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Subcontractor Report

Brighter than a Hundred Suns: Solar Power for the Southwest

Period of Performance: November 20, 2001 to October 31, 2002

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Executive Summary

Although renewable energy development will be hindered by a persistent electric generating capacity surplus and lower power prices in the Southwest through the end of the decade, we believe that the attributes of renewable energy such as power at a guaranteed price and zero air emissions will continue to stimulate investment in new projects. Indeed, the desire to avoid energy price volatility and mounting environmental concerns have already spurred policy makers to adopt policies that ensure that renewable energy will play an increasing role in meeting the Southwest's electricity needs. For example, both California and Nevada have recently enacted renewables portfolio standards requiring utilities to provide a minimum percentage of their energy from renewable sources. On a national level, policy makers are considering stepping up renewable energy tax incentives, which would reduce the technologies' cost and simulate new development.

In many ways, photovoltaic (PV) and concentrating solar power (CSP) technologies are an ideal energy solution for the Southwest. Our analysis shows that a small fraction of the land in the Southwest with premium solar resources, that is areas that receive average daily sunshine in excess of seven kilowatt-hours per square meter per day (>7 kWh/m^2/day), alone are capable of producing nearly all of the electricity currently consumed in the region. If excellent (6.5-7.0 kWh/m^2/day) and good (6.0-6.5 kWh/m^2/day) solar resources are included, the solar generating potential is nearly twice the current electric energy demand, but would occupy less than one percent of Southwestern lands. Not only are solar resources abundant in the Southwest, they are also close to metropolitan areas greatly reducing the need to invest in transmission capacity in order to bring solar power to consumers.

While PV systems are well suited for distributed and remote power applications, CSP is the preferred technology for utility-scale power generation. Not only is the cost of power from CSP lower, but CSP can also address the intermittence of sunshine through hybridization with fossil fuels and solar heat storage. However, to date, the high initial cost of CSP compared to conventional power sources has limited the penetration in power markets to 354 MW of CSP currently operating in California. At approximately 11 cents per kilowatt-hour (¢/kWh), the cost gap between the lowest cost CSP technology and the market price of power is on the order of 6 ¢/kWh. But when the price stability of CSP energy and consumer interest to buy renewable energy are valued explicitly the cost gap reduces to 3 ¢/kWh.

Our analysis indicates that the remaining gap may be overcome through continued research and development, experience with new CSP projects, and development of a solar industry. However, in order for this to occur, new projects must be built. Given the current cost gap, this will require policies designed to stimulate near-term deployment. With the assistance of policy initiatives that contain cost- and risk-reduction measures for investments in CSP, the technology has the potential to reach cost competitiveness by the end of the decade. However, in the absence of such policy initiatives, new utility-scale solar power projects in the Southwest—or elsewhere in the country—are unlikely.

Note: This report on the potential of solar power for the Southwest is based on a study sponsored by the Department of Energy, *"Fuel From the Sky: Solar Powers Potential for Western Energy Supply,"* by Dr. Arnold Leitner, Platts Research & Consulting, government publication NREL/BK-550-32160, July 2002, Boulder, Colorado.

Brighter Than a Hundred Suns: Solar Power for the Southwest

Renewable Energy in the Southwest

The Southwest: California and the Desert

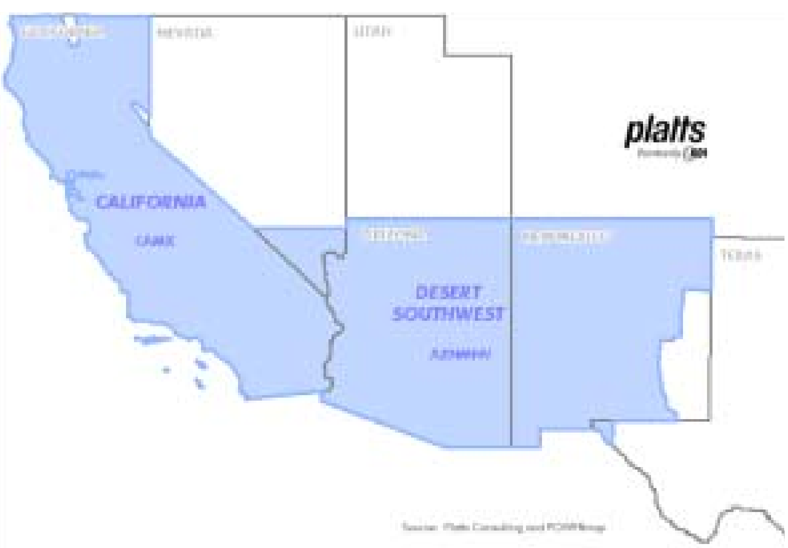
The geographic region that we refer to as the Southwest is an area that greatly overlaps with the major metropolitan areas of the four-state region of California, Nevada, Arizona, and New Mexico and which forms the Southwestern transmission grid[1] (Figure 1). This power market is electrically well interconnected, and power prices across the region are within a few percent of each other during most hours of the year. In addition, this region contains most of the solar resources of the four states. This Southwestern power market is, therefore, a natural choice for a discussion on the potential of solar power for the southwestern United States. Northern Nevada, Utah, and Colorado also have considerable solar resources, but these resources are either not close to load centers, as in Utah and northern Nevada, or not as high as in the rest of the Southwest, as is the case in Colorado.

The State of Power in the United States

After an unprecedented power plant construction boom over the past four years, in which more than 80 gigawatts (GW) of electric generating capacity were brought to market and 122 GW remain under construction, most power markets in the United States are now highly overbuilt.[2] This overbuild combined with reduced electricity demand growth due to slow economic growth in the country has sent electricity prices sharply lower in many regions.

Furthermore, the California energy crisis and the collapse of Enron have done severe damage to the public's trust that competitive power markets can function properly. Consequently, a number of states that were considering deregulation have postponed—or even rolled back—their plans for competitive power markets.

Figure 1. The Southwest



What a difference a few years can make! In the late 1990s electric power generation seemed brisk with opportunity, and deregulation was sweeping the country. Now the market is beginning to cope with the reality of providing electricity in a competitive environment. At first blush, the capacity glut and the confidence crisis appear to dim the prospects for renewable energy as well, but we believe that the new reality in power markets may, in fact, aid investments in new renewable energy projects for the following reason. The lack of confidence in the deregulated market may lead power plant development from the high-risk/high-reward "merchant" model, in which power plants sell all or a portion of their electricity into the competitive spot market, back to the more traditional approach, which is centered around long-term power off-take agreements between a power generator and a utility. This shift may be favorable for renewable energy technologies, which are unable to compete in the merchant world, because their high initial cost puts too much capital at risk, but which promise electricity to utilities at guaranteed prices.

A Case for Renewable Energy

As a result of the recent power plant construction boom and the return to normal hydro conditions in the Pacific Northwest, power markets in the Southwest are now enjoying a growing generation surplus that is expected to last through the end of the decade. However, in spite of this surplus, we believe that the risk-reduction and environmental attributes of renewable energy technologies will stimulate new investment in renewable energy over the next decade. It is our view that the potential for volatility in natural gas prices and more stringent air emissions regulations will emerge as the key drivers of this trend.

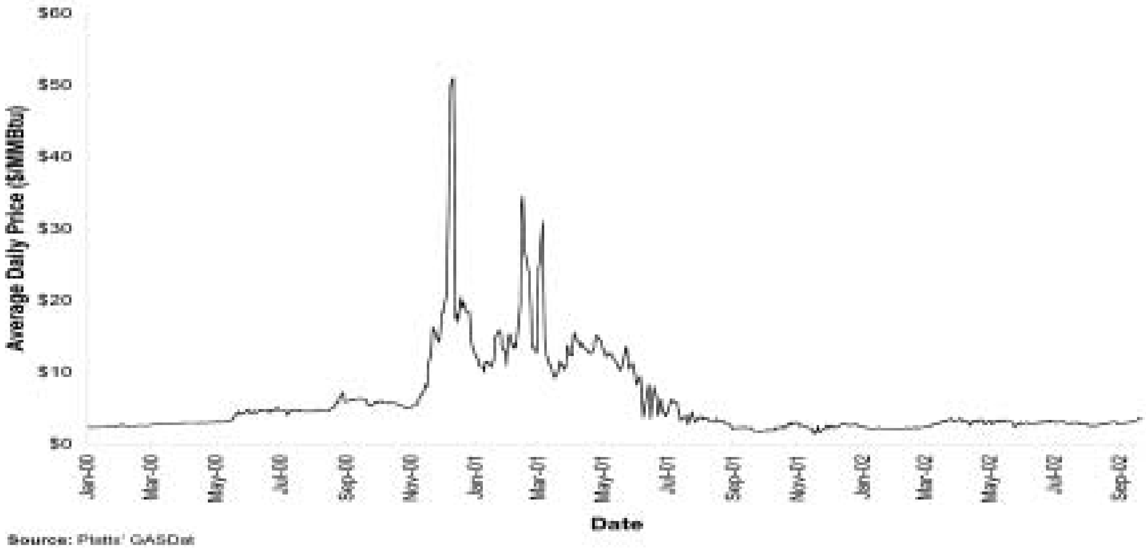
Natural Gas Prices May Be Volatile

The run-up of natural gas prices from $2 per million British Thermal Unit (MMBtu) to over $50/MMBtu at the end of 2000 and subsequent spikes in the $30/MMBtu-range in the spring of 2001 (Figure 2) provide a vivid example and a painful reminder of natural gas price risk. With almost all of the new generation burning natural gas, gas-fired generation will begin to set power prices more hours of the day, and the volatility of electricity prices will increasingly reflect the radical movements of natural gas prices. Regulators will likely face increasing pressure to protect consumers against financially onerous price increases, and renewable energy sources with guaranteed energy cost could provide an intriguing alternative.

Clean Air Is Important As Ever

Concerns about local and regional air pollution and greater awareness of the danger of global climate change may also open the door to new renewable energy projects. During the recent construction boom, coal plant development was hampered by increasingly onerous air pollution regulations. Now concerns about the possibility of future greenhouse gas emissions regulation are coming increasingly to the forefront. We believe that this trend will only become stronger, thereby creating new opportunities for renewable technologies, which unlike fossil fuel power plants, produce no air emissions (Table 1).

Figure 2. Natural gas prices in the Southwest (January 2000 – September 2002)



Indeed, the desire to avoid electricity price volatility and mounting environmental concerns have already spurred policy makers to adopt policies that ensure that renewables will play an increasing role in meeting the Southwest's electricity needs. Both California and Nevada have recently enacted renewables portfolio standards that require utilities to provide a minimum percentage of their supply from renewable energy sources. National policy-makers are considering stepping up renewable energy tax incentives, which promise to reduce technology costs and simulate new development.

Table 1. Air Emissions by Plant Type

Plant Type	Heat Rate (HHV) Btu/kWh	NO_x Lbs/MWh	SO_2 (1) Lbs/MWh	CO_2 Lbs/MWh	Particulates Lbs/MWh
Coal	9,500	1.52	1.62	1,930	0.01
Combined Cycle	7,100	0.21	0.01	830	–
Gas Boiler	10,500	0.84	0.01	1,230	–
Combustion Turbine	11,500	0.58	0.01	1,345	–
Solar, Wind, Hydro, and Nuclear	None	None	None	None	None

SOURCE: U.S. Department of Energy, Market-Based Advanced Coal Power Systems, May 1999, and Platts Research & Consulting analysis.

NOTE: Based on 2000 average sulfur content in western coal plants of 1.3 lbs/mmBtu.

Market Challenges

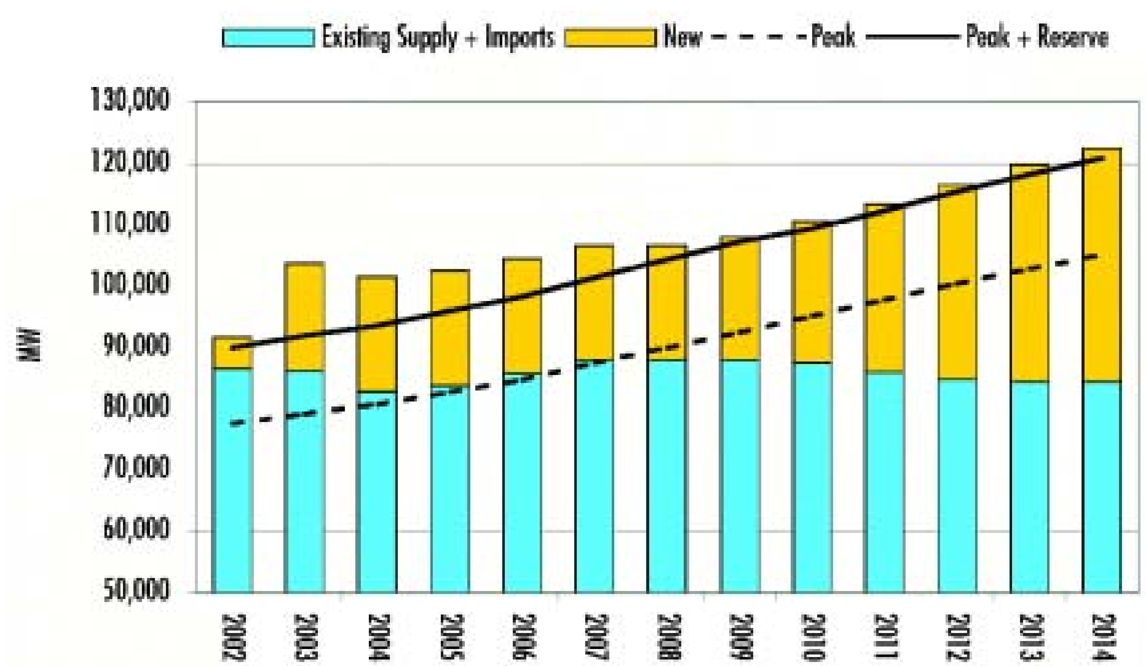
While there are many benefits to using renewable energy, electric power from renewable sources is generally more expensive than electricity from conventional sources of power. This cost gap becomes even more apparent when power markets are overbuilt and power prices are depressed, as is currently the case. A surplus of generating plants and low prices are forecast to persist in the Southwest for a number of years, and this poses a significant challenge to renewable energy projects during that time.

A Growing Generation Surplus

Our analysis indicates that after 2002, the Southwest will enjoy a surplus of power well above the 15-16% target reserve margin until nearly the end of the decade (Figure 3). Through 2010, our analysis suggests that retirements of older plants will be more than offset by additional power available to the region through imports. This reduces the need for new capacity additions through the end of the decade and has been considered in the forecast.

It is important to note that our analysis does not yet reflect recent project delays in California, which have started to mount in response to the state's decision to renegotiation long-term power contracts that it entered into with generators during the energy crisis. Some developers, wary of the political situation in California, have elected the short-term response of walking away from their projects. As a result, less capacity than expected may be completed in the Southwest, which could result in the need for new power plants earlier in the decade. Thus, the generation surplus may be less pronounced than anticipated.

Figure 3. Demand and supply balance in the Southwest, 2002-2004



Source: Platts Research & Consulting, NEWGen, and Outlook for Power Service Q2 2002.

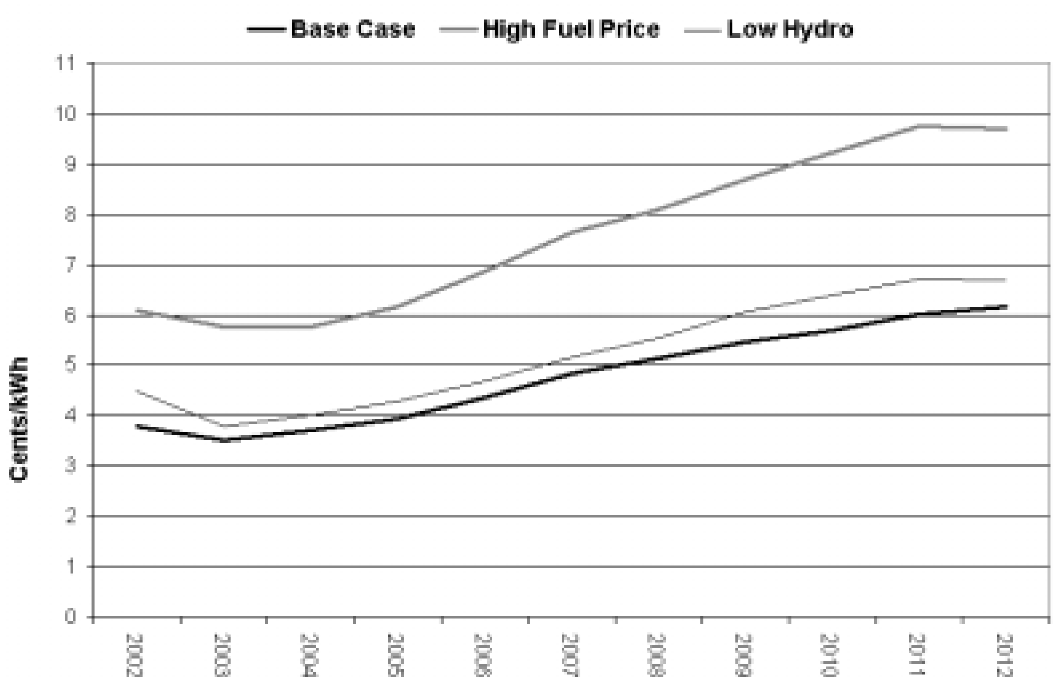
Low Electricity Prices

The surplus of capacity evident in Figure 3 leaves its mark on power prices. Figure 4 shows our forecast of on-peak power prices in the Southwest.[3] Peak periods in the region last for 16 hours each day from Monday through Saturday and thus account for nearly 60% of all hours. These high-price periods are of great interest to solar power technologies that can deliver power during those hours. To show the influence of a low snow pack in the West and high fossil fuel prices, we also provide prices in a "Low Hydro" scenario, in which hydro capacity is 20-24% lower than average, and in a "High Fuel Price" scenario, in which natural gas prices are 70% higher and coal prices 10% higher.

Power prices are approaching a record low. Prices are so low that many power plants will have a hard time making money in this market, and some may need to refinance their debt or will even fail. This is expected to result in a credit crunch for many developers, and signs of this crunch are already appearing. This financial turmoil may change the economic playing field in power markets, and the effect of this credit crunch is not included in our analysis. It is possible that this could push up the price of power in the Southwest beyond the values indicated in Figure 4.

However, regardless of this trend, we believe that a persistent capacity surplus and lower power prices will exist in the Southwest through the end of the decade. New investments in higher-cost renewable capacity could be hindered by these market realities.

Figure 4. Forecast on-peak power prices in the Southwest, 2002-2012



Source: Platts Research & Consulting, Outlook for Power Servic Q2.
Note: Price includes both energy and capacity payments.

Energy Resource Options

Meeting the electricity needs of the fast-growing, modern society of the Southwest is a daunting challenge. While a choice of conventional and renewable energy exists, each energy resource option has its advantages and its disadvantages. In this section, we survey the characteristics of different sources of power. This will lead towards a more detailed discussion of solar energy, which appears to emerge as the ideal energy solution for the Southwest.

Fossil and Nuclear Energy

Natural Gas

More than 95% of all new capacity installed during the recent construction boom in the Southwest is fired by natural gas. Many factors converged to make natural gas the fuel of choice for the fleet of new power plants, including the following:

- technological advances
- availability of equipment
- low capital and production costs.

Natural gas-fired plants are also compact and relatively clean burning, which allows developers greater access to sites near load centers. However, concerns about price volatility and reliability of supply could threaten the dominance of gas. The role of natural gas in the coming decade and beyond will depend greatly upon the industry's ability to provide gas to the market at stable and competitive prices.

Coal

Although coal-fired generators currently account for 30% of the Southwest's generating capacity, the development of new coal-fired capacity will continue to be difficult. The lack of long-haul transmission capacity, long lead times for coal power plant development, and concerns about air quality will hinder the development of new coal-fired capacity. These obstacles are likely to diminish the role that coal-fired power will play in meeting the Southwest's electricity needs.

Nuclear

Until the nuclear accident at Three Mile Island in 1979, the future of nuclear power looked bright. However, the nuclear power industry never fully recovered from the incident. Despite safe operation of nuclear power stations over the past two decades and improved performance, deep-seated concerns about public safety and the thorny issue of waste disposal continue to plague nuclear power. Nuclear plants also have high up-front capital cost. This, combined with long lead times, makes nuclear power very difficult to finance. As such, we do not foresee any new nuclear power stations in the Southwest.

Renewable Energy

Hydro

Today, opportunities for new large-scale hydro generation in the Southwest are practically gone. Not only are the hydrological resources largely exhausted, but environmental considerations also preclude further development of large hydro dams. It has been repeatedly argued that the American West has many opportunities for small hydro generation at existing or new dams. However, the total amount of this capacity is small and would likely come at a high cost. Any new hydro dam, however small, will face the same environmental opposition as large projects.

Wind

The emergence of wind power as a mainstream electricity generating technology is one of the greatest technology success stories of the last decade. Developed in the United States in the 1980s and embraced and brought to maturity in Europe, wind power has returned to America. Falling costs and favorable policies, such as the 10-year 1.8 cents per kilowatt-hour Production Tax Credit (PTC), make wind power competitive with conventional technologies. Domestic wind capacity[4] has grown from approximately 2.2 gigawatts (GW) at the end of 2000, to just over 4.7 GW by mid-2002.

However, despite its recent success, wind power still faces significant barriers to widespread adoption. Wind is an intermittent resource, which makes it difficult for grid operators to schedule wind power. Wind resources are also notoriously volatile, at times rapidly ramping up from near zero output to peak output and back again in a matter of hours. This variability clashes with transmission operator rules and raises questions regarding the impact of wind energy on grid reliability. Despite these issues, the low energy cost of wind power and consumer demand for "green" energy is likely to continue to drive new wind power development through the next decade and beyond.

Geothermal

There is approximately 3 GW of geothermal capacity operating in the United States, most of it in the Southwest. Most of this capacity came on line during the 1980s when stable market conditions created by the Public Utility Regulatory Policy Act of 1978, tax incentives, and a federal loan guarantee program worked together to create a wave of geothermal development that lasted for a decade. Today, geothermal power is nearly competitive with natural gas- and coal-fired units. If a PTC similar the credit now available to wind power and closed-loop biomass systems is granted to geothermal, then geothermal power will achieve cost-parity with conventional technologies. And, as a baseload power source, geothermal does not suffer from intermittency, giving it an edge as a reliable source of renewable power.

Barriers remain, however, to the widespread adoption of geothermal power in the Southwest. First, the magnitude and quality of available geothermal resources is unknown, and the costs associated with determining the potential at specific sites are uncertain and high (often equaling the cost of the entire power plant.) This adds additional development costs and also makes geothermal a risky venture that requires a high rate of return from investors. Second, many of the best geothermal sites are located in remote areas that would require expensive transmission investments in order to deliver power to load centers. Although these barriers will continue to hinder the adoption of geothermal power, the picture is decidedly positive for this renewable power source, particularly in the context of new Renewables Portfolio Standard (RPS) requirements in the geothermal-rich states of California and Nevada.

Biomass

In the United States, nearly all biomass generation is based on wood-derived fuels. Delivering cost-effective biomass fuel remains a challenge, and only waste products, such as sawdust, or subsidized agricultural crops can approach cost effectiveness today. However, the call for thinning of national forests has been renewed due to violent wild fires in the West in 2002, and this may lead to the development of forest management plans that could provide a reliable stream of cost-effective biomass fuel. Ultimately, dedicated "energy crops" will be needed for large-scale biomass electricity production. This appears untenable at present because it would require large amounts of arable land and water—resources that are already strained in the Southwest.

Solar

Solar power technologies fall into two classes—solar photovoltaics and concentrating solar power systems. Photovoltaics (PV), also referred to as solar cells, convert sunlight directly into electricity using semiconducting materials. Concentrating solar power (CSP) systems use mirrors to concentrate sunlight on a receiver holding a fluid or gas, heating it, and causing it to turn a turbine or push a piston coupled to an electrical generator. As we shall see, both technologies are well suited to particular segments of the southwestern power market. However, to date, the high cost of these technologies has limited market penetration.

Solar Power For the Southwest

In order to estimate the potential of solar power in the Southwest, it is important to know how much solar resource exists in the region. Why invest time and effort in a renewable energy technology if it can only provide a small fraction of our energy needs? So, how much solar energy falls on a patch of land in the Southwest, and is there enough land for large-scale solar generation?

The answer is that solar energy is an abundant and underutilized energy source in the Southwest. Given the geographic and climatic conditions of the Southwest, solar resources are, potentially, the best in the world. Hundreds of square miles of land could be used for solar generation, and this land is close to major metropolitan areas, including Los Angeles, Las Vegas, Phoenix, and Tucson, where large quantities of electricity are consumed. Our analysis shows that these solar energy resources are commensurate with electricity demand.

Intensity of Sunshine

When sunlight passes through the Earth's atmosphere, a portion is scattered or absorbed—by haze, particles, or clouds. However, on a clear day in the Southwest most of the solar radiation entering the atmosphere reaches the ground, and in Las Vegas, Nevada, sunshine can be as intense as 1,100 watts per square meter. While even on a clear day, a small portion of the sunshine is scattered light, most sunshine comes on an undisturbed, direct normal path from the sun. While photovoltaics (PV) can use any form of sunlight, concentrating solar power (CSP) can only used the direct normal radiation. However, in the sunniest regions of the Southwest, nearly all light is direct normal and the distinction becomes less important.

Solar energy is affected by weather conditions and the position of the sun above the horizon. The angle of the sun's rays relative to the Earth's surface changes during the day and with the seasons. In the winter, the sun is lower in the sky and less energy reaches the ground. In the summer, the sun is overhead and sunshine is stronger. In the Southwest, toward the fall and winter, cloud cover increases and sometimes shields the sun.

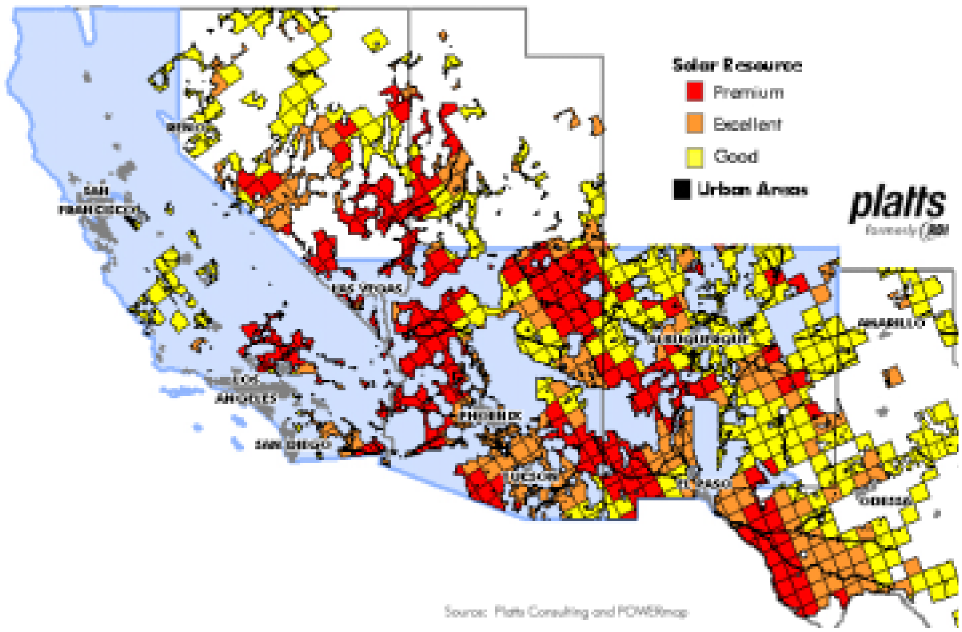
The Solar Generating Potential

When siting commercial solar power plants, developers are looking for an annual average amount of solar energy in excess of 6.0 kilowatt-hours per square meter per day (kWh/m^2/day). Fortunately, large areas of the Southwest receive sunshine above 6 kWh/m^2/day. However, some of this land is already occupied by cities, used for farming, or simply unsuitable, such as mountainous terrain. Therefore, in order to assess the feasibility of meeting large amounts of electricity with solar power, it is important to estimate how much land could be made available for solar power plant development, how good the solar resources are, and how much energy could be generated on this land?

In estimating the solar power potential for the Southwest's energy supply, we first determined the amount of land that is potentially available for solar power plant development and its solar resource by using a geographic information system (GIS) analysis. This GIS analysis allowed us to map and calculate land potentially available for solar power plants. For this purpose, we identified areas with premium (>7 kWh/m^2/day), excellent (6.5-7.0 kWh/m^2/day), and good (6.0-6.5 kWh/m^2/day) solar resources, excluded areas we deemed unavailable or unsuitable, and surrounded them with buffer zones.[5] The results of this analysis are shown in Figure 5.

On this map, land that is excluded from use for solar power plants or has inadequate solar resources is colored white. Land that is potentially available for solar power plant development is colored by its resource class. In order to estimate the amount of land likely to be available for solar power plant development, we started with Figure 5 and then only kept 3% in premium areas, 2% in excellent areas, and 1% in good solar resource areas. By considering only this small percentage, we hope to account for land that is further excluded because of ownership, ranching, ruggedness of terrain, or other reasons. The results are shown in Table 2.

Figure 5. Solar resources in the Southwest



To calculate the electric power that could be generated by these solar resources, we used parameters for land requirements and efficiencies of solar power plants, which are typical for CSP technologies, but also provide a good estimate for PV. We converted the estimated solar resources into electric capacity and energy by assuming that 1 MW of solar power requires five acres of land. We also assumed that the solar collector fields of these plants would have the following capacity factors: 25% in premium, 22.5% in excellent, and 20% in good solar resource areas.[6] As can be seen in Table 2, at more than 400,000 gigawatt-hours (GWh), premium solar resources alone are capable of producing nearly all of the 390,000 GWh of electricity expected to

Table 2. Estimate of the Solar Electric Generating Potential in the Southwest

Region		Solar Resources			
		Premium	Excellent	Good	Land as % of Region
California	MW	17,194	5,363	7,051	0.15%
	GWh	37,655	10,571	12,354	
	Acres (000)	86	27	35	
Desert Southwest	MW	190,279	78,670	57,003	1.10%
	GWh	416,711	155,058	99,870	
	Acres (000)	951	393	285	
Southwest	GWh	454,365	165,629	112,223	0.70%
	2002 Demand GWh	390,320			N/A

SOURCE: Platts Research & Consulting and POWERmap
NOTE: Solar resources 7.0 kWh/m2/day are considered premium, 6.5-7.0 excellent, and 6.0-6.5 good. See text for detailed explanation of resource analysis.

be consumed in the Southwest in 2002. If excellent and good solar resources are included, the western solar generating potential is nearly twice the current electric energy demand, but would only require 0.7% of southwestern land. This analysis shows that the Southwest's solar generating potential is vast, and the availability of solar resources is unlikely to pose an impediment for the large-scale deployment of solar power in the region.

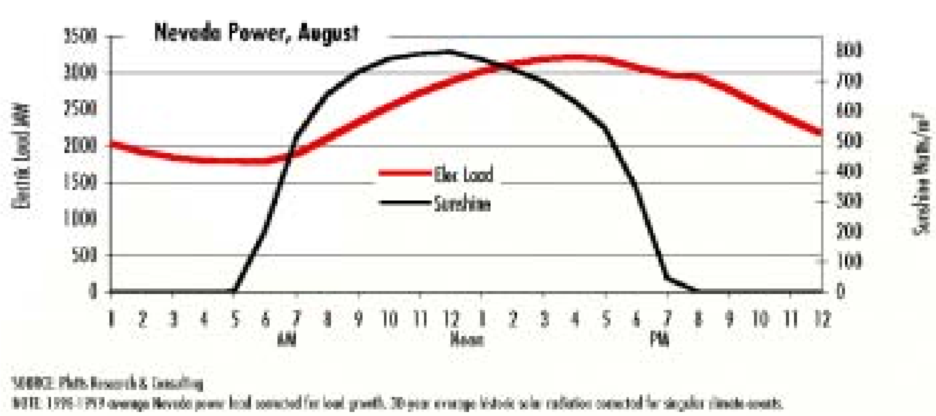
Sunshine and the Demand for Power

Like wind, the sun is an intermittent resource. No solar radiation is available at night, and cloud cover, smog, or haze can further limit generation from a solar power plant. The arrival of night in the Southwest causes solar radiation to go to zero within an hour across the entire region. While local weather conditions can vary across the Southwest, the nightly setting of the sun occurs nearly at the same time.

While geographic diversity can address weather-related intermittence, the nightly setting of the sun requires some form of supplemental "off-sun" generation. For CSP systems, fossil fuel hybridization provides a means to produce power even after the sun has set or when clouds move in. In addition, heat energy storage is possible for two CSP technologies—power tower and parabolic trough (discussed later in this report). In the Southwest (and as is typical in nearly every region of the country), electric demand continues to be relatively high for a few hours into the night, which suggests that off-sun generation, either with fossil fuels or heat energy storage, would be beneficial for solar power plants.

Figure 6 shows the average daily load in Nevada Power's service territory and average sunshine during August, the month of highest electricity demand in Nevada and the Southwest. Although solar energy generally overlaps well with the demand for power, there is a four-hour offset between maximum solar energy, which occurs at noon, and the peak in electric demand at about 4 PM, which is close to the daily peak temperature. In addition, by the time of the peak load, solar energy has already dropped off by 20%. Therefore, while in this example solar energy and daily loads track well—and the situation in similar in other regions of the Southwest—technologies that can address this offset of load and solar energy would provide additional value.

Figure 6. Daily sunshine and demand



Why Concentrating Solar Power (CSP)?

The most ubiquitous and well-know solar power generating technology is the crystalline silicon photovoltaic (PV) cell, which is easily recognized by its bluish tint and a lattice of metallic leads on its surface. Penetration of flat-panel PV has increased in recent years, and new technologies, such as amorphous silicon PV cells, have entered the market. However, despite PV's success and visibility, the amount of renewable energy currently generated by this solar generating technology is very small. At the high cost of the technology—unless large incentives are in place such as the residential tax credits and deductions in California—applications of PV remain limited to distributed and remote power applications. In remote power markets, in particular, PV's exceptional reliability and simplicity make it an excellent technology choice. In this market, PV is best suited economically to small (watts to few kilowatts) installations in applications such as billboard lighting and emergency telephones along highways.

However, for large-scale power generation, concentrating solar power (CSP) systems are the solar technology of choice. In the late 1980s and early 1990s, 354 MW of CSP parabolic trough plants were built in the Mojave Desert. For more than a decade, these plants have delivered reliable power to southern California and have demonstrated the commercial practicality of solar power generation. There are three types of CSP technologies: power towers, parabolic troughs and dish engine systems. These will be discussed individually in the following sections.[7]

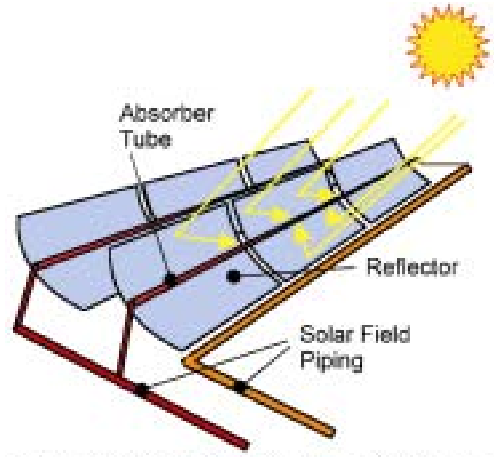
Parabolic Trough

The solar field of a parabolic trough plant consists of long parallel rows of trough-like reflectors—typically made of glass mirrors (Figure 7). As the sun moves from east to west, the troughs follow the trajectory of the sun by rotating along their axes. Each trough focuses the sun's energy on a pipe located along its focal axis.

A heat-transfer fluid is circulated through the pipes and then pumped to a central power block area, where it passes through a heat exchanger. There the hot heat-transfer fluid generates steam, which in turn drives a conventional steam turbine generator. Beyond the heat exchanger, a parabolic trough plant is a conventional steam plant. For this reason, parabolic trough plants, like power towers (discussed in the next section), can use stored heat or hybridization with fossil fuels to generate electricity when the sun does not shine.

Of all thermal CSP technologies, parabolic trough technology has proven itself in the market place. Several commercial parabolic trough units with sizes up to 80 MW have been built and still operate today. The Solar Energy Generating Stations (SEGS) in the Mojave Desert have a combined capacity of 354 MW and are the largest solar power installation in the world—by orders of magnitude. At all but one unit, fossil fuel hybridization with natural gas is used for "off-sun" power generation to meet the power delivery obligations of the units when solar radiation falls short, such as under adverse weather conditions or during short winter days.

Figure 7. Design of a parabolic trough

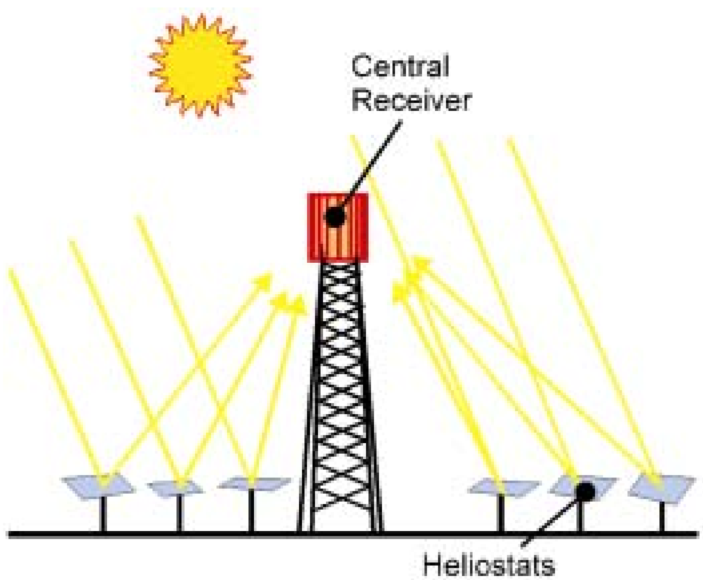


SOURCE: *Status Report on Solar Thermal Power Plants*, Pilkinton Solar International, 1996. Used with permission.

Power Tower

In the power tower concept, a large array of mirrors, called heliostats, tracks the sun in a way that reflects the sunlight onto a central receiver mounted on top of a tower (Figure 8). The sunlight is absorbed and turned into heat, which in turn powers a steam cycle. Power towers are particularly well suited to use molten-salt heat storage to generate power when the sun does not shine because of the centralized design of the power tower and the high temperature of the molten salt, which is both the heat transfer fluid as well as the heat energy storage medium.[8] Just like parabolic troughs, power towers can also be hybridized with fossil fuels.

Figure 8. Design of a power tower



SOURCE: *Status Report on Solar Thermal Power Plants*, Pilkinton Solar International, 1996. Used with permission.

A key design strategy for power towers that use heat energy storage is to oversize the power tower in relation to the generator. Extra thermal energy can be dumped into storage while the plant continues to run at full electrical output. The stored heat can be used subsequently to generate power, which increases the utilization of the plant. The ratio of the solar thermal capacity to electric generating capacity is called the "solar multiple." The same design can be applied to parabolic trough plants and, in practice, even without heat energy storage, a slightly oversized solar field has operational advantages. Two power tower demonstration systems were built in the United States in the 1980s and 1990s. The units operated with some success, but were decommissioned after the demonstration period.

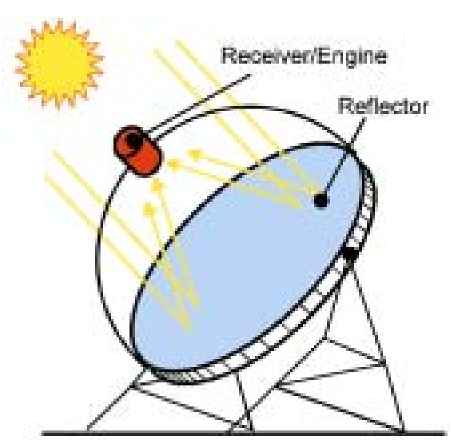
Dish Engine

A dish engine system consists of a parabolic-shaped point focus concentrator in the form of a dish that reflects solar radiation onto a heat engine mounted at the focal point. The concentrator is mounted on a pedestal and can pivot on two axes to follow the sun. This two-axis tracking mechanism allows the capture of the highest amount of solar energy possible (Figure 9).

Stirling cycle engines are currently receiving the most attention for power conversion, although high-performance PV modules and micro-turbines are also being considered because of their potentials for improved reliability. Dish engine systems using Stirling motors have achieve peak efficiencies of up to 30% (net) and hold the efficiency record for thermal solar power generation. Conceptually, the dish engine system is the simplest of all thermal solar technologies, but finding a reliable, inexpensive, and efficient engine for the system remains a struggle.

Dish systems share many characteristics with wind turbines. Like wind turbines, dish engines are a primarily intermittent energy sources, have only a pedestal as footprint, can be built within days, and come in small sizes (1-25 kW) and are thus modular. Dish engine plants allow for smaller solar farms that may fit better into renewable energy portfolios, especially if solar allocations in these portfolios are small—as they typically are.

Figure 9. Design of dish engine system



SOURCE: Status Report on Solar Thermal Power Plants, Pilkinton Solar International, 1996. Used with permission.

Advantages of CSP

CSP technology, while expensive compared to conventional generating technologies, has a significant cost advantage over PV, but it is the operational characteristics that really comprise the greatest advantages of CSP and increase its value in the power market. As we will show in this section, CSP can match the shape of electricity demand in the Southwest and can effectively address intermittency. This makes CSP technology compatible with the electrical grid and the energy needs of a modern society.

Heat Energy Storage

Of course, all solar technologies can store energy in batteries to provide supplemental power, but the high cost of battery storage again limits batteries to remote power application, where it is typically found in combination with PV. Recently, flow batteries have entered the market and have a potential to change the economics of battery storage. [9] However, the technology remains expensive.

A distinct advantage of CSP plants is the availability of a relatively inexpensive way of storing energy in the form of heat. Solar power plants with heat storage collect thermal energy during the day by increasing the temperature of a large heat reservoir. The power tower demonstration project, Solar Two, demonstrated an effective and safe molten-salt storage system, which is considered for future storage applications.

Heat storage systems are not useful for large-amounts or long-term energy storage, but heat equivalent to up to 1-2 days of full plant output can still be stored for later use. In practice, stored energy would be used the following night or to keep the plant at full output when clouds pass over the plant location. Many of the high-load/high-price periods in the desert Southwest occur in the three to four hours after dark—a time period the operator could target for dispatch. Heat storage could also be used to store thermal energy on holidays or Sundays for dispatch during the higher-price periods the following workday. Thus, energy storage allows the power tower or parabolic trough plant operator to maximize profits, which may justify the cost of adding heat storage to the solar power plant.

Additional flexibility in the operation of a thermal solar plant with storage comes from over-sizing the solar collector field. That is, the collectors generate more heat than normally required by the steam turbine of the plant. For example, a 100-MW solar plant could have a solar field that generates enough heat for 150 MW of electricity at full sunshine. Of this, 100 MW would be used to generate electric power, while the other 50 MW would go into storage for later use. Such a plant would have a solar-multiple of 1.5 (150 MW/100 MW = 1.5.) This over-sizing of the solar field combined with heat storage allows the plant to run at a higher capacity factor. In the example, the capacity factor[10] of the electric generator would increase from about 25% to 38%. Thermal storage can be designed to be cost effective to meet capacity factors as high as 50% for parabolic trough systems, and up to 70% for power tower systems. These capacity factors are commensurate with the hours of peak demand in the Southwest.

Fossil Hybridization

CSP systems have the option of hybridization with fossil fuels, because plain heat is what generates electricity in the engine or turbine—and that heat can come from any source. Hybridization is particularly straightforward for trough and tower plants, but it has also been demonstrated for dish engine systems. Fossil fuel hybridization has been used successfully at the parabolic trough SEGS in the Mojave Desert for more than a decade.

Hybridization with fossil fuels allows around-the-clock generation. The supplemental firing can be used at night, during cloud cover, or to even-out seasonal variations in sunshine. When running on natural gas, parabolic trough or power tower plants become ordinary steam units. However, the modest efficiency of hybridization makes running on natural gas only a supplemental source of power, because this electricity is produced at a higher cost and with more air emissions than would be available from a gas-fired combined cycle plant. However, hybridization can provide additional benefits such as improving operation of the plant and the ability to bid firm capacity into the market.

Matching Demand

Although the daily output from a solar power plant overlaps significantly with the demand for power in the Southwest, the correlation is not perfect. This is because the intensity of sunshine peaks around noon, whereas the peak in electric demand occurs later in the afternoon and evening hours, close to the daily peak temperature.

The situation is similar, yet on a longer time scale, when seasonal solar outputs and loads are compared. While more sun shines in the summer, when electric energy demand increases, the peak in solar energy production occurs in June and has fallen off by about 10% in August. August is when the Southwest experiences the warmest and most humid weather of the year, and electric loads reach their peaks, driven by air conditioning demand.

The availability of heat energy storage and fossil fuel hybridization for thermal CSP plants greatly enhances the value of the generating capacity in the energy market. For example, heat energy storage allows the CSP plant to shift production and to target peak hours. Aside from increasing the revenues for the plant during these high-price periods, the solar generating capacity is now able to make other capacity in the market unnecessary. This is because with heat storage the solar plant is able to "shave" the peak load. At times when the solar power plant does not generate, the average load has already fallen off significantly.

Fossil fuel hybridization could be used similarly, but this would result in a large amount of power generated by the CSP plant to come from fossil fuel. It is, therefore, more desirable to use hybridization to boost output during cloudy days or during months of high electrical load, but reduced sunshine. Hybridization could play an important role to add that extra little bit that the sun can no longer produce, thus allowing the plant run at full capacity to meet contractual output obligations or to maximize profits.

Eliminating Intermittence

The intermittence of wind and solar are often cited as the key obstacles to the large-scale use of these technologies. Output from a wind farm may vary not only from day to day, but also from minute to minute. In top solar resource areas in the Southwest, cloud cover is relatively rare, especially in the summer. According to the operators of the parabolic trough solar plants near Kramer Junction, California, next-hour sunshine can be forecast very well. Thus, while solar power is considered an intermittent resource the very good predictability of solar generation on an hour-ahead, or even day-ahead basis, simplifies the task of managing this resource. Moreover, the ability of thermal CSP plants to use heat energy storage and hybridization to keep a constant electric output from the plant, eliminates any concerns arising from intermittence.

Eliminating intermittence provides great value to thermal CSP. It takes the uncertainty out of the delivery of power, relieves concerns regarding electrical interconnection and transmission tariffs, and improves the value of the plant to the owner. Solar power generated by CSP can provide a renewable form of energy that is compatible with the needs of the power grid and consumers by being reliable and dispatchable.

From "Concentrating" to "Competitive" Solar Power

As we have demonstrated, CSP technologies have all the characteristics required to play an important role in meeting the energy needs of the Southwest. However, market conditions and high up-front capital cost of these technologies continue to create a significant barrier to market adoption. In this section we will show the current cost of CSP and indicate how today's cost disadvantage of CSP may be overcome.

Cost of Concentrating Solar Power

In Table 3, we show our estimate of the cost of electricity (COE) from a new CSP power plant. At approximately 11 cents per kilowatt-hour (¢/kWh), the COE from the lowest-cost CSP power technology—parabolic troughs—still exceeds the average on-peak price of power in the Southwest in the next 10 years by a factor of 2.5. Electricity from dish engine systems is considerably more expensive, but dish systems have the advantage of a small unit size, thus making it easier to built the first unit.

Table 3. Cost of Electricity from New Concentrating Solar Power Plants

Technology	Cost of Electricity (cents/ kWh)
Parabolic Trough	11.0
Power Tower	11.5
Dish Engine	27.9

NOTE: First-year cost of electricity is the first year cost-of-electricity expressed in plant start year dollars. All plants in this analysis are assumed to begin operation in 2004.

Source: Platts Research & Consulting

Closing the Cost Gap

As our forecast of on-peak power prices in Figure 3 shows, on-peak power prices are expected to range from 4 to 6¢/kWh over the next 10 years. This means that CSP technologies must be able to deliver power at approximately 5¢/kWh in order to be competitive in the Southwest. Thus, the cost gap between CSP and the market price of power is at least 6¢/kWh. This is a formidable gap; significant cost reductions through technology improvements, manufacturing learning, and economies-of-scale will be required if new CSP plants are to be built using non-subsidized private-sector capital. Fortunately, CSP technologies provide additional value beyond the market price of power. When this value is quantified, the magnitude of the cost gap begins to diminish.

Financial Value of Price Stability

CSP, like other renewable sources of power, provides an intrinsic hedge against price volatility.[11] As previously indicated, we anticipate that the desire to avoid price volatility will be one of the primary drivers of renewable energy over the next decade. The value of price stability provided by CSP can be estimated by examining the cost of "hedging" for gas-fired generation.

The exposure to short-term natural gas price fluctuations—the key driver of power prices in the Southwest—can be mitigated through the use of physical hedges, such as long-term fuel supply contracts, or through the use of financial instruments, such as swaps, options, or futures contracts. Physical and financial hedging strategies are increasingly popular following the extreme energy price spikes associated with the winter of 2000/2001. Approximately 40% of utilities now use fixed-price contracts to hedge at least part of their supply portfolio.[12] Half of those hedged at least 50% of their supply.[13]

Of course, physical and financing hedging is not free. Utilities must pay a premium to natural gas suppliers to lock in gas prices. In the long run, this premium reflects the natural gas supplier's cost of underground storage, which is the mechanism that suppliers use to meet the obligations of fixed-price contracts. Typical storage costs range[14] from $0.50–$1.00/MMBtu. This corresponds to an increase in the cost of electricity of a gas-fired combined-cycle plant of 0.35 to 0.7¢/kWh. Given this cost, we believe that 0.5¢/kWh is a good proxy for the value of price stability.

We note, however, that this value does not include the costs associated with increases in the average price of natural gas (i.e., an upward trend in gas prices); it only accounts for the costs associated with dampening the variation around the average. Yet, CSP—and other renewables—also provide valuable insurance against longer-term rises in gas prices that are a result of scarcity. The value of this "insurance policy," surely one of the most important advantages of renewables, has yet to be quantified on a per-kWh basis.

Valuing "Green" Power

In the context of emerging retail competition, a growing number of electricity consumers are given a choice of who supplies their power and how that power is generated. Today, more than one-third of all consumers in the United States have an option to purchase some type of "green" power product—that is, power from a renewable energy resource. In many cases, consumers choose to purchase green power. When consumers make this choice, they are willing to pay a premium reflecting the higher cost of energy from renewables. We believe this premium should be credited as a benefit to CSP. Analysis conducted by the National Renewable Energy Laboratory shows a national median retail green power price premium[15] of 2.5¢/kWh, which is a good proxy for the value of the environmental benefits provided by CSP and other sources of renewable power.

Again, we must remark that this proxy is likely to miss the true value of the environmental benefits provided by renewable energy, which many argue is higher. Rather, the premium reflects the willingness of consumers to pay for renewable energy resources. It does not represent the costs of environmental impact of conventional sources of generation, which are generally external to the economic system and are notoriously difficult to quantify.

Bringing Down Technology Cost

By taking the values of price stability and green power into account, the cost gap shrinks from 6 to 3¢/kWh. The remaining gap must be closed in order for CSP to play a role in meeting the future energy needs of the Southwest. We have reasonable expectations that the remaining cost gap can be eliminated through continued research and development (R&D, much of which requires public sponsorship), production-related learning effects, and economies of scale.

Publicly sponsored R&D rapidly advanced CSP technologies in the aftermath of the energy shortages of the 1970s, leading to the early commercial implementation of CSP in the mid-1980s. Since then, research efforts have led to additional advances in system performance, reliability, lifetime, and cost. The first CSP trough plants produced power for about 35¢/kWh (in 2002 dollars). Technology advances and learning have since dropped to the cost to 11¢/kWh.

As new CSP systems are built, we expect the cost of electricity from CSP to decrease rapidly. To estimate the impact of learning effects and economies-of-scale, we derived a learning curve for new CSP technologies as a function of new capacity (Figure 10). Our learning curve is based on analysis of manufacturer-supplied production cost estimates and historical comparisons with emerging technologies. Our analysis also indicates that the cost of energy will decline at a rate of 6-8% for every doubling of new capacity. However, for this to occur, new CSP units must be built; given the current size of the cost gap, this will require a package of policies designed to stimulate near-term deployment.

Solar Policies Are Needed

Given the relatively high costs of new CSP systems today and the low market price of power, a policy package will be required to stimulate private-sector investment in new CSP capacity. Further, because CSP technologies are perceived as risky because of limited commercial experience relative to conventional alternatives, the solar policy package must include both cost- and risk-reduction measures.

The 10% investment tax credit (ITC), which is currently available to solar and geothermal power projects and the 10-year 1.8¢/kWh production tax credit (PTC), which is currently available to wind and closed-loop biomass power projects, are examples of effective policies. The ITC

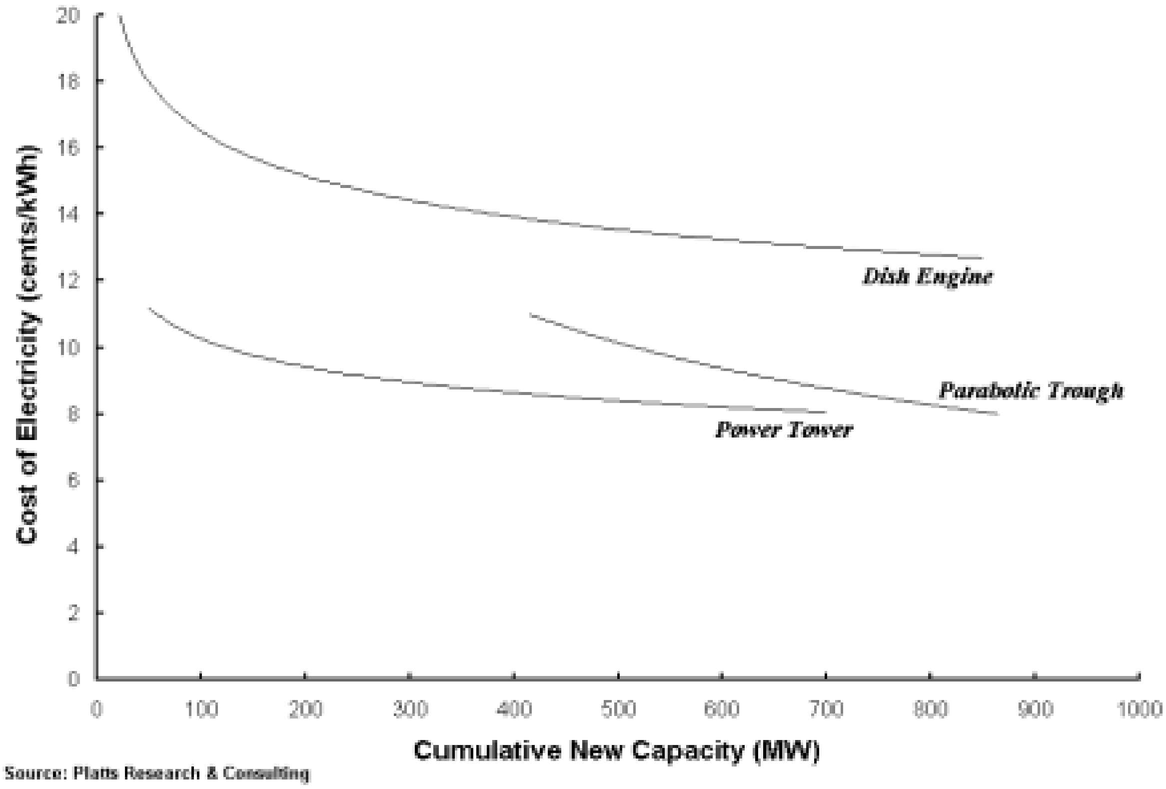


Figure 10. Estimated learning curve for concentrating solar power

provides cost reduction by allowing developers to write-off 10% of depreciable capital costs in the year taken. The PTC provides a multi-year stream of tax benefits by allowing developers to take a 1.8¢/kWh tax credit for all power generated in the first 10 years of project operation. The PTC is generally more highly regarded than the ITC because it provides an incentive to produce electricity. However, for CSP projects the ITC has been very successful. Every CSP plant that was constructed during ITC availability is still under operation; and all of these plants have experience substantial cost reductions throughout their lifetimes. Given the relatively high costs of new CSP systems, a 30% ITC combined with a 1.8¢/kWh PTC would be required to make CSP cost-competitive.

The U.S. government has a long history of providing risk-reduction measures in support of new energy technologies. Loan guarantees have been the principal means by which the government has historically mitigated the risk of new energy investments. For example, a federal loan guarantee program was successfully used in the late 1970s to support the deployment of geothermal energy technologies. By sharing the risk of early geothermal development, the geothermal loan guarantee program made private sector capital available and jump-started a surge in geothermal development that lasted a decade. A similar program would be needed today to attract private-sector lenders to CSP projects.

With the assistance of a policy package that contains a combination of cost- and risk-reduction measures, CSP has the potential to reach cost competitiveness in the next decade. A package that contains tax incentives and loan guarantees should attract private-sector debt and equity capital to initiate the near-term deployment of new CSP systems. In the absence of such a policy package, we are unlikely to see new CSP development in the next decade.

Endnotes

[1] These are the CAMX and AZMNV electric reliability regions of the North American Electric Reliability Council (NERC).
[2] Platts' NewGen database, release: 7/2002.
[3] The prices shown in Figure 4 include both the energy and the capacity price paid to generators.
[4] NewGen release 7/2002.
[5] Excluded land and the corresponding buffers were military bases with a one-mile buffer; national wilderness areas with a five-mile buffer; Fish and Wildlife Service land with a one-mile buffer; National Park Service land with a five-mile buffer; National Forest Service land; cropland; major highways with a half-mile buffer; navigable waterways with a half-mile buffer; lakes with a two-mile buffer; major urbanized areas with four-mile buffer; railroads with a 500-foot buffer; and locations 9,000 feet above sea level with a 4.5-mile buffer around each point. Indian lands were not excluded from our resource assessment, because of tribes' interest in development of renewable energy on their land.
[6] These are the equivalent electric capacity factors of the solar field. However, in power tower and parabolic trough technologies, the solar field can be oversize with regards to the generator. If excess thermal energy is stored then the capacity factor of the generator can exceed the capacity factors listed here.
[7] In addition to these technologies, Concentrating PV (CPV), a technology that uses a dish-concentrator or lenses to concentrate light on high-efficiency PV cells, has recently surfaced as a promising solar technology. While promising, the potential of this technology can only be assessed after additional research and development is conducted.
[8] In molten-salt technology, salt is heated to a point at which it liquefies, hence the term molten salt.
[9] See Platts Research & Consulting (PRC) (2002), *Liquid Electricity: Flow Batteries Expand Large Scale Energy Storage Markets*, E-Source DE-18, June 2002, Boulder, Colorado.
[10] In premium solar resource area.
[11] The value of this hedge is diminished for any electricity generated by hybridization with natural gas.
[12] American Gas Association (AGA) (2002), *LDC Supply Portfolio Management During the 2001-2002 Winter Heating Season*, July 2002, Washington, D.C.
[13] AGA 2002.
[14] Simmons & Company International (2000), *Underground Natural Gas Storage*, June 2000, Houston, Texas.
[15] Swezey, Blair, and Lori Bird (2000), "Green Power Marketing in the United States: A Status Report, Fifth Edition," National Renewable Energy Laboratory: Golden, Colorado, NREL/TP-620-28738.

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Although renewable energy development will be hindered by a persistent electric generating capacity surplus and lower power prices in the Southwest through the end of the decade, we believe that the attributes of renewable energy such as power at a guaranteed price and zero air emissions will continue to stimulate investment in new projects. With the assistance of policy initiatives that contain cost- and risk-reduction measures for investments in Concentrating Solar Power, the technology has the potential to reach cost competitiveness by the end of the decade. However, in the absence of such policy initiatives, new utility-scale solar power projects in the Southwest—or elsewhere in the country—are unlikely.

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