating solar power. By achieving that level of solar power—and developing the manufacturing capacity needed to sustain it—America would be well poised to achieve even greater development of solar thermal power in the decades ahead, precisely the time when the nation will need to dramatically reduce its emissions of global warming pollution.

Concentrating Solar Power: A Viable Choice Today

Concentrating solar power plants have delivered consistent, reliable power for decades. The technologies to take advantage of solar thermal power exist today, and continual refinement of those technologies is making them less expensive and more efficient over time. CSP is cost-competitive today with other forms of zero-carbon baseload power, and is economically competitive as a source of peak power as well. In addition, concentrating solar power plants can be built quickly, meaning that CSP has the potential to make a large contribution to America's near-term efforts to reduce global warming pollution.

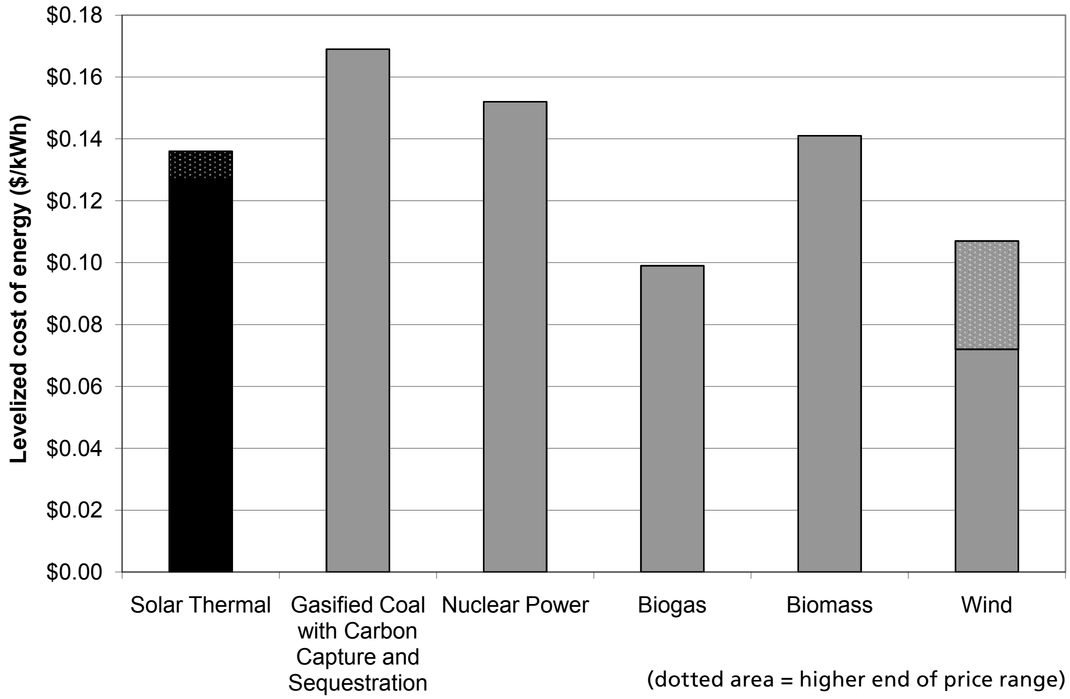
CSP Is Cost-Effective

The projected levelized cost of energy for new solar thermal trough plants is currently estimated at approximately 14-16 cents/kWh.[61] Those costs are significantly higher than the cost of new fossil fuel-fired power plants that do not control their emissions of carbon dioxide. But, when compared to other zero-carbon resources capable of producing baseload power, solar thermal power is cost-competitive.

A recent draft analysis conducted by Energy and Environmental Economics, Inc. for the California Public Utilities Commission (CPUC), estimated the cost of energy for concentrating solar thermal power in California at approximately 12.7 to 13.6 cents per kilowatt-hour (not including transmission costs).[62] By contrast, the cost of energy from new nuclear power plants was estimated at 15.2 cents per kilowatt-hour and the cost of energy from gasified coal power plants that capture and store their carbon dioxide emissions underground was estimated at 16.9 cents per kilowatt-hour. (See Figure 4.) The analysis is noteworthy because it factors in the recent sharp increase in the cost of building all types of power plants—cost increases that have hit coal and nuclear power plants particularly hard. (See, "The Rising Cost of Conventional Power Plants," page 22.)

As can be seen in Figure 4, solar thermal power is still more expensive than some other forms of renewable power generation, such as wind power and biogas. However, CSP with thermal storage is not

Figure 4. Projected Cost of Energy for California-Sited Power Plants[66]



an intermittent source of power like wind, meaning that a larger share of solar thermal power could eventually be integrated into the electric grid. Moreover, unlike biogas, which has limited available and sustainable supply, the potential for CSP development at reasonable cost is vast.

CSP with thermal storage is also currently cost-competitive with some natural gas-fired power plants that provide power at peak periods. A 2007 study conducted for the National Renewable Energy Laboratory (NREL) found that parabolic trough CSP systems built in California in 2007 would already be cheaper than simple-cycle natural gas peaking power plants (including the 30 percent federal investment tax credit for solar technologies).[67]

It is important to note that the cost figures cited here relate only to parabolic trough plants, which were, until very recently, the only form of CSP technology that had been developed commercially. Other CSP technologies could potentially produce power at lower costs, but their ability to do so has not been tested under real-world market conditions. Linear Fresnel reflector systems, for example, could be produced with less expensive materials, bringing costs down significantly. The California-based company, Ausra, Inc., for example, states that its compact LFR technology will be cheaper than natural gas-fired power plants by 2010.[68]

The cost of CSP should continue to decline in the years ahead as new technological innovations bring down costs and improve efficiency and as volume production of CSP components begins. The projected (inflation adjusted) cost of energy from solar troughs in the U.S. has already fallen by nearly 50 percent since 1989.[69] Given the potential for further technological improvements and economies of scale from mass production, those costs should continue to fall.

The Rising Cost of Conventional Power Plants

In recent years, and particularly during 2007, the cost of constructing new power plants ballooned, the result of rising prices for commodities such as concrete and steel, as well as other factors.

Cambridge Energy Research Associates (CERA) estimates that the cost of building nuclear power plants has increased by 185 percent since 2000, with wind power costs up 95 percent, natural gas power plant costs up 90 percent, and coal-fired power plant costs up 70 percent. The increase in costs has accelerated in the last year, with CERA's Power Capital Cost Index increasing by 27 percent in just 12 months. [63]

The increase in costs of conventional power plants is being felt in a variety of ways. The U.S. Department of Energy recently canceled its investment in the "FutureGen" project, which endeavored to build a first-of-its-kind coal-fired power plant with carbon capture and sequestration and the ability to produce hydrogen. The cost of the project had ballooned to $1.8 billion for a power plant capable of producing only 275 MW of electricity—a cost of more than $6,500 per kW.[64] The rising cost of nuclear power could also derail plans for new nuclear power plants in the United States. In late 2007, Moody's Investor Services estimated that the cost of new nuclear reactors could approach $6,000 per kW—well above previous estimates.[65]

No similar price index exists for concentrated solar power plants, although some of the trends that are driving up costs for conventional power plants are likely to affect CSP developers as well. However, rapid technological innovation in concentrating solar power—coupled with the fact that CSP is already cost-competitive with other zero-emitting alternatives—creates an opportunity for CSP to gain a foothold in the marketplace.

SunLab (a partnership between Sandia National Laboratories and the National Renewable Energy Laboratory) has projected that prices for parabolic troughs will decrease an additional 50 percent by 2020.[70] The U.S. Department of Energy is seeking to dramatically reduce CSP prices to 7-10 cents/kWh by 2015 and to 5-7 cents/kWh by 2020.[71] Data from ECOSTAR, a CSP focus group of the European Union, also demonstrate the potential for decreasing CSP costs, estimating a 55 to 65 percent reduction in overall costs by 2020.[72]

CSP Can Be Deployed Quickly

Another advantage of solar thermal power is that it can be deployed quickly. CSP plants are built largely from widely available and easily manufactured materials such as glass, steel and concrete. And experience confirms that rapid construction is possible with CSP plants. The Nevada Solar One project, for example, one of the world's newest solar thermal plants, achieved construction in less than

16 months.[73] By contrast, large nuclear power plants can take from four years or more to build.[74]

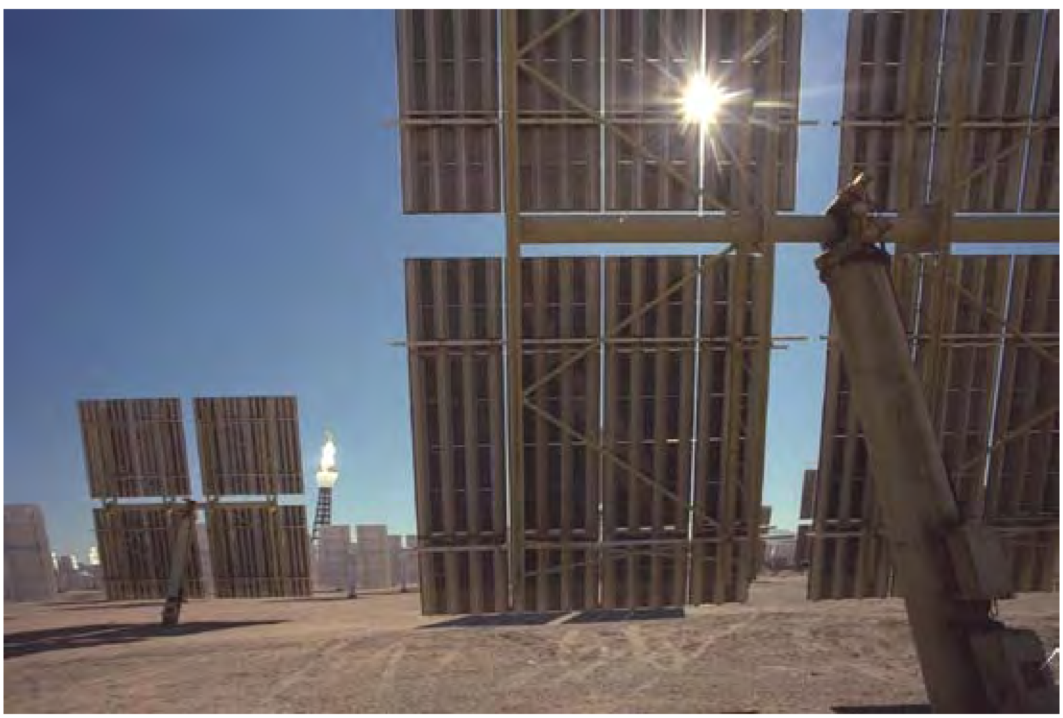
CSP Installations Are Increasing Dramatically—Both in the United States and Around the World

The last several years have seen a dramatic resurgence in interest in CSP—interest that is now translating into a boom in CSP development in several parts of the world.

Governments and companies in Algeria, Australia, Egypt, Greece, India, Iran, Israel, Italy, Mexico, and Morocco are backing a variety of parabolic trough projects totaling more than 400 MW of solar thermal power.[75] In 2006, Spain inaugurated PS10, a central receiver tower near Seville and the first of its kind in Europe.[76] Two larger, 50 MW solar thermal facilities are also under construction outside Granada.[77] Overall, Spain plans to add 2,570 MW of CSP power to its grid by 2012, with over 60 projects in its construction pipeline.[78]

In 2006, America's first solar thermal power plant in 15 years went on-line in Arizona, and in 2007, the 64 MW Nevada Solar One plant began operation.

The opening of two new solar thermal power plants is just the beginning of a cascade of new plants that could take root in the American Southwest over the next several years. As of February 2008, California utilities had signed contracts for between 1,600 MW and 2,500 MW of solar thermal power to be developed in California and neighboring states.[79] In February



A central receiver tower generating electricity in the California desert, viewed from behind a heliostat. (Credit: James Pacheco, Southern California Edison/Sandia National Laboratories)

2008, the Arizona Public Service Company announced plans to build a 280 MW parabolic trough plant by 2011.[80] CSP is even making inroads outside of the Southwest. Florida Power & Light has committed to building 300 MW of concentrating solar power in Florida, provided that an initial 10 MW plant meets its cost and performance goals.[81]

In total, CSP projects currently in the development pipeline in the U.S. could contribute 2,855 MW of power by 2012, or nearly 0.3 percent of current U.S. electric generating capacity.[82] And the projects for which contracts have been signed with utilities represent just the tip of the iceberg of interest in CSP. In California alone, as of March 2008, the federal Bureau of Land Management had received requests for rights of way on federal land sufficient to produce more than 38 GW of solar thermal power. All of those requests have been filed since the beginning of 2006, and the vast majority were filed in 2007.[83] While only a fraction of those projects are likely ever to be completed, the large number of applications is an indicator of the accelerating interest in CSP development.

One possible hurdle in the rapid development of CSP is the lack of manufacturing capacity for CSP components. But in this area, too, there have been important recent developments. In December 2007, Ausra, Inc. announced plans to construct a solar thermal manufacturing and distribution center in Nevada.[84] According to Ausra's projections, the plant will have the capacity to produce 700 MW of solar collectors per year.[85] Similarly, the German company, Schott AG, recently announced plans to build a manufacturing facility in Albuquerque to produce both photovoltaic panels and solar thermal receivers.[86] The Western Governors' Association reports that a recent poll of the CSP industry showed production capability for deploying over 13 GW (13,000 MW) of solar thermal power in the American Southwest by 2015.[87]

Concentrating solar power is already a cost-competitive, zero-carbon resource that can be deployed quickly. Interest in CSP development has increased in the past two years, with several important projects completed or under contract. And with additional manufacturing capacity on the way, CSP is poised for dramatic growth in the years to come.

The Benefits, Challenges and Promise of Concentrating Solar Power

Concentrating solar power has the potential to significantly reduce America's contribution to global warming, and do so in the near term. CSP can also deliver a host of other benefits to America's environment and economy. The future development of CSP, however, faces significant challenges—some of which can be addressed through public policy.

A technician surveys the solar field at Kramer Junction. (Credit: Gregory Kolb, Sandia National Laboratories)

Environmental Benefits of Concentrating Solar Power

Global Warming Pollution Reductions

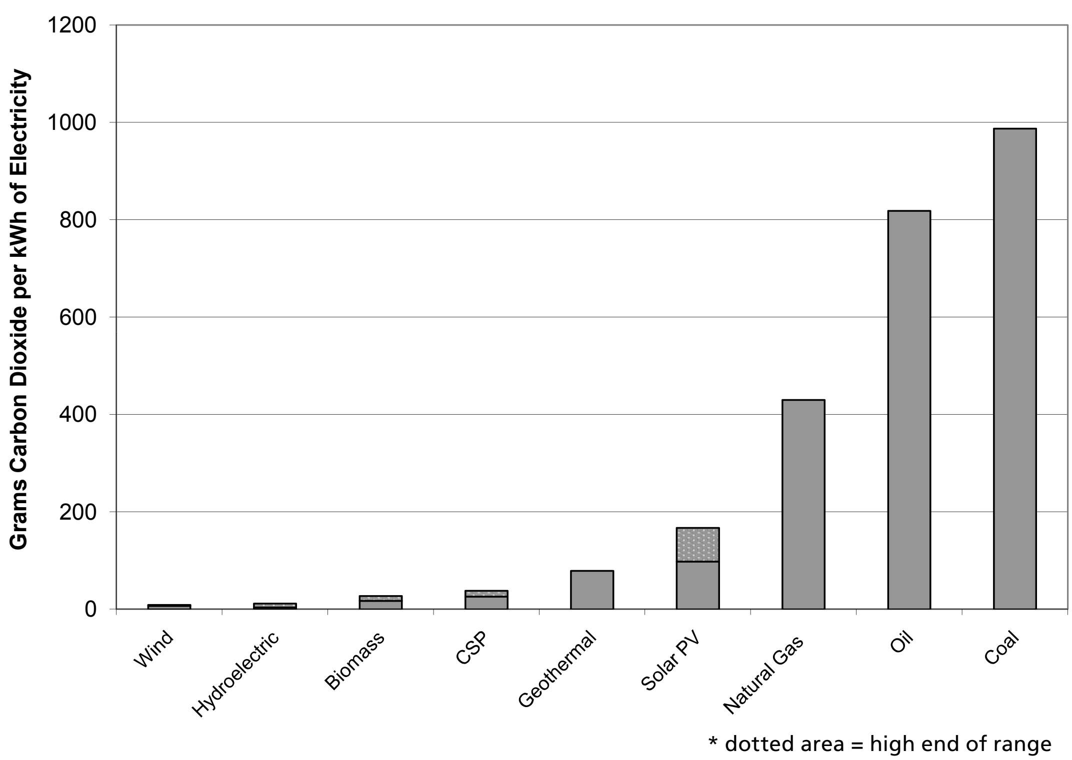
CSP can play a central part in America's efforts to reduce global warming pollution. Over a CSP plant's entire life-cycle, it will produce 30 times less carbon dioxide per unit of power produced than a coal-fired power plant and 13 times less than a modern natural gas-fired power plant. [88] The pollutants commonly emitted from fossil fuel power plants—greenhouse gases such as carbon dioxide, among others—are completely absent from the CSP process. CSP's only necessary emission, water vapor, is harmless.

Just how much global warming pollution can be avoided by CSP use? Data from the Western Governors' Association Solar Task Force suggests that CSP would save 545 metric tons of carbon dioxide annually for every gigawatt-hour of CSP power generation.[90] Substituting 80 GW of solar thermal power would save 152 million metric tons of carbon dioxide emissions annually, or 6.6 percent of carbon dioxide emissions from the U.S. electricity industry in 2000.[91] This is the rough equivalent of removing 28 million cars from the road, and is greater than the amount of carbon dioxide produced annually by the entire economies of the states of Arizona or Colorado.[92] Further expansion of CSP generating capacity can make an even greater dent in America's emissions of global warming pollution.

Reductions in Other Air Pollutants

Unlike fossil-fuel power generation, CSP plants also do not produce any toxic

Figure 5. Life Cycle Carbon Dioxide Emissions from Various Electricity Generating Technologies[89]



emissions, such as mercury, smog-forming chemicals and particulate "soot." Mercury contaminates our water supply and food chain, and can result in health problems, particularly in developing fetuses.[93] CSP plants also produce no emissions of particulate matter and ozone, which damage air quality and can aggravate respiratory illnesses.[94]

Water Consumption

Solar thermal power plants vary in their consumption of water, a precious commodity in the arid Southwest, but can be designed to consume far less water than existing conventional power plants. CSP plants, like conventional power plants, can be wet-cooled, dry-cooled, or use a combination of the two approaches. Wet-cooled CSP plants could be expected to consume about as much water as fossil fuel-burning plants for the amount of power they produce.[95] Dry-cooled plants consume far less water, but tend to be less efficient and more costly. Some forms of CSP technology, like Stirling engines, are inherently air cooled and consume virtually no water. CSP plants also generally require the use of a small amount of water to keep reflectors clean.

Economic Benefits of Concentrating Solar Power

Natural Gas Cost Savings

CSP can also play an important role in hedging against volatile natural gas prices, which hit electricity consumers, industries and homeowners hard. By reducing demand for natural gas in power plants, CSP and other renewable energy technologies can contribute to lower natural gas prices. A 2006 study conducted for the National Renewable Energy Laboratory found that installing 4 GW of CSP in California could save Californians between $60 million and $240 million per year in the cost of natural gas.[96]

Job Creation and Economic Benefits

New solar thermal plants create permanent jobs in communities neighboring their sites—communities which tend to be located in rural areas. A University of Nevada–Las Vegas study projected, for example, that 1000 MW of new CSP power facilities in Nevada would create more than 3,000 jobs per year during the construction phase, and would sustain roughly 1,800 jobs in the long run.[97] A similar analysis in California estimated that 100 MW of CSP would create 94 permanent jobs, not including jobs created during construction of the plant.[98] At these rates, construction

Technicians inspect the local controller on a parabolic trough array at Kramer Junction, California. (Credit: Gregory Kolb, Sandia National Laboratories) of 80 GW of new CSP power would create between 75,000 and 140,000 long-term "green" jobs.

Development of CSP also has broader economic benefits. The California analysis described above found that each dollar invested in CSP contributed approximately $1.40 to California's Gross State Product (compared to $0.90 to $1 per dollar invested for natural gas-fired plants).[99] Similarly, the Nevada study estimated that construction of 1,000 MW of CSP capacity would provide a long-term boost of $9.37 billion to total personal income in Nevada and add $9.85 billion to the Gross State Product.[100]

Challenges Facing Concentrating Solar Power

Falling costs and the growing need for solutions to global warming are among the factors driving the deployment of concentrating solar power in the United States. However, CSP still faces significant obstacles—including potential siting challenges, transmission access, and lack of consistent public policy support—that could hamper development of the technology in the years ahead.

Siting, Land Use and Environmental Concerns

CSP plants consume significant amounts of open space. And since CSP plants are generally located in deserts—which are both ecologically fragile and relatively undisturbed—there is reason for concern about the impact that CSP power plants can have on the broader environment.

However, while concentrating solar power does require significant amounts of land, it is actually more land-efficient than some other forms of power generation. For example, a CSP plant the same size as Lake Mead, the 250-square-mile reservoir created by construction of the 2,000 MW Hoover Dam, would produce roughly 13 times more electricity per year.[101]

America's current electricity demand could be satisfied with solar thermal power plants on a 100-mile-square area of the desert Southwest (10,000 square miles)—an area equal to 9 percent the size of Nevada.[102] By contrast, more than 9,000 square miles of the United States has been disturbed by coal mining over the nation's history. And at least 1,644 square miles are disturbed by current mining operations (based on an incomplete estimate of impacts in only 19 of 32 coal-mining states and tribal entities).[103] In contrast to CSP, the impact of coal mining on land is severe and often irreversible, and includes other environmental impacts—such as water pollution and the disposal of hazardous coal mining wastes—that can occur far from the mine site.

CSP plants will have an impact on the environment and wildlife wherever they are sited, and these impacts must be taken into account in siting decisions. Proposed CSP plants should be rigorously evaluated for their environmental impacts—including both the impact on the local environment and the environmental benefits produced from averted emissions of global warming pollutants. Continued technological advances in CSP systems hold the potential to produce more energy from smaller areas of land, and thereby reduce the potential for land-use conflicts in the future.

Transmission Access

Electricity from concentrating solar power plants is only useful if it can be delivered to consumers. Building large amounts of CSP in the desert Southwest will require access to transmission.

New transmission lines are often controversial, both because of their expense and the potential for damage to the environment and wildlife. Moreover, the expansion of transmission lines can also create additional capacity for fossil fuel-fired power plants, undercutting the environmental benefits of adding new renewable capacity.

The good news for CSP is that large amounts of solar thermal potential are located in close proximity to existing transmission lines. A 2006 assessment by the Western Governors' Association found that there were enough "prime" sites for CSP development—including sites in close proximity to existing transmission lines—to accommodate 200 GW of CSP capacity.[104] Not all of that capacity could be delivered with current transmission infrastructure, but the location of so much CSP capacity near existing transmission corridors suggests that a great deal of solar thermal power could be developed without clearing new corridors for transmission.

Western governors and policy-makers are involved in efforts to plan for future transmission system expansion. Those efforts should focus on the development of transmission lines that are designed to bring renewable energy into the grid and minimize environmental impacts.

Lack of Consistent Public Policy Support

The recent surge in interest in CSP and other forms of renewable energy is no accident. Public policy has played an important role in promoting renewable energy in recent years. Renewable electricity standards (RESs) in states such as California, Arizona and Nevada have prompted utilities to take a fresh look at renewable energy and to sign contracts for CSP power plants. At the same time, tax incentives—most notably the federal solar investment tax credit—have provided additional financial incentives for solar power developers.

However, the level of public policy support for CSP—particularly at the federal level—has been inconsistent. In 2005, the U.S. Congress increased the renewable energy investment tax credit from 10 percent to 30 percent for qualifying expenditures. However, the tax credit is currently scheduled to run out at the end of 2008. Allowing the tax credit to expire—or even extending it for only a short period of time—would fail to provide the certainty that investors need to pursue solar energy projects. Indeed, some currently planned CSP projects, such as a recently announced 280 MW CSP facility in Arizona, could be scuttled without a long-term extension of the tax credit.[105]

The United States needs to move beyond reliance on on-again, off-again incentives to promote the development of renewable energy. The federal government should adopt a long-term extension of the investment tax credit and establish a federal renewable electricity standard that would require at least 25 percent of America's electricity to come from renewable energy by 2025.

The Promise of Concentrating Solar Power

Addressing global warming is the foremost challenge of our time. America has a range of powerful tools at our disposal to reduce our emissions of global warming pollution—from the great potential for energy efficiency improvements in our homes, businesses and vehicles to our nation's extensive renewable energy resources.

Concentrating solar power is one more powerful tool in America's global warming toolbox. Our nation's solar resource is vast. The technologies we need to tap that resource exist today. And competition among a variety of companies is helping to foster further technological innovation.

In the near term, concentrating solar power can provide an increasing share of emission-free power to the fast-growing

Southwest. In the long run, CSP has the potential to provide clean electricity to areas far from the Southwest, provided that transmission capacity exists to deliver that power to distant markets.

Emissions-free solar thermal electricity could also play a role in reducing America's dependence on oil and global warming pollution from transportation. "Plug-in" hybrids and pure electric vehicles have the potential to reduce global warming pollution from transportation—particularly if they are powered by clean, renewable energy. Expanding production of electricity from CSP could allow those vehicles to be operated with minimal impacts on the environment and the climate, while helping to wean America from its dependence on oil.

America's energy challenges are large and likely to become only greater in the decades to come. Continuing to rely on dirty, highly polluting sources of energy will make it difficult, if not impossible, for the United States to do its share to prevent catastrophic impacts from global warming. Concentrating solar power is now ready to play a critical role in addressing these challenges. But the only way it will do so is if America prioritizes the development of renewable sources of energy—and uses the opportunity provided by the development of those resources to reduce our emissions of global warming pollution.

Seizing the Opportunity

Concentrating solar power is a powerful tool in moving America toward a New Energy Future. To make the vision of clean electricity in America a reality, our leaders must enact policies to spur immediate construction of CSP plants, speed innovation, support research and development, and facilitate investment in clean renewable technologies. They can accomplish this by taking six key actions:

- **Enact a national renewable electricity standard (RES) with a solar energy carve-out.** The standard should require the country to draw 25 percent of its energy from clean and renewable energy sources by 2025, including solar, wind, geothermal, tidal power and other forms of clean, renewable energy. The standard should require that a significant portion of the renewable share be derived from solar-powered sources. Such a requirement will encourage private sector investment in CSP technology, speeding construction, innovation and cost reduction.

  States can also play an important role by adopting or expanding their own renewable electricity standards and by taking other actions to ensure a smooth transition to cleaner sources of electricity. State RES policies in the Southwest are already driving significant investments in CSP and other forms of renewable energy and states should continue to update and revise their renewable energy targets to ensure continued momentum toward a clean energy future.

- **Expand and extend the Renewable Electricity Investment Tax Credit.** The Renewable Electricity Investment Tax Credit (ITC) allows companies to claim a tax credit equal to 30 percent of the capital costs of a renewable energy project. The tax credit has been a key factor fueling the recent growth in CSP, but the short-term nature of the credit has hampered the ability of developers to plan for future growth. The federal government should extend the credit for a minimum of eight years in order to provide assurance of support to renewable energy developers and investors.

- **Cap national and state-level carbon emissions.** Adding large amounts of renewable energy creates the opportunity for the United States to phase-out its dirtiest and highest-polluting forms of power generation. But this will only occur if the nation also places a cap on global warming pollution. The cap should be designed to limit emissions of global warming pollution to at least 20 percent below 2000 emission levels by 2020 and to 80 percent below those levels by 2050 – the minimum reductions science tells us are necessary to avoid the worst effects of global warming. Money raised from the auctioning of allowances under a national cap-and-trade program for global warming pollutants should be used to facilitate a clean energy transition and to reduce the cost of the program to consumers.

- **Establish feed-in tariffs for renewable resources.** In a feed-in tariff, the government ensures that renewable energy developers receive a guaranteed price for the energy they supply to the power grid. Many countries, including Spain, Germany, Ireland, France, and Austria, are successfully using feed-in tariffs to grow renewable energy penetration in their energy markets.[106] The feed-in tariffs are generally customized for each renewable technology, helping them individually reach common competitive and non-subsidized cost levels. Feed-in tariffs can be used to spur the development of resources like CSP with large long-term potential.

- **Provide access to transmission for CSP.** Concentrating solar power can only make an impact if it can be delivered to consumers. There is ample CSP potential in areas with access to the West's existing transmission network, but congestion on transmission lines could reduce the potential of CSP to deliver emission-free power to the Southwest and beyond. Governors of western states should continue to explore ways to provide access to transmission for concentrating solar power. New transmission lines should be built to renewable resource areas before they are built to fossil fuel-powered generators, and the federal government should provide funds to expand existing research and development on a high-voltage direct current transmission backbone that could deliver renewable electricity from the Southwest to load centers around the country. In addition, any new transmission corridors should be selected and developed with minimal impacts on the surrounding environment.

- **Increase research & development and deployment funding.** Congress should create an annual $3 billion fund for research and development of renewable energy for 2009. The fund should be renewed for the next 10 years, committing $30 billion over the next decade. Increasing funding will hasten innovation, lowering end costs by capturing increased efficiencies in production, deployment, and operation of solar thermal power.

Notes

1. Carbon dioxide equivalent.

2. U.S. generating capacity from Energy Information Administration, *Existing Capacity by Energy Source*, 22 October 2007. CSP generating potential from Mark S. Mehos and David W. Kearney, National Renewable Energy Laboratory and Kearney & Associates, *Potential Carbon Emissions Reductions from Concentrating Solar Power by 2030*, in Charles F. Kutscher, ed., American Solar Energy Society, *Tackling Climate Change in the U.S.*, January 2007, 83.

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5. National Aeronautics and Space Administration, *NASA Examines Arctic Sea Ice Changes Leading to Record Low in 2007* (press release), 1 October 2007.

6. See note 4.

7. See note 3.

8. See note 4.

9. Kerry Emanuel, "Increasing Destructiveness of Tropical Cyclones Over the Last 30 Years," *Nature*, 436:686-688, 4 August 2005.

10. HM Treasury, *Stern Review: The Economics of Climate Change*, 2006, 57; Rachel Warren, "Impacts of Global Climate Change at Different Annual Mean Global Temperature Increases," in Hans Joachim Schnellnhuber, ed., *Avoiding Dangerous Climate Change*, Cambridge University Press, 2006.

11. Ibid.

12. Ibid.

13. S.H. Schneider, et al., "Assessing Key Vulnerabilities and Risk from Climate Change," in *Climate Change 2007: Impacts, Adaptation and Vulnerability, Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, 2007, 794.

14. Greenland from S. Solomon, et al., "2007: Technical Summary" in *Climate Change 2007: The Physical Science Basis, Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, 2007, 80. "Possibly much faster" based on James Hansen, "A Slippery Slope: How Much Global Warming Constitutes 'Dangerous Anthropogenic Interference?' " *Climatic Change*, 68. 68:269-279, 2005. West Antarctic ice sheet from S.H. Schneider, et al., "Assessing Key Vulnerabilities and Risk from Climate Change," in *Climate Change 2007: Impacts, Adaptation and Vulnerability, Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, 2007, 794.

15. See note 13, 789.

16. Ibid.

17. Intergovernmental Panel on Climate Change,

"Summary for Policy Makers," *Climate Change 2007: Mitigation of Climate Change, Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, 2007, 23.

18. U.S. Department of Energy, Energy Information Administration, *Emissions of Greenhouse Gases in the United States 2006*, 28 November 2007.

19. U.S. Department of Energy, Energy Information Administration, *Emissions of Greenhouse Gases in the United States 2006*, November 2007; U.S. Department of Energy, Energy Information Administration, *International Energy Annual 2005*, September 2007.

20. Ibid.

21. U.S. Department of Energy, Energy Information Administration, *Annual Energy Outlook 2008: Revised Early Release*, March 2007.

22. "Between 15 percent and 24 percent" based on a scenario in which carbon dioxide emissions from electricity generation are reduced to 20 percent below 2000 levels by 2020. The level of carbon dioxide emission reductions required to hit this target were calculated by subtracting the 2020 target emission level from projected emissions from the electricity sector in 2007 (i.e., assuming zero growth in electricity consumption or emissions between 2007 and 2020). These savings were then converted into kilowatt-hours of renewable energy by dividing the required carbon dioxide emission reductions by one of two emission factors: the average emissions produced per kWh of electricity by the projected electric power system of 2020 and the average emissions per kWh of coal-fired power plants in 2020. The same analysis was conducted for a case that called for 40 percent emission reductions by 2030. All data for this analysis were obtained from U.S. Department of Energy, Energy Information Administration, *Annual Energy Outlook 2008: Revised Early Release*, March 2008.

23. The average capacity factor of U.S. renewable generators was 39 percent in 2005, based on U.S. Department of Energy, Energy Information Administration, *Annual Energy Outlook 2008: Revised Early Release*, March 2008.

24. Charles F. Kutscher, ed., American Solar Energy Society, *Tackling Climate Change in the U.S.: Potential Emissions Reductions from Energy Efficiency and Renewable Energy by 2030*, January 2007.

25. Based on Ryan Wiser and Mark Bolinger, U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, *Annual Report on U.S. Wind Power Installation, Cost, and Performance Trends: 2006*, May 2007; American Wind Energy Association, *Installed U.S. Wind Capacity Surged 45% in 2007: American Wind Energy Association Market Report* (press release), 17 January 2008.

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27. U.S. Department of Energy: Energy Efficiency and Renewable Energy, *DOE Solar Energy Technologies Program: FY2006 Annual Report*, 2007, 107.

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