Chapter 5

Western Energy Policies Regarding Solar Power

State Legislation

The generation of power is becoming deregulated on a state-by-state basis (and in fits and starts). Despite this, policy makers and regulators still exercise influence over the generation portion of the electricity business. For example, tax incentives can be used to promote certain types of generation, or utility commissions can require distribution utilities, all of which are still regulated, to procure power from certain types of electric generation.

Recently, some regulators have required the inclusion of more renewables into some states' resource mix—often with surprising success. The motivation behind such stewardship probably varies. The promotion of renewables is a way to carry some of the old utilities' mission of serving the public good into a new and uncertain marketplace. It is also a way of responding to the public's uneasiness with deregulation—the same way that rate freezes have been conceived as a way to protect customers in the transition to a deregulated market. Finally, the deregulation process is also an opportunity to realize change.

No two states have decided to promote renewables in exactly the same way; both the methods and the scope by which renewables are promoted vary. The lack of precedent in applying such incentives may explain the variety of approaches. Other states that are contemplating deregulation or that have pending legislation are carefully observing the success of these programs.

Despite the state-to-state differences, five basic tools are being tried to further the deployment of renewable power. These include:

- renewable portfolio standards (RPS), which require utilities to build, purchase, or sell a certain amount of renewable energy;
- system benefit charges (SBC), which charge utility customers a small fee to fund renewables programs;
- green energy programs, which allow customers to choose a renewable electricity product;

- tax incentives, which encourage investment in renewable energy sources through tax structures; and

- net metering programs, which reimburse utility customers for electricity they generate from their renewable energy systems.

Renewable Portfolio Standards (RPS)

RPS require utility systems to sell, purchase, or build minimum amounts of renewably generated electricity. These requirements are usually expressed as a percentage of electricity sold or as a capacity requirement. An example is Texas' 2,000-MW (about 3% of the state's electricity) renewables requirement by 2009. RPS laws appear to be effective in promoting the installation of thousands of megawatts of new renewable capacity.

System Benefit Charges (SBC)

SBC are funds collected through utility revenues used to promote renewables (as well as other energy-related public goods goals). SBC monies may be disbursed in the form of grants or subsidized financing to assist initiatives such as new large-scale projects, buy-downs for distributed renewables, customer credits for green markets, or other types of renewable infrastructure promotion. Oregon has set up an SBC-based renewables fund that receives about 0.5% of utility revenues under deregulation. In California, SBC-based support has assisted about 1,000 MW of new (planned or operating) large-scale renewables projects, and helped 200,000 customers switch to green power in the state's green energy market.

Green Energy Programs

Green energy programs allow customers to purchase "green" products that contain significant fractions of renewably generated electricity. Green energy programs fall into two broad categories. First, green market programs are offered in deregulated areas, where competitive marketers, such as Green Mountain Energy, offer green market products. More than one marketer may enter the market and compete for retail customers as well as wholesale renewable electricity suppliers. Green marketers bear the risk of acquiring or building renewable energy supplies in green markets. California is one of the first and largest green markets.

Green pricing programs, on the other hand, are usually offered in regulated utility areas by the local utility. In green pricing programs, the utility builds or purchases a supply of renewably generated electricity and markets the green product to its retail customers. The utility faces no competition in offering a green product, but it bears the risk of acquiring the green electricity. A regulated utility has the backstop of rate recovery to reduce the potential risk of fewer customers buying the green product than anticipated. Also, the utility may build incremental renewable generation as more customers sign up. Xcel Energy's Windsource program in Colorado has signed up more than 15,000 customers and supports 56 MW of wind capacity.

Green markets have spurred 170 MW of installed or planned renewable capacity additions, while green pricing programs have spurred 280 MW of installed or planned renewable capacity.

Tax/Financial Incentives

Tax and financial incentives for renewable energy projects include property tax exemptions, franchise tax exemptions, corporate income tax exemptions, personal income tax credits, production tax credits (PTC), and loan programs. One of the strongest state tax incentives for renewable energy is Minnesota's 1.5 ¢/kWh PTC for wind energy projects under 2 MW in size. Minnesota's tax credit supplements the 1.7 ¢/kWh federal PTC for qualifying renewable generation.

Net Metering

Net metering laws require distribution utilities to compensate distributed renewable generators for the electricity they produce. These payments encourage investment in distributed renewables. The prototypical example is a rooftop PV system on a home, with the owner receiving payment for any net excess generation (NEG). Some net metering programs have no system size limit, however, and encourage development of large renewable systems at distributed locations. In Germany, utilities are required to pay for distributed renewable generation at a rate that is 90% of the retail residential rate. The Electricity Feed Law, as it is known, is more generous than most U.S. programs, and has helped Germany to install more than double the wind capacity installed to date in the U.S. Thirty-five states in the U.S. currently have a net metering law in place.

View of the Western Governors' Association (WGA)

To maintain the Western governors' commitment to a viable economy and a clean and healthy environment in the West, the western governors believe that western states need to pursue an energy policy that will result in a diverse energy portfolio, including conventional and alternative energy resource development, energy efficiency, and conservation. The western governors support the development of renewable sources of energy that could offset, through emissions trading, additional emissions as fossil-fueled plants come on-line.

In the view of the WGA, such joint resource generation could be an important part of a comprehensive energy strategy in the West that would enable the region to capitalize on its renewable and non-renewable resources. The WGA supports pursuing accelerated development and deployment of promising renewable energy technologies through the extension and expansion of state and federal production tax credits and state and tribal policies, such as system benefits charges, renewable portfolio standards, renewable resource-based utility tariffs, and/or creative new incentives.

The WGA also recognizes the contribution that the National Renewable Energy Laboratory (NREL) and other national laboratories have made in developing technologies that enable the cost-effective use of western renewable energy resources. The WGA will promote renewable energy, including the efforts of NREL and other national labs, to continue outreach to western states to ensure that their research and development efforts are germane to the western resource base and thereby offer technology options that can contribute to increasing the availability of renewable power generation.

Chapter 6

Wind Power's Success Could Be a Proxy for Solar

During a meeting organized by the Department of Energy in Albuquerque, New Mexico, in November 2001, a review panel asked representatives of the national labs, industry, and independent experts to identify the obstacles to be overcome before solar power can provide significant amounts of western electricity. The consensus among the experts was that only one thing prevented the solar power industry from providing larger amounts of renewable, clean, and domestic energy from the sun—political will.

Even though some solar generating technologies could benefit from research and development, it was made clear that solar resources are abundant; are located where they are needed; that efficiencies from concentrating solar power (CSP) are good enough to justify deployment; and cost projections are very promising. All that solar power required, in the opinion of the experts, is an incubation period, where incentives are put in place that allow the transition of this emerging generating technology into the mainstream. It is our view that providing such an incubation period is not a leap of faith, but a proven recipe of success, as the emergence of wind generating technology in Europe has shown.

Wind power was developed from concept to practicality in the U.S., starting in the 1980s, when the number of wind turbines began to mushroom in California, which has become an icon of wind energy deployment. However, by the end of the decade, no new wind turbines were built. Those that were in place did not perform as well as anticipated and poor siting of the turbines resulted in considerable numbers of bird kills. In the 1990s, Kenetech, one of the major developers at the time, filed for bankruptcy, further tainting the image of wind power.

In the mid-1980s, Europe developed a greater awareness of environmental issues, and Germany and Denmark, in particular, provided market incentives that promoted the development of renewable energies. Germany's Electricity Feed Law provided high prices to anyone who could feed green power into the grid in those countries (see "Net Metering"). With little solar resources, wind was the logical choice of renewable energy, as Germany had adequate wind resources ripe for development.

In the mid and late 1990s, wind power developers aggressively pursued generation opportunities in Germany and Denmark, and soon the installed wind capacity in these two countries began to dwarf the 1,742 MW installed in California in the 1980s. European companies such as Nordex, NEG Micon, and Vestas began to scale up turbines and cut costs. Today, wind turbine capacities reach 3.8 MW, are up to 500 feet tall, and are even installed offshore and serviced by helicopters. The development was so fast and successful that even visionaries were surprised.

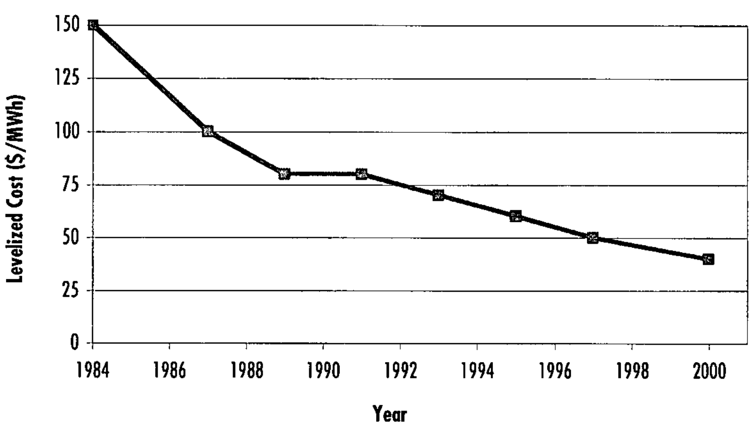
While the German and Danish governments provided the long-term financial stability and incentives that allowed high-price wind power to enter the market, the technology development was left to the wind companies themselves. The foundation of research and development had already been laid and had brought wind turbine technology to a point where it was practical. Pushing the technology to new limits was left to the power of market competition.

With an opportunity to make money in the market, wind turbine manufacturers brought down the cost of wind power dramatically. In Exhibit 44 we show that the levelized cost of wind power over the last 15 years has dropped by 70% from 150 \$/MWh (15 ¢/kWh) in 1984 to 40 \$/MWh (4 ¢/kWh) in 2000 and the cost continues to decline. Today, the energy cost of wind is beginning to compete with the cost of gas-fired generation at 45-48 \$/MWh (assuming a natural gas price of 3.87 \$/mmBtu).

This dramatic reduction in the cost of electricity from wind is driven both by reductions in capital cost as well as improvements in the capacity factor of turbines. For example, new wind turbines located in Texas have shown capacity factors of up to 48% over the initial months of operation, and capacity factors of newer turbines if located at the same site are estimated to be 52%.

Today, with the exception of Enron Wind (formerly Zond), the world wind turbine market is firmly in European hands. Wind power is a technology that was developed in the U.S. and paid for by

Exhibit 44: Levelized Cost of Wind Power, 1984-2000



SOURCE: American Wind Energy Association (AWEA)
NOTE: Levelized cost does not include the 10-year federal production tax credit.

American tax dollars, but today the country is importing this technology. At the same time, shareholder value and jobs in wind power are created in Europe. American financial institutions are also missing out on the business of thousands of megawatts of new wind currently being installed in the U.S. This is because the default of Kenetech left American banks skittish, while European banks are willing to put up the capital for new wind turbines in the U.S. and elsewhere.

While it is a bitter lesson for American policy makers, the success of wind could be a proxy for the deployment of solar power in the U.S. Today, however, it is possible that solar power will be the next renewable generation technology that the U.S. will import from Europe. This could happen unless policy makers are able to get legislation enacted that results in the deployment of new solar capacity in the West. This is because European countries, and in particular Spain and Italy, are ready to move. Ironically, the next large international meeting on solar generating technologies is scheduled to take place in—cloudy and overcast—Berlin. The American solar power industry is trying to bring this meeting to the U.S., where this renewable energy technology was invented.

But even if this meeting were held in the U.S., the solar power industry will move where it finds political will and money. And currently those places appear to be in Europe. With little imagination, it appears likely that next generation of solar power plants could carry the "Made in Europe" label. And it is only a matter of time when, after incubating in Spain or Italy, solar power plants will be imported to this country.

RDI Consulting sees great similarities in the complexity of technology, engineering obstacles, efficiency, and cost reduction potential between wind power and CSP solar generating technologies. It appears likely that the success of wind power could be repeated for solar power. Today, a decade after the last parabolic trough solar power plant was built near Harper Lake, California, there is ample proof that CSP plants can operate reliably over decades, and also that, as wind has shown, technology incubation works.

The success of an incubation period for solar power is all but guaranteed. This is because, unlike similar promises by the industry to introduce electric cars, CSP plants have already achieved a level of performance that makes them practical. They have proven their merit in over a decade of operation in the Mojave Desert, and cost-reduction projections for CSP technologies are based on the fact that they use ordinary technology in an extraordinary way.

Therefore, it is our belief that a large-scale deployment of solar power will bring with it considerable cost reductions. In the light of our analysis, the secret of solar power success is simply new projects. It is up to regulators and policy makers to make it happen. And it appears that all it takes is to follow a proven recipe.

Chapter 7

A Closer Look at Energy Resource Options

Here we will take a closer look at each western energy resource option. The goal is to understand the generating capacity these resources could provide, their depletion rates, and the environmental impact that the use of each of these resources would have on the western states. We will also discuss some of the economics surrounding the use of each resource.

Fossil Fuels

Fossil fuels provide most of the U.S. energy needs, yet from resource recovery to combustion, the use of fossil fuels comes with a price to our environment and our health.

The oil, gas and coal industry is making great efforts to mitigate the impacts of exploration, extraction, and transportation of fossil fuels on the environment. For example, directional drilling allows reducing the number of drills in recovering an oil or gas reservoir. Nevertheless, fossil resource recovery often comes with a cost to the environment. The mining of coal requires mountaintop removal in Virginia and has poisoned groundwater and rivers in Pennsylvania. The oil spill of the Exxon Valdez killed millions of birds, fish, and mammals in Alaska's coastal waters, and drilling operations near Farmington, New Mexico, have marred the landscape with a network of roads and pumps.

The combustion of fossil fuels releases sulfur, CO_2, and other elements such as mercury, a heavy metal poisonous to most living organisms, into the air. These chemical substances that had been sequestered in the crust of the Earth—by living organism and geological deposition—are now being introduced into the atmosphere at a rapid pace. This has caused great concern among atmospheric scientists, who believe this may result in global climate change. Atmospheric studies, computer models, and laboratory experiments all suggest that, in particular, the release of CO_2 will result in a global warming of the atmosphere. Temperature data and singular events such as volcanic eruptions, which emit similar pollutants, confirm that the effects of these pollutants will result in a significant change of our world climate.

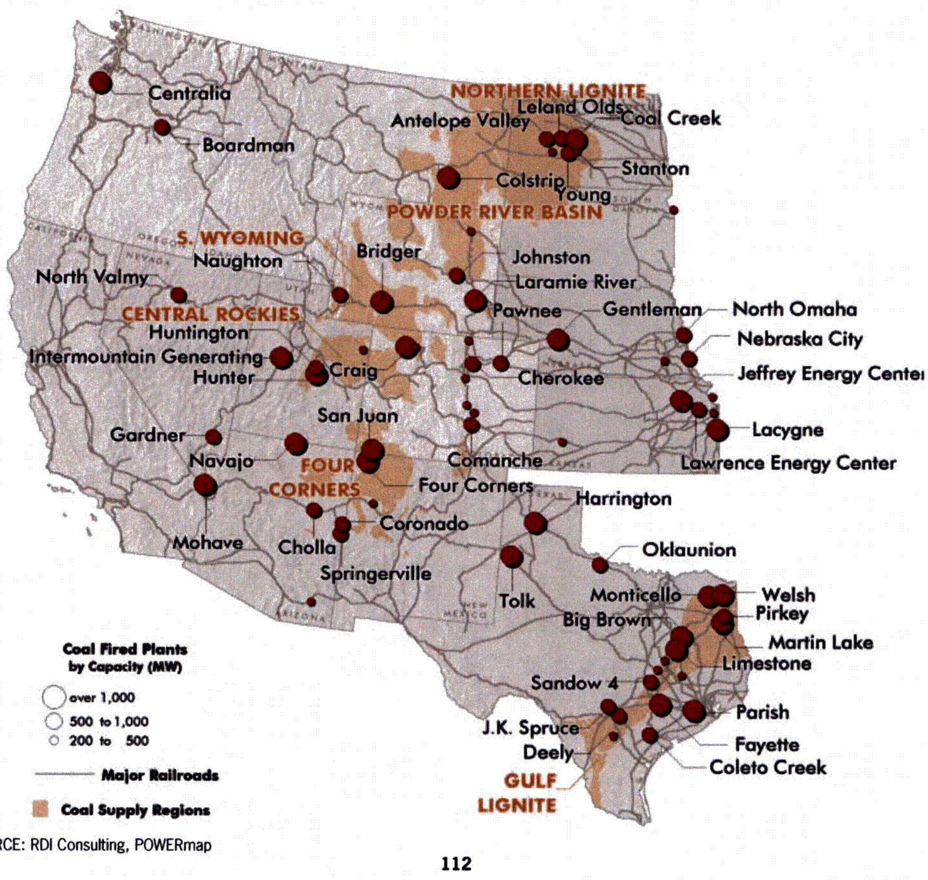
With the world's population growing, the use of fossil fuels will continue to grow in the near term and so will its impact. In the history of mankind, fossil fuels have played a key role in allowing the cultural and technological development of humankind. As long as other energy sources are not used more heavily, fossil fuels will continue to play an important role. Nevertheless, there is now interest to accelerate and increase the use of pollutant-neutral sources of energy, such as renewables, fission, and—possibly one day—fusion. In the transition period, a shift to low-emission fossil fuel generating technologies will continue to make fossil fuels an important part of our energy solution.

The western states have most of the country's fossil fuel resources. Oil, because of its importance in transportation and its relative scarcity compared to coal and natural gas, plays a small and decreasing role in power generation. In the next sections, we will take a closer look at western coal and gas resources.

Coal

In 1998, coal production in the United States reached 1.12 billion tons and then declined, slightly, to 1.08 billion tons in 2000. Power generation consumes about 86% of all the coal produced in the country. The West contains some of the biggest coal reserves, shown in Exhibit 45. There are six major coal regions: the Powder River Basin (PRB) in Wyoming and Montana; the Central Rockies, which spans Colorado and Utah; Four Corners; Southern Wyoming; Northern Lignite; and Gulf Lignite.

Exhibit 45: Western Coal Fields, Railroads, and Coal Power Plants



SOURCE: RDI Consulting, POWERmap

While coal production from mines outside the West has stagnated, western coal mines and, in particular, the mines of the PRB have seen a tremendous increase in production. From 1970 through 2000, coal production in the PRB increased from 50 million to 362 million tons, or ten-fold. The reasons for this increased U.S. market share are the easy access to coal in the PRB through surface mining and the low sulfur content of the coal. At sulfur contents as low as 0.40 lb/mmBtu, coal from the PRB is compliant with the Clean Air Act and its amendments, which define "compliance coal" as coal with a sulfur content of less than 1.2 lb/mmBtu. Therefore, PRB coal is preferred by many power plants around the country since it complies with the act even without sulfur emissions control equipment.

Western coal plants account for 27% of the capacity (61,840 MW) in the West and provide 44% of western electric energy. Coal-fired power plants in the West are generally newer than their counterparts in the East. Because of access to competitively priced coal from western mines, the coal's low sulfur content, and growing demand, coal-fired power plants in the West run at some of the highest utilization rates (capacity factors) in the country. For example, coal plants in the Southwest, Northwest, and Colorado and Wyoming (no large coal-fired power plant exists in California) operate at an average 83% capacity factor. Coal plants in the Prairie States, which fire mostly lignites and PRB coal, have capacity factors of 60% to 75%. Texas coal plants operate at a 79% utilization rate. Because these capacity factors, except in the Prairie States, come close to the plant operational availability, little additional energy can be obtained from existing coal plants. If western states decided to obtain more power from coal plants, new capacity would have to be built or existing plants would have to be up-rated.

Western coal resources are vast and provide no limits to the amount of capacity and energy that could be provided from coal-fired power plants. Exhibit 46 shows RDI Consulting's estimate of economically recoverable coal reserves in western states. The starting point of our analysis is the demonstrated reserve base of coal by potential mining methods. We then derated the demonstrated reserves in order to arrive at estimated economically recoverable reserves. In our view, about one-third of the underground reserves and 70% of the demonstrated surface reserves are economically recoverable.

Exhibit 46: Estimate of Economically Recoverable Coal Reserves in the West

Region	Million Tons		Avg. Heat Content Btu/lbs	Avg. Sulfur Content lbs/mmBtu
	Underground	Surface		
Northwest	21,693	36,584	9,062	1.2
Prairie States	–	8,052	9,592	2.2
CO & WY	16,332	22,598	8,938	0.8
California	–	–	–	–
Southwest	3,569	4,949	11,413	0.8
Texas	–	9,698	6,413	3.1
TOTAL/AVERAGE	41,590	81,889	9,034	1.3

SOURCE: Energy Information Administration (EIA), "U.S. Demonstrated Reserve Base of Coal by Potential Mining Method," January 1, 2001, and RDI Consulting analysis
NOTE: Assumes that 30% of underground and 70% of surface demonstrated coal reserve base is economically recoverable.

Using our in-house databases, we then calculated the average heat and sulfur content of the coal and in Exhibit 47 we see that, in aggregate, the West has about 41,590 million tons of economically recoverable underground reserves and 81,889 million tons of surface reserves. On average we estimate that this coal has a heat content of 9,034 Btu/lb and a sulfur content of 1.3 lb/mmBtu. In the section, "Resource Options for the Future," we show that this amounts to 215 years of electric energy if all of western energy were derived from coal generation at 2001 demand levels. With at least two centuries of coal reserves left, coal is the largest fossil energy source in the West

There are three fundamental ways of generating electricity from coal: pulverized coal (PC) combustion, fluidized bed combustion (FBC), and integrated gasification combined cycle (IGCC). For PC coal plants, the unit types are: subcritical (36% net efficiency), supercritical (38%), and ultra-supercritical (41%). The efficiency of FBC plants is lower at only 34%, but they allow for greater fuel flexibility and lower emissions than PC facilities. IGCC has 40% net efficiencies and the lowest emissions of all coal-fired technologies. In IGCC, coal is first converted into natural gas and then burned in a combined cycle plant. The primary disadvantages are high capital costs and reliability questions.

RDI Consulting analysis indicates that, even with required environmental control technologies, supercritical PC is the most competitive coal technology in the West, particularly for larger installations. Nevertheless, the technology choice is often situation dependent. Where low-grade coal of variable heat content is available, FBC may be a more economic choice.

While coal—at first glance—may appear the solution to western energy woes, there are many impediments to further expansion of coal generation.

At current capital costs and efficiency, coal-fired power plants will only be able to compete with natural gas-fired power plants at low fuel costs and high capacity factors, even if natural gas prices remain at 3.25-3.50 $/mmBtu. A new coal plant would need to obtain coal at 1.00 $/mmBtu and run at a (very high) capacity factor of 88% to be profitable. While these economics can be achieved, they are not easy to reach. Natural gas-fired generation, because of its high efficiency, remains a formidable competitor with coal.

We also project a considerable surplus of generating capacity in the West from new gas-fired power plants by the time the first coal-fired projects would come on-line. In addition to higher cost at the plants, modern gas-fired plants also have an edge over coal because they are cleaner and can be sited near loads and thus can avoid most of the cost associated with transmission line expansions. In contrast, the need for low fuel cost and the environmental impacts of coal plants suggest mine-mouth projects, which are, in most cases, far from the load and require investments in transmission.

While forecast gas prices and the expected glut of gas-fired generation in the region are obstacles for additional coal plant developments in the West, one of the greatest impediments for new coal plants is their air emissions. Although it is possible to significantly reduce the levels of emissions, this comes with additional cost and further disadvantages coal. And, even after installation of best available control technology (BACT), emissions from coal remain much higher than from a modern gas-fired combined cycle power plant.

While air emissions are already on a collision course with local or regional regulations, they will also cause concerns with local residents. Opposition to coal projects in the West is likely to be formidable, because of the dramatic demographic changes in the West. New residents in the West are typically well educated and affluent and have decided to live closer to wild and scenic areas. Even developers of clean-burning, gas-fired power plants face a battle over nearly every new plant they try to build in the West.

Environmental Impacts of Coal Mining and Power Generation

Five major pollutants are produced from the combustion of coal in conventional boilers:

- nitrogen oxides (NO_x)
- sulfur dioxide (SO_2)
- particulate matter ($PM_{2.5}$)
- mercury
- carbon dioxide (CO_2)

Small particles from the combustion process with sizes of 2.5 microns and less (often referred to as $PM_{2.5}$) and mercury emissions are not yet regulated. No federal CO_2 emissions regulations exist in the U.S. and only a few states, such as Oregon, have CO_2 legislation in place, but this pollutant is the focus of the Kyoto Protocol, an international treaty to protect the atmosphere (see "Global Warming Policies Could Restrain Generation" and "Solar Power Insurance Against Kyoto Protocol.")

Fossil fuel-fired power plants and, in particular, coal-fired power plants are significant sources of air pollution. These emissions can be associated with significant health problems, including respiratory and cardiopulmonary disease, cancer, and birth defects. In addition, they can be harmful to forests, water bodies, and fish, and can decrease visibility in scenic areas.[1] Coal-fired power plants contribute to air pollution more than natural gas because coal contains elements and compounds other than carbon. For example, coal from the southern PRB, one of the cleanest coals in the U.S., still consists of 0.31% sulfur and 5.13% of other non-combustible material, collectively referred to as ash.

Various emissions-control technologies for NO_x, SO_2, and mercury exist, but these technologies are costly and are not 100% efficient. In fact, the presence of small amounts of ash in the fumes—the majority of the ash settles at the bottom of the boiler—is one of the reasons why pollution control in coal-fired power plants is so difficult and why engineers try to remove sulfur and ash before the pollutants enter the combustion chamber.

One approach is IGCC, one of the clean coal technologies put forward in the President's National Energy Policy. The first stage is a coal-to-gas conversion plant with a first-stage emissions control system and then a regular combined cycle plant with standard post-combustion emissions control technology. Other advanced coal combustion technologies are being considered but are still in the research and development stage. [2]

However, given the forecast natural gas prices, IGCC is currently not cost-efficient, because of the high capital cost of building a gasification plant and, then, a combined cycle (CC) plant. The cost of gasification is not offset by the higher efficiency of the CC process. It is telling that the only existing IGCC plant in the West, Piñion Pine in Nevada, which came on-line in 1998, has been using natural gas for its fuel—bypassing the coal-gasification facility. It is not clear whether IGCC will be an economically viable alternative, at least over the next few years.

Therefore, based on economics, it appears that only conventional boiler-based coal-fired power plants could compete in the West, even though many FBCs have recently been proposed as well. However, the emission controls that would pay for themselves indicate that new coal plants could trigger a SO_2 trading program under the Western Regional Air Partnership (WRAP), which could ultimately limit the number of plants that are built.[3] The Western Regional Council (WRC) estimates that between 4,510 and 13,100 MW of new coal-fired capacity could be added in western states over the next 18 years without triggering the trading program, while the WGA estimates that figure to be in the range of 7,000 to 19,000 MW.

And finally, CO_2 emissions are a big burden for coal plants because of the lower efficiency of coal-fired generation, which means that a larger amount of fuel needs to be burned to provide the same amount of electricity, and because of the chemistry of the coal combustion process, which contains more carbon atoms per unit of heat than natural gas. The heat rate (a measure of efficiency) of a new state-of-the-art conventional coal plant is about 9,500 Btu/kWh. In comparison, any modern gas-fired CC plant would be expected to reach heat rates as low as 7,100 Btu/kWh. In the end, even the best coal-fired power plant produces two to three times more CO_2 per kilowatt than a gas-fired combined cycle plant.

On the fuel side of power generation from coal, the mining of coal has a substantial and often lasting impact on the environment in many regions. Any form of mining, and especially coal mining, where large volumes of material are extracted from the earth, disturbs the region's geology and hydrology. But while this is true for many mining technologies, it is not true for all. For example, deep underground mining operations using longwall techniques result in insignificant impacts on the environment. Nevertheless, in general, the impact of recovery of coal resources on the environment remains another liability for coal.

Natural Gas

The western United States has abundant reserves of natural gas, which is found in Texas, along the central Rockies, the Dakotas and in California. Exhibit 47 shows a map of western gas supply regions, pipelines, and major gas-fired power plants. We can see that, in 2001, most gas-fired generation was located in Texas due to the proximity to natural gas and in California, because of the state's indigenous supply and its emphasis on air quality.

In contrast, the states of the central Rockies and the Dakotas provide little generation from their natural gas reserves. This is because of the abundance of even lower-cost coal in the region and because the Central Rockies are an emerging gas supply region. The gas fields in California and Texas have seen extensive resource recovery while the supply regions of the Central Rockies are becoming the focus of exploration and production.

In Exhibit 47 we have labeled the four most important emerging natural gas supply regions, all located in the Central Rockies. These regions are the Uinta and Green River basins and the supply regions in the Wind River area and the Powder River Basin, which is also the West's biggest coal region.

As can be seen in Exhibit 47, new pipelines are now planned to bring gas from these emerging regions into regions with an increasing demand for natural gas. A number of pipelines are in the works to bring natural gas from the Central Rockies into the Northwest, California, and the Desert Southwest.

As the power industry's current fuel of choice, natural gas will play an increasing role in meeting western electric energy demand and, as we have shown in Exhibit 9, 81% of new and forecast power plants will be running on natural gas. Currently, about 24% of all western electricity is generated with natural gas and this percentage will increase dramatically. Naturally, a question poses itself: Are there enough western gas resources to meet the increasing appetite of power for this clean-burning fuel? In Exhibit 48, we show current proven and likely reserves of western gas that are economically recoverable, according to our analysis. Just as with coal resources, the 655 Tcf of estimated reserves will remain a moving target, because technological advances may be able to unlock greater amounts of natural gas. Nevertheless, this figure provides a current estimate of the order of magnitude of western gas reserves.

On average, natural gas has a heat content of 1,010 Btu/ft^3 and contains small amounts of sulfur and only traces of other gases. According to the above estimate, at current consumption (for power generation and other uses), about 70 years of natural gas are left in the West. If all

Exhibit 47: Western Gas Resources, Pipelines, and Gas-fired Power Plants

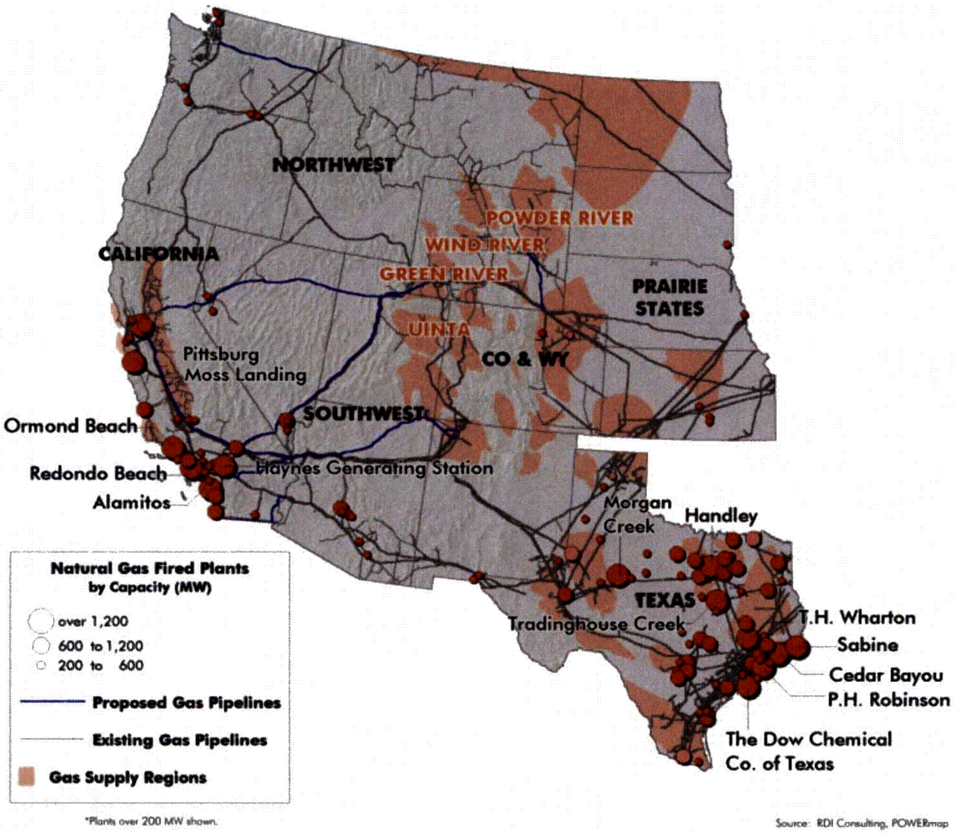


Exhibit 48: Proven and Likely Western Natural Gas Reserves

Region	Billion Cubic Feet
Northwest	59,435
Prairie States	10,718
CO & WY	287,448
California	14,768
Southwest	72,311
Texas	132,542
TOTAL	577,222

Note: Average heat content 1,010 Btu/ft^3.

electric power were derived from this fuel, 42 years from now reserves would be exhausted. Certainly, some new reserves will be found and modern drilling techniques will allow extracting more gas from the ground than before. Nevertheless, according to our analysis, it appears that the remaining natural gas supplies can be measured in decades, not centuries, even though the exact number of years is uncertain.

Renewables

Renewable energy sources generate electricity without increasing the concentration of CO_2 in the atmosphere, are inexhaustible, and, with the exception of biomass, produce little to no pollution. The five major renewable energy sources are: hydro, wind, solar, geothermal, and biomass. Other renewable forms of energy exist, but are not widely used.[4]

In subsequent sections, we will look at these five major renewable categories in greater detail.

Hydro

Only hydro generation provides a large amount of renewable energy in the West. Eighteen percent of all western energy is generated by hydro. Today opportunities for new large-scale hydro generation in the West 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 West has many opportunities for small hydro generation at existing or new dams. However, this incremental capacity would likely come at a high cost in most instances and new small hydro dams will face the same environmental opposition as large projects. It is also unlikely that repowering of new dams can provide more capacity, because the output of hydro dams is usually not limited by capacity, but by energy. For example, the Glen Canyon dam (Lake Powell) has a nominal capacity of 1,300 MW, but never generates more than about 800 MW, because of the limited amount of water that enters the reservoir.

The environmental impact of the dams along the Columbia River Basin and the Colorado Plateau are the subject of one of the longest and most emotional battles among environmentalists, fishermen, dam operators, farmers, and other stakeholders. The breaching of many of the existing smaller and larger dams has become the life's work of many. Because some of the calls for dam removal resonate with the public and policy makers, it is possible that some of the existing dams may be removed upon expiration of their operating licenses. Exhibit 49 shows the amount of hydro capacity that would be lost if operating licenses at western dams were not renewed upon their expiration.

Exhibit 49 shows that over 13,000 MW of hydro projects, or one quarter of Western capacity, would be lost if licenses are not renewed. It is difficult to forecast how many dams will indeed be breached, but it appears possible that some of the more controversial dams could be removed, especially in the Northwest. The enormous success of the Bonneville Power Administration's request for proposals for 1,000 MW of wind power will provide arguments for opponents of Northwest dams that wind generation could substitute for the lost generation while producing no pollution, and not harming fish and wildlife.

As Exhibit 50 shows, the seasonal variation of hydro generation in the West has been dramatic. For example, generation in 1995 was one-third lower than in 1998. And the California energy crisis in the spring of 2001 was compounded by very low water levels in the Northwest. Because hydro generation experiences large variations in output, a large reserve margin in the region is required. This also results in an inefficient use of the transmission system, because lines need to be in place to move the power when needed, but are underutilized in low-hydro years and after the spring runoff when hydro generation subsides to lower summer levels. The average utilization of hydro in the West is 44.8%—a capacity factor that already reflects a considerable derate of western hydro capacity.

Hydro generation will play an important role in future western energy supply, but some existing dams may be dismantled, and thus western hydro capacity could fall somewhat over the next decade. Renewable energy generation from wind and solar in the Southwest may prove to be the substitute energy sources for displacement. While the breaching of larger dams in the Northwest is a possibility, we do not believe that any of the large dams along the Colorado River will disappear, because these dams play an important role in water resource management and recreation.

Wind

Exhibit 49: Reduction of Western Hydro Capacity, if Licenses Are Not Renewed

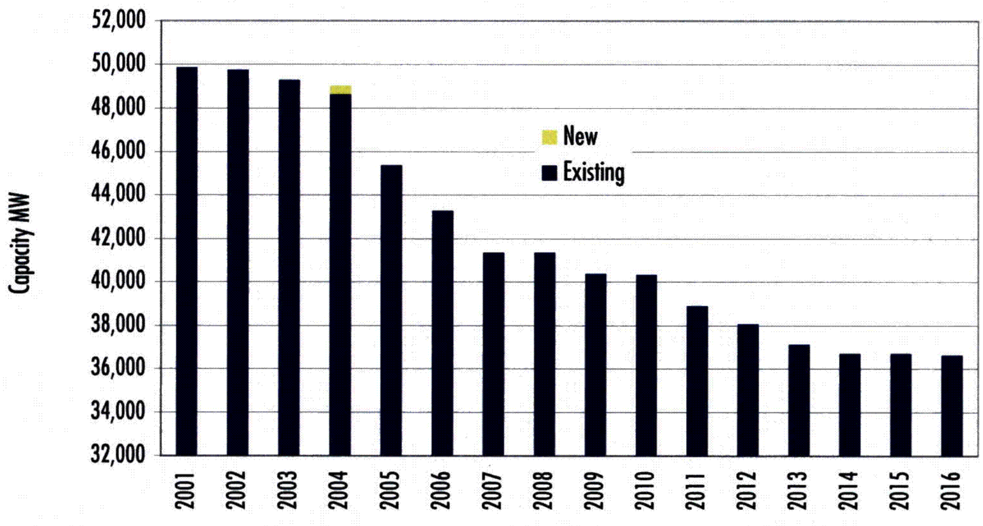
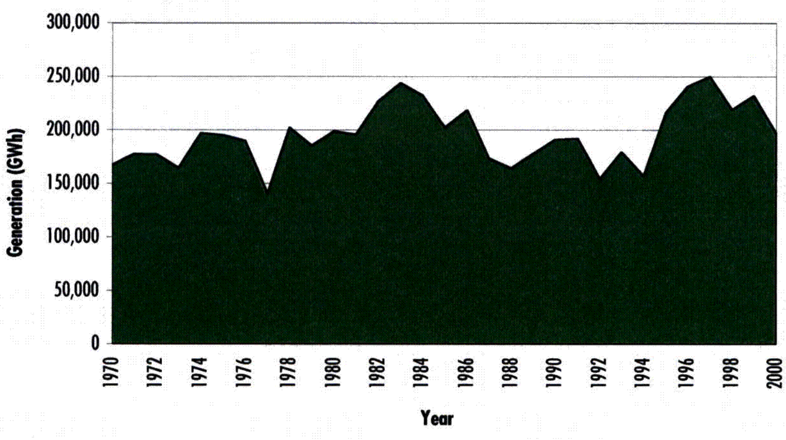


Exhibit 50: Hydro Generation in the West, 1970-2000



The emergence of wind power as a mainstream generating technology is one of the greatest technology success stories of the last decade. Developed in the U.S. in the 1980s and embraced and brought to maturity in Europe, in particular in Germany and Denmark in the 1990s, wind power is returning to America. Today wind power's cost is approaching that of conventional generating technologies. Next generation turbines are 3.8 MW, which produces enough energy for thousands of homes, and capacity factors of some wind farms in Texas are over 48%.

In Exhibit 51 we show a map of western wind resources that are potentially available and of interest to developers. The wind data in Exhibit 51 comes from NREL and was imported into RDI's POWERmap, a GIS that contains detailed data of land use and energy infrastructure.

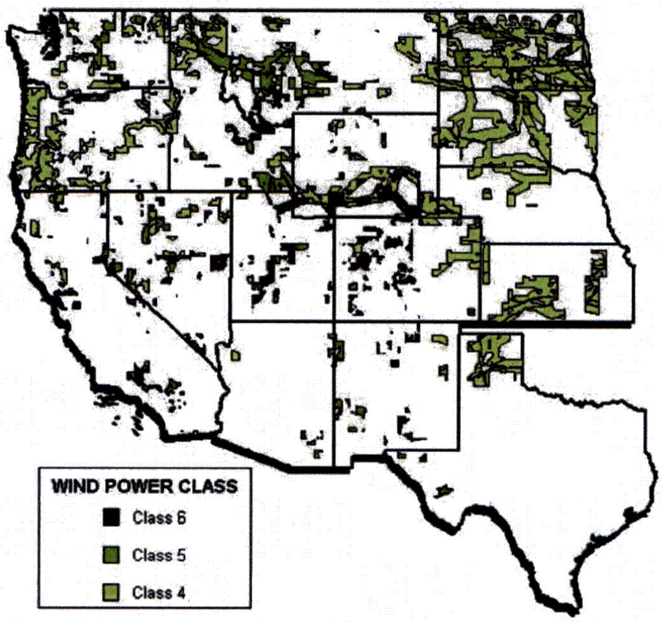
In our analysis we have excluded any wind resources on western land that is unavailable such as urbanized areas and national parks. This analysis is similar in methodology to that used for solar resources, which is presented in the section, "The Solar Energy Potential."

However, for the wind resource analysis, we made the following changes and considerations:

- Only wind resources of Class 4 and 5 and higher were considered (based on discussions with a leading wind power developer).
- Cropland was included as potential land for wind power development.
- Only land within a 10-mile corridor adjacent to a transmission line of 100 kV or greater was considered.

Otherwise all the exclusions of our solar resource analysis were also applied to eliminate land

Exhibit 51: Wind Resources in the Western United States



that is not available.

Because land use underneath a wind farm, such as farming and ranching, can continue almost undisturbed, we kept a relatively large portion of the potential wind resources as available land for wind farm development. For Class 4 and 5 wind resources we assume that 5% of the land could be used for wind power and 10% for wind resources of Class 6 and higher.

Exhibit 53 shows our estimates of the amount of available wind resources. Available land is a percentage (depending on the resource class) of the potential wind resources according to our GIS analysis. To estimate the capacity and energy that could be derived from available wind resources, we assumed that 20 MW of wind require about one square mile of land for all wind classes. For wind Class 4, Class 5, and Class 6 we assumed capacity factors of 35%, 38%, and 45%, respectively. Elsewhere in the country, wind farms are erected in wind power classes as low as Class 3, but such wind resources are considered marginal in the West, where currently all development focuses on wind classes of 5 and higher.

With these assumptions, we conclude there are about 176,022 MW of Class 4 wind power resources, 47,278 MW of Class 5, and 59,2007 MW of Class 6+. Combined, these wind energy resources could generate 930,455 GWh of electricity, or 85% of western energy. If wind farms are dispersed around the West and if a robust transmission system could send the power from where the wind is blowing to where it is not, then the inherent intermittence problems of wind could be greatly mitigated.

According to this analysis based on wind data from NREL, the Southwest has little wind resources compared to states in the north, most notably the Dakotas. Nevertheless, recent installations of wind turbines in Texas, a state that according to our analysis (see Exhibit 53) has rather marginal wind resources, has shown that wind resources can be bigger than anticipated.[5] With this caveat, it appears likely that actual wind resources may be better (or worse) than the GIS mapping and our analysis suggests. Nevertheless, we believe that our analysis provides a reasonable estimate that allows a comparison with solar energy resources calculated using a similar methodology.

Exhibit 52: Existing and New Wind Capacity in the West

Region	Wind Capacity MW	
	Beginning of 2001	New in 2001
Northwest	40	225
CO and WY	80	45
California	1,900	132
Southwest	–	–
Prairie States	3	113
Texas	170	714
TOTAL	2,193	1,229

Exhibit 53: Estimate of Western Wind Resources

Region		Wind Resources			
		Class 6	Class 5	Class 4	Land as % of Region
Northwest	MW	11,014	27,279	45,359	1.06%
	GWh	43,418	90,805	139,070	
	Acres (000)	352	873	1,451	
CO & WY	MW	24,730	1,121	20,280	1.1%
	GWh	97,484	3,733	62,179	
	Acres (000)	791	36	649	
California	MW	3,256	2,094	3,625	0.3%
	GWh	12,834	6,970	11,115	
	Acres (000)	104	67	116	
Southwest	MW	19,828	9,083	6,718	0.4%
	GWh	78,163	30,234	20,597	
	Acres (000)	635	291	215	
Prairie States	MW	–	6,941	90,862	1.59%
	GWh	–	23,104	278,583	
	Acres (000)	–	222	2,908	
Texas	MW	379	761	9,177	0.2%
	GWh	1,494	2,533	28,138	
	Acres (000)	12	24	294	
TOTAL	GWh	233,393	157,379	539,682	0.8%
2001 Demand	GWh	1,092,160			

SOURCE: RDI Consulting and POWERmap

In addition, we have mentioned that hydro generation in the West is energy-constrained, which in turn constrains capacity. On average, a dam cannot run at a higher capacity than the dam is replenished by water. However, wind generation in the Northwest could allow the dams to hold back generation, thus temporarily filling the reservoir. When output from wind farms in a region drops, hydro generation could be increased. This would have a number of beneficial effects for both hydro and wind. In particular it would:

- mitigate the intermittence of wind;
- provide more stable river flows; and
- result in much better transmission line load factors in certain regions.

In a sense, wind and hydro generation in the Northwest could be used in tandem to deliver more reliable combined generation. This in effect would also allow a lower reserve margin in the region (and the Western Interconnection as a whole). An example of using hydro storage to firm up wind capacity is already underway in southeastern Washington. For the 48-MW Nine Mile Canyon Wind Project,[6] the Bonneville Power Administration will utilize its vast hydroelectric system for storing excess production and making up shortfalls and provide transmission scheduling services for an additional $0.013/kWh.

Solar

Just like for wind, California was the birthplace of solar power. In the late 1980s and early 1990s, a remarkable U.S.-Israeli consortium built 354 MW of thermal parabolic trough solar power in the Mojave Desert (see "The 354-MW SEGS Power Plants"). Over the last decade these units have delivered reliable power to Southern California Edison and have demonstrated the commercial practicality of solar power generation. Two power tower demonstration projects, Solar One and Solar Two, were also built during that time period and during their demonstration period verified the power tower concept and the effectiveness of molten-salt heat storage. During the same time period, dish Stirling solar power systems have quietly accumulated thousands of operating hours at various experimental sites in the Southwest.

Over the past couple of years, there has been renewed interest in solar generating technologies. Companies interested in utility-scale solar generation realized that CSP, which includes dish Stirling, parabolic trough, power tower, and CPV, was the only currently practical means of generating electricity from the sun. Flat panel PV, aka solar cells, are neither efficient nor cost-effective enough for large-scale power generation and are not expected to be so for a while. Inspired by visions of a cleaner world and motivated by the stunning success of wind power, these companies and the Department of Energy have recently decided to start a new initiative for solar power.

Our analysis finds that solar energy is a good match for electricity load shapes in the West and that the available solar energy resources are double the current energy demand in the West. In the section, "The Solar Energy Potential," we provide an overview of the sun as an energy resource and present an estimate of western solar energy resource potential.

Thermal solar generating technologies, including parabolic trough, power tower, and dish Stirling plants are likely to play a dominant role, because of their high efficiency, low cost, and track record. In addition, parabolic trough and power towers have the ability to store solar energy as heat and thus can avoid a great deal of the intermittence issues that are a challenge for wind power and other forms of solar generation. In addition, hybridization with fossil fuels is possible for all thermal solar power plants, allowing around-the-clock generation.

From an operational point of view, solar power appears to be the preferred renewable energy source in the Southwest. Solar power output is generally correlated with daily and seasonal loads, while—except in a few places—wind generation is essentially random. In addition, the Southwest has better solar resources than wind resources.

If space were the only consideration, solar plants in premium solar resources areas can produce 3.5 times more energy per square mile than a wind power plant located in the highest wind resource class. Of course, land use underneath a wind farm can continue undisturbed while a solar farm requires all the land, but at the same time solar resources are almost always located in deserts.

From a transmission point of view, solar resources are also preferred because some of the best solar resources are located close to load centers—cities such as Phoenix and Las Vegas. The much lower visibility of solar plants compared to the hundreds-of-feet-tall wind turbines also makes it easier to site these plants close to urban areas.

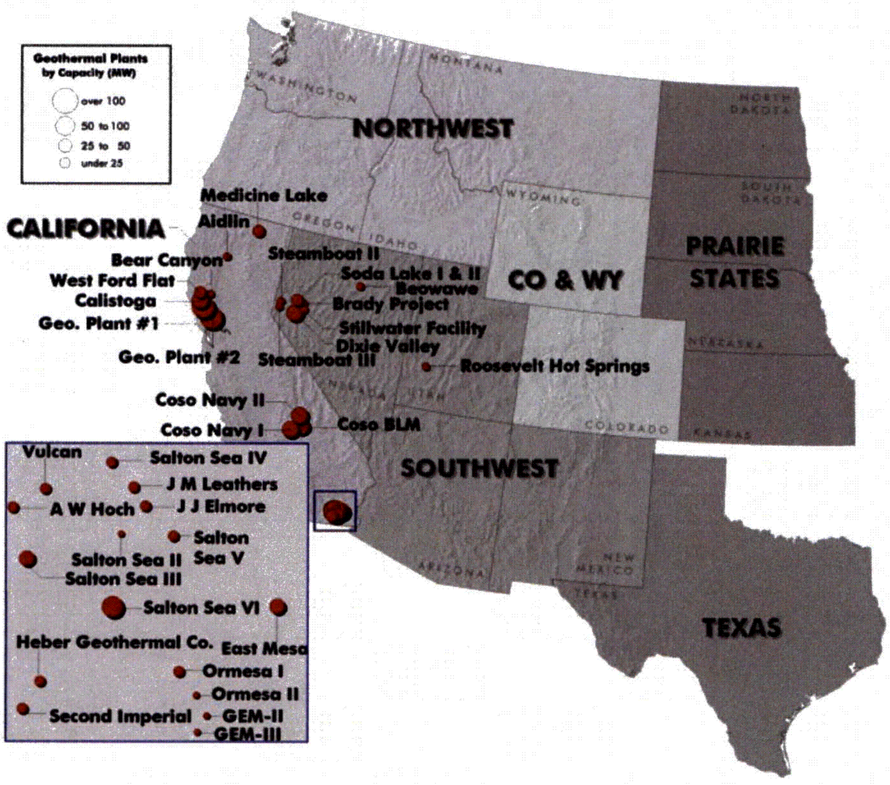
For all these reasons, energy from solar power appears to be the preferred renewable energy source in the Southwest. Western states that do not have good solar resources are fortuitously endowed with plenty of wind resources. Solar power and wind energy are found—except in a few fortunate places—in different locales in the West.

Geothermal

Geothermal power plants use the heat of the Earth's rock to generate power. Only in a few places in the country do we find geological conditions that produce natural steam wells or where rocks are so hot that water injected into the rocks returns as hot steam. Naturally, all these locations are in areas that are geologically active, such as Hawaii and the Rocky Mountain area.

In Exhibit 54 we show a map of geothermal power plants in the West. There are 53 geothermal power stations with a combined nominal capacity of 3,276 MW of capacity. The only western states with geothermal generation are Hawaii, California, and Nevada.

Exhibit 54: Geothermal Power Plants in the West



A great advantage of geothermal power plants is that they can operate like a conventional steam plant. But geothermal power plants also face challenges. For example, the geothermal resources often show effects of depletion. The Geysers, an area of California that has some of the largest geothermal generating capacity, can only generate half the power that it could originally. Further, in some instances, geothermal steam contains pollutants that can escape into the air.

In this study we make no attempt to estimate the geothermal generating potential for various reasons. First, we could not locate a reliable data base on geothermal resources. Second, the energy that can be obtained from a resource is largely unknown until after the resource is explored. Third, modern directional drilling and rock cracking techniques developed by the oil industry now allow for a much better resource extraction than in the past. However, these drilling techniques have not been used with geothermal resources to date and thus their effectiveness cannot be judged at this point.

In summary, geothermal power is an excellent source of renewable energy, and it is likely that the resource base will increase the more intensely we look for geothermal steam. However, cost reductions for geothermal plants below what has been historically experienced are not expected.

Biomass

Wood, grass, or dung is the source of fuel for billions of people around the world, mostly in developing nations. Nevertheless, compared to the energy required to fuel the U.S. economy and our way of life, the amount of energy that can be derived from biomass is likely to be small. Especially in the West, limited water resources are a problem for biomass. Further, unless biomass is available as agricultural or forestry waste products, it is also unlikely to be cost-effective without permanent subsidies. Also, while biomass generation is "carbon neutral" with regard to the Kyoto Protocol, it still produces emissions that can cause local air pollution, including regional haze.

Nevertheless, in some cases, biomass production can benefit farmers and the forest industry. Grass can be co-fired in coal-fired power plants, producing revenues for farmers, and sawdust from wood processing plants can provide cogeneration opportunities. Nevertheless, these are niche applications and the amount of electricity that can be generated by biomass will be small compared to other sources of energy.

Nuclear

"Nuclear power" has become a term that describes the generation of energy by nuclear fission, in which a chain nuclear reaction with uranium is used to generate heat. But a different, and promising future technology, is nuclear fusion, in which energy is released when hydrogen is "fused" into helium. This process, the same one that provides the sun's energy, also results in the release of enormous amounts of heat.

Fission has been used for power generation for many decades, while power generation from fusion is still decades away. In the next two sections we will briefly describe the use of fission for western energy supply and the promise that fusion holds.

Fission

Some 18,795 MW of nuclear power in the West generate about 11% of western electricity. Each region has some nuclear power generation except for Colorado and Wyoming, where the only nuclear plant in the region, Fort St. Vrain, was converted to a gas-fired power plant. The Washington Public Power Supply System, in the Northwest, has several unfinished nuclear power plant projects.

In the 1960s and 1970s, nuclear power was praised as the form of energy that would be "too cheap to meter." The reality of the development of the more than 100 power plants in the U.S. over three decades has been different. Nuclear power turned out to be expensive, especially in light of retrofits required after the incident at Three Mile Island. Nevertheless, since then, nuclear power has overcome many of its initial problems, and modern nuclear reactors are well designed, with construction costs likely in the $2,000/kW range.

However, given the current political and economic climate, the development of new nuclear power plants is unlikely, despite the emphasis on nuclear power in the President's National Energy Policy.

Today, nine out of ten megawatts are built by IPPs and financed by capital markets. IPPs are already finding it difficult to build gas-fired power plants in western communities, where gas-fired generation technology is clean and poses no danger to the public. New nuclear unit construction will need to be championed by the electric utilities themselves and will require strong political support and increased volatility of natural gas prices. Finally, nuclear power, despite much better plant design, is fraught with the questions of operating safety, storage of nuclear material, and the danger of terrorist attacks.

It is our view that, in light of these considerations, the construction of new nuclear facilities is unlikely. We predicted that existing nuclear facilities would uprate, if technically and economically possible, and this trend has materialized. We further believed that the Nuclear Regulatory Commission (NRC) would grant extension of licenses for the operating life of nuclear facilities if the facilities were deemed safe for continued operation. This trend, too, has come true.

Such uprates and extensions of operating licenses are economically favorable, because nuclear plants' large capital costs have already been recovered from ratepayers, and the additional capacity or additional years of generation come at low cost. Finally, these nuclear facilities are in communities that are accustomed to the power plants in their neighborhoods and are unlikely to mount opposition.

In summary, RDI Consulting does not believe that new nuclear power plants are likely to be built in the West. Existing nuclear units are likely to increase their capacity and energy production and some nuclear units will seek the extension of their operating licenses.

Fusion

Fusion can take advantage of, for all practical purposes, an inexhaustible fuel supply and create only small amounts of radioactivity, which decays within 100 years. If ever technically feasible, fusion will be the answer to all energy needs. A thimbleful of liquid hydrogen fuel could produce as much energy as 20 tons of coal.[7]

It is for that reason that the U.S. and the European Union have invested billions of dollars into fusion research. Although fusion has been achieved on a laboratory scale, when and if fusion can be used for power generation is still unclear. Some estimates put the first commercially available units at 2050. However, formidable obstacles remain.

While research into fusion should remain a high priority research topic, fusion will play no role in the world's energy supply for decades or even centuries to come. Therefore, fusion is not a resource option that should be considered by western states.

Endnotes

[1] The White House, National Energy Policy, May 2001, p. 3-3.

[2] Alternative clean coal technologies to IGCC, in particular, a system where liquid combustion products are formed, have been proposed, but to date these technologies exist only on paper.

[3] Currently, no legislation is in place that could enforce the targets of WRAP.

[4] Recently wave energy, which captures energy contained in the waves of oceans, is being pursued as a new renewable generating technology.

[5] To illustrate this point, compare Texas wind sources shown in Figure 51 with the location of new wind farms shown in Figure 10.

[6] *Wind Power Monthly*, Vol. 17, No. 12, p. 8.

[7] Gerold Yonas, "Fusion and the Z Pinch," *Scientific American*, August 1998.

State-by-State Appendices

Overview of Regional Power Markets

At the beginning of 2001, a total of 234,178 MW of capacity was available to meet summer peak demand in the West.[1] Overall, the West is characterized by large amounts of coal- and gas-fired generation, which each accounts for about one-quarter of the installed capacity. Overall hydroelectric accounts for 13% of the capacity in the states of the Western Governors' Association. This is because the large amounts of hydro capacity in the Northwest are offset by virtually no hydro capacity in Texas—the largest load region in the West. Nuclear plants in the West provide 7% of the capacity. Great differences in the generation mix exist across the various regions.

The Northwest

The capacity mix in the Northwest is very different than the rest of the West. Here hydro makes up 77% of installed generating capacity. Hydro generation is subject to wide year-to-year variations owing to annual differences in rain and snowfall and from month-to-month within a year owing to seasonal patterns. Other generation must fill in when water levels are low. As in other parts of the country, excess capacity has largely been absorbed by demand growth, leading to a shortage. This was particularly true in 2000 when high demand in California resulted in price spikes even in the Northwest, whose entire surplus power, if any, was sent to the south.

Fish restoration efforts are a wild card in the Northwest. Changes in the operation of federal dams since the early 1980s to create more favorable conditions for endangered fish species have reshaped the seasonal pattern of hydro generation and reduced firm generating capability by an average of 1,200 MW. A further 1,200 MW would be lost in a proposal to breach four dams on the lower Snake River—Ice Harbor, Lower Monumental, Little Goose, and Lower Granite—and to lower the reservoir behind the John Day dam on the Columbia River.

Coal is the second most important power supply resource in the Northwest, making up 12% of installed generating capacity. Oil- and gas-fired generation contribute 9% to the generating capacity. Fossil generation is the "swing" generation that accommodates hydro variability.

Therefore, the operating costs of these units set market prices in most hours of the year.

Delivered gas prices into the Northwest are heavily influenced by Canadian gas supply prices. Because Canadian gas prices are typically lower than other gas sources, generators in the Northwest have historically enjoyed some of the lowest gas prices in the country.

The Northwest, in particular, Washington and Oregon, appears to have a large capacity surplus when measured in terms of generating capacity relative to peak demand. However, because of the variability of hydro conditions from year to year, a high capacity surplus is required to cover for a dry year. In 2000, the Pacific Northwest had reached the critical point at which new generating capacity is required.

California

California's mix of capacity is atypical when compared to the rest of the country. First, there is virtually no coal-fired generation in California. This is due to a combination of the distance from western coalfields and state environmental restrictions. The state has a significant amount of renewable capacity, including traditional hydro, geothermal, wind, and other types of renewables. There are also two large nuclear plants located in California. A significant amount of the state's capacity, roughly 53%, is oil- and gas-fired baseload capacity. Many of these units, which mostly burn gas for environmental reasons, constitute a high cost resource. Some of these plants are operated by IPPs that sell power to local utilities under "must-take" contracts. In other cases, purchases from other regions, especially the Northwest, are used to reduce or eliminate the need for generation from the old, gas-fired steam units. In 1999, these old and inefficient gas-fired units operated at an average 30% capacity factor and experienced capacity factors below 20% in the previous two years.

Southwest

Arizona Public Service and Salt River Project are the largest utilities in the Southwest. Nevertheless, the Western Area Power Administration (WAPA), a federal agency, is the largest owner of generating capacity in the region. WAPA markets power from the Hoover and Glen Canyon dams and the Navajo coal-fired project, as well as many smaller dams. Also, a significant amount of capacity in this region is owned by or allocated to California utilities, including parts of the Mohave, Navajo, Four Corners, and Palo Verde plants.

In 2001, coal accounted for 52% of the capacity in the Southwest. Nuclear comprised 12% of capacity, while oil and gas contributed 11%; hydro accounted for 10% of capacity. This mix will change substantially as the Southwest, in particular the Phoenix and Las Vegas areas, experiences an influx of gas-fired merchant plant additions.

Texas

At the beginning of 2001, approximately 73,000 MW of generating capacity was installed in Texas. Gas-fired units account for the majority of the installed capacity in the state, representing roughly 66% of the total. Coal-fired capacity is 24% of the total and the Comanche Peak and South Texas nuclear plants represent 6% of installed capacity. Practically no hydro generation exists in the state.

In Texas, plant capacity factors have increased in recent years, but still vary widely among generation types. Nuclear capacity factors have ranged between 87% and 92% and coal between 73% and 76%, as would be expected of baseload plants. Nuclear performance has dramatically improved, as engineering and operating issues at the South Texas Nuclear Project were largely resolved in 1993. The average capacity factor for nuclear plants has improved from 49% in 1989 to 92% in 1998. The capacity factor of coal-fired generation has also improved in recent years and coal-fired units now operate at close to an 80% capacity factor, exceeded only by those in the Northwest and Colorado and Wyoming.

Exhibit 55: States and U.S.-flag Islands of the Western Governors' Association and Regions

State	Region
California	California
Wyoming	CO & WY
Colorado	CO & WY
Idaho	Northwest
Oregon	Northwest
Montana	Northwest
Washington	Northwest
Alaska	Other
Mariana Island	Other
American Samoa	Other
Guam	Other
Hawaii	Other
Kansas	Prairie States
South Dakota	Prairie States
Nebraska	Prairie States
North Dakota	Prairie States
Arizona	Southwest
Nevada	Southwest
Utah	Southwest
New Mexico	Southwest
Texas	Texas

Alaska

Demand

TBD

Power Plant Development

No forecast provided.

Solar Energy Resources

No premium, excellent or good solar resources.

State Legislation Regarding Renewable Energy Sources

No legislation in place.

Arizona

Demand

Energy and Peak Demand Forecast

	2001	2002	2003	2004	2005	2010
Peak Demand MW (1)	13,505	13,894	14,298	14,567	14,873	16,694
Energy Demand GWh (2)	63,675	65,511	67,416	68,685	70,125	78,714
Growth Rate	–	2.90%	2.90%	1.90%	2.10%	2.30%
Target Reserve Margin (1)	21%	21%	21%	21%	21%	20%

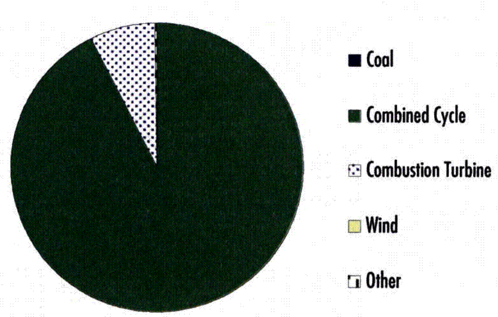
(1) RDI Consulting estimate
(2) RDI Consulting base case forecast.

Power Plant Development

RDI Forecast of New Generating Capacity and Additional Proposed Capacity

	2001	2002	2003	2004	2005	2010
Began Operating	1,276	–	–	–	–	–
Under Construction	620	1,710	2,383	–	–	–
Forecast New	–	–	1,150	575	1,080	600
Additional Proposed	9,628					

Fuel Mix of RDI Forecast of New Generating Capacity



Solar Energy Resources

	Solar Resources			
	Premium	Excellent	Good	TOTAL
MW	172,106	89,547	23,914	285,567
GWh	376,912	176,496	41,897	595,305
Acres (000)	861	448	120	1,429

SOURCE: POWERmap and RDI Consulting analysis.
NOTE: Solar resources ≥ 7.0 kWh/m2/day are considered premium, 6.5-7.0 excellent, and 6.0-6.5 good. Estimates for electric generation assume 5 Acres/MW and capacity factors of 25% for premium, 22.5% for excellent, and 20% for good.

State Legislation Regarding Renewable Energy Sources

Renewable Portfolio Standard (RPS)

Arizona mandates a 0.2% RPS by 2001, climbing to 1.1% by 2007. At least 50% of the generation must come from solar sources in 2001-2003, increasing to 60% starting in 2004. Costs partially paid by (SBC) funds.

System Benefit Charge (SBC)

A 0.0875 ¢/kWh systems benefit charge is collected from different customer classes with various caps.

Green Energy Programs

Three utilities offer green pricing programs in Arizona.

Tax/Financial Incentives

Sales tax exemption for solar and wind, up to $5,000.

Income tax credit: 10% credit toward corporate or personal income taxes for the construction of a renewable energy equipment manufacturing facility.

Personal tax credit: credit against personal income tax of up to 25% of the cost of a solar or wind energy device, maximum credit $1,000.

Revolving commercial loan program: loans between $10,000 and $500,000 available for companies that either manufacture renewable energy equipment or acquire such equipment for use in their business.

Net Metering

Renewables and cogeneration eligible, ≥ 100 kW, no overall enrollment limit, net excess generation purchased at avoided cost.

California

Demand

Energy and Peak Demand Forecast

	2001	2002	2003	2004	2005	2010
Peak Demand MW (1)	52,805	53,830	54,926	56,133	57,809	66,804
Energy Demand GWh (2)	266,883	272,064	277,601	283,704	292,174	337,635
Growth Rate	–	1.90%	2.00%	2.20%	3.00%	2.90%
Target Reserve Margin (1)	21%	21%	21%	21%	21%	20%

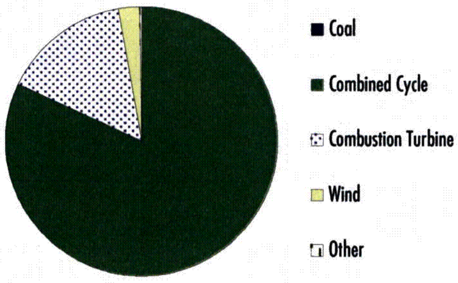
(1) RDI Consulting estimate
(2) RDI Consulting base case forecast.

Power Plant Development

RDI Forecast of New Generating Capacity and Additional Proposed Capacity

	2001	2002	2003	2004	2005	2010
Began Operating	1,551	–	–	–	–	–
Under Construction	1,086	3,151	1,457	–	–	–
Forecast New	–	990	2,660	1,758	499	–
Additional Proposed	15,297					

Fuel Mix of RDI Forecast of New Generating Capacity



Solar Energy Resources

	Solar Resources			
	Premium	Excellent	Good	TOTAL
MW	61,617	14,809	21,743	98,169
GWh	134,942	29,189	38,093	202,224
Acres (000)	308	74	109	491

SOURCE: POWERmap and RDI Consulting analysis.
NOTE: Solar resources ≥ 7.0 kWh/m2/day are considered premium, 6.5-7.0 excellent, and 6.0-6.5 good. Estimates for electric generation assume 5 Acres/MW and capacity factors of 25% for premium, 22.5% for excellent, and 20% for good.

State Legislation Regarding Renewable Energy Sources

System Benefit Charge (SBC)

$135 million per year from 1998 through 2011.

Green Energy Programs

California has a competitive green energy market in most areas. However, most green marketers have left the market in the wake of wholesale energy market problems, and the status of retail choice is uncertain in California. Also, seven utilities offer green pricing programs in areas where green market choices are not available.

Tax/Financial Incentives

Low-interest (5%) loan program to small businesses for the demonstration of alternative energy technologies

Customer credit: 1.0 ¢/kWh credit for customers purchasing qualifying green energy projects with non-utility renewable energy sources (SBC funding).

New renewable resources program: California has held two competitive solicitations, allocating $202 million thus far, to subsidize large-scale renewable energy projects. These auctions are proposed to occur biennially through 2011, with about $121 million to be distributed in each round (SBC funding).

Emerging renewable resources program: a buy-down program for up to the lesser of 50% or $3/watt for distributed renewable energy systems. Some funds are available for systems over 50 kW (SBC funding).

Net Metering

Solar and wind eligible, residential and commercial customer classes eligible, ≥ 1 MW, no overall enrollment limit, net metering customers are billed annually (effectively a month-to-month carry-over) with excess generation granted to the utility.

Colorado

Demand

Energy and Peak Demand Forecast

	2001	2002	2003	2004	2005	2010
Peak Demand MW (1)	7,508	7,729	7,956	8,113	8,287	9,135
Energy Demand GWh (2)	44,651	45,967	47,317	48,248	49,284	54,328
Growth Rate	–	2.90%	2.90%	2.00%	2.10%	2.00%
Target Reserve Margin (1)	18%	18%	18%	18%	18%	17%

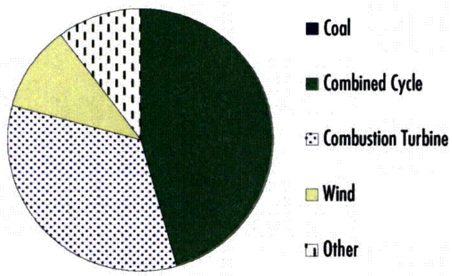
(1) RDI Consulting estimate
(2) RDI Consulting base case forecast.

Power Plant Development

RDI Forecast of New Generating Capacity and Additional Proposed Capacity

	2001	2002	2003	2004	2005	2010
Began Operating	250	–	–	–	–	–
Under Construction	430	525	–	–	–	–
Forecast New	–	298	278	80	–	–
Additional Proposed	2,697					

Fuel Mix of RDI Forecast of New Generating Capacity



Solar Energy Resources

	Solar Resources			
	Premium	Excellent	Good	TOTAL
MW	2,513	13,141	22,598	38,252
GWh	5,504	25,901	39,591	70,996
Acres (000)	13	66	113	192

SOURCE: POWERmap and RDI Consulting analysis.
NOTE: Solar resources ≥ 7.0 kWh/m2/day are considered premium, 6.5-7.0 excellent, and 6.0-6.5 good. Estimates for electric generation assume 5 Acres/MW and capacity factors of 25% for premium, 22.5% for excellent, and 20% for good.

State Legislation Regarding Renewable Energy Sources

Green Energy Programs

Ten utilities offer green pricing programs in Colorado.

Net Metering

Wind and PV eligible, all customer classes eligible, ≥ 3 kW wind, ≥ 10 kW PV, no overall enrollment limit, net excess generation carried over month to month.

Hawaii

Demand

TBD

Power Plant Development

No forecast provided.

Solar Energy Resources

No analysis performed.

State Legislation Regarding Renewable Energy Sources

Green Energy Programs

Hawaiian Electric Co. offers a green pricing program.

Tax/Financial Incentives

Personal and corporate income tax exemption for 20% of the cost of a wind energy system.

Idaho

Demand

Energy and Peak Demand Forecast

	2001	2002	2003	2004	2005	2010
Peak Demand MW (1)	3,763	3,844	3,928	3,978	4,038	4,381
Energy Demand GWh (2)	26,369	26,937	27,525	27,878	28,295	30,702
Growth Rate	–	2.20%	2.20%	1.30%	1.50%	1.60%
Target Reserve Margin (1)	21%	21%	21%	21%	21%	20%

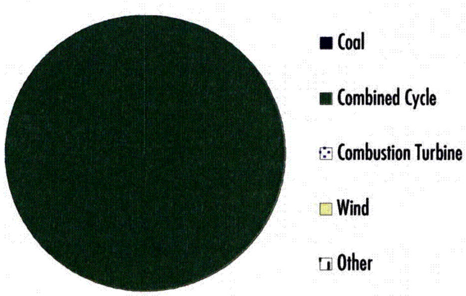
(1) RDI Consulting estimate
(2) RDI Consulting base case forecast.

Power Plant Development

RDI Forecast of New Generating Capacity and Additional Proposed Capacity

	2001	2002	2003	2004	2005	2010
Began Operating	–	–	–	–	–	–
Under Construction	270	–	–	–	–	–
Forecast New	–	–	–	–	–	–
Additional Proposed	2,485					

Fuel Mix of RDI Forecast of New Generating Capacity



Solar Energy Resources

	Solar Resources			
	Premium	Excellent	Good	TOTAL
MW	–	–	4,821	4,821
GWh	–	–	8,446	8,446
Acres (000)	–	–	24	24

SOURCE: POWERmap and RDI Consulting analysis.
NOTE: Solar resources ≥ 7.0 kWh/m2/day are considered premium, 6.5-7.0 excellent, and 6.0-6.5 good. Estimates for electric generation assume 5 Acres/MW and capacity factors of 25% for premium, 22.5% for excellent, and 20% for good.

State Legislation Regarding Renewable Energy Sources

Tax/Financial Incentives

Personal income tax deduction of 40% of the cost of a wind, solar, or geothermal residential energy system.

Low interest loans: 5-year loans at 4% available for renewable energy systems. Loans available for residential systems in amounts between $1,500-$10,000 and up to $100,000 for commercial/industrial applications.

Net Metering

Renewables and cogeneration eligible, residential and commercial Idaho Power customers eligible, ≥ 100 kW, no overall enrollment limit, net excess generation purchased at avoided cost.

Indian Nations

Demand

No data.

Power Plant Development

No data.

Solar Energy Resources

	Solar Resources			
	Premium	Excellent	Good	TOTAL
MW	48,099	9,152	4,685	61,936
GWh	105,337	18,039	8,209	131,585
Acres (000)	240	46	23	309

SOURCE: POWERmap and RDI Consulting analysis.
NOTE: Solar resources ≥ 7.0 kWh/m2/day are considered premium, 6.5-7.0 excellent, and 6.0-6.5 good. Estimates for electric generation assume 5 Acres/MW and capacity factors of 25% for premium, 22.5% for excellent, and 20% for good.

Tribal Legislation Regarding Renewable Energy Sources

No information available.

Kansas

Demand

Energy and Peak Demand Forecast

	2001	2002	2003	2004	2005	2010
Peak Demand MW (1)	9,082	9,279	9,470	9,653	9,825	10,522
Energy Demand GWh (2)	43,363	44,305	45,219	46,092	46,910	50,238
Growth Rate	–	2.20%	2.10%	1.90%	1.80%	1.40%
Target Reserve Margin (1)	17%	17%	17%	17%	17%	16%

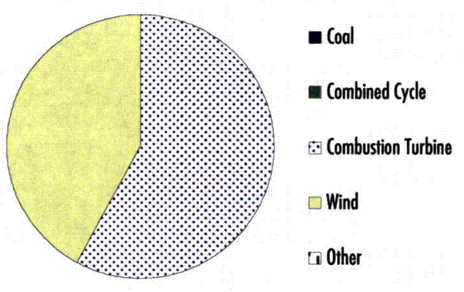
(1) RDI Consulting estimate
(2) RDI Consulting base case forecast.

Power Plant Development

RDI Forecast of New Generating Capacity and Additional Proposed Capacity

	2001	2002	2003	2004	2005	2010
Began Operating	151	–	–	–	–	–
Under Construction		110	–	–	–	–
Forecast New	–	–	–	–	–	–
Additional Proposed	1,200					

Fuel Mix of RDI Forecast of New Generating Capacity



Solar Energy Resources

	Solar Resources			
	Premium	Excellent	Good	TOTAL
MW	–	2,082	4,731	6,813
GWh	–	4,105	8,288	12,393
Acres (000)	–	10	24	34

SOURCE: POWERmap and RDI Consulting analysis.
NOTE: Solar resources ≥ 7.0 kWh/m2/day are considered premium, 6.5-7.0 excellent, and 6.0-6.5 good. Estimates for electric generation assume 5 Acres/MW and capacity factors of 25% for premium, 22.5% for excellent, and 20% for good.

State Legislation Regarding Renewable Energy Sources

Green Energy Programs

Two utilities offer green pricing programs in Kansas.

Tax/Financial Incentives

Grant program available for renewable energy systems in the residential, commercial, and industrial sectors. Grants available up to $50,000 each, with total available annual funds about $500,000.

Net Metering

All renewables eligible, residential, and commercial customers eligible, ≥ 25 kW residential and ≥ 100 kW commercial, no overall enrollment limit, net excess generation credited to customer or paid at 150% of avoided cost.

Montana

Demand

Energy and Peak Demand Forecast

	2001	2002	2003	2004	2005	2010
Peak Demand MW (1)	2,354	2,388	2,426	2,446	2,472	2,611
Energy Demand GWh (2)	16,494	16,735	16,999	17,138	17,321	18,296
Growth Rate	–	1.50%	1.60%	0.80%	1.10%	1.10%
Target Reserve Margin (1)	21%	21%	21%	21%	21%	20%

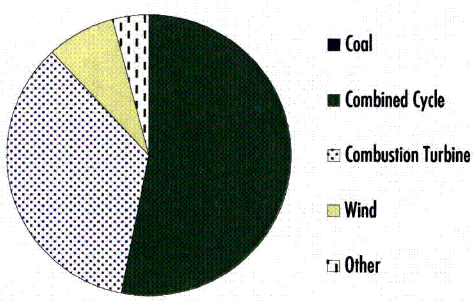
(1) RDI Consulting estimate
(2) RDI Consulting base case forecast.

Power Plant Development

RDI Forecast of New Generating Capacity and Additional Proposed Capacity

	2001	2002	2003	2004	2005	2010
Began Operating	–	–	–	–	–	–
Under Construction	–	–	–	–	–	–
Forecast New	19	39		400	–	–
Additional Proposed	2,697					

Fuel Mix of RDI Forecast of New Generating Capacity



Solar Energy Resources

No premium, excellent, or good solar resources.

State Legislation Regarding Renewable Energy Sources

System Benefit Charge

About $2 million per year from 1999 through 2003.

Green Energy Programs

Flathead Electric Cooperative offers a green pricing program in its territory.

Tax/Financial Incentives

Corporate or personal income tax credit of 35% for any individual or corporation that makes a $5,000 or greater investment in a wind generating or wind generating equipment manufacturing facility.

Property tax exemption: exempts the value of renewable energy systems at residential or commercial sites from property taxes for 10 years. Single-family residential systems up to $20,000 in value or multi-family residential and commercial systems up to $100,000 in value qualify for the exemption.

Net Metering

Solar, wind or hydro eligible, all customer classes eligible, ≥ 50 kW, no overall enrollment limit, net excess generation credited to following month; unused credit is granted to utility at end of 12-month period.

Nebraska

Demand

Energy and Peak Demand Forecast

	2001	2002	2003	2004	2005	2010
Peak Demand MW (1)	5,105	5,212	5,314	5,412	5,503	5,897
Energy Demand GWh (2)	26,443	26,995	27,525	28,030	28,501	30,545
Growth Rate	–	2.10%	2.00%	1.80%	1.70%	1.40%
Target Reserve Margin (1)	18%	18%	18%	18%	18%	17%

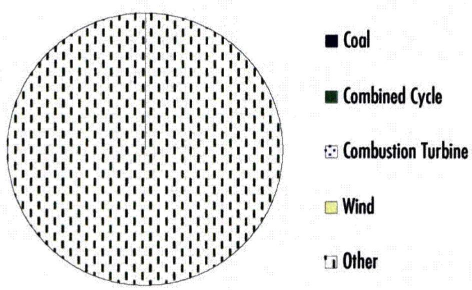
(1) RDI Consulting estimate
(2) RDI Consulting base case forecast.

Power Plant Development

RDI Forecast of New Generating Capacity and Additional Proposed Capacity

	2001	2002	2003	2004	2005	2010
Began Operating	–	–	–	–	–	–
Under Construction	–	–	–	–	–	–
Forecast New	–	–	–	400	–	–
Additional Proposed	390					

Fuel Mix of RDI Forecast of New Generating Capacity



Solar Energy Resources

No premium, excellent, or good solar resources.

State Legislation Regarding Renewable Energy Sources

Green Energy Programs

Three utilities offer green pricing programs in Nebraska.

Tax/Financial Incentives

Low-interest (one-half market rate) loan program for qualifying renewable energy systems at residential and commercial sites.

Nevada

Demand

Energy and Peak Demand Forecast

	2001	2002	2003	2004	2005	2010
Peak Demand MW (1)	5,738	5,903	6,074	6,193	6,327	7,115
Energy Demand GWh (2)	27,053	27,832	28,638	29,202	29,834	33,548
Growth Rate	–	2.90%	2.90%	2.00%	2.20%	2.40%
Target Reserve Margin (1)	21%	21%	21%	21%	21%	20%

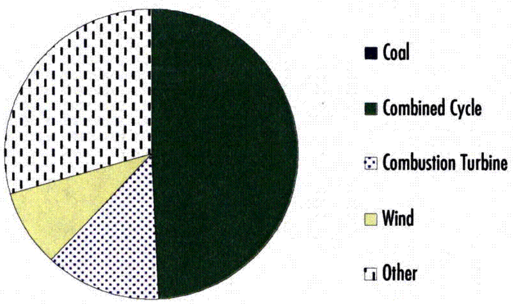
(1) RDI Consulting estimate
(2) RDI Consulting base case forecast.

Power Plant Development

RDI Forecast of New Generating Capacity and Additional Proposed Capacity

	2001	2002	2003	2004	2005	2010
Began Operating	363	–	–	–	–	–
Under Construction	–	–	–	–	–	–
Forecast New	–	115	500	1,575	–	500
Additional Proposed	6,353					

Fuel Mix of RDI Forecast of New Generating Capacity



Solar Energy Resources

	Solar Resources			
	Premium	Excellent	Good	TOTAL
MW	81,997	46,171	37,655	165,823
GWh	179,574	91,004	65,972	336,550
Acres (000)	410	231	188	829

SOURCE: POWERmap and RDI Consulting analysis.
NOTE: Solar resources ≥ 7.0 kWh/m2/day are considered premium, 6.5-7.0 excellent, and 6.0-6.5 good. Estimates for electric generation assume 5 Acres/MW and capacity factors of 25% for premium, 22.5% for excellent, and 20% for good.

State Legislation Regarding Renewable Energy Sources

Renewable Portfolio Standard

0.2% renewables in 2001, 5% in 2003, continuing to increase at 2% every other year to 15% in 2013; 5% of renewables must be solar.

Tax/Financial Incentives

Property tax exemption: The value of qualified renewable energy systems is exempted from property tax assessment. Industrial, commercial, and residential sites all qualify, and there is no time limit on the exemption.

Net Metering

Solar and wind eligible, all customer classes eligible, ≥ 10 kW, 100 customers per utility enrollment limit, generation annualized for billing but no payment required for net excess generation.

New Mexico

Demand

Energy and Peak Demand Forecast

	2001	2002	2003	2004	2005	2010
Peak Demand MW (1)	4,158	4,245	4,337	4,396	4,464	4,876
Energy Demand GWh (2)	19,603	20,018	20,448	20,728	21,050	22,990
Growth Rate	-	2.10%	2.20%	1.40%	1.60%	1.80%
Target Reserve Margin (1)	21%	21%	21%	21%	21%	20%

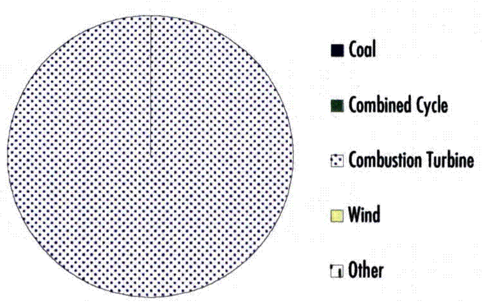
(1) RDI Consulting estimate
(2) RDI Consulting base case forecast.

Power Plant Development

RDI Forecast of New Generating Capacity and Additional Proposed Capacity

	2001	2002	2003	2004	2005	2010
Began Operating	-	-	-	-	-	-
Under Construction	-	-	-	-	-	-
Forecast New	-	50	-	-	-	-
Additional Proposed	1,470					

Fuel Mix of RDI Forecast of New Generating Capacity



Solar Energy Resources

	Solar Resources			
	Premium	Excellent	Good	TOTAL
MW	94,103	51,973	73,345	219,421
GWh	206,086	102,439	128,500	437,025
Acres (000)	471	260	367	1,098

SOURCE: POWERmap and RDI Consulting analysis.
NOTE: Solar resources ≥ 7.0 kWh/m2/day are considered premium, 6.5-7.0 excellent, and 6.0-6.5 good. Estimates for electric generation assume 5 Acres/MW and capacity factors of 25% for premium, 22.5% for excellent, and 20% for good.

State Legislation Regarding Renewable Energy Sources

System Benefit Charge

$4 million per year from 2007 through 2012.

Green Energy Programs

Southwestern Public Service offers a green pricing program.

Net Metering

Renewables and cogeneration eligible, all customer classes eligible, ≥10 kW, no overall enrollment limit, net excess generation purchased at avoided cost or credited on the next month's bill.

North Dakota

Demand

Energy and Peak Demand Forecast

	2001	2002	2003	2004	2005	2010
Peak Demand MW (1)	2,027	2,061	2,095	2,128	2,159	2,272
Energy Demand GWh (2)	10,496	10,676	10,851	11,021	11,180	11,766
Growth Rate	-	1.70%	1.60%	1.60%	1.40%	1.00%
Target Reserve Margin (1)	18%	18%	18%	18%	18%	17%

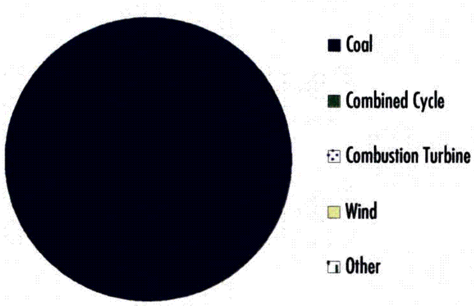
(1) RDI Consulting estimate
(2) RDI Consulting base case forecast.

Power Plant Development

RDI Forecast of New Generating Capacity and Additional Proposed Capacity

	2001	2002	2003	2004	2005	2010
Began Operating	-	-	-	-	-	-
Under Construction	-	-	-	-	-	-
Forecast New	-	-	-	-	-	500
Additional Proposed	500					

Fuel Mix of RDI Forecast of New Generating Capacity



Solar Energy Resources

No premium, excellent, or good solar resources.

State Legislation Regarding Renewable Energy Sources

Green Energy Programs

Minnkota Power Cooperative offers a green pricing program.

Tax/Financial Incentives

Property tax incentive: solar, wind or geothermal energy systems are exempt from property taxes for five years following installation at commercial and residential sites.

Income tax incentive: 5% of equipment costs for wind, solar, and geothermal energy systems are deductible from income tax for three years following installation. Commercial and residential taxpayers qualify.

Net Metering

Renewables and cogeneration eligible, all customer classes eligible, ≥100 kW, no overall enrollment limit, net excess generation purchased at avoided cost.

Oregon

Demand

Energy and Peak Demand Forecast

	2001	2002	2003	2004	2005	2010
Peak Demand MW (1)	7,981	8,142	8,315	8,505	8,769	10,122
Energy Demand GWh (2)	55,933	57,062	58,269	59,602	61,450	70,932
Growth Rate	-	2.00%	2.10%	2.30%	3.10%	2.90%
Target Reserve Margin (1)	21%	21%	21%	21%	21%	20%

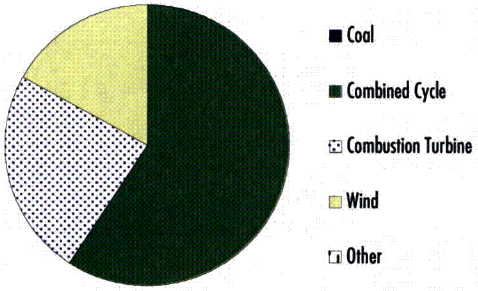
(1) RDI Consulting estimate
(2) RDI Consulting base case forecast.

Power Plant Development

RDI Forecast of New Generating Capacity and Additional Proposed Capacity

	2001	2002	2003	2004	2005	2010
Began Operating	-	-	-	-	-	-
Under Construction	464	531	530	-	-	-
Forecast New	-	50	-	-	500	-
Additional Proposed	2,638					

Fuel Mix of RDI Forecast of New Generating Capacity



Solar Energy Resources

	Solar Resources			
	Premium	Excellent	Good	TOTAL
MW	-	1,791	10,588	12,379
GWh	-	3,529	18,549	22,078
Acres (000)	-	9	53	62

SOURCE: POWERmap and RDI Consulting analysis.
NOTE: Solar resources ≥ 7.0 kWh/m2/day are considered premium, 6.5-7.0 excellent, and 6.0-6.5 good. Estimates for electric generation assume 5 Acres/MW and capacity factors of 25% for premium, 22.5% for excellent, and 20% for good.

State Legislation Regarding Renewable Energy Sources

System Benefit Charge

About $8.6 million per year from 2001 through 2011.

Green Energy Programs

Six utilities offer green pricing programs in Oregon.

Tax/Financial Incentives

Business energy tax credit: a 35% tax credit of up to $100,000 for renewable energy systems installed at business facilities. The renewable system must replace at least 10% of the facility's usage of electricity, oil, or gas. The 35% credit is spread over five years.

Personal income tax credit: This credit is based on the amount of energy that a qualifying renewable energy system saves in a year. Up for renewal in 2001.

Property tax incentive: exempts the added value of a qualifying renewable energy system from property tax assessment.

Loan program: long-term, low-interest loans are available to renewable energy project developers through the Small Scale Energy Loan Program (SELP). The program is funded through bond sales, and has funded projects up to $15 million in size.

Net Metering

Solar, wind, fuel cell and hydro eligible, all customer classes eligible, ≥ 25 kW, minimum 0.5% of utility's peak load enrollment limit, net excess generation purchased at avoided cost or credited to following month.

U.S.-flag Pacific Islands

Demand

No data.

Power Plant Development

No data.

Solar Energy Resources

No data.

Legislation Regarding Renewable Energy Sources

No data.

South Dakota

Demand

Energy and Peak Demand Forecast

	2001	2002	2003	2004	2005	2010
Peak Demand MW (1)	1,818	1,856	1,892	1,925	1,957	2,093
Energy Demand GWh (2)	9,417	9,613	9,798	9,972	10,134	10,840
Growth Rate	-	2.10%	1.90%	1.80%	1.60%	1.40%
Target Reserve Margin (1)	18%	18%	18%	18%	18%	17%

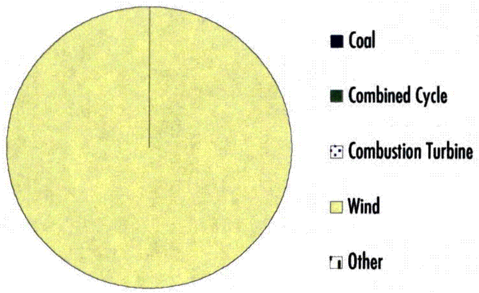
(1) RDI Consulting estimate
(2) RDI Consulting base case forecast.

Power Plant Development

RDI Forecast of New Generating Capacity and Additional Proposed Capacity

	2001	2002	2003	2004	2005	2010
Began Operating	-	-	-	-	-	-
Under Construction	-	-	-	-	-	-
Forecast New	-	3	200	-	-	-
Additional Proposed	3,001					

Fuel Mix of RDI Forecast of New Generating Capacity



Solar Energy Resources

No premium, excellent, or good solar resources.

State Legislation Regarding Renewable Energy Sources

Green Energy Programs

East River Electric Power Cooperative offers a green pricing program to its customers.

Tax/Financial Incentives

Property tax exemption for renewable systems at residential and commercial sites. Full value of system exemption for residential systems and 50% exemption for commercial systems for the first three years after installation, with depreciation thereafter.

Texas

Demand

Energy and Peak Demand Forecast

	2001	2002	2003	2004	2005	2010
Peak Demand MW (1)	65,973	67,407	68,824	70,064	71,625	79,778
Energy Demand GWh (2)	338,285	345,635	352,904	359,261	367,263	409,072
Growth Rate	-	2.20%	2.10%	1.80%	2.20%	2.20%
Target Reserve Margin (1)	16%	16%	16%	16%	16%	15%

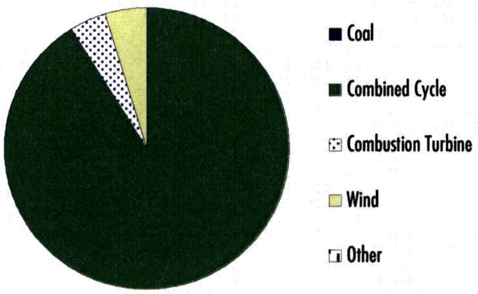
(1) RDI Consulting estimate
(2) RDI Consulting base case forecast.

Power Plant Development

RDI Forecast of New Generating Capacity and Additional Proposed Capacity

	2001	2002	2003	2004	2005	2010
Began Operating	5,471	-	-	-	-	-
Under Construction	4,529	4,703	1,700	-	-	-
Forecast New	-	357	1,049	2,010	2	-
Additional Proposed	19,639					

Fuel Mix of RDI Forecast of New Generating Capacity



Solar Energy Resources

	Solar Resources			
	Premium	Excellent	Good	TOTAL
MW	38,842	50,681	38,264	127,787
GWh	85,064	99,892	67,039	251,995
Acres (000)	194	253	191	638

SOURCE: POWERmap and RDI Consulting analysis.
NOTE: Solar resources ≥ 7.0 kWh/m2/day are considered premium, 6.5-7.0 excellent, and 6.0-6.5 good. Estimates for electric generation assume 5 Acres/MW and capacity factors of 25% for premium, 22.5% for excellent, and 20% for good.

State Legislation Regarding Renewable Energy Sources

Renewable Portfolio Standard

New and existing renewables: 1,280 MW by 2003, 2,880 MW by 2009. 2,000 MW of total must come from new renewable resources.

Green Energy Programs

Texas has a competitive green market in some areas. Also, four utilities offer green pricing programs.

Tax/Financial Incentives

Property tax exemption for the full value of a wind or solar generating system.

Franchise tax exemption: Qualifying renewable energy system costs are deductible from a company's taxable capital. Alternately, the company may deduct 10% of the system cost from its income. A similar exemption is available for manufacturers and installers of wind and photovoltaic systems.

Net Metering

Only renewables eligible, all customer classes eligible, ≥ 50 kW, no overall enrollment limit, net excess generation purchased at avoided cost.

Utah

Demand

Energy and Peak Demand Forecast

	2001	2002	2003	2004	2005	2010
Peak Demand MW (1)	5,242	5,368	5,497	5,580	5,674	6,198
Energy Demand GWh (2)	24,717	25,311	25,918	26,311	26,752	29,223
Growth Rate	-	2.40%	2.40%	1.50%	1.70%	1.80%
Target Reserve Margin (1)	21%	21%	21%	21%	21%	20%

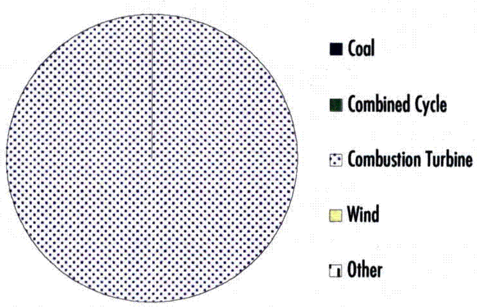
(1) RDI Consulting estimate
(2) RDI Consulting base case forecast.

Power Plant Development

RDI Forecast of New Generating Capacity and Additional Proposed Capacity

	2001	2002	2003	2004	2005	2010
Began Operating	100	-	-	-	-	-
Under Construction	30	-	-	-	-	-
Forecast New	-	-	-	-	-	-
Additional Proposed	6,371					

Fuel Mix of RDI Forecast of New Generating Capacity



Solar Energy Resources

	Solar Resources			
	Premium	Excellent	Good	TOTAL
MW	28,943	24,181	21,215	74,339
GWh	63,384	47,661	37,168	148,213
Acres (000)	145	121	106	372

SOURCE: POWERmap and RDI Consulting analysis.
NOTE: Solar resources ≥ 7.0 kWh/m2/day are considered premium, 6.5-7.0 excellent, and 6.0-6.5 good. Estimates for electric generation assume 5 Acres/MW and capacity factors of 25% for premium, 22.5% for excellent, and 20% for good.

State Legislation Regarding Renewable Energy Sources

Green Energy Programs

Utah Power (PacifiCorp) offers a green pricing program.

Tax/Financial Incentives

Personal income tax credit: credit against personal income taxes for 25% of the cost of a qualifying renewable energy system on a residence, up to $2,000. Credit expired on January 1, 2001.

Washington

Demand

Energy and Peak Demand Forecast

	2001	2002	2003	2004	2005	2010
Peak Demand MW (1)	15,561	15,828	16,121	16,452	16,923	19,179
Energy Demand GWh (2)	109,052	110,922	112,976	115,298	118,598	134,409
Growth Rate	-	1.70%	1.90%	2.10%	2.90%	2.50%
Target Reserve Margin (1)	21%	21%	21%	21%	21%	20%

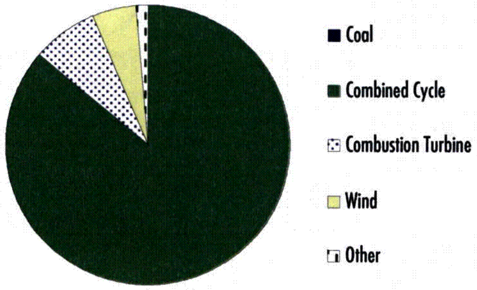
(1) RDI Consulting estimate
(2) RDI Consulting base case forecast.

Power Plant Development

RDI Forecast of New Generating Capacity and Additional Proposed Capacity

	2001	2002	2003	2004	2005	2010
Began Operating	40	-	-	-	-	-
Under Construction	170	496	-	-	-	-
Forecast New	-	204	1,086	974	-	-
Additional Proposed	7,258					

Fuel Mix of RDI Forecast of New Generating Capacity



Solar Energy Resources

No premium, excellent, or good solar resources.

State Legislation Regarding Renewable Energy Sources

Green Energy Programs

Four utilities offer green pricing programs in Washington.

Tax/Financial Incentives

Corporate excise tax exemption for qualifying high technology (including renewable energy) manufacturers.

Net Metering

Solar, wind, fuel cells, and hydropower eligible, all customers classes eligible, ≥ 25 kW, 0.1% of peak demand enrollment limit, net excess generation credited to following month; unused credit is granted to utility at end of annual period.

Wyoming

Demand

Energy and Peak Demand Forecast

	2001	2002	2003	2004	2005	2010
Peak Demand MW (1)	2,274	2,314	2,355	2,380	2,409	2,549
Energy Demand GWh (2)	13,523	13,761	14,004	14,157	14,330	15,157
Growth Rate		1.80%	1.80%	1.10%	1.20%	1.10%
Target Reserve Margin (1)	18%	18%	18%	18%	18%	17%

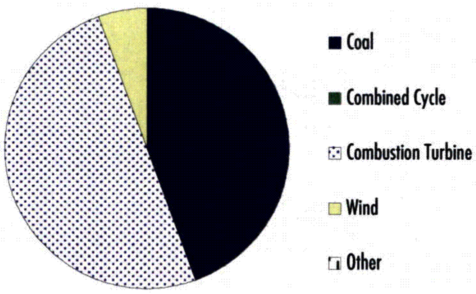
(1) RDI Consulting estimate
(2) RDI Consulting base case forecast.

Power Plant Development

RDI Forecast of New Generating Capacity and Additional Proposed Capacity

	2001	2002	2003	2004	2005	2010
Began Operating	-	-	-	-	-	-
Under Construction	50	-	80	-	-	-
Forecast New	-	50	-	-	-	-
Additional Proposed	1,750					

Fuel Mix of RDI Forecast of New Generating Capacity



Solar Energy Resources

	Solar Resources			
	Premium	Excellent	Good	TOTAL
MW	-	5,283	1,596	6,879
GWh	-	10,412	2,797	13,209
Acres (000)	-	26	8	34

SOURCE: POWERmap and RDI Consulting analysis.
NOTE: Solar resources ≥ 7.0 kWh/m2/day are considered premium, 6.5-7.0 excellent, and 6.0-6.5 good. Estimates for electric generation assume 5 Acres/MW and capacity factors of 25% for premium, 22.5% for excellent, and 20% for good.

State Legislation Regarding Renewable Energy Sources

Green Energy Programs

Pacific Power (PacifiCorp) offers a green pricing program in its Wyoming service territories.

Net Metering

Solar, wind, and hydro eligible, all customer classes eligible, ≥ 25 kW, no overall enrollment limit, annual net excess generation purchased at avoided cost.

Endnotes

[1] Total nameplate capacity in the West is higher than 234,178 MW, but the large amounts of hydro generation in the West need to be derated from the nameplate capacity to account for the annual differences in river flows from year to year and month to month. In addition most of the generation in the Prairies States is designated to meet load in the Midwest outside the WGA region.

Glossary

Abbreviations

BACT—best available control technology

BLM —Bureau of Land Management

Btu —British thermal unit

Cal ISO—California independent system operator

CC —combined cycle

CO_2 —carbon dioxide

CPV—concentrating photovoltaics

CSP—concentrating solar power

EFOR—equivalent forced outage rate

EIA—Energy Information Administration

EPA—Environmental Protection Agency

EPC—engineer, procure, construct

ERCOT—Electric Reliability Council of Texas

FBC—fluidized bed combustion

GDP—U.S. gross domestic product

GIS—geographic information system

GW—gigawatt

GWh—gigawatt-hour

HCE—heat collecting elements

IGCC—integrated gasification combined cycle

IPP—independent power producer

IREMM—Interregional Electric Market Model

IRR—internal rate of return

ISO—independent system operator

kW—kilowatt

kWh—kilowatt-hour

LBNL—Lawrence Berkeley National Laboratory

mmBtu—million Btu

MW—megawatt

MWh—megawatt-hour

NEG—net excess generation

NERC—North American Electric Reliability Council

NO_x —nitrogen oxides

NRC—Nuclear Regulatory Commission

NREL—National Renewable Energy Laboratory

O&M—operations and maintenance

PBMR—Pebble Bed Modular Reactor

PC—pulverized coal

$PM_{2.5}$—particulate matter at 2.5 microns

PPA—power purchase agreement

ppm—parts per million

PRB—Powder River Basin

PTC—production tax credit

PURPA—Public Utility Regulatory Policies Act

PV—photovoltaics

RPS—renewable portfolio standard

SAIC—Systems Applications International Corp.

SBC—system benefit charge

SCE—Southern California Edison

SES—Stirling Energy Systems

Tcf—trillion cubic feet

T&D—transmission and distribution

TW—terrawatt

TWh—terawatt-hour

VLR—voluntary load reduction

VOC—volatile organic compounds

WAPA—Western Area Power Administration

WGA—Western Governors' Association

WRC—Western Regional Council

WRAP—Western Regional Air Partnership

WSCC—Western Systems Coordinating Council

Terms

Average annual demand—total annual energy divided by the 8,760 hours in a year.

Capacity factor—the ratio of total energy generated by a generating unit for a specified period to the maximum possible energy it could have generated if operated at the maximum capacity rating for the same specified period, expressed as a percent.

Combined cycle—an electric generating technology in which electricity is produced from otherwise lost waste heat exiting from one or more gas (combustion) turbines. The exiting heat is routed to a conventional boiler or to a heat recovery steam generator for utilization by a steam turbine in the production of electricity. This process increases the efficiency of the electric generating unit.

Combustion turbine—a plant in which the prime mover is a gas turbine. A gas turbine consists typically of an axial-flow air compressor, one or more combustion chambers, where liquid or gaseous fuel is burned and the hot gases are passed to the turbine and where the hot gases expand to drive the generator and are then used to run the compressor.

Dish Stirling—a parabolic-shaped point focus concentrator in the form of a dish that reflects solar radiation onto a receiver mounted at the focal point. Two axes follow the sun. The collected heat is utilized directly by a heat engine mounted on the receiver that moves with the dish structure.

Equivalent forced outage rate (EFOR)—the hours a generating unit, transmission line, or other facility is removed from service, divided by the sum of the hours it is removed from service, plus the total number of hours the facility was connected to the electricity system expressed as a percent.

Fossil fuel hybridization—using a fossil fuel, generally natural gas, to supplement fuel at a thermal solar power plant.

Heat rate—the amount of additional heat that must be added to a thermal generating unit at a given loading to produce an additional unit of output. It is usually expressed in Btu per kWh (Btu/kWh) of output.

Heat storage—storage of electricity in a form such as molten salt or a mineral oil that later allows recovery of the heat to be used to generate electricity.

Load factor—the ratio of average demand divided by peak demand.

Parabolic trough—parabolic troughs track the sun using one axis to concentrate solar power along a line, usually a tubular receiver, that then heats a heat transfer fluid to power a motor or steam cycle.

Parasitic load—electricity consumed by the power generation technology itself.

Photovoltaic—also known as a solar cell, the heart of a PV cell is a semiconductor junction that absorbs light within a certain frequency range and creates an electric potential.

Peak demand—the maximum load during a specified period of time.

Power tower—a solar technology in which a large array of mirrors tracks the sun to reflect the sunlight onto a central receiver mounted on the top of a tower. The sunlight is converted into heat that in turn powers a steam cycle.

Reserve margin—the amount of unused available capability of an electric power system at peak load for a utility system as a percentage of total capability.

Solar-to-electric capacity ratio—the ratio of solar field thermal capacity to electric capacity.

Solar thermal—these solar power plants use the heat of the sun to raise the temperature of a heat transfer fluid that is used to power motors or turbines to generate electricity.

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A reliable and affordable supply of electricity is essential to protect public health and safety and to sustain a vigorous economy in the West. Renewable energy in the form of wind or solar provides one of the means of meeting the demand for power while minimizing adverse impacts on the environment, increasing fuel diversity, and hedging against fuel price volatility. Concentrating solar power (CSP) is the most efficient and cost-effective way to generate electricity from the sun. Hundreds of megawatts of CSP solar-generating capacity could be brought on-line within a few years and make a meaningful contribution to the energy needs of the West.

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Brighter than a Hundred Suns: Solar Power for the Southwest

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

A. Leitner and B. Owens
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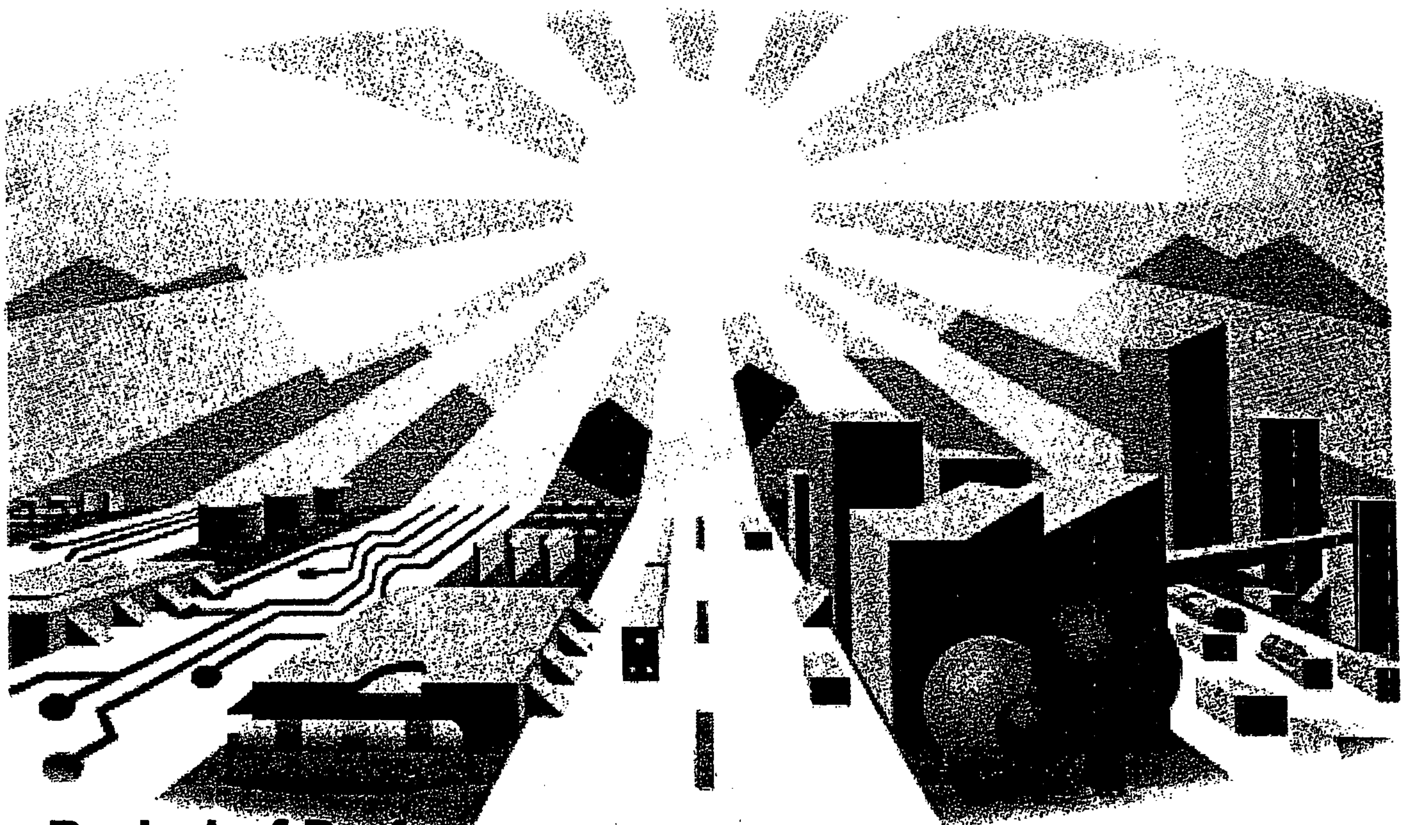

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Executive Summary

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

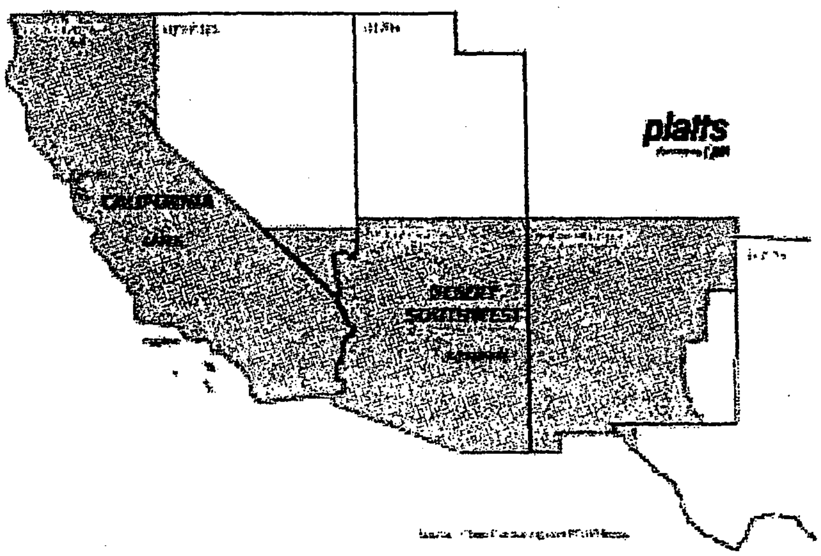
The geographic region that we refer to as the Southwest is an area that greatly overlaps with the major metropolitan areas of the four-state region of California, Nevada, Arizona, and New Mexico and which forms the Southwestern transmission grid[1] (Figure 1). This power market is electrically well interconnected, 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.

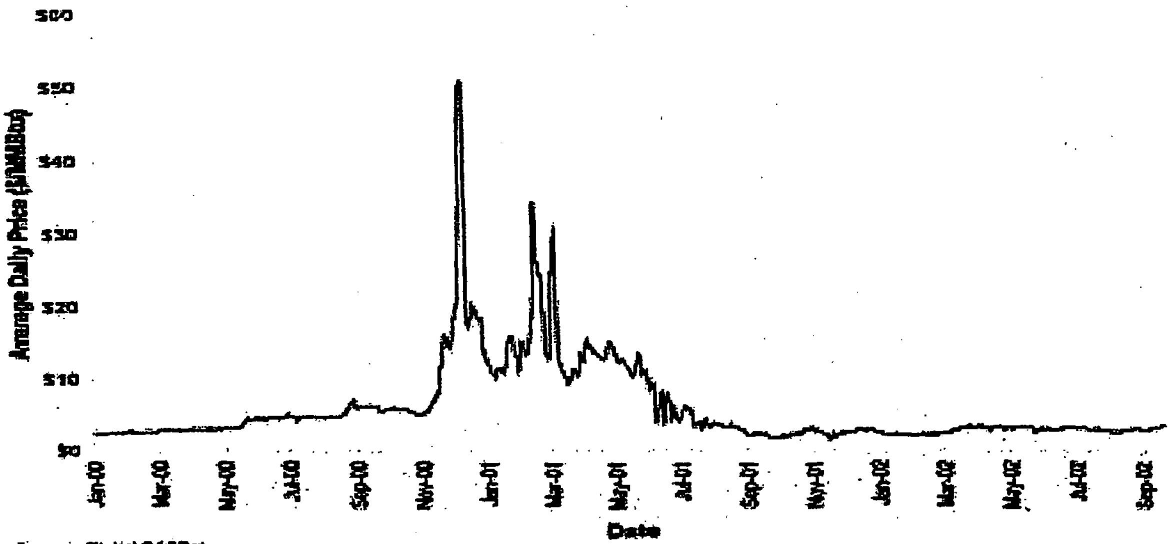
Natural Gas Prices May Be Volatile

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

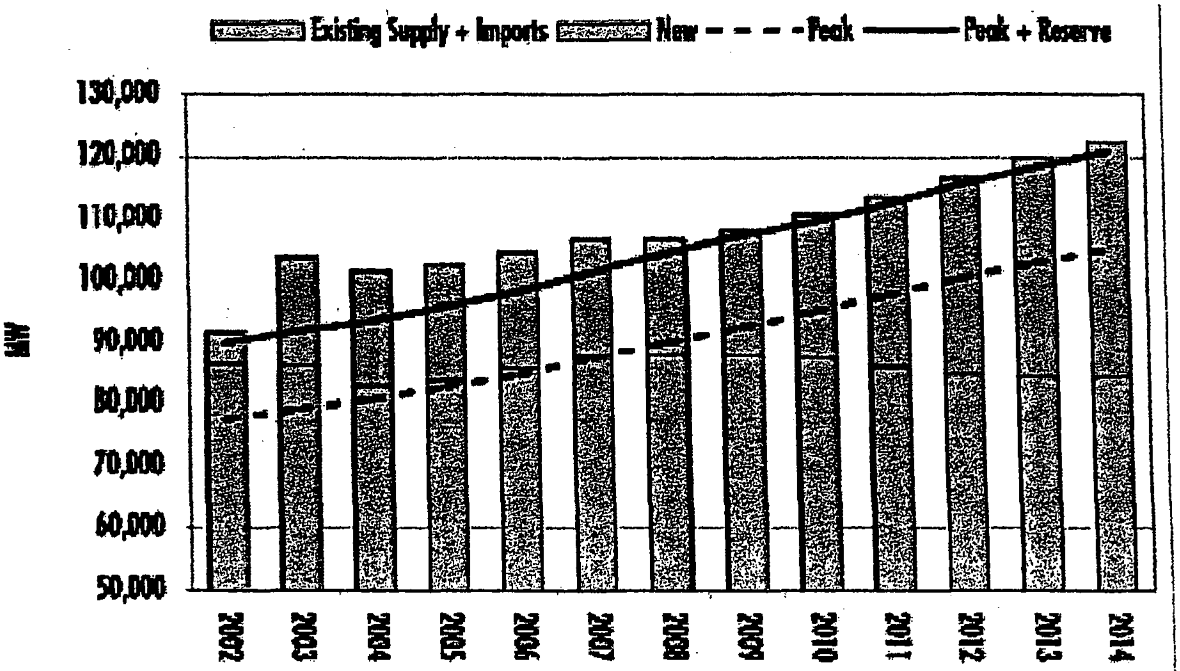
While there are many benefits to using renewable energy, electric power from renewable sources is generally more expensive than electricity from conventional sources of power. This cost gap becomes even more apparent when power markets are overbuilt and power prices are depressed, as is currently the 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.

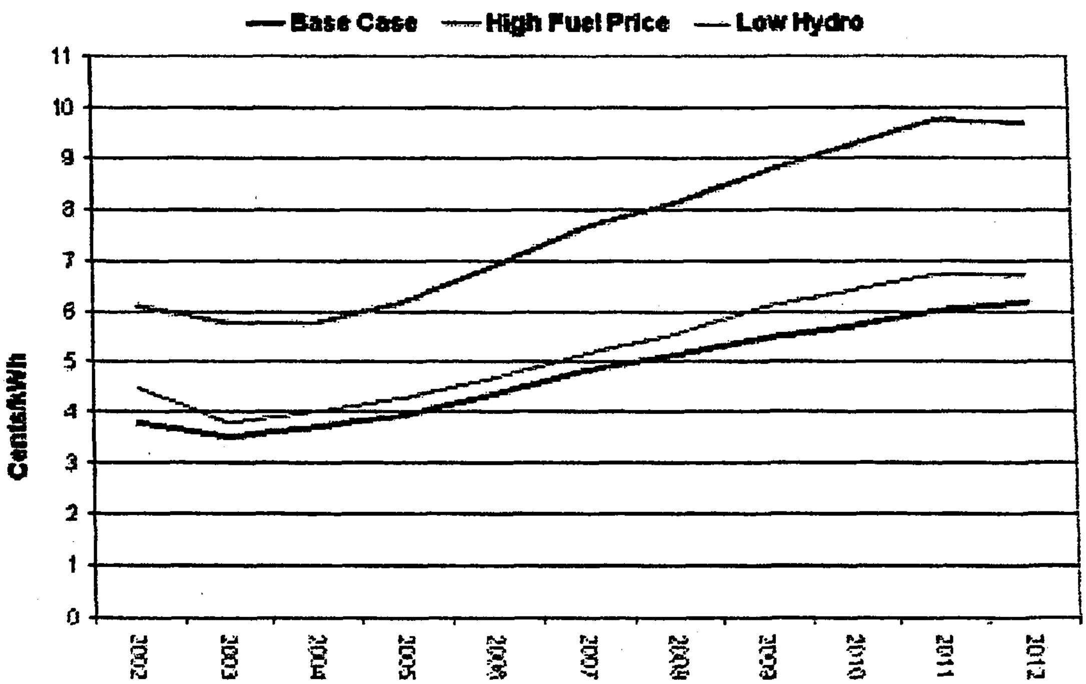
Low Electricity Prices

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 Series 02.
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.

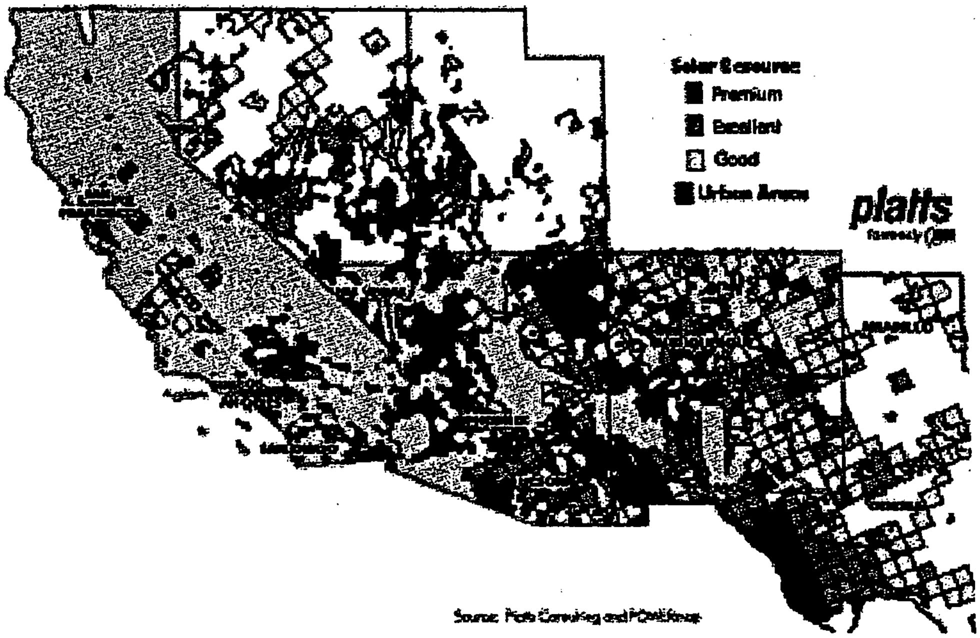
The Solar Generating Potential

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.

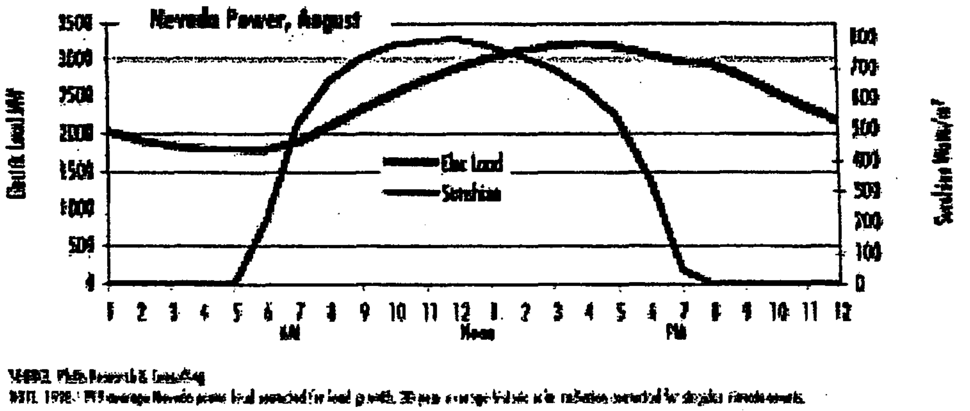
Sunshine and the Demand for Power

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]

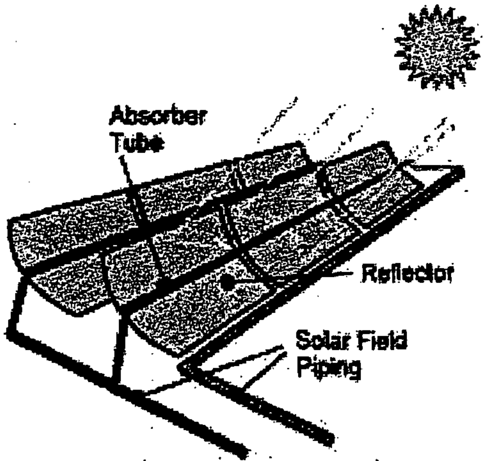
Parabolic Trough

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

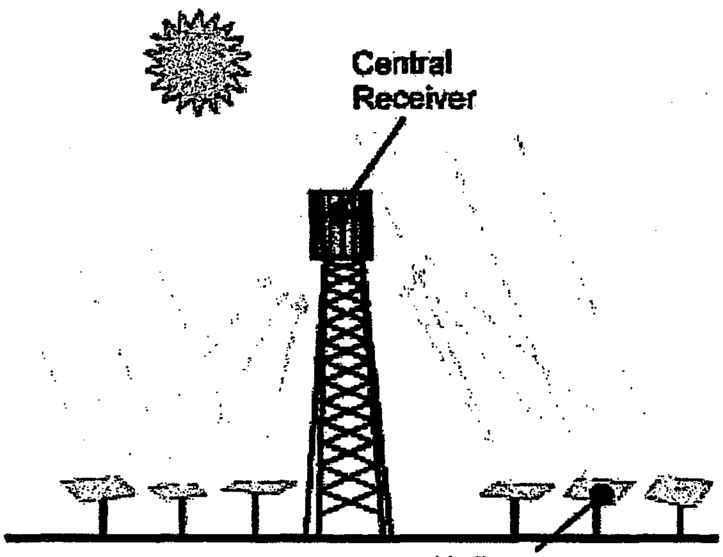


SOURCE: Status Report on Solar Thermal Power Plants, Pilkington Solar International, 1996. Used with permission.

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, Pilkington 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.

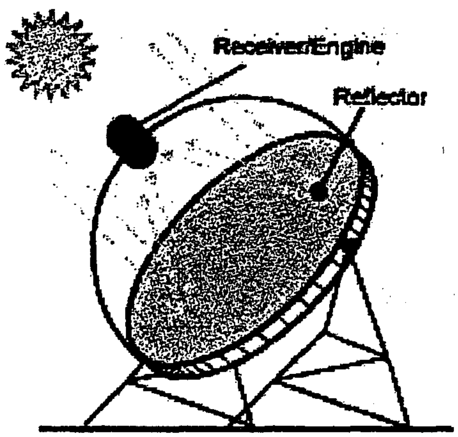
Dish Engine

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, Pilkington 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

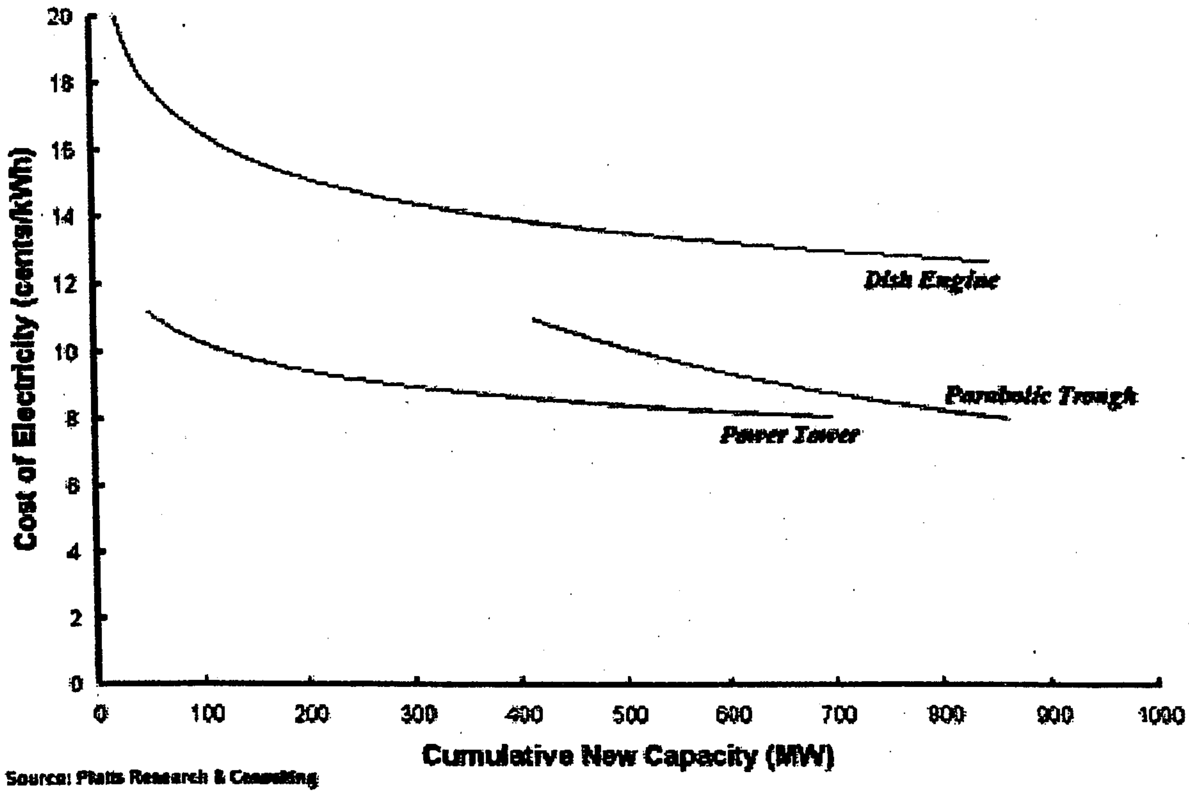


Figure 10. Estimated learning curve for concentrating solar power

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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Future for Offshore Wind Energy in the United States

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FUTURE FOR OFFSHORE WIND ENERGY IN THE UNITED STATES

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Abstract

Until recently, the offshore wind energy potential in the United States was ignored because vast onshore wind resources have the potential to fulfill the electrical energy needs for the entire country. However, the challenge of transmitting the electricity to the large load centers may limit wind grid penetration for land-based turbines. Offshore wind turbines can generate power much closer to higher value coastal load centers. Reduced transmission constraints, steadier and more energetic winds, and recent European success, have made offshore wind energy more attractive for the United States. However, U.S. waters are generally deeper than those on the European coast, and will require new technology. This paper presents an overview of U.S. coastal resources, explores promising deepwater wind technology, and predicts long-term cost-of-energy (COE) trends. COE estimates are based on generic 5-MW wind turbines in a hypothetical 500-MW wind power plant. With sufficient R&D technology improvements and volume production, analysis shows that costs could reach $0.051/kWh for deployment of deepwater offshore wind turbines by 2015, and $0.041/kWh by 2012 for shallow water in class 6 winds. Offshore wind systems can diversify the U.S. electric energy supply and provide a new market for wind energy that is complementary to onshore development.

Background

The worldwide installed capacity of grid-connected wind power has now exceeded 40 GW, corresponding to an investment of approximately $40 billion [1]. The global wind energy installed capacity has increased exponentially over a 25-year period, and in the process the cost of energy (COE) from wind power plants has been reduced by an order of magnitude.

Wind energy installations in the United States have grown during the past decade from about 1800 MW in 1990 to more than 6,000 MW at the end of 2003. Development has mainly focused on Class 6 (high wind sites with an annual average wind speed of 15 mph) in remote areas of the West, and on a few ridgelines in the East. To take advantage of much broader resources closer to load centers, the U.S. Department of Energy (DOE) is conducting the Low Wind Speed Technology Project, which targets development of cost-effective wind turbines for Class 4 sites (13-mph average annual wind speed) that can produce electricity onshore for $0.03/kWh and offshore for $0.05/kWh by the end of 2012. This will open up 20 times more land in the United States for wind energy development, and since many of these sites tend to be closer to urban load centers, the problem of transmission line expansion will be greatly simplified. However, many large East Coast load centers will never be able to benefit from the energetic winds that sweep the Midwest. For those regions, offshore wind is the logical solution.

Offshore wind turbines have a number of advantages over onshore ones. The size of onshore turbines is constrained by capacity limitations of the available transportation and erection equipment. Transportation and erection problems are mitigated offshore where the size and lifting capacities of marine shipping and handling equipment still exceed the installation requirements for multimegawatt wind turbines. Onshore, particularly in Europe or on the East Coast of the United States, the visual appearance of massive turbines in populated areas may be undesirable. At a sufficient distance from the coast, visual intrusion is minimized and wind turbines can be larger, thus increasing the overall installed capacity per unit area. Similarly, less attention needs to be devoted to reduce turbine noise emissions offshore, which adds significant costs to onshore wind turbines. Also, the wind tends to blow faster and more uniformly at sea than on land. A higher, steadier wind means less wear on the turbine components and more electricity generated per square meter of swept rotor area. Onshore turbines are often located in remote areas, where the electricity must be transmitted by relatively long power lines to densely populated regions, but offshore turbines can be located close to high-value urban load centers, simplifying transmission issues.

On the negative side of offshore development, investment costs are higher and accessibility is more difficult, resulting in higher capital and maintenance costs. Also, environmental conditions at sea are more severe: more corrosion from salt water and additional loads from waves and ice. And obviously, offshore construction is more complicated.

Despite the difficulties of offshore development, it holds great promise for expanding wind generation capacity. In Europe and the eastern United states, the amount of space available for offshore wind turbines is many times larger than for onshore ones. A sizable fraction of the future growth in Europe will likely happen offshore [2]. Indeed, the European wind industry has already begun to shift its focus offshore. At the end of 2003, the total installed capacity of offshore wind energy was 529 MW [3].

Offshore Resource

Mesoscale weather prediction models have recently been refined and are used to map the wind resource potential on land. This resource estimation methodology has been validated for onshore applications against actual anemometer data for several U.S. geographic regions. Although these models are new and have not been fully validated in all climatological situations, they are more accurate than the earlier boundary layer prediction methods used in conjunction with measured data. Mesoscale modeling used to determine the onshore wind resource for many of the coastal states has also provided preliminary estimates of wind resources out to 50 nautical miles (nm) offshore for recently mapped regions of the United States [4]. The new resource maps indicate immense areas of Class 5, 6, and some Class 7 winds at distances from 5 nm offshore to 50 nm offshore (see Figure 1). Table 1 gives the annual average wind speed at 50-m height above the ground for the various wind speed classes determined for offshore sites. This table includes the effects of wind shear referenced to a 50-m elevation.

Table 1 – Reference Table for Wind Speed Classes at Offshore Sites (Ranges are given in m/s)

WS m/s 50 M	Class
5.6-6.4	Class 2
6.4-7	Class 3
7-7.5	Class 4
7.5-8	Class 5
8-8.8	Class 6

Although the modeling is not fully validated for offshore conditions, and modeling of the entire U.S. coastline has not been completed, the data provide the best current estimate of the offshore wind potential for the United States. Table 2 provides a summary of the estimated offshore resource by region and water depth. Deep water is defined as greater than 30 m.

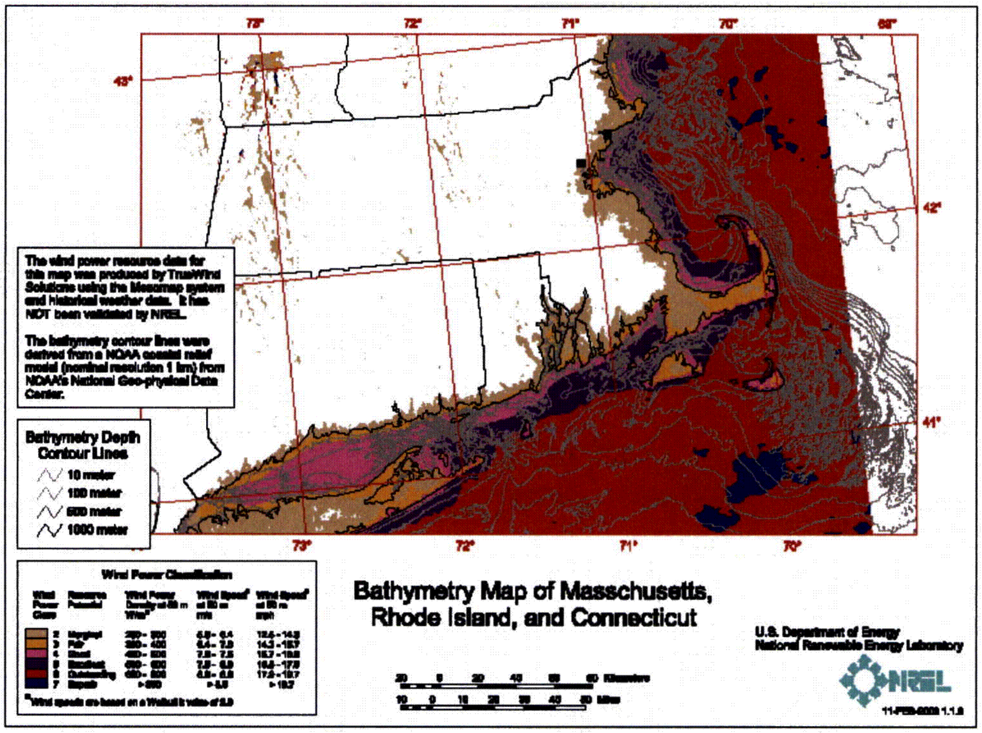

Figure 1 – Offshore Wind Energy Resource for New England

Table 2 – U.S. Offshore Wind Energy Resource by Region for Shallow and Deep Water

Offshore Resource Estimates Resource in MW						
	5-20 Nautical Miles			20 - 50 Nautical Miles		
Region	Shallow <30 m	Deep	% Exclusion	Shallow <30 m	Deep	% Exclusion
New England	9,900	41,600	67%	2,700	166,300	33%
Mid Atlantic States	46,500	8,500	67%	35,500	170,000	33%
California	2,650	57,250	67%	0	238,300	33%
Pacific Northwest	725	34,075	67%	0	93,700	33%
Totals	59,775	141,425	67%	38,200	668,300	33%

In the analysis it was assumed that the offshore zone from the shoreline to 5 nm is 100% excluded to reduce viewshed issues and to avoid the rich ecosystem near shore, where environmental concerns are likely to be of primary concern. Furthermore, for the estimates in the offshore zone from 5 nm to 20 nm, where there are more avian, marine mammal, fish, and view shed concerns, 67% of the potential area is excluded. The reduction of 67% represents the most severe constraint previously used for onshore estimates. The reductions need to be refined by developing overlay maps of the wind resource and the restricted areas to eliminate environmentally sensitive areas, shipping routes, fisheries, various animal habitats, and other restricted areas. For the zone from 20 nm to 50 nm, where there are fewer environmental concerns and wind farms are not visible, the exclusion was reduced to 33%, which again represents onshore experience for situations with moderate restrictions. These are the best available estimates of offshore wind resource, but the results were compiled from computer runs made with different versions of the model as it was improved over time. Some of the earlier runs may have to be verified. In addition, the exclusions need to be established more rigorously. The models also need to be validated from wind speed measurements made at sea. Methods are under development to measure wind speed over the water at elevations where turbines operate.

All told, areas between 5 nm and 50 nm off the coast of the United States contain about 907 GW of wind potential; an amount greater than current installed U.S. electrical capacity. Additional resources in the Gulf Coast and Great Lakes regions have yet to be fully characterized and have not yet been quantified. Much of this resource lies close to major urban load centers with high energy costs, and can be brought to market with less new transmission construction.

Water Depth

Offshore wind development has been limited to waters shallower than 30 m in the North and Baltic Seas. At depths less than 30 m, the established monopile foundation technologies can be deployed without significant R&D effort. For many European countries, such as Denmark, the Netherlands, Germany, and the United Kingdom, these shallow water sites appear to be abundant, and should allow offshore wind installations to proliferate rapidly in the near term. In the United States, approximately 500 MW of shallow water development is underway, but to date, no installations have been permitted. Our estimates indicate that of the 907 GW offshore wind resource outside 5 nm, a little more than 10% or 98 GW is over shallow water (depth of less than 30 m). The remaining 810 GW of offshore wind resource is over water 30 m and deeper. New technologies will need to be developed to take advantage of this vast resource.

Current Offshore Turbine Technology

Present-day offshore wind power plants are located in very shallow water of 5 m to 12 m. Turbine manufacturers have taken conventional land-based turbine designs, upgraded their electrical and corrosion control systems to marinize them, and placed them on concrete bases or steel monopiles to anchor them to the seabed. An offshore substation boosts the collection system voltage, and a buried undersea cable carries the power to shore where another substation provides a further voltage increase for transmission to the loads.

Operating experience has shown that there is much to be learned about deployment of offshore wind turbines in terms of achieving the same reliability and low COE as their land-based counterparts. Increased complexity of offshore construction and operation and maintenance (O&M) has begun to bring in a higher regimen of new technologies derived from the marine and offshore industries. Offshore projects must be larger, in terms of both turbine size and project scale, to pay for the added turbine seabed support structures and cabling costs. In addition, turbine structural dynamics and fatigue loadings are much more complex and difficult to analyze offshore. All these complexities add uncertainty and cost that must be reduced through supporting R&D and demonstrative experience, to validate to investors the turbine designs and prove the viability and profitability of offshore wind. The application-specific experience now being gained on the proving grounds of these early installations will be essential as the wind industry expands offshore technology to other oceans and greater depths.

Future Deepwater Wind Turbine Technology

When offshore wind installations arrive in the United States, more severe ocean conditions and greater water depths will challenge designers. Wind, wave, tide, and current conditions are less well defined in the Atlantic than for the shallower and more sheltered Baltic and North Seas. New wind and wave interaction models will need to be developed. As the shallowest sites are developed, installations will naturally progress into deeper water that will require alternative substructures to support the turbines. These structures may require a more complicated subsea tripod or truss tower arrangement for fixed bottom systems. The 98 GW of shallow water wind energy potential (5 to 50 nm offshore) offers an early market for the wind industry to develop technical capabilities, experience, and sales. At some depth, the development of floating platforms for wind turbines will be necessary to deploy wind turbines in even deeper waters. This progression is illustrated in Figure 2.

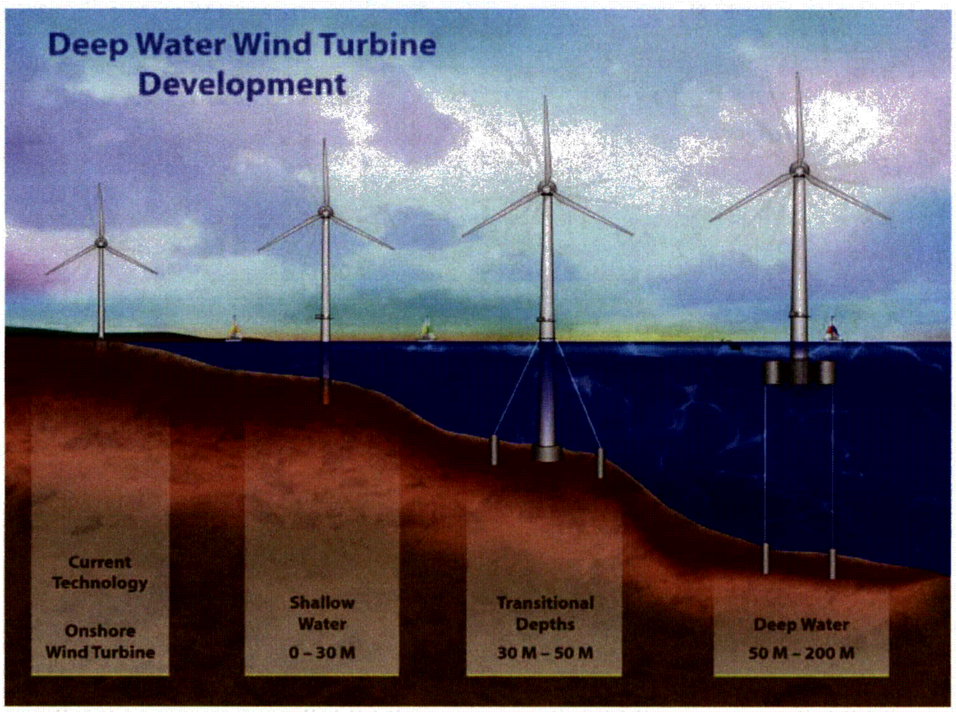

Figure 2 – Progression of Expected Wind Turbine Evolution to Deeper Water

This deepwater technology will require a more extensive development effort because of the added complexity of dynamic floating platforms and other design conditions at the more exposed sites further from shore. Floating structures have already been successfully demonstrated by the marine and offshore oil industries. However, the technical requirements and economics that allowed the deployment of thousands of offshore oilrigs have yet to be demonstrated for floating wind turbine platforms.

Basically, a floating structure will replace conventional steel monopiles or concrete bases. The additional capital costs for the wind turbines will not be significantly higher than current marinized turbines in shallow water. Therefore, the economics of deepwater wind turbines will be determined primarily by the additional cost of the floating structure and power distribution system. The floating structure must provide enough buoyancy to support the weight of the turbine and to restrain pitch, roll, and heave motions caused by the wind and wave forces.

The proven offshore floating platforms used by the oil and gas industry have characteristics similar to those being considered for floating wind turbine platforms, but their differences will allow the necessary cost reductions.

- Oil platforms' safety margins are higher to provide permanent residences for personnel.
- Oil platforms must allow for personnel evacuation. Wind platforms are mostly unmanned.
- Oil platforms must provide additional safety margins and stability for spill prevention. These are not concerns with wind platforms.
- Wind platforms need only be deployed in water as deep as 600 ft. Floating oil tension leg platforms range in depths from 1500 ft to 8000 ft.
- Wind turbine platforms can be submerged to minimize the structure exposed to wave loading. Oil platforms maximize above-water deck area and payload.

The biggest challenge for deepwater wind turbines will be to merge the mature but expensive technologies borne of the oil and gas industry with the experience and low-cost economic drivers fueling the shallow water offshore wind energy industry.

Estimated Cost of Energy

The approach that was taken for this cost study was to assume a nominal 500-MW wind plant composed of 100 machines, each with a 5-MW rating. The cost of the machines, including marinization and industry data, was scaled from WindPACT studies [5,6,7,8]. Two platform concepts were used, as described by Musial and Butterfield [9]. One was a concept developed by NREL; the other under a European study [10]. Costs were scaled over time with learning curves, which are typical of wind industry experience [14,15,18]. These costs were compared to long-term cost expectations for shallow water. This allowed a tangible starting point for cost estimates.

First the cost estimates for shallow water technology, taken from a number of European offshore project papers, are provided in Table 3 [15,16,17,18,19]. These estimates are based on water shallower than 30 m, consistent with the deepest European experience. Foundations are based on steel monopile foundations. Because the turbines in this study are larger than those currently used in Europe (2- to 2.5-MW units), the foundation costs were scaled to match the increased loading for a 5-MW unit. The wind farm is 15-nm offshore, out of site from land. It is assumed to be a Class 6 wind site, which is consistent with the resource estimates described earlier. Cost projections have been made at 6 intervals from 2006 through 2025.

Table 3 – Shallow Water Cost Estimates for Offshore Wind – Class 6 Winds

Shallow Water Wind COE Estimates - Class 6 - <30-m depth, 15-miles from shore ($ in Thousands)						
	Year of Installation					
	2006	2009	2012	2015	2020	2025
Turbine Size	5	5	5	5	5 MW	5 MW
Wind Farm Size	500 MW	500 MW	500 MW	500 MW	500 MW	500 MW
Rotor Diameter	128	128	128	128	128 M	128 M
Hub Height	80	80	80	80	80 M	80 M
Assumed Water Depth	<30-m	<30-m	<30-m	<30-m	<30-m	<30-m
Turbine Cost (total plant)	$338,730	$308,244	$289,750	$258,746	$237,184	$229,278
Monopile foundations (total plant)	$99,200	$87,296	$76,820	$67,602	$61,969	$59,903
Electrical Infrastructure	$159,300	$144,963	$136,265	$128,089	$117,415	$113,501
ICC / Rating ($/kw)	$1,194	$1,081	$1,006	$909	$833	$805
O&M ($/kwh)	$0.0150	$0.0132	$0.0116	$0.0102	$0.0092	$0.0083
LRC (Yr/total plant)	$5,000	$5,000	$5,000	$5,000	$5,000	$5,000
Capacity Factor (%)	0.42	0.44	0.47	0.47	0.47	0.47
Availability (%)	0.85	0.9	0.95	0.95	0.95	0.95
[illegible]	[illegible]	[illegible]	[illegible]	$0.037	[illegible]	[illegible]

All costs are estimated at the point of onshore delivery to the utility bus bar and are assumed to be unsubsidized. Future cost projections account for improvements in technology, increased production volume at current growth rates, learning curve effects, and improvements in operational proficiency.

A range of turbine design options that have been restricted in land-based units may have the potential for reducing offshore costs. Studies have shown that very high tip-speed designs and reduced blade chord can reduce loads throughout a wind turbine structure and reduce costs. These designs have been restricted on land because of increased aero-acoustics noise emissions, but offshore installations would not be subject to the same limitations. Based on the WindPACT rotor study [5], these improvements can reduce the COE by as much as 15%. Design modifications such as downwind operation and the possibility of using high-tip speed flexible designs could further reduce capital cost. Such design improvements are assumed in the model to yield a 5% cost improvement in the year 2015.

Another major factor, which must be included in any projections of offshore development, is the production learning curve. This is often expressed as a reduction in cost for each doubling in installed capacity. It is based on the fact that increased production volume results in improvements in manufacturing, assembly, and installation techniques, which in turn lower the per-unit costs. Higher volumes mean costs from suppliers are also reduced. The International Energy Agency estimates that learning curve cost reductions for wind turbines are 18% per doubling of installed capacity. In a 2002 study Milborrow determined using worldwide production data that wind turbine prices have been declining at a rate of 15.3% [18]. This same study indicates lower rates of 12.4% for an individual supplier. Milborrow forecasts that larger machines and improved production techniques will cause an onshore wind turbine's cost to fall by 15% for every doubling of global installed capacity – and historically doubling has occurred about every 2.88 years. Milborrow contends that if these trends continue, costs will fall about 40% by 2012 [14]. Based on these reports, a learning curve factor of 12% cost reduction for each doubling in production appears reasonable. Further, since installed wind energy capacity has doubled every 3 years since 1990, offshore installation rates would presumably follow a similar trend for the early stages of development. However, if the existing world capacity of 40-GW doubles every three years over the next two decades, installed wind capacity will exceed the demand. To address this, two learning curves were used for the analysis; one to cover the turbine and electrical infrastructure, and one to cover the foundations and O&M costs. Turbines and electrical infrastructure are more mature and costs will be an extension of the learning curve already in progress for land-based wind systems. The less mature offshore foundation and O&M technologies will experience more rapid declines and start from a smaller base of machines. For the near term, both trends were assumed to use the 12% learning curve factor. The rate of doubling for turbines and infrastructure was assumed to ramp quickly to 6 years, while the doubling rate for foundations and O&M stayed at 3 years. O&M costs for offshore turbines is likely to remain significantly higher than for onshore systems due to the added complexities of working at sea. A baseline variable O&M rate of $.015/kWh was used for the shallow water turbines. This is up to three times higher than typical onshore rates [20].

Deepwater Cost of Energy – Results

For deepwater systems, costs have been calculated for a 600-ft water depth, although studies show that significant resources can be developed in much shallower water with correspondingly lower costs. The deepwater turbine and tower are assumed to be the same for shallow and deep water, with an initial marinization cost premium of 11% higher than the land-based value. The major differences between deep and shallow water were due to the higher cost of floating platforms and the additional electrical cabling in deeper water. In addition, baseline O&M costs for deepwater turbines were assumed to be higher ($.018/kWh) than shallow water turbines due to the added platform hardware and nominally greater distances to shore. Most other assumptions remain the same.

Electrical infrastructure costs were based on an unpublished NREL report [21]. These costs were higher for the deep-water cases because of greater distances offshore and riser designs necessary to reach from the bottom to the floating platforms. In both cases 34.5-kV service was used for distribution among the wind plant and 138 kV was used for interconnection from the plant to shore. Redundancy was incorporated in the distribution system to allow for full power transmission with a single fault within the system.

Musial et al. [9] estimated platform costs for two 5-MW floating platform configurations, one designed by NREL (Figure 3) and a Dutch Tri-Floater concept (Figure 4) designed under a European Union-funded study on floating platforms [10]. NREL's design was less detailed than the Dutch Tri-Floater, but NREL used the Dutch study to attain similar levels of conservatism and estimates for miscellaneous hardware. These assumptions are described by Musial et al. [9].

This study focuses on the NREL TLP concept. Musial et al. estimate that low volume TLP production costs would be $2.88 to $6.50 million. The midrange cost of $4.69 million was chosen as the mean baseline deepwater platform cost, with the upper and lower costs estimates taken as conservative and optimistic values to define a range of reasonable baseline platform costs. These costs are shown in Table 4.

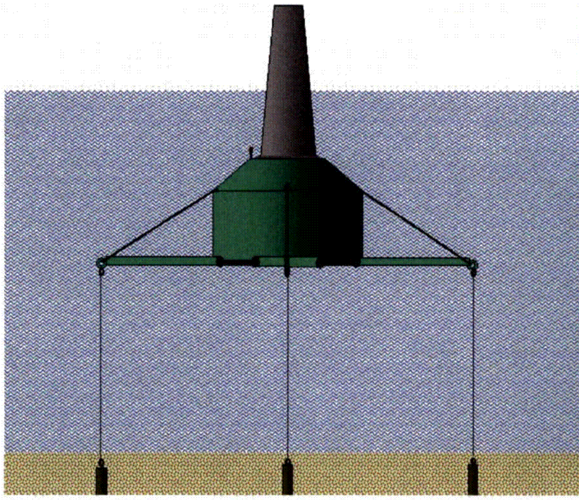

Figure 3 – NREL TLP Concept

Figure 4 – Dutch Trifloater Concept

With the assumptions stated earlier, and if research, design, and production begin in the near future, results shown in Table 4 indicate that class 6 baseline deepwater COE estimates for wind energy will range from $0.095/kWh to $0.071/kWh. The mean baseline for class 6 winds is $0.083/kWh. By 2020, mean costs drop below $0.045 for the NREL TLP. These costs put deepwater offshore wind energy solidly in competition with onshore electrical energy generating sources, but they are not possible without research to initiate the technology.

Table 4 – NREL TLP Cost of Energy Projections – Class 6 Winds

NREL Deep Water Wind COE Estimates - Class 6 ($ in Thousands)						
	Year of Installation					
	2006	2009	2012	2015	2020	2025
Turbine Size	5	5	5	5	5 MW	5 MW
Wind Farm Size	500 MW	500 MW	500 MW	500 MW	500 MW	500 MW
Rotor Diameter	128	128	128	128	128 M	128 M
Hub Height	80	80	80	80	80 M	80 M
Assumed Water Depth	600 ft	600 ft	600 ft	600 ft	600 ft	600 ft
Turbine Cost (total plant)	$338,730	$308,244	$289,750	$245,128	$224,701	$217,211
Mean Floating Platform (total plant)	$469,000	$384,580	$329,200	$289,696	$231,757	$185,406
Electrical Infrastructure	$194,200	$176,722	$166,119	$156,152	$143,139	$138,368
ICC / Rating ($/kw)	$2,004	$1,739	$1,570	$1,382	$1,199	$1,082
O&M ($/kwh)	$0.0180	$0.0148	$0.0126	$0.0111	$0.0102	$0.0099
LRC (Yr/total plant)	$5,000	$5,000	$5,000	$5,000	$5,000	$5,000
Capacity Factor (%)	0.42	0.44	0.47	0.47	0.47	0.47
Availability (%)	0.85	0.90	0.95	0.95	0.95	0.95
[redacted]	[redacted]	[redacted]	[redacted]	$0.051	[redacted]	[redacted]
COE - Conservative Estimate $/kWh	$0.095	$0.077	$0.066	$0.058	$0.050	$0.046
COE - Optimistic Estimate $/kWh	$0.071	$0.059	$0.051	$0.045	$0.040	$0.037

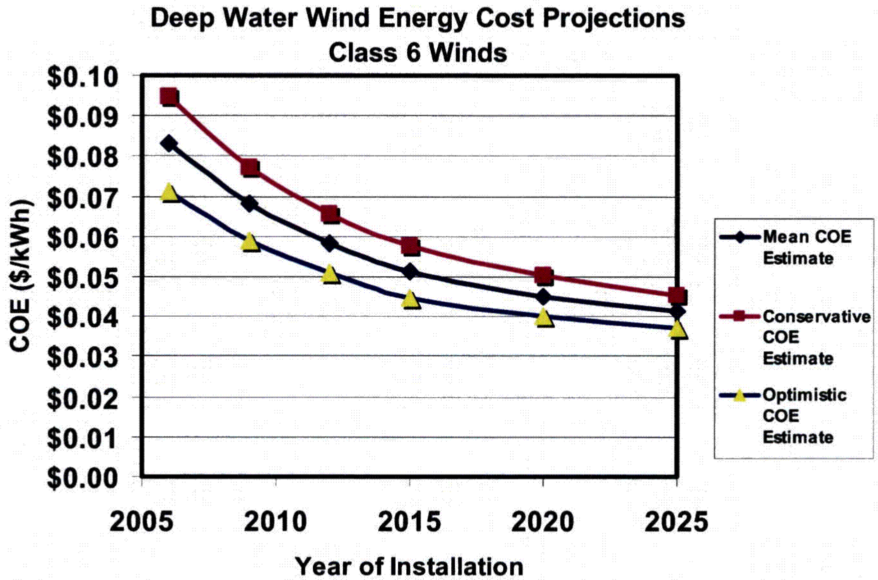

Figure 5 – COE Projections for NREL TLP Concept in Class 6 Winds

Deepwater Research and Development Strategy

In the arena of floating wind energy platforms, a pathway composed of a comprehensive R&D program, commercial demonstration, and subsequent mass production can probably reduce costs by 50% or more. Significant research is needed in the areas of anchoring, platform/turbine interactions, and understanding wind and wave loading on structures. Use of cheaper materials, such as concrete with composites, may further reduce the cost of buoyancy tanks and pontoons. Wind turbine design optimization for offshore conditions is also expected to reduce total operating costs in multiple ways. Lighter turbines and support structures will reduce system weight and hence the buoyancy requirements for floating platforms. To reduce system weight, wind turbines are expected to take advantage of higher tip speeds, advanced lightweight materials for blades, smaller and lighter weight generators, and perhaps new rotor configurations with two blades instead of three. Furthermore, the system cost can be reduced through improved rotor designs that increase energy capture. The need for greater machine reliability in these remote locations may drive turbine designs toward simpler, lighter weight drive trains, such as direct-drive generators without mechanical gearboxes. But to achieve these ends, design and implementation must use a total systems approach that assesses each design step according to its impact on the total system's weight and cost.

To successfully achieve cost-competitive deepwater technologies, key collaborations must take place between three critical groups:

1) The oil and gas/marine industry
2) The present shallow water offshore wind energy industry
3) A targeted deepwater wind energy research community

The first group possesses generations of experience in building and operating large structures and vessels at sea. Oil and gas companies have deployed thousands of offshore oil platforms.

Demonstrably, the technology to make floating structures survive at sea under extreme conditions is understood. But these industries work under a different set of market constraints that involve a higher degree of human and environmental safety. The competitive wind energy markets need to redefine these technologies in terms of their own risk and reliability criteria specified by the wind energy experts.

Thus, the second group will develop and transfer essential experience in offshore wind turbine operation that is directly applicable to deep water. These issues include O&M experience, safety and reliability specifications, turbine marinization, wind and wave interactions, array effects, permitting and ecological issues, and standardization models. Without question, many of these areas will have to be taken to a new level of sophistication for deepwater deployments, but the technical foundations will be formed through this shallow water experience. Without wind energy experience in shallow water, the risk to deepwater wind projects may be too great, and oil and gas cost drivers may result in noncompetitive pricing.

The experience gained from the petroleum and the offshore wind industries together is essential—but not sufficient—to achieve cost-competitive deepwater wind energy in the next decade. Most countries that are actively engaged in the development of offshore wind, such as Denmark, Netherlands, and Germany, may be satisfied with shallow water technology for the near term, because the North Sea has an abundance of shallow water wind sites. To activate the deepwater wind energy resource in the United States, a concerted R&D effort must be commissioned to address the issues specific to this technology, including dynamic modeling of the turbine and floating platform, floating platform optimization, low-cost mooring and anchor development, floating wind turbine COE optimization strategies, deepwater erection and decommissioning, standards governing floating wind turbines, deepwater resource assessment, and other specific deepwater concerns. These relationships are shown in Figure 6.

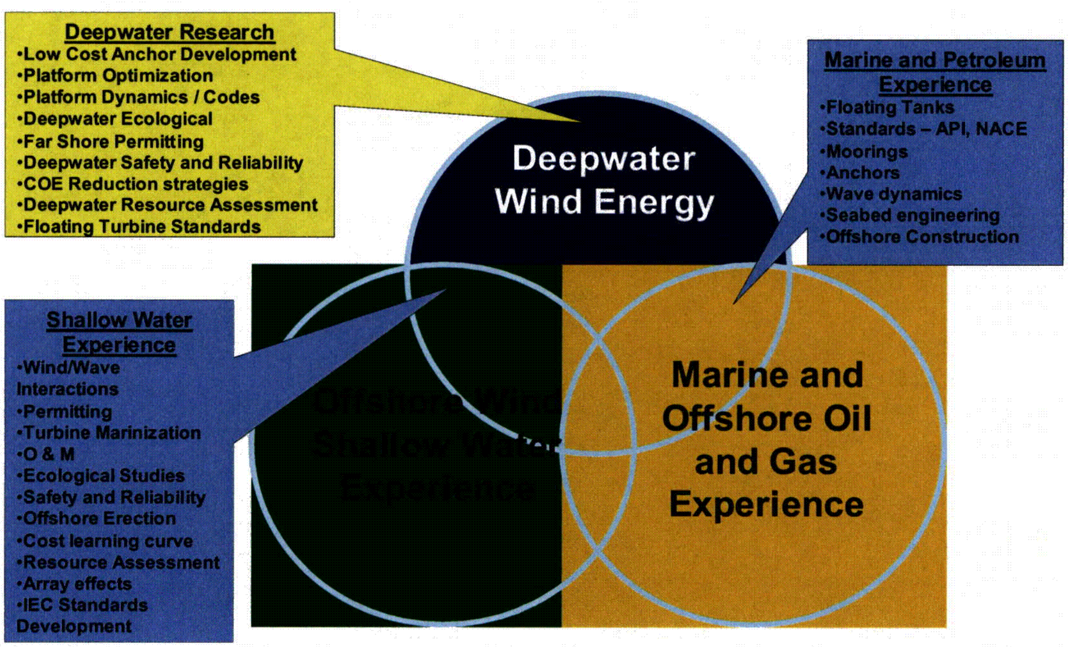

Figure 6 – Deepwater Research and Development Strategy

Summary

Offshore wind energy development is an unexplored U.S. domestic power resource that is estimated to be economically developable using megawatt-scale wind turbines in large offshore wind farms within a decade. Taking into account significant exclusions for shipping lanes, environmental easements, and viewshed concerns, areas off the coast of the United States, within a 50-nm limit, contain resources of almost 907 GW; an amount greater than current installed U.S. electrical capacity. When additional resources in the Gulf Coast and Great Lakes regions are determined, this number will grow. Much of the offshore wind resource lies close to major urban load centers with high-energy costs, and can be brought to market with minimal new transmission construction.

With 98 GW of this resource located in waters shallower than 30 m, a near-term market is available for the industry to gain experience and mature the technology. This analysis shows that deepwater offshore wind development is practical with a proactive R&D agenda involving close collaborations between the oil and gas industry, and the offshore wind community. Demonstrations that prove the viability and cost effectiveness of this new technology for large-scale offshore applications will be critical to securing financing and insurance in the earlier stages. As the first projects are deployed over the next few years, the permitting process will become better defined and more streamlined to ensure that offshore wind projects are deployed with care and consideration to all ocean stakeholders without adding undue risk.

New wind technology can be developed that could make floating wind turbines economical, at energy costs as low as $0.051/kWh in Class 6 winds by 2015, given sufficient volume production. Though current technologies can be deployed today in shallow water, improvements in wind turbine design and installation methods are essential to minimize the COE and make offshore wind electricity competitive with conventional generation technology.

Acknowledgments

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14. **ABSTRACT** *(Maximum 200 Words)*
Until recently, the offshore wind energy potential in the United States was ignored because vast onshore wind resources have the potential to fulfill the electrical energy needs for the entire country. However, the challenge of transmitting the electricity to the large load centers may limit wind grid penetration for land-based turbines. Offshore wind turbines can generate power much closer to higher value coastal load centers. Reduced transmission constraints, steadier and more energetic winds, and recent European success, have made offshore wind energy more attractive for the United States. However, U.S. waters are generally deeper than those on the European coast, and will require new technology. This paper presents an overview of U.S. coastal resources, explores promising deepwater wind technology, and predicts long-term cost-of-energy (COE) trends. COE estimates are based on generic 5-MW wind turbines in a hypothetical 500-MW wind power plant. Technology improvements and volume production are expected to lower costs to meet the U.S. Department of Energy target range of $0.06/kWh for deployment of deepwater offshore wind turbines by 2015, and $0.05/kWh by 2012 for shallow water. Offshore wind systems can diversify the U.S. electric energy supply and provide a new market for wind energy that is complementary to onshore development.

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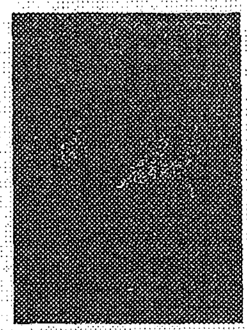


Wind Energy Resource Atlas of the United States

Table of Contents

Chapter 2 The National Wind Resource

Chapter 3: Regional Summaries

This chapter presents a summary of the United States wind energy resource on a region-by-region basis. The regions are identified on the map shown in Map 3-1; the numbers on the map indicate the order in which the regional information is presented. For each region, major wind resource areas are described that have been estimated to have suitable wind energy potential for wind turbine applications (class 3 or greater annual average wind power).

The regional summaries are accompanied by regional and state maps. The regional maps display major cities, mountain ranges, and geographic features. The state maps show the geographic distribution of annual average wind power and depict prominent wind energy areas and other geographic features. Chapter 1 gives information on interpreting the wind power maps.

A latitude-longitude grid is superimposed on each state map to facilitate locating specific places on the maps. The grid cells are 1/4° latitude by 1/3° longitude for states in the contiguous United States. This corresponds to grid cells that are approximately 25 by 25 km (15 by 15 mi). For Alaska, grid cells are 1/2° latitude by 1° longitude. For Hawaii, Puerto Rico, and the U.S. Virgin Islands, grid cells are 1/8° latitude by 1/8° longitude.

Some of the larger states (i.e., Alaska, California, and Texas) are subdivided for the purpose of presenting the analyses more clearly. Some of the smaller states (i.e., Massachusetts, Connecticut, and Rhode Island; Vermont and New Hampshire; and Maryland and Delaware) are combined as a set of states on one map.

Atlantic Coastal Areas

The annual average wind power for exposed coastal areas of Delaware, Maryland, Virginia, and North Carolina is estimated to be class 3. South of Cape Lookout, North Carolina, wind power decreases to class 2. There is a steep gradient in the estimated wind power within several kilometers of the coastline because of the abrupt change in surface roughness between the land and open water, even though relatively flat, smooth plains extend far inland along the entire length of the East Central region's coastline. While most of the coastline is oriented such that the prevailing wind direction (from the southwest across most of the region) is offshore, there is considerable variation in the orientation from one area to another.

Winter and spring are the seasons of maximum power for the coastal areas of the region, with class 4 wind power from Cape Hatteras northward. In summer, wind power decreases to a minimum of class 1 and 2 along the coastal areas.

Chesapeake and Delaware Bays

Much of the Chesapeake and Delaware bays are estimated to have class 3 wind power. Areas of highest wind resource are expected where there is a large fetch over open water for the prevailing strong winds, which come from the west through north directions. The complexity of the Chesapeake Bay shoreline, with its many islands and inlets, suggests a high variability of wind power in this area.

Exposed Mountain Ridges and Summits

Class 3 or higher wind power is estimated for exposed mountain summits and ridge crests in western North Carolina, eastern Tennessee, eastern West Virginia, western Maryland, and portions of Virginia. Average wind speeds may vary considerably from one ridge-crest site to another and are primarily influenced by the height and slope of the ridge, orientation to the prevailing winds, and the proximity and relative height of other mountains and ridges. Most of the ridges in Virginia, West Virginia, and western Maryland are oriented perpendicular to the prevailing westerly winds. As a result, the higher ridges may experience wind power that is considerably enhanced by a venturi speed-up effect - wind flows are compressed as they are forced over the ridges. Winter is the season of maximum wind power over the mountain summits and ridge crests of the East Central region because mean upper-air wind speeds are highest during this season. In contrast to valley and plain locations, the daily maximum wind speed for mountain summits and ridge crests generally occurs at night; this situation occurs because the frictional boundary layer is more shallow as a result of the absence of solar heating and associated vertical mixing.

The Southeast Region

The Southeast region consists of Alabama, Florida, Georgia, Mississippi, and South Carolina. The region's total population in 1980 of 24,746,000 represents approximately one-tenth of the nation's population. Nearly three-quarters of the people in the Southeast live on the East Coast from South Carolina to Florida. The major cities, rivers, mountain ranges, and geographical features of the Southeast are shown in Map 3-34.

With the exception of the north-central portion of the Southeast region and a few scattered areas, the topography is relatively low and flat. Roughly 41% of the topography in the Southeast is irregular plains, 41% is flat and smooth plains, and only 18% is tableland, hills, and low mountains, which lie in the north-central part of the Southeast. The northern half of Alabama, the northern part of Georgia, and the far northwestern corner of South Carolina have the most complex terrain of the region, with tablelands, hills, and low mountains.

There is little wind energy potential in the Southeast region for existing wind turbine applications (Zabransky et al. 1981). Even along coastal areas, existing data from exposed sites indicate at best only class 2 at 50 m (164 ft) above ground. The only places in the Southeast region estimated to have class 3 or higher annual average wind resource are the exposed ridge crests and mountain summits confined to northeastern Georgia and extreme northwestern South Carolina, as described below. Maps of annual average wind power are presented in Maps 3-35 through 3-39 for Alabama, Florida, Georgia, Mississippi, and South Carolina.

Mountains of South Carolina and Georgia

The exposed ridge crests and mountaintops of the southern Appalachians in extreme northwestern South Carolina and northeastern Georgia have annual average wind power densities of class 3 to class 5. This area is highly confined and represents an extremely small percentage of exposed land in the Southeast region.

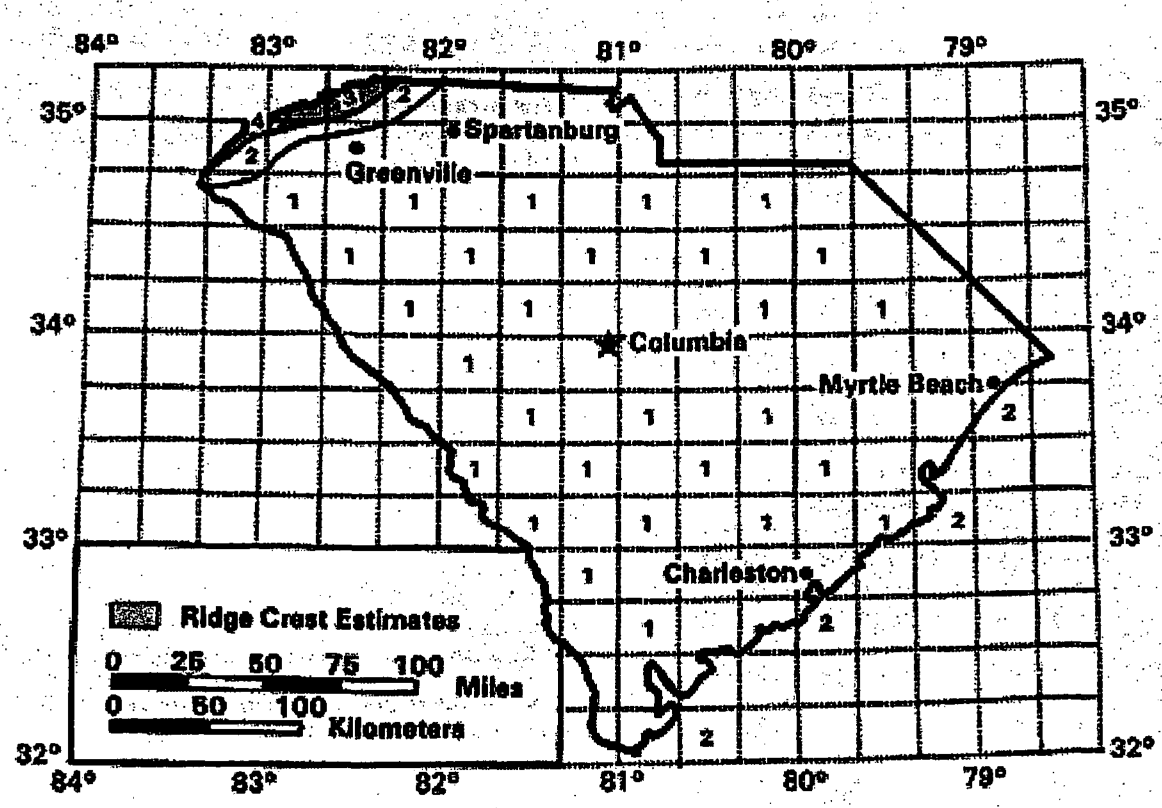
The South Central Region

The South Central region, consisting of Arkansas, Kansas, Louisiana, Missouri, Oklahoma, and Texas, is about the same size as Alaska and equal to one-fifth the area of the 48 contiguous states. Texas has 45% of the area and slightly more than 45% of the region's population. Over 40% of the people in the South Central region live in the six metropolitan areas that have over one million inhabitants each. In order of decreasing population, these are Dallas-Fort Worth, Texas; Houston, Texas; St. Louis, Missouri; Kansas City, Kansas; Kansas City, Missouri; New Orleans, Louisiana; and San Antonio, Texas. The major cities, rivers, mountains, and national parks of the South Central region are shown in Map 3-40.

The South Central region extends from the interior plains to the coastal plains with a few interior highlands in the east-central part. The Mississippi River makes up most of the eastern boundary of the region as it flows south to the Gulf of Mexico. The only major portions of the region that are mountainous are the western tip of Texas, and parts of Arkansas, Missouri, and extreme eastern Oklahoma.

A substantial portion of the South Central region has class 3 or higher annual average wind power. The most extensive area of wind resource includes most of Kansas, Oklahoma, and northwestern Texas, where a large fraction of the land area is well exposed to power-producing winds. Other areas of significant wind resource in the region include the Texas coast and exposed hilltops, ridge crests, and mountain summits in parts of southern Missouri, western Arkansas, eastern Oklahoma, and extreme western Texas.

Since the completion of the regional wind energy atlas (Edwards et al. 1981), many new sites have been instrumented to measure the wind resource throughout much of Kansas, western Oklahoma, and northwestern Texas. Wind measurements at levels up to 46 and 50 m (150 to 164 ft) above ground have been taken at 16 new sites in this area. Four of these were sites instrumented for the DOE candidate site program. These were located near Amarillo, Texas; Meade and Russell, Kansas;



3-39 South Carolina annual average wind power

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ENERGY EFFICIENCY AND RENEWABLE ENERGY CLEARINGHOUSE

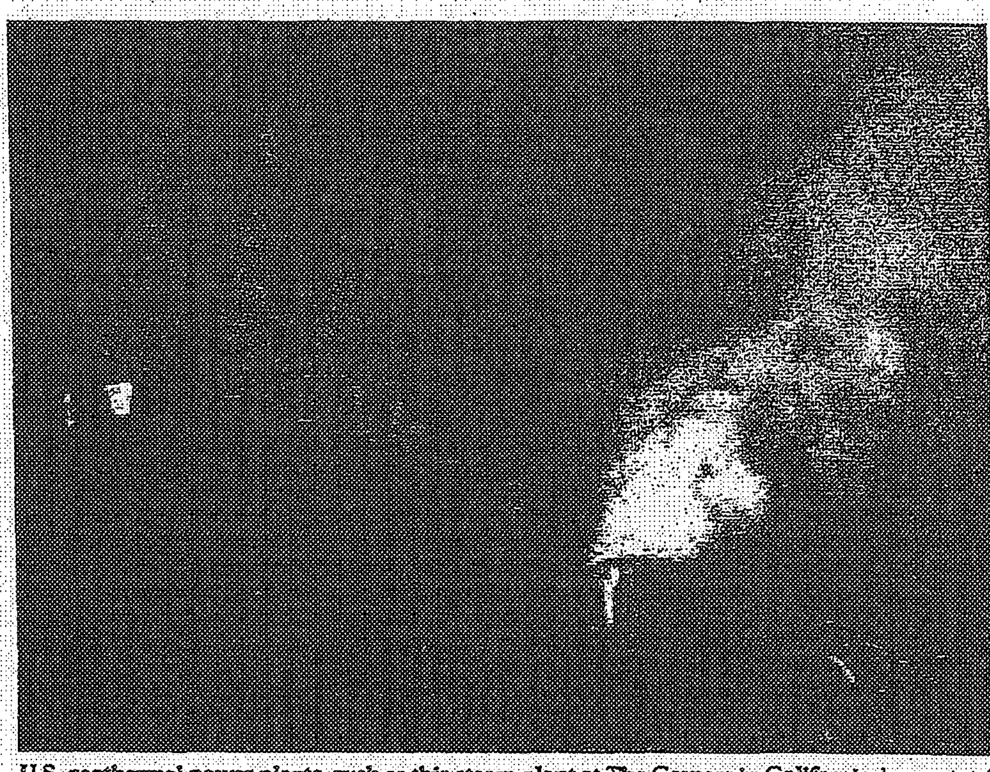
SCEG-337

Geothermal Energy... Power from the Depths

The Earth's crust is a bountiful source of energy—and fossil fuels are only part of the story. Heat or thermal energy is by far the more abundant resource. To put it in perspective, the thermal energy in the uppermost six miles of the Earth's crust amounts to 50,000 times the energy of all oil and gas resources in the world!

The word "geothermal" literally means "Earth" plus "heat." The geothermal resource is the world's largest energy resource and has been used by people for centuries. In addition, it is environmentally friendly. It is a renewable resource and can be used in ways that respect rather than upset our planet's delicate environmental balance.

Geothermal power plants operating around the world are proof that the Earth's thermal energy is readily converted to electricity in geologically active areas. Many communities, commercial enterprises, universities, and public facilities in the western United States are heated directly with the water from underground reservoirs. For the homeowner or building owner anywhere in the United States, the emergence of geothermal heat pumps brings the benefits of geothermal energy to everyone's doorstep.



Dave Parsons / NREL / pix 01045

U.S. geothermal power plants, such as this steam plant at The Geysers in California, have a total generating capacity of 2700 megawatts, enough to provide electricity for 3.7 million people.

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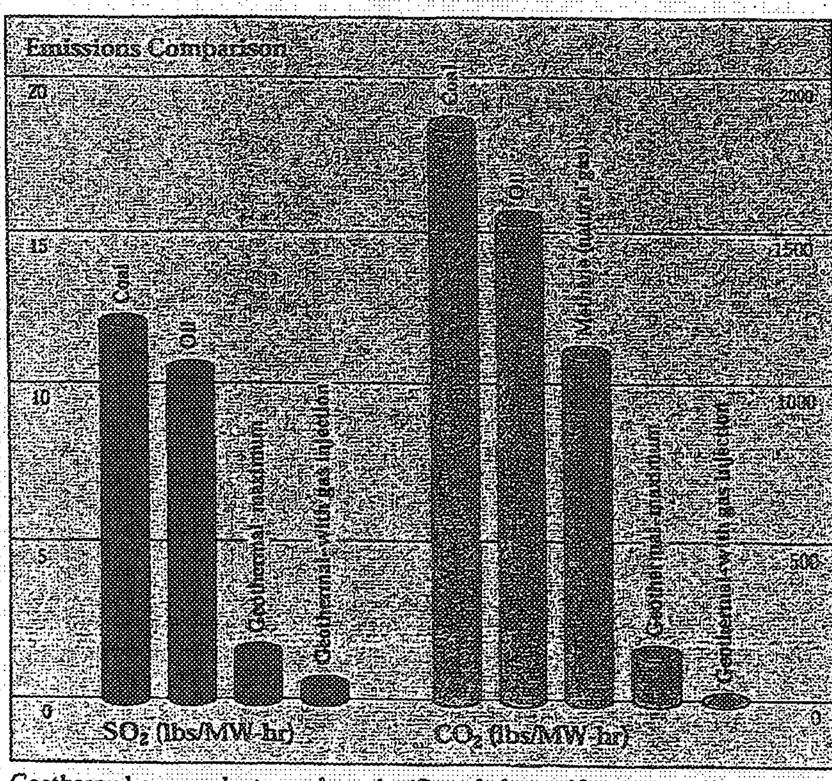
The Basics

There's a relatively simple concept underlying all the ways geothermal energy is used: The flow of thermal energy is available from beneath the surface of the Earth and especially from subterranean reservoirs of hot water. Over the years, technologies have evolved that allow us to take advantage of this heat.

In fact, electric power plants driven by geothermal energy provide over 44 billion kilowatt hours of electricity worldwide per year, and world capacity is growing at approximately 9% per year. To produce electric power from geothermal resources, underground reservoirs of steam or hot water are tapped by wells and the steam rotates turbines that generate electricity. Typically, water is then returned to the ground to recharge the reservoir and complete the renewable energy cycle.

Underground reservoirs are also tapped for "direct-use" applications. In these instances, hot water is channeled to greenhouses, spas, fish farms, and homes to fill space heating and hot water needs.



Energy & Geoscience Institute, *Geothermal Energy*, February 1998.

Geothermal power plants produce significantly less sulfur dioxide (SO_2) and carbon dioxide (CO_2) than do conventional fossil-fueled power plants.

Geothermal energy use extends beyond underground reservoirs. The soil and near-surface rocks, from 5 to 50 feet deep, have a nearly constant temperature from geothermal heating. As a homeowner or business owner, you can use the Earth as a heat source or heat sink with geothermal heat pumps. According to the U.S. Environmental Protection Agency (EPA), geothermal heat pumps are one of the nation's most efficient—and therefore least polluting—heating, cooling, and water-heating systems available. In winter, these systems draw on "earth heat" to warm the house, and in summer they transfer heat from the house to the earth, which ranges in temperature from 50° to 70°F (10° to 21°C) depending on latitude.

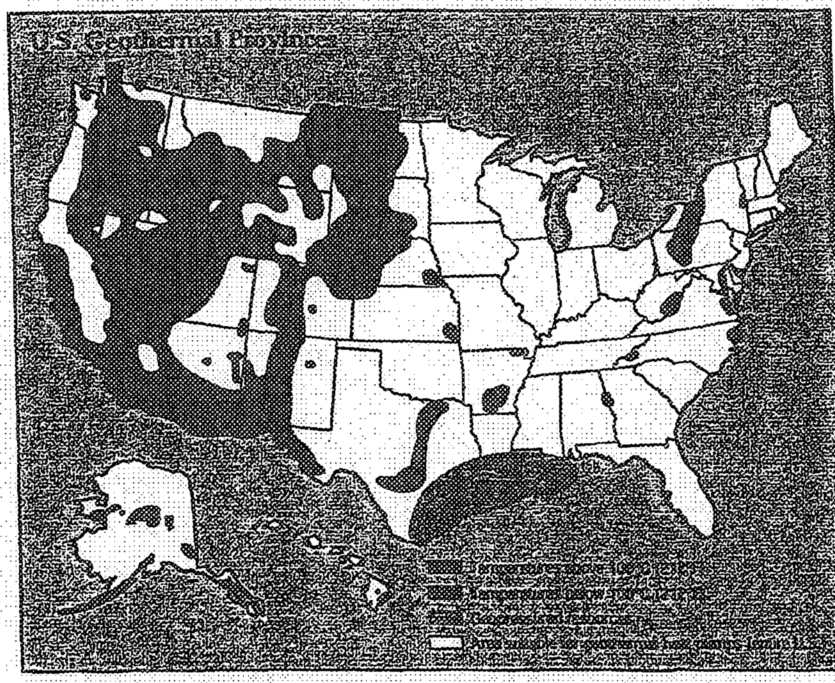
A Clear Advantage

Geothermal energy delivers some powerful environmental and economic benefits. If you live in an area that uses geothermal resources for electricity production, you're quite fortunate. Consider Lake County, California, which is home to many of the geothermal power plants at our nation's best-developed geothermal resource, The Geysers. It's no coincidence that the Lake County air basin is the first and only one in compliance with all of California's stringent air quality regulations.

Perhaps you own a greenhouse and need to cut exorbitant energy bills in order to stay in business. If you are located near a geothermal resource, you should know that most greenhouse growers estimate that direct use of geothermal resources instead of traditional energy sources reduces heating costs by up to 80%. This can save about 5% to 8% in total operating cost.

Assume you're a home or business owner who has installed a geothermal heat pump. You're not only doing your part to help make the world a cleaner place to live and breathe, you're rewarded with low operating and maintenance costs, and, usually, lowest life-cycle costs. (Life-cycle cost is the total cost of the equipment spread over the useful life of the equipment.) In practical terms, your heat pump investment may cost you $15 per month more in mortgage payments, but it may save you $30 per month on your electric bill.

In all three of these cases, domestic, not foreign, resources are being used—a practice that has merits all its own. Nearly half of our nation's annual trade deficit would be obliterated if we could displace imported oil with domestic energy resources. A nation's trade deficit represents a permanent loss of wealth for the citizens of that nation. Keeping the wealth at home translates to more jobs and a robust economy. And not only does our national economic and employment picture improve, but a vital measure of national security is gained when we control our own energy supplies.



Energy and Geoscience Institute, Geothermal Energy, February 1995.

Much of the western United States has geothermal resources suited to power production (above 100°) and direct uses (from 20°C and 150°C). The Gulf Coast region contains geopressured resources, and the entire country is suitable for geothermal heat pumps.

Types of Geothermal Resources

The center of the Earth is 4000 miles (6400 kilometers) deep. How hot is this region? Our best guess is 7200°F (4000°C) or higher. Partially molten rock, at temperatures between 1200° and 2200°F (650° to 1200°C), is believed to exist at depths of 50 to 60 miles (80 to 100 kilometers).

Heat is constantly flowing from the Earth's interior to the surface. Most types of geothermal resources—hydrothermal, geopressured, hot dry rock, and magma—result from concentration of Earth's thermal energy within certain discrete regions of the subsurface.

Hydrothermal resources are reservoirs of steam or hot water, which are formed by water seeping into the earth and collecting in, and being heated by fractured or porous hot rock. These reservoirs are tapped by drilling wells to deliver hot water to the surface for generation of electricity or direct use. Hot water resources exist in abundance around the world. In the United States, the hottest (and currently most valuable) resources are located in the western states, and Alaska and Hawaii. Technologies to tap hydrothermal resources are proven commercial processes.

Geopressured resources are deeply buried waters at moderate temperature that contain dissolved methane. While technologies are available to tap geopressured resources, they are not currently economically competitive. In the United States, this resource base is located in the Gulf coast regions of Texas and Louisiana.

Hot dry rock resources occur at depths of 5 to 10 miles (8 to 16 kilometers) everywhere beneath the Earth's surface, and at shallower depths in certain areas. Access to these resources involves injecting cold water down one well, circulating it through hot fractured rock, and drawing off the now hot water from another well. This promising technology has been proven feasible, but no commercial applications are in use at this time.

Magma (or molten rock) resources offer extremely high-temperature geothermal opportunities, but existing technology does not allow recovery of heat from these resources.

Earth energy is the heat contained in soil and rocks at shallow depths. This resource is tapped by geothermal heat pumps.

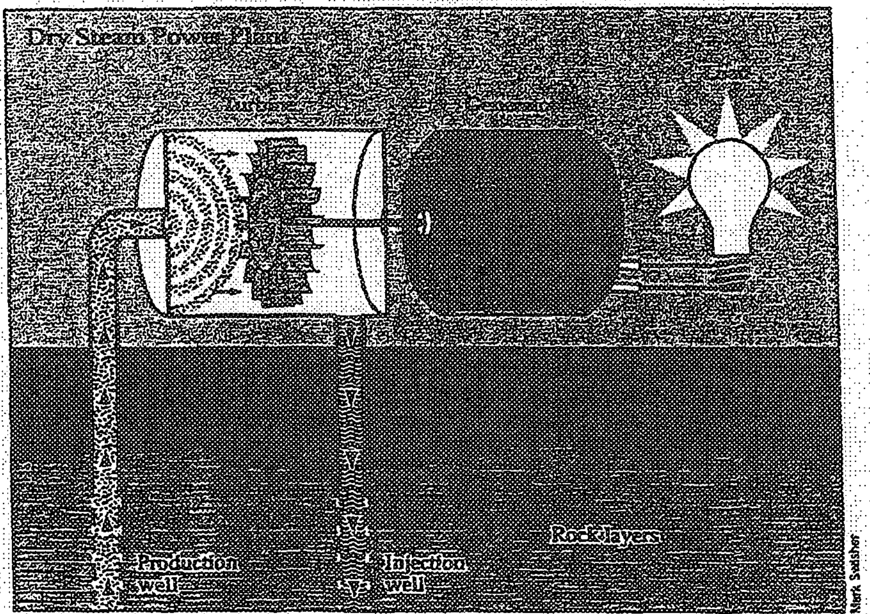
Geothermal plants emit minimal amounts of carbon dioxide—1/1000 to 1/2000 of the amount produced by fossil-fuel plants.

Geothermal Power Plants—from Water to Light

Flip a switch and light up a room—what could be easier? Push a button on the TV remote control and be entertained. It all seems so simple that we are often unaware of the true environmental and social cost of these conveniences—and who would want to give them up even if we had to account for every penny?

But rather than thinking in terms of giving things up, let's think positively: in the United States, right now, the installed generating capacity for geothermal stands at about 2700 megawatts. That's the equivalent of about 58 million barrels of oil, and provides enough electricity for 3.7 million people. The cost of producing this power ranges from 4¢ to 8¢ per kilowatt hour. The geothermal industry is working to achieve a geothermal life-cycle energy cost of 3¢ per kilowatt hour. And remember, this is clean energy produced from domestic resources.

How clean? In terms of air emissions, geothermal power plants have an inherent advantage over fossil fuel plants because no combustion takes place. Geothermal plants emit no nitrogen oxides and very low amounts of sulfur dioxide—allowing them to easily meet the most stringent clean air standards. The steam at some steam plants contains hydrogen sulfide, but treatment processes remove more than 99.9% of those emissions. Typical emissions of hydrogen sulfide from geothermal plants are less than 1 part per billion—well below what people can smell. The low levels of air emissions produced are mostly carbon dioxide, which many people believe acts as a greenhouse gas to trap heat within Earth's atmosphere. Even so, geothermal plants emit minimal amounts of carbon dioxide—1/1000 to 1/2000 of the amount produced by fossil-fuel plants.



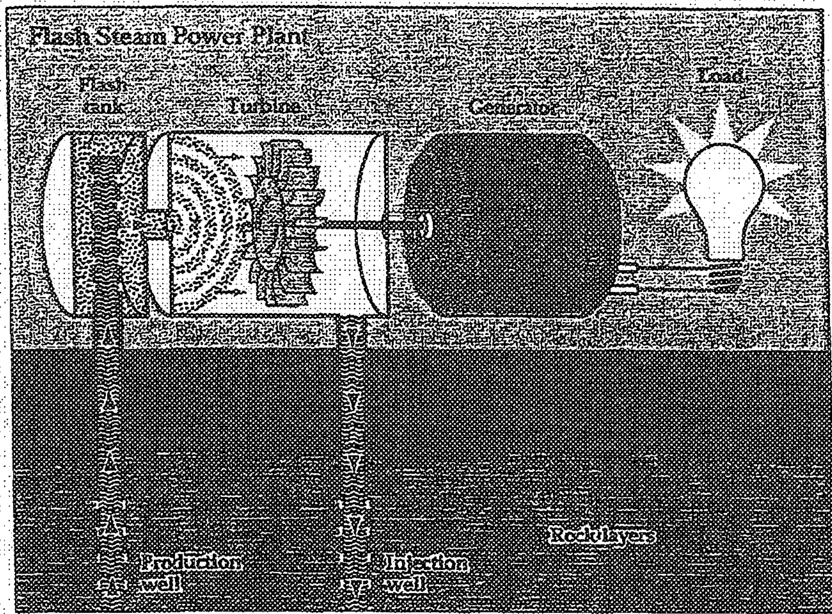
A dry steam power plant draws steam from a hydrothermal production well and sends it to a turbine/generator. The steam turns the turbine to generate electricity and is then condensed and returned to the geothermal reservoir via an injection well.

Geothermal water sometimes contains salts and dissolved minerals. In the United States, the geothermal water is usually injected back into the reservoir from where it came, at a depth well below groundwater aquifers, after its heat energy has been extracted. This recycles the geothermal water and replenishes the reservoir. However, some geothermal plants also produce some solid materials, or sludges, that require disposal in approved sites.

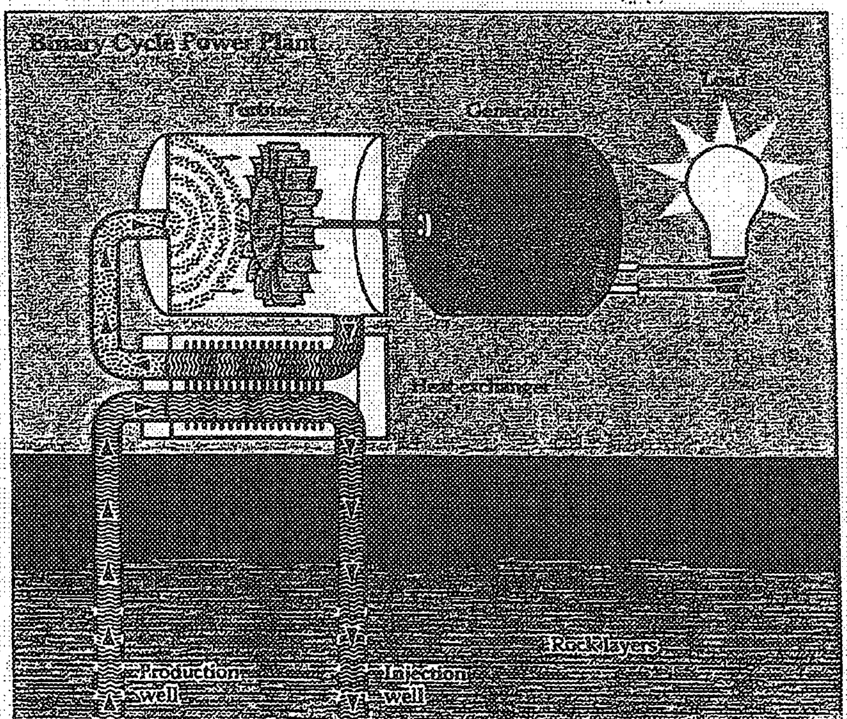
All U.S. geothermal power plants are located in the states of California, Nevada, Utah, and Hawaii—home to some of the most majestic scenery on Earth. It's fortunate, then, that these plants consume only a small amount of land, and can coexist with numerous other land uses, including agriculture, with minimal impact on the surrounding beauty.

They're reliable and efficient, too. Taken as a group, geothermal power plants are available to generate power 95% or more of the time; they are seldom off-line for maintenance or repair. And, they have the highest capacity factors of all types of power plants. Capacity factor is the ratio of the amount of electricity a plant produces to how much electricity it is capable of producing.

Dry Steam Power Plants were the first type of geothermal power plant (in Italy in 1904). The Geysers in northern California, which is the world's largest single source of geothermal power, is also home to this type of plant. These plants use the steam



A flash steam power plant draws hot water from a hydrothermal production well to a flash tank where a drop in pressure "flashes" the water to steam. The steam turns a turbine/generator that generates electricity. The steam is then condensed and, with any hot water not flashed to steam, returned to the geothermal reservoir via an injection well.



Using two closed loops, a binary cycle power plant pumps hot water from a hydrothermal production well to a heat exchanger where the geothermal water is used to boil a working fluid. The resulting working-fluid vapor turns a turbine/generator that generates electricity. After passing through the heat exchanger, the geothermal water is returned to the reservoir via an injection well, and the working-fluid vapor is condensed and recirculated through the working-fluid loop.

as it comes from wells in the ground, and direct it into the turbine/generator unit to produce power.

Flash Steam Power Plants, which are the most common, use water with temperatures greater than 360°F (182°C). This very hot water is pumped under high pressure to equipment on the surface, where the pressure is suddenly dropped, allowing some of the hot water to "flash" into steam. The steam is then used to power the turbine/generator. The remaining hot water and condensed steam are injected back into the reservoir.

Binary Cycle Power Plants operate on the lower-temperature waters, 225° to 360°F (107° to 182°C). These plants use the heat of the hot water to boil a "working fluid," usually an organic compound with a low boiling point. This working fluid is then vaporized in a heat exchanger and used to turn a turbine. The geothermal water and the working fluid are confined to separate closed loops, so there are no emissions into the air.

Because these lower-temperature waters are much more plentiful than high-temperature waters, binary cycle systems will be the dominant geothermal power plants of the future.

Developing and commercializing geothermal power technologies contributes not only to a cleaner environment, but to a healthy U.S. industrial base, as well. Around the developing countries of the world, demand for electric power is burgeoning—and nearly half of these countries have geothermal resources. These markets have proven particularly receptive to clean energy produced with indigenous resources, creating attractive export options for geothermal technologies and expertise. In fact, U.S. geothermal companies have signed contracts worth more than $6 billion in the past few years to build geothermal power plants in some of these developing countries.

Direct Use of Geothermal Energy

If you've ever soaked in water from a natural hot spring, you're one of the millions of people around the world who has enjoyed the direct use of geothermal energy. And while this naturally occurring hot water may be the perfect tonic for frayed nerves and sore muscles, it's capable of much more.

Geo-Heat Center / pix 03708

The Milgro Nurseries' greenhouse near New Castle, Utah, is one of approximately 40 greenhouses nationwide that benefit from the direct use of geothermal energy.

The consumer of direct-use geothermal energy can reduce fuel costs by as much as 80%, depending on the application and the industry.

In the United States alone, direct geothermal applications (not including geothermal heat pumps) have an installed capacity of 500 thermal megawatts, which is roughly equivalent to saving half a million barrels of oil per year. This includes approximately 40 greenhouses, 30 fish farms, 190 resorts and spas, 125 space and district heating projects, and 10 industrial projects.

The resource required for these applications is widespread across the western third of the United States. This is water in an underground reservoir, at low-to-moderate temperatures usually ranging from 68° to 302°F (20° to 150°C). The consumer of direct-use geothermal energy can count on savings in energy costs—as much as an 80% reduction from traditional fuel costs, depending on the application and the industry. Direct-use systems typically require a larger initial investment, but have lower operating costs and no need for ongoing fuel purchases, therefore reducing life-cycle costs.

In a typical application, a well brings heated water to the surface; a mechanical system—piping, heat exchanger, controls—delivers the heat to the space or process; and a disposal system either injects the cooled geothermal fluid underground or disposes of it on the surface.

The direct use of geothermal energy offers some heartening possibilities. Imagine an entire community of people having their homes heated geothermally. Sound like something way off in the future? Not at all. In 1893, the citizens of Boise, Idaho, put their pioneering spirit to work and built the world's first geothermal district heating system by piping water from a nearby hot spring. Within a few years, the system was providing heat to 200 homes and 40 downtown businesses—and the system continues to flourish today.

There are now 18 district heating systems in the United States (including one in Klamath Falls, Oregon, that melts snow from the city's downtown sidewalks), and the potential for more is tremendous. A recently updated resource inventory of 10 western states identified 271 communities located within 5 miles (8 kilometers) of a geothermal resource.

Greenhouse operators are taking advantage of geothermal direct use in growing numbers, with nearly 40 greenhouses (many of which are several acres in size) producing vegetables, flowers, houseplants, and tree seedlings in eight western states. Operators of fish farms are profiting from the lower energy costs and improved fish growth rates that geothermal energy delivers. Other industrial and commercial applications that match well with geothermal direct use include food dehydration, laundries, gold processing, milk pasteurizing, and swimming pools and spas.

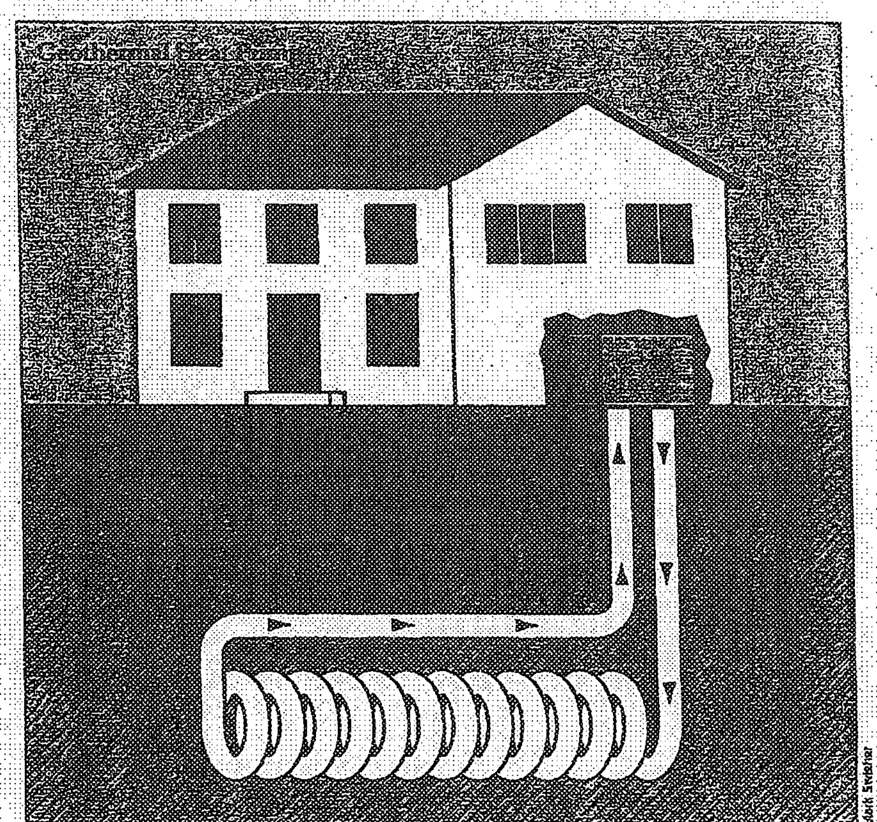
The Heat Pump Solution

The geothermal heat pump doesn't create electricity—but it greatly reduces consumption of it. If you would like to reduce the cost of heating and cooling your home, you might want to consider installing a geothermal heat pump, an economical and energy-efficient technology for space heating and cooling and water heating. Nationwide, more than 350,000 of these systems are in operation in homes, schools, and businesses. And the geothermal heat pump industry expects to be installing 40,000 systems per year by 2000.

In winter, heat pump systems draw thermal energy from the ambient temperature of the shallow ground, which ranges between 50° and 70°F (10° to 21°C) depending on latitude. In summer, the process is reversed to a cooling mode, using the ground as a sink for the heat contained within the building. The system does not convert electricity to heat; rather, it uses electricity to move thermal energy between the building and the ground and condition it to a higher or lower temperature according to the heating or cooling requirements. Consumption of electricity is reduced 30% to 60% compared to traditional heating and cooling systems, allowing a payback of system installation in 2 to 10 years. And these low-maintenance systems have long lives of 30 years or more. Some systems are also capable of producing domestic hot water at no cost in summer and at small cost in winter.

An analysis by the EPA found these systems to be among the most efficient space-conditioning technologies available—with the lowest environmental cost of all that were analyzed. But this might be the most compelling statistic: Surveys show that the number of satisfied geothermal heat pump customers stands at 95% or higher.

The number of satisfied geothermal heat pump customers stands at 95% or higher.



Geothermal heat pumps use the stable temperature of the shallow ground as a heat source to warm buildings in the winter and as a heat sink to cool them in the summer.

Source List

The following organizations serve as excellent resources for information on geothermal energy and its various applications.

U.S. Department of Energy (DOE)
Office of Geothermal Technologies, EE-12
1000 Independence Ave., S.W.
Washington, DC 20585-0121
(202) 586-5340
http://www.eren.doe.gov/geothermal/

Sponsors research to develop geothermal science and technology, and works closely with industry to develop advanced technologies and help commercialize research discoveries. Publishes brochures and newsletters focused on geothermal energy and applications.

Energy and Geoscience Institute
423 Wakara Way, Suite 300
Salt Lake City, UT 84108
(801) 581-5126
http://www.egi.utah.edu/

Conducts applied geoscience research pertaining to geothermal resources, fossil fuels, minerals, and environmental assessment; works cooperatively with universities, government agencies, national energy companies, and a global network of collaborating scientists. The institute has a professional staff of more than 40 scientists and engineers.

The Energy Efficiency and Renewable Energy Clearinghouse (EREC)
P.O. Box 3048
Merrifield, VA 22116
(800) DOE-EREC (363-3732)
E-mail: doe.erec@nciinc.com

Provides free general and technical information to the public on the many topics and technologies pertaining to energy efficiency and renewable energy.

Geo-Heat Center
Oregon Institute of Technology
3201 Campus Drive
Klamath Falls, OR 97601-8801
(503) 885-1750
http://www.oit.osshe.edu/~geoheat/

Provides technical information regarding direct-use geothermal energy to consultants, developers, potential users, and the general public; information has been developed through extensive research and firsthand experience with hundreds of projects. Publishes a quarterly bulletin. The center's resources are available to the public through the auspices of DOE.

Geothermal Education Office
664 Hilary Drive
Tiburon, CA 94920
(800) 866-4GEO
http://geothermal.marin.org

Focuses on helping students learn about geothermal energy. Provides K-12 teachers and other interested parties with free booklets, posters, global statistical maps, and reference material. A grade school video, activity-packed curriculum , and a high school video with curriculum supplement are available at cost.

Geothermal Energy Association
122 C Street, N.W., Suite 400
Washington, DC 20001
(202) 383-2676
http://www.geotherm.org

Serves as the trade association for U.S. companies that support the use of geothermal resources worldwide. Assists the U.S. geothermal industry in the export of goods and services; interacts with federal entities, the financial community, and environmental and other renewable energy groups; and provides education, outreach, and publications about geothermal energy.

Geothermal Heat Pump Consortium, Inc.
701 Pennsylvania, NW
Washington, DC 20004-2696
(202) 508-5500
http://www.ghpc.org/

Provides extensive information regarding geothermal heat pumps. Web page contains case studies, published articles, list of service providers, and workshop schedules and locations. The consortium, established under President Clinton's "Climate Change Action Plan," has broad-based support and participation from DOE, the utility sector, and geothermal associations and manufacturers.

Geothermal Resources Council
2001 Second Street, Suite 5
Davis, CA 95617-1350
(916) 758-2360
http://www.demon.co.uk/geosci/grcdoc.html

Publishes a monthly bulletin (11 issues a year); provides videos, maps, and posters. Develops and convenes special meetings, workshops, conferences, courses, and symposia on a full range of subjects pertaining to geothermal exploration, development, and use. Periodically schedules a basic introductory course on geothermal energy.

International Geothermal Association
c/o Institute of Geological and Nuclear Sciences
Wairakei Research Centre, Private Bag 2000
Taupo, New Zealand
64-7-374-8211
http://www.demon.co.uk/geosci/igahome.html

Publishes the "IGA News" (quarterly). Provides information about geothermal industry associations worldwide. Encourages the development and use of geothermal resources worldwide through the compilation, publication, and dissemination of scientific and technical data and information. Organizes the international geothermal congress every five years.

International Ground-Source Heat Pump Association
490 Cordell South
Stillwater, OK 74078-8018
(405) 744-5175
(800) 626-4747
http://www.igshpa.okstate.edu/

Established in 1987 to advance geothermal/ground source heat pump technology on a local, state, national, and international level. Publishes "The Source," a bimonthly newsletter. Sponsors the annual Geothermal Heat Pump Technical Conference and Expo. Offers numerous booklets and brochures for contractors, homeowners, students, and the general public.

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National Renewable Energy Laboratory

GIS (Home)

About GIS | About the Map Server | Index of Maps | Index of GIS Data

Solar Maps

How to use the U.S. Solar Atlas (MS Word 1 MB)

Note: This site works the best in Microsoft Internet Explorer.

United States Solar Atlas
This map interface accesses monthly average solar resource information for any given location in the United States. It also provides access to spreadsheets giving average monthly radiation for 14 different types of solar collectors. Data for individual collectors is also available for fixed, flat-plate (photovoltaic) collectors on five different orientations. Added features include a zoom tool which allows the user to zoom to zip codes and latitude/longitude locations. See the US Solar Atlas. *(If you have pop-up blockers enabled, the PVWATTS Version 2 application on this Web site will not work properly. To fix this, you can go to your tool menu and allow popups from the mapsever1.nrel.gov site.)*

PVWATTS Version 2
PVWATTS calculates electrical energy produced by a grid-connected photovoltaic (PV) system. Researchers at the National Renewable Energy Laboratory developed PVWATTS to permit non-experts to quickly obtain performance estimates for grid-connected PV systems within the United States. To access this calculator, go to PVWATTS Version 2. You can obtain more information on the PVWATTS calculator at Learn More. (If you have pop-up blockers enabled, the page displaying the calculator will not launch properly. To fix this, you can go to your tool menu and allow popups from the mapsever1.nrel.gov site.)

PV Solar Radiation (Flat Plate, Facing South, Latitude Tilt) Maps (jpeg images ranging in size from 260-273kb)
These maps provide monthly average daily total solar resource information on grid cells of approximately 40 km by 40 km in size. The insolation values represent the resource available to flat plate collector, such as a photovoltaic panel, oriented due south at an angle from horizontal equal to the latitude of the collector location. Read more.

Annual (JPG 263 KB)
January (JPG 256 KB)
February (JPG 267 KB)
March (JPG 272 KB)
April (JPG 270 KB)
May (JPG 267 KB)
June (JPG 261 KB)
July (JPG 267 KB)
August (JPG 269 KB)
September (JPG 273 KB)
October (JPG 268 KB)
November (JPG 262 KB)
December (JPG 260 KB)

Direct Normal Solar Radiation (Two-Axis Tracking Concentrator) Maps (jpeg images ranging in size from 268-299kb)
These maps provide monthly average daily total solar resource

Legend

Latitude Longitude Lines

Lakes

Hawaii NSRDB Locations with Hot Link to RReDC

Alaska NSRDB Locations with Hot Link to RReDC

Lower 48 NSRDB Locations with Hot Link to RReDC

Lower 48 Direct Normal

8.5-9.0
8.0-8.5
7.5-8.0
7.0-7.5
6.5-7.0
6.0-6.5
5.5-6.0
5.0-5.5
4.5-5.0
4.0-4.5
3.5-4.0
3.0-3.5
2.5-3.0
2.0-2.5

Mexico

Canada

Alaska Elevation

Hawaii Elevation

Lower 48 Elevation

State Boundaries 1