Fuel from the Sky

Solar Power's Potential for Western Energy Supply

July 2002
NREL/SR-550-32160

Fuel From the Sky: Solar Power's Potential for Western Energy Supply

Dr. Arnold Leitner
Senior Consultant, RDI Consulting

July 2002

NREL is the U.S. Department of Energy’s premier laboratory for renewable energy & energy efficiency research, development, and deployment.

July 2002 NREL/SR-550-32160
August 1, 2001 to December 30, 2002
Prepared under Subcontract No. NAA-1-31470-01

Dr. Leitner is a senior consultant with RDI Consulting, a strategic information and consulting firm serving the energy industry with research reports, studies, consulting and information services; RDI consulting is a trademark of Platts, a unit of the McGraw-Hill Companies, Inc.
Dr. Leitner specializes in the analysis of the cost and performance of conventional and emerging generating technologies and the North American and international electricity supply and demand balance. Leitner developed RDI's new generating capacity information service, NEWGen. This data and analysis service provides a detailed assessment of the status of proposed power plants and competitive information on major industry players. This work led Leitner to comprehensively investigate the issues surrounding new plant development and its impact on the future demand and supply balance. Dr. Leitner received a PhD in superconductor physics from the University of Colorado at Boulder. He has published in professional scientific journals and has been an invited speaker.

Analysts

Jack Ihle, Associate
Andrea Capra, Associate
Jeff Campbell, Associate

GIS and Mapping

Keith Holecheck
Kari Dosemagen

Cover Art

Michael P. Marasch

Reviewers

Dr. Doug Logan, Principal, RDI Consulting
Ellen Ewart, Senior Consultant, RDI Consulting
David W. Kearney, Kearney & Associates
Henry W. Price, National Renewable Energy Laboratory (NREL)
Mark S. Mehos, NREL
Hughes Reilly, Sandia National Laboratories (Sandia)
Thomas R. Mancini, Sandia
Robert R. Liden, Stirling Energy Systems
Stan Pinkowski, The Boeing Co.

Technical Writer

Jill S. Tietjen (Technically Speaking)

Production Team
Editorial: Kathy Kaiser
Production and Graphics: Heather Arellano, Brent Zeinert, Rob Fair, Jill Kosbau

***Fuel from the Sky* is a multi-client study, which is sponsored by**
The National Renewable Energy Laboratory (NREL),
Stirling Energy Systems (SES) and
STM Power.

The following RDI databases were used in developing the historical data and the assumptions underlying the projections herein.

NEWGen®

The NEWGen database provides comprehensive coverage of North American new and planned generating capacity. NEWGen includes detailed information on all potential merchant plants, independent power projects with contracts for output, utility-built capacity additions, return of off-line capacity, and re-rates of existing capacity. NEWGen provides details for each project, including project overview, project participants, project status, unit detail, upstream and downstream participants, and financing details.

POWERdat®

POWERdat is the most widely used strategic intelligence tool in the electric power industry. It contains data on more than 5,000 North American electric power companies and their plants, including investor-owned utilities, municipalities, rural electric cooperatives, public authorities, nonutility generators, power marketers, and power pools. Over 120 files containing more than 6,000 individual data items are included in POWERdat. Ten years of historic data, plus monthly updates, provide users with a valuable time series plus the latest information available.

POWERmap®

POWERmap is a strategic desktop mapping and analysis system that contains more than 60 map layers and key statistical data pertaining to North American energy markets. The software allows users to understand key geographic relationships in their data and helps answer questions that drive energy markets. POWERmap enables companies to visually perform key energy market applications such as market segmentation, merger and acquisition analysis, new generating station site selection, competitor intelligence, and customer retention.

Further information about RDI’s database products is available at www.rdionline.com.

Table of Contents

State-by-State Appendices:

Executive Summary

The Potential of Solar Power for Western Energy Supply

A reliable and affordable supply of electricity is essential to protect public health and safety and to sustain a vigorous economy in the West. Rolling blackouts in California in 2000 and 2001, low hydro generation in the Pacific Northwest in 2001, and a power plant construction boom in Texas have drawn attention to electricity issues in the West. All across the nation, demand for and supply of electricity have become unbalanced in the late 1990s, but nowhere has the issue been more pressing than in the West.

With population growing in the western states, electricity demand is poised for growth for the remainder of this decade. Both energy demand, that is the number of megawatt-hours (MWh) consumed over the course of the year, as well as peak demand, the highest hourly demand across the hours of the year, will continue to increase. Economic activity and population growth continue to be the most important drivers of electricity demand.

In 2001, a total of about 237,078 megawatts (MW) of capacity was installed in the West. Coal-fired generation provided about 44% of the electricity generated in the West and gas-fired generation accounted for about 24%. Hydroelectric power accounts for 22% of capacity and 18% of the generation in the states of the Western Governors' Association (WGA). Nuclear plants provide 7% of capacity and 11% of the energy. Of the remainder, about 1.5% comes from non-hydro renewables.

For almost 20 years, little new generating capacity has been built in the U.S. Now, however, new projects totaling over 133,747 MW by 2010 have been announced. Although not all of the announced projects will be completed, many thousands of megawatts, primarily gas-fired combined cycle power plants, are expected to come on-line in the West. The large amount of gas-fired capacity planned may result in more volatile gas prices for customers and will increase the reliance on fossil fuels for power generation. Energy conservation and energy efficiency can help offset the need for new generating capacity. However, 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. Solar energy is an abundant and underutilized energy source in the West. Solar conditions are optimal in the Desert Southwest and, given the geographic and climatic conditions, potentially the best in the world. In addition, these areas of premium, excellent, and good solar resources are located near major metropolitan areas. Solar generating capacity in the form of CSP can be brought on-line rapidly, subject to the ability to build the appropriate interconnection facilities and whatever electric transmission is required.

Solar technologies, both photovoltaic (PV) and thermal, are not radically new technologies. Thermal CSP technologies, in the form of parabolic troughs, dish Stirling, and power towers, were demonstrated in California in the 1980s and 1990s. In the Mojave Desert, 354 MW of parabolic trough thermal solar generating capacity has been operating for over a decade. Most of the public is familiar with PV cells, used on everything from emergency road signs to National Park Service outhouses.

Issues associated with the intermittence of the sun, due both to cloud cover and the fact that the sun sets each night, can be addressed through the addition of heat storage or fossil fuel hybridization. Heat storage, expected in the form of molten salt, retains the heat from the daytime when the sun is shining and allows generation during hours when the sun is not shining. Both parabolic trough and power towers are capable of providing dispatchable electricity from heat storage. Fossil fuel hybridization allows a CSP solar power plant to also run on a fossil fuel, usually natural gas, when sunlight is not adequate. This ability to deliver power on demand greatly increases the value of CSP to the owner of the plant.

Premium solar power resources are by and large found in the desert areas of the Southwest. This means that lands that may not otherwise have an economic use are available for solar development. Solar technologies, unless configured with fossil fuel hybridization, produce zero emissions, which is a desirable attribute for permitting and siting. Solar radiation peaks during the summer as do the loads of the area's utilities, although some offsets in timing by hour and month will need to be accommodated.

The success of wind power developers in upgrading the technology to address environmental and design concerns holds much promise for the potential for solar power. CSP technologies, including parabolic trough, power towers, and dish Stirling, appear to be ready for commercial use. As with most other renewable forms of energy, CSP technologies will require incentives, such as buydowns, investment and production tax credits, and green energy premiums paid by utility customers, until sufficient cost reductions have been achieved to make CSP competitive against conventional generating technologies.

The solar resource in the West is quite large. With the appropriate political will and an adequate transmission system, this resource could provide a significant portion of the West's energy needs.

Chapter 1

Western Electricity Markets

An Overview

A reliable and affordable supply of electricity is essential to protect public health and safety and to sustain a vigorous economy in the West.

Rolling blackouts in California in 2000 and 2001, low hydro generation in the Pacific Northwest in 2001, and a power plant construction boom in Texas have drawn attention to electricity issues in the West. All across the nation, demand for and supply of electricity have become unbalanced in the late 1990s, but nowhere has the issue been more pressing than in the West.

This white paper on the potential of solar power for western energy supply defines the West as the area made up by the states of the Western Governors' Association (WGA). This area includes 16 states west of the 93rd meridian, Alaska, Hawaii, and three U.S.-flag Pacific islands. The territory encompassed by the WGA is shown in Exhibit 1.

The states of the WGA in the Lower 48 are geographically contiguous, but electrical interconnections between the states are regional. It is for this reason that sub-regions must be defined when describing western electricity issues.

In this paper we have created regions that follow state boundaries, and at the same time approximate regions that are defined by transmission constraints. Indeed, some states are split electrically and belong to multiple electrical reliability regions. In such cases we assigned the state to the region where most of its load is located. This approach allows us to disaggregate and re-aggregate data on a state-by-state level and permits reasonable comparisons to data based on electric reliability regions defined by the North American Electric Reliability Council (NERC).[1]

Exhibit 1: States and Regions of the Western Governors' Association

Other states and U.S.-flag islands of the Western Governors' Association that were not assigned a specific region.

SOURCE: RDI Consulting, POWERmap

The *Northwest* consists of the four states of Montana, Idaho, Washington, and Oregon. *Colorado* and *Wyoming* comprise another region. Utah, Nevada, New Mexico, and Arizona make up the *Southwest*, while California is its own region. We have called the Dakotas, Nebraska, and Kansas the *Prairie States*. Texas is its own region, because most of the state is electrically isolated from the rest of the West. The remaining states and territories of the WGA are not examined in this report in any depth as the focus herein is on the continental U.S. (the Lower 48).

In 2001 Electricity Supply in the West Remains Tight

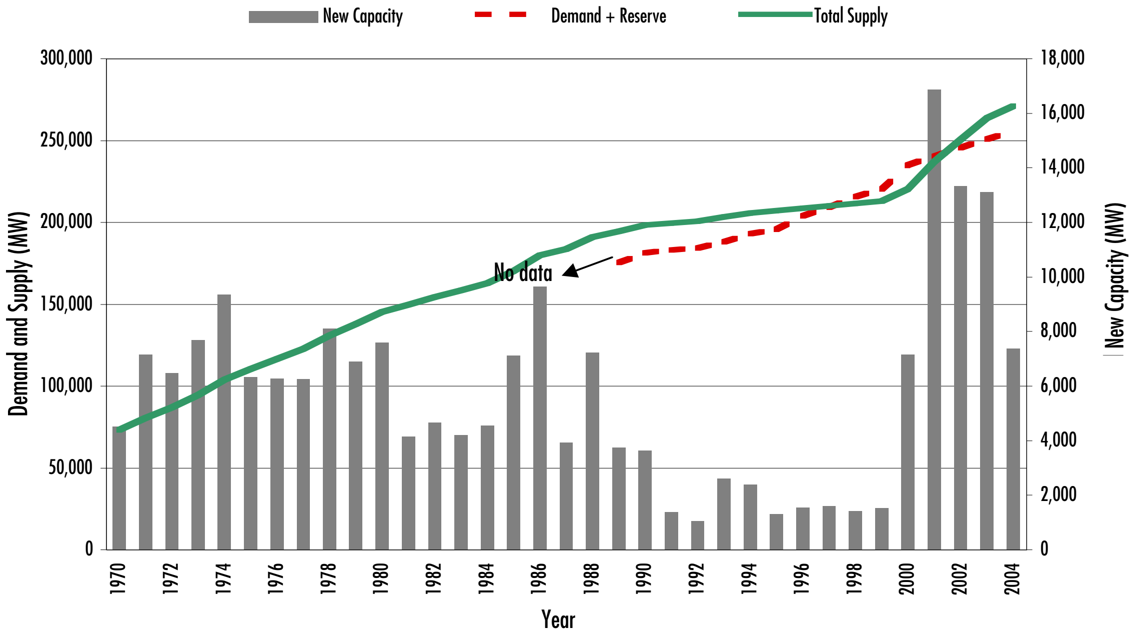
In the first six months of 2001, California had rolling blackouts on six days. A report by the California Independent System Operator (Cal ISO) published in March 2001 painted a gloomy picture of the summer and stated that "minimizing blackouts will require … a bit [of] luck." The cataclysmic events of late 2000 and the spring of 2001, with massive power curtailments in the state, sent a shock wave through the Golden State. As a result, consumers have made great strides in conserving energy. Data by the California Energy Commission indicate that the state's peak demand in August 2001 was 8.9% below expected levels, even though the month belonged to the top quartile of warm August months in California, where peak demand is strongly influenced by summer temperatures.

In the end, Californians made their own luck. Conservation measures, the startup of about 2,000 MW of new capacity by July 2001, the return of generating units to service after maintenance, a slight easing of drought conditions in the Northwest, and more gradual load control procedures during system emergencies effectively avoided outages during the summer and early fall. In addition, weather conditions in the state were rather modest, even though August was warmer than usual.

The supply shortage in California, the most populous state in the West and the sixth largest economy in the world as measured by gross state product, has sent ripples across the West, especially into the Northwest, an area strongly interconnected with California. High power prices in California also resulted in higher prices in the Pacific Northwest. Other states of the WGA experienced higher prices as well or the political reverberations from the California crisis. Coloradans hurried to hold an energy summit to assess the situation in their state, while Texas rested in the comfort of having more than adequate generating capacity.

In 2001, electric energy supplies in the West remained tight. Elsewhere, regions that had previously been critically short reached balance or near balance as a result of new power plants coming on-line. New supply additions and demand growth in the West from 1970 through 2004 are reflected in Exhibit 2. The core of the problem that led to the electricity crises in the West is also reflected: Supply additions in the 1990s fell far short of demand growth, and demand eventually outgrew supply.

Exhibit 2: Generating Capacity Additions and Demand Growth in the West, 1970-2004



The Making of the Electricity Crisis

In the 1970s, the West added power plants at an average rate of 7,000 MW per year. Demand growth rates decreased in the 1970s below what was projected, which resulted in significant surplus capacity by the early 1980s. During the 1980s power plant construction continued, though at a slower average pace of 5,600 MW per year. In the 1990s, as a result of the combination of a capacity surplus, the inability of the utilities to get recently constructed power plants into their rate bases, and the influx of independent power producers (IPPs), power plant construction essentially stopped for the entire decade, while demand growth picked up and ate away at the surpluses until demand eventually outstripped supply.

Over the past few years, reserve margins in California moved steadily downward to reach crisis levels in 2000. From 1988 to 1997, the 10-year average forecast reserve margin for California was 29.4%. The Cal ISO's first calls for voluntary reductions in electricity usage due to low reserves occurred during the summer of 1998, even though hydro availability was higher than expected. The situation reached a crisis in 2000 when the Cal ISO called for conservation measures for 30 days through mid-September. Shortage-driven power prices hit price caps numerous times in the summer of 2000, including almost every day in August.

In 2000, inadequate reserve margins in California, delayed power plant construction, a historic low snowpack in the Northwest, and natural gas pipeline transmission constraints into California created the perfect electrical storm: the California energy crisis. While 2000 and early 2001 were a disaster for the West, 2001 appears to be the turning point, and RDI Consulting's forecast of demand and capacity additions through 2004 shows that after this past summer the worst seems to be over. In the following section we will look at some of the hot spots that may remain in the region.

Demand and Supply out of Balance

Exhibit 2 suggests that, by 2002, the West as a whole will again have an adequate supply of electricity, but the new generating capacity that will come on-line is not distributed evenly. While some regions will see, or already have, sufficient generating capacity, other regions will continue to be in a tight situation. Nevertheless, our forecast suggests that no regions will be in a critical situation, especially in the light of the recent slowdown in electric demand growth. In Exhibit 3, we show the estimated supply and demand balance in the West during summer 2001.

The Northwest, Colorado and Wyoming, California, and the Southwest are all part of the Western Interconnection and are able to exchange electricity. Exhibit 3 shows that all regions but the Northwest fall short of their target reserve margins. The situation is especially critical in California and the Southwest, where reserve margins are 3% and 6%, respectively, and dangerously short of the 16% target. In 2001, the Western Interconnection was still greatly affected by drought conditions in the Northwest, but significant energy conservation measures helped avoid the kind of power shortages that threw the Western Interconnection into turmoil in late 2000 and early 2001.

The Prairie States, which are within the Eastern Interconnnection, have only limited electrical ties to the Western Interconnection and are better interconnected to the North (Canada), East, and South. Small portions of Texas are in the Western Interconnection, but most of the state is an island unto itself—the Electric Reliability Council of Texas (ERCOT). According to our analysis, Texas had a substantial surplus of power in 2001 due to an early and strong power plant construction boom that still continues. For the Prairie States, the demand and supply balance is a little more difficult to assess because this region is part of two NERC reliability regions, but our demand and supply balance analysis in Exhibit 3 suggests that the Prairie States currently enjoy a slight surplus of power.

Exhibit 3 shows that the demand and supply balance in the West is different from region to region. While, as a whole, the West is only slightly short of capacity in 2001, some western regions, such as California, are still short, at least when historic demand levels are assumed. However, because of interregional transmission, which was built to enable the West to take advantage of regional diversity and reduce the need for power plant construction in the West, some of the worst problems have been avoided. In fact, if power were able to flow freely all across the West, the demand and supply situation would have been almost in balance. This suggests that interregional transmission—by sending power from where it is abundant to where it is needed—can play an important role in providing reliability. This is especially true when a large amount of regional capacity is derived from renewable energy sources. This issue will be the topic of the next section.

Exhibit 3: Demand and Supply Balance in the West, Summer 2001

Region	Peak Demand (MW)	Available Supply (MW) (3)	Reserve Margin		
			Actual	Target	Surplus (MW)
Northwest	29,637 (1)	41,415	40%	29%	3,183
CO and WY	9,782 (2)	11,154	14%	18%	-389
California	52,805 (1)	54,361	3%	16%	-6,893
Southwest	28,311 (1)	29,979	6%	16%	-2,862
Prairie States	16,920 (2)	20,169	19%	17%	373
Texas	65,973 (1)	77,100	17%	16%	571
TOTAL/AVERAGE	203,428	234,178	15% (4)	18% (4)	-6,016

(1) NERC region 2001 summer assessment.
(2) RDI Consulting estimate.
(3) Regionally installed capacity and net imports.
(4) Average weighted by regional peak demand.

Transmission Wires Are Stretched

Traditionally utilities provide generation, transmission, and distribution. In this vertical business model, utilities provide electricity services to customers by optimizing the entire generation and delivery system with the objective of providing power at the lowest cost. In many cases, it may be more economical to transmit generation from a cheap power source over a long distance than to build a new power plant close to the load. Such thinking, for example, was behind the construction of the transmission system bringing inexpensive hydroelectric generation from the Northwest and inexpensive coal-fired generation from the Four Corners region into California.

The development of the transmission system was further shaped by the nature of the utility business. Early in the history of the industry, utilities were mainly concerned with meeting their own loads. The transmission network was generally laid out to connect neighboring utilities to the extent that it allowed for delivery of remote capacity owned by the receiving utility (for long-term power purchases and sales between utilities) or for emergency transfers. In the West, however, utilities perceived significant benefits that could be achieved through strong transmission interconnections. Four massive ties exist between the Pacific Northwest and California, allowing power to flow south in the summer when loads peak in California and north in the winter when loads peak in the Northwest. Strong ties exist between California and the Southwest to accommodate transfer of power from jointly owned power plants (California utilities are part owners) in the Southwest to California.

However, significant transmission bottlenecks still exist across the West, which would limit the transactions desired in a liquid electricity commodity market or to accommodate large scale development of renewable energy resources, such as solar, from the Desert Southwest. These bottlenecks were identified in the August 2001 WGA report, *Conceptual Plans for Electricity*

Transmission in the West (Figure 6 of the report), which was fittingly titled "Location of Famous Transmission Constrained Paths in the Western Interconnected System."

The Impact of Deregulation on Transmission

Deregulation was driven by the belief that the regulated monopoly, vertically integrated utility business was outdated and that competition would benefit the industry and consumers. Because the generation business lends itself best to competition, restructuring in many states of the WGA and elsewhere in the country has included a requirement that utilities sell off (divest) all or part of their generation assets. The business of providing electric generation has migrated to IPPs and non-regulated utility affiliates. Regulators hoped that these IPPs and affiliates could produce power more economically than the utility monopolies.

Regulators and policy makers acknowledge that the transmission and distribution (T&D) system is a natural monopoly and does not lend itself to deregulation. However, the decoupling of T&D from generation has resulted in little incentive for utilities to add transmission capacity. Conversely, generators are reluctant to build or upgrade transmission lines, because their investment in electric lines may benefit their competitors just as much as themselves.[2,3] Therefore, while load and generation have grown, transmission expansion has not kept up.[4] Consequently, with more power on the lines and minimal line additions, transmission bottlenecks have developed which, in many parts of the country, have resulted in significant differences in regional prices during peak hours.

Transmission in the West

The states of the WGA are located in all of the three synchronous electric interconnections in the Lower 48: Western, Texas, and Eastern. Most states and regions are within the Western Interconnection; this includes the Northwest, California, Southwest, and Colorado and Wyoming regions. Transmission is particularly strong between the first three regions, and, unless regional demand greatly exceeds the transmission capacities for the exchange of power, power prices across the regions track fairly well. For example, wholesale power prices in San Diego, Phoenix, or Las Vegas are within a few percent of each other during most hours of the year.

In the current environment, power plant developers site their projects to take advantage of the existing transmission system or avoid it by building close to the load, so that sellers are only a short distance from buyers. For gas-fired power plants, with their low emissions and small visual impacts, the latter strategy works, even though these projects often still face fierce opposition from the communities that these generators are trying to serve. For coal-fired power plants this does not work, as both economic and environmental reasons demand that the plants be built close to the mine and far from consumers. This, however, means investing in new transmission line construction or transmission line upgrades. Just such a trend can currently be observed at proposed coal-fired power plants.[5]

Ideas for a Future Transmission System

An adequate transmission system will be required for both a renewable and a non-renewable energy future. The following considerations about the future of the transmission system should be part of any discussions by the Western governors in shaping their policy recommendations.

- A well-connected and well-designed transmission system will assure a high level of reliability and can minimize market power by a few generators in load pockets.
- Modern transmission technologies allow the development of a system with higher performance and less impact. High-voltage electric transmission is a very efficient and practical way to move energy.
- Energy resources are not distributed evenly in the West. If fuel diversity is a strategic goal, then its realization will require expansion and improvement of the transmission system.
- Geographic diversity can greatly mitigate the intermittence issue of wind and solar resources through averaging. Therefore, if the West wants to adopt a widespread use of intermittent renewable energy sources, an adequate transmission system is important.[6]
- Local opposition to high-voltage transmission lines remains strong, because of alleged health problems, aesthetics, rights-of-way, and property value issues.

In summary, a strong transmission system is in the interest of western states and is essential if western states intend to provide a large portion of their energy needs from intermittent renewable energy sources such as wind and solar.

Meeting Future Electricity Demands

With population growing in the western states, electricity demand is poised for growth for the remainder of this decade. Both energy demand, that is the number of megawatt-hours consumed over the course of the year, as well as peak demand, the highest hourly demand across the hours of the year, will continue to increase. Peak demand in the West is typically 60% to 65% higher than the average annual demand.[7] This relationship has not exhibited any particular trend over the course of the last decade and, for our base case demand forecast, we assume that this relationship continues to hold over the next 10 years. Therefore RDI Consulting's projected demand growth rates are the same for energy and peak demand.

For purposes of reliability, peak demand is what matters in most regions.[8] If peak demand outstrips supply, blackouts occur or consumers are asked to conserve. However, if consumers are exposed to real-time energy prices, peak demand growth could slow relative to energy. This is because it is expensive to provide large amounts of power for only a few hours of the year, and real-time prices would result in higher bills for consumers who use power during peak periods. Our research shows that consumers exposed to real-time price signals will shed certain loads to avoid this higher cost of power, thus reducing peak demand. We will look at the potential for peak demand reductions in greater detail in the section, "Price-Responsive Demand."

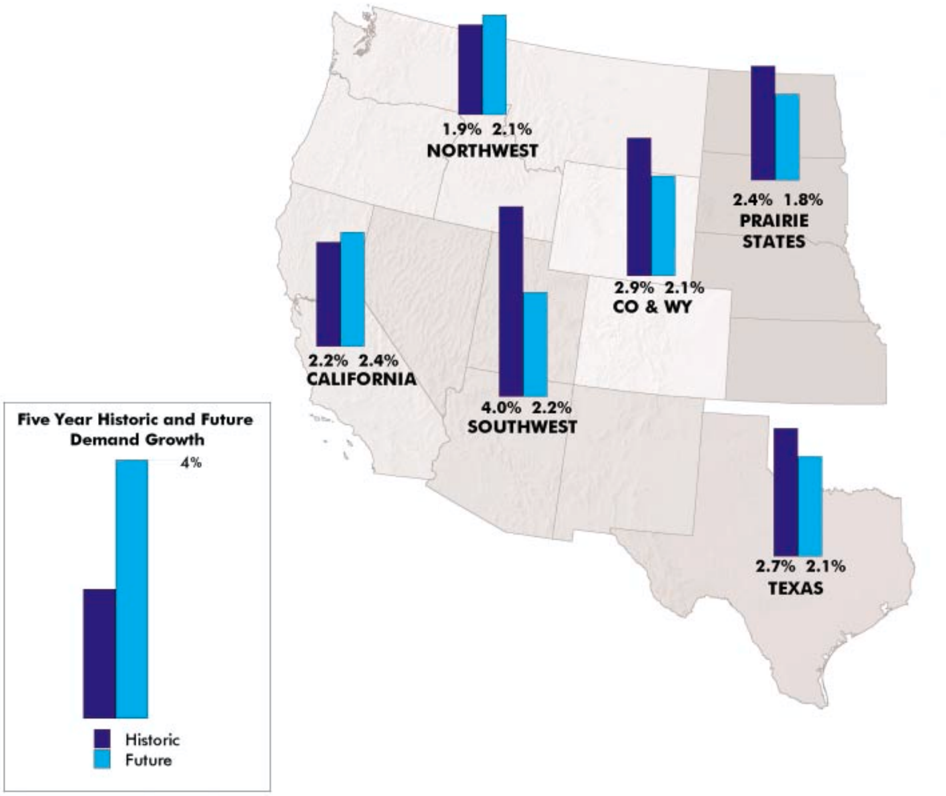
Demand for Power Growing

RDI Consulting's forecast of future demand is slightly lower, but close to historical levels, except for the Southwest, where we expect a substantial slowdown in demand growth. Exhibit 4 shows the five-year historic and forecast demand, which has been adjusted to account for the effects of weather and has been revised downward to account for the higher prices in California and adjacent states in 2001.

This forecast represents RDI Consulting's base case forecast, which makes certain assumptions about population growth and future economic activity. The regional growth rates in Exhibit 4 were created from state-level data, which are provided in the "State-by-State Appendices."

In Exhibit 5 we show the forecast energy demand growth by region for the next 10 years. By 2010 western energy demand is expected to grow by 23% from 1,092,160 gigawatt-hours (GWh, that is, thousands of megawatt-hours) in 2001 to 1,333,945 GWh in 2010.

Exhibit 4: Five-year Historic and Forecast Demand Growth



SOURCE: RDI Consulting, POWERmap

Exhibit 6 shows RDI Consulting's base case forecast peak demand,[9] which is growing at the same rate and by 2010 is expected to have increased by 45,091 MW to 248,518 MW.

Exhibit 5: Energy Demand Forecast by Region, 2001-2010

Region	Energy Demand (GWh)					
	2001	2002	2003	2004	2005	2010
Northwest	207,693	211,499	215,608	219,753	225,496	254,148
CO and WY	58,174	59,728	61,321	62,405	63,614	69,485
California	266,883	272,064	277,601	283,704	292,174	337,635
Southwest	133,487	137,074	140,784	143,265	146,072	162,629
Prairie States	87,637	89,461	91,221	92,901	94,473	100,976
Texas	338,285	345,635	352,904	359,261	367,263	409,072
TOTAL	**1,092,160**	**1,115,462**	**1,139,439**	**1,161,290**	**1,189,092**	**1,333,945**

SOURCE: RDI Consulting
NOTE: Base case forecast. Gigawatt-hours are a thousand times megawatt-hours (MWh).

Exhibit 6: Peak Demand Forecast by Region, 2001-2010

Region	Peak Demand (MW)					
	2001	2002	2003	2004	2005	2010
Northwest	29,637	30,180	30,766	31,357	32,177	36,265
CO and WY	9,782	10,043	10,311	10,493	10,696	11,684
California	52,805	53,830	54,926	56,133	57,809	66,804
Southwest	28,311	29,072	29,859	30,385	30,980	34,492
Prairie States	16,920	17,272	17,612	17,936	18,239	19,495
Texas	65,973	67,407	68,824	70,064	71,625	79,778
TOTAL	**203,427**	**207,803**	**212,297**	**216,369**	**221,527**	**248,518**

SOURCE: RDI Consulting
NOTE: Base case forecast.

The Drivers of Growth

Since the 1991 recession, annual growth in U.S. gross domestic product (GDP) has averaged about 4%. During the same time period, annual electric demand growth has averaged about 2.7% nationwide. The consensus among economists is that real GDP growth will be slower by an average of 0.5% to 1.0% through 2005. A slower U.S. economy will mean lower economic activity in the West and lower demand for western goods and services.

In the short term, RDI Consulting believes that an economic slowdown will not have a substantial impact on electricity demand growth, although the impacts will vary with regions. A prolonged economic slowdown, however, will have a more substantial impact on demand as structural shifts in the economy and population migration occur. Economic activity and population growth continue to be the most important drivers of electricity demand.

The Dampening Effect of High Prices

We might expect that higher energy prices would result in lower electricity demand. History, however, may not provide as much insight as required to determine the impact of retail prices on electricity demand. This is primarily because retail customers do not in general get price signals at or near the time that they consume electricity. Their signal is the bills they receive for electricity consumed in the previous month. Thus, price elasticity for electricity is relatively hard to determine. We can, however, use observed rates of conservation as a proxy.

Not since the 1970s have consumers experienced rapid price increases of the magnitude experienced over the past year. Substantial reductions in demand are indicated from data from California, because price increases were allowed to be passed through in the retail electricity rates, as well as from anecdotal evidence of companies and private consumers, whose actions will continue to cause substantial drops in electricity demand. Some of these drops may reflect the "crisis mentality" that was spurred by the California energy crisis, but some changes are destined to be long term. For example, hotels that replaced incandescent light bulbs with capital cost-intensive low-energy light bulbs are unlikely to switch back.

Procedures that companies developed in California during 2000 and 2001 to save energy and that turned out to be little more than a change in routine are also likely to stay. This is because even with normal electricity prices, these energy savings translate into improvements in the bottom line of businesses. If the economy should slow more than expected, companies will continue seeking to cut their costs, and conserving electricity is one way to accomplish this. However, not enough data are available to know what the long-term impact of the California energy crisis will be.

Computers, the Internet Not Driving Demand

RDI and its sister organization E SOURCE, which specializes in end user demand, can garner no evidence that computers and the Internet have spurred, or will spur, demand growth. If anything, the digital economy seems to have resulted in higher energy efficiency as measured by the relation of energy consumption to GDP. That is, fewer kilowatt-hours (kWh) today are consumed for every dollar earned than ever before. Previous analyses performed on the subject, suggesting that, in 1998, 13% of total U.S. electricity consumed went to powering Internet-related activities,[10] are no longer considered to reflect actual experiences.

Researchers at the Lawrence Berkeley National Laboratory (LBNL) in California have shown that computers and the Internet consume at most 3% of U.S. electricity demand.[11] Statistics by the Department of Energy's Energy Information Administration (EIA) support the conclusion by LBNL.

A large portion of the energy consumption by the Internet in previous analyses was based on the power demand of server farms—also known as Internet hotels. Research, however, shows that these server farms will add only 1,500 MW of incremental demand between 1998 and 2003 nationwide, or less than an average of 300 MW a year. Even if this entire load were located in the West, it would constitute less than 6% of the total demand growth—a rather small impact that could be more than compensated for by the observed higher energy efficiency of the digital economy.

In summary, population growth and economic activity remain the classic drivers of demand. However, in the future, price-responsive demand may result in significant reductions of peak demand due to load shifting. Higher electricity prices are expected to dampen overall energy demand. With its emphasis on service industries and increased electronic traffic, the digital economy coincides with a reduction of electricity demand growth, not an increase.

Reserve Margin Requirements

The target reserve margins used in this analysis are the reserve margins at which we expect that new power plants would earn an adequate return on capital and that consumers would obtain the level of reliability they are willing to pay for. At reserve margins higher than the target, we expect prices to fall to levels that do not provide adequate return on new investment (absent regulatory intervention), while at lower reserve margins, generators could receive above-average returns. They are not the actual reserve margins in the region or the reserve margins required by the system operator, regulator, or NERC region.

RDI Consulting's regional target reserve margins reflect certain assumptions about the availability and reliability of power plants, required levels of operating reserves, hourly load profiles, weather patterns, and the value consumers attach to reliability. For example, in the Northwest, where hydro dams account for 77% of all the installed generation in the region, required reserve margins are higher than in regions with lower dependence on hydro. Because of the dominance of hydro in the Northwest and the fact that demand peaks in the winter (when hydro generation is limited), the target reserve margin would have to be even higher than the 29% shown in Exhibit 3 in order to provide adequate reliability absent an interconnection. However, the Western Interconnection allows power exchange and thus overall lower reserve margins.

Going forward, the construction of large amounts of gas-fired combined cycle plants, which are expected to have higher reliability than existing fossil plants, could mean that lower reserve margins could provide the same reliability as we have today. In addition, if regulatory practice were changed to allow price-responsive demand, this could result in significant load shifting, which would reduce peak demand and thus allow for lower installed capacity as well as lower reserve margins. A lower reserve margin could result, because meeting peak demand could become less essential due to the responsiveness of load.

On the other hand, demand for higher power quality for electronic devices could put upward pressure on reserve margins. Overall, consumers may demand a higher power quality than in recent history—but certainly not at the level demanded by server farms. This is because power quality comes with a cost, and the value of 99.9999% power reliability to consumers is likely to be much lower than thought. Server farms will meet their power quality needs internally. And, as computers become more portable in the form of battery-powered laptops or personal digital assistants (aka PDAs) and less dependent on instantaneous availability of grid power, power quality may not be that important.

The Need for Large Amounts of Capacity Additions

Existing Resources

As of 2001, a total of about 237,078 MW of capacity was installed in the West.[12] Exhibit 7 shows the capacity mix in each region. The West is characterized by large amounts of gas- and coal-fired capacity, which account for 24% and 44%, respectively, of the electricity generated. That is, over two-thirds of western electricity is derived from fossil fuels.

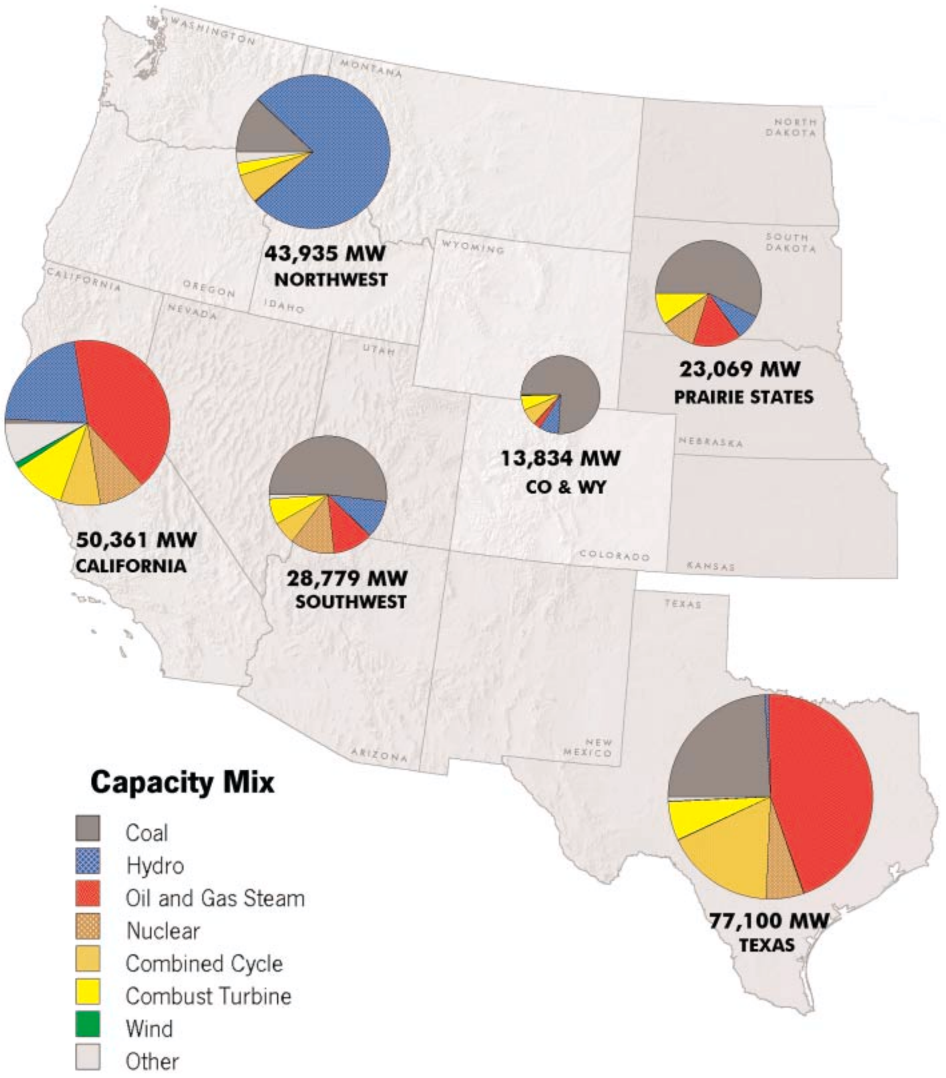
Overall, hydroelectric capacity accounts for 22% of the capacity and 18% of the generation in the states of the WGA. This is because the large amounts of hydro capacity in the Northwest are offset by virtually no hydro capacity in Texas—the largest load region in the West.

The nuclear plants in the West account for 7% of the capacity and 11% of the electricity generated. Generation from other sources amounts to 2% of all generation in the West, of which about 1.5% comes from non-hydro renewables. Great differences in the generation mix exist across the various regions, as can be seen in Exhibit 7. The generation in GWh by fuel type in the West for 2001 is shown in Exhibit 8.

The large amount of hydroelectric capacity in the Northwest provides power to California and the Southwest, but increasing demand in the Northwest and recent low hydro conditions have resulted in less hydro capacity available for exports to the south than in the past. California is unique among western states in that it relies on imports from other states for a significant portion of its power needs and that the state has practically no low-cost coal-fired generation. In contrast, generation in Colorado and Wyoming is dominated by coal with over 75% of the capacity.

The Colorado and Wyoming region is the only area that has no nuclear capacity. One nuclear project, Fort St. Vrain in Colorado, retired prematurely because of high maintenance costs and has recently been repowered as a natural gas-fired combined cycle plant. The presence of a low-cost supply of natural gas has made Texas a leader in gas-fired power plant development. No other region in the West, indeed the country, has as much generation coming from modern gas-fired combined cycle plants as the Lone Star state.

Exhibit 7: Capacity Mix in 2001, by Region



SOURCE: RDI Consulting, POWERmap

Note: Hydro capacity has been derated to average capabilities during summer peak demand. Wind power capacity has been derated by 70%.

Exhibit 8: 2001 Generation by Fuel (modeled)

Fuel	GWh
Coal	482,226
Oil and Gas	259,604
Nuclear	124,306
Hydro	199,400
Other	26,625
TOTAL	1,092,161

SOURCE: Interregional Electric Market Model (IREMM) and RDI Consulting

NOTE: Hydro generation re-normalized to average weather conditions

The only meaningful amount of non-hydro renewable generation as a percentage of total supply is found in California, where about 1,750 MW come from wind farms, 354 MW from thermal solar power plants, and 2,595 MW from geothermal generation. Texas also recently saw large amounts of new wind capacity installed in response to requirements of the state's renewable energy portfolio standard.

Nevertheless, aside from the large amounts of hydro capacity in the Northwest (and some in California), renewable energy sources play a small role in western energy supply. Increasing the share of non-hydro renewable energy sources will require a conscious effort on the part of the western states. As we will show later, wind and solar appear to be the primary sources of renewable energy available in the West. Fortunately, the West has large amounts of both.

Current Power Plant Development

For a decade, little new generating capacity was built in the U.S. and the West, and the excess generation capacity created in the 1970s and early 1980s began to shrink. This was due to:

- the Arab oil embargo during the 1970s;
- the resulting extremely high inflation that caused significant increases in the costs of power plants then under construction;
- the rise of environmental awareness after Earth Day in 1970;
- the passage of the Fuel Use Act, which prohibited the use of natural gas as a fuel for new power plants;
- the accident at Three Mile Island, which significantly increased the cost of new nuclear generation;
- the passage of the Public Utility Regulatory Policies Act (PURPA); and
- the unwillingness of state regulatory commissions to allow utilities to recover the cost of their investments in new power plants.

These historical events all combined to reduce utilities' willingness to build additional generation. By the middle of the 1990s, it became clear that new generation would be needed to meet new demand, which had continued to increase due to population growth and the longest economic expansion in U.S. history.

With the passage of the Energy Policy Act in 1992, it became clear to utilities that deregulation appeared to be the future for the industry. And as deregulation was originally conceived, one of the features was that utilities might be required to divest themselves of their generation.

Because the risk of building new generation had become so high, with cost recovery increasingly uncertain and because non-utility generation in the form of independent power production was encouraged by PURPA, utilities essentially ceased construction of new power plants. IPPs were now building the large majority of whatever power plants were being built.

IPPs had been building and operating primarily cogeneration facilities and were familiar with combined cycle power plants. At the end of the 1990s turbine manufacturers had excess turbine production capacity because of the slump in new plant construction. The IPPs and turbine manufacturers realized that, with the low natural gas prices at the time and rock-bottom prices for turbines, combined with the efficiency advances and the ability to burn natural gas in power plants again, gas-fired combined cycle plants had come of age. Fast and cheap to build, cleaner than any other fossil fuel plant, and at $2 to $3 per million Btu (mmBtu) gas prices, gas-fired power plants were now the fossil-fired power plant of choice.

Today nearly 90% of all new capacity is built by IPPs—a result of the conditions of the 1970s and 1980s and associated legislation. With few exceptions, all IPP capacity runs on natural gas.

The first IPP projects were built in California in the 1980s encouraged by attractive power purchase agreements (PPAs), primarily in the form of what were called Standard Offer 2 and Standard Offer 4. Later, IPPs became active in the Northeast and in Texas. Both areas jumped into electric industry restructuring by allowing retail competition. This allowed wholesale generators to sell electricity to marketers, instead of to utilities, which, in turn, were now able to market the power directly to retail customers. The presence of high-cost utility generation in both regions created an opportunity for generators to win market share from the incumbent utilities. In the Northeast, the expectation of low-cost Canadian gas further encouraged the development of gas-fired IPP generation. In Texas, easy access to natural gas supplies and favorable permitting rules made the state one of the most popular development areas. Large amounts of capacity were proposed and built in the state—so much indeed that today Texas has more generating capacity than it needs.

Obstacles to construction of new power plants, whether by utilities or IPPs, include: markets that limit prices to levels below the cost of building new capacity; significant uncertainty about what rules and regulations will be in the future; and opposition to construction by local communities. In most regions of the country, these obstacles have not been significant enough to slow the pace of power plant development. In California, however, each of these factors was present and the result was a hiatus in plant construction at levels commensurate with the increase in demand. This and other factors, such as low hydro generation in the Northwest, a hot summer, and gas-pipeline transmission congestion, created the supply shortage that became the California energy crisis.

In Exhibit 9 we show the technology mix of new western power plants that began operation in 2001, are currently under construction, or are forecast to come on-line in the future. The map in Exhibit 10 shows all power plants proposed in the West since the beginning of 1999.

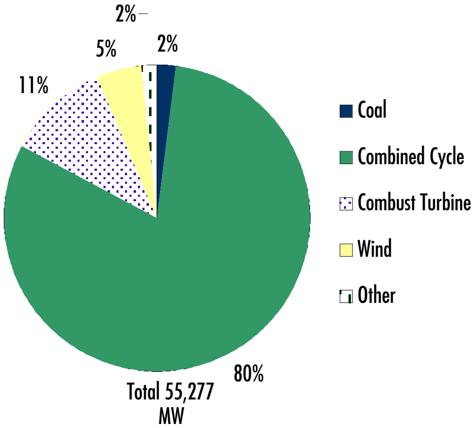
Independent Power Producers and Renewable Energy

Today, the state of California and the rest of the West understand that an economic and regulatory environment needs to be in place that allows for the construction or refurbishing of power plants. The question that remains is: What degree of interest do the governments of the western states have in the resource mix? The love affair of IPPs with gas-fired generation has its reasons. Currently, based on environmental and economic considerations, gas-fired power plants, even at considerably higher forecast natural gas prices, are the most rational answer to the question of what conventional power plant to build in many states, except possibly those with large coal reserves, including Colorado, Montana, New Mexico, and Wyoming.

IPPs, who are unregulated, contrary to the traditional utility, have not only embraced the combined cycle power plant as the cleanest fossil fuel generating technology, but will also bring on-line nearly all of the 1,229 MW of wind power in 2001. In the West, 5% of all new capacity additions are forecast to be wind power.

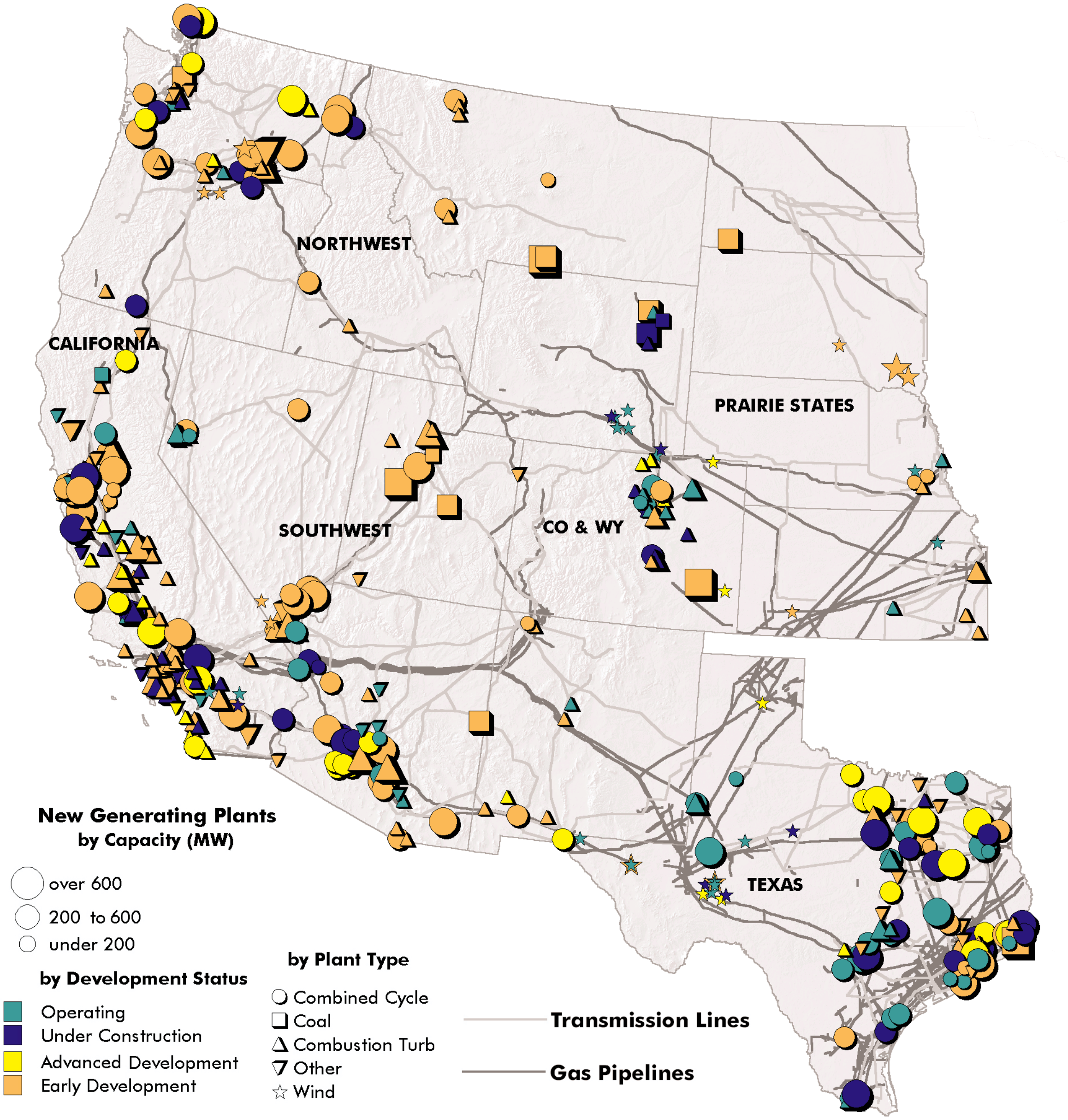
IPPs are looking at all generating technologies, from gas to coal to renewables. If the public, policy makers, and regulators want to create more fuel diversity and desire renewable energy generation as a large contribution to western energy supplies, then regulatory certainty, tax incentives, and other measures need to be put in place. With the proper economic incentives, IPPs will seize the opportunity and build.

Exhibit 9: New Capacity that Began Operating, Is Under Construction, or Is Forecast to Come On-line by 2005



SOURCE: NEWGEN, RDI Consulting

Exhibit 10: New and Proposed Capacity by Plant Type and Development Status



SOURCE: RDI Consulting, POWERmap

For example, Texas is way ahead of schedule in meeting its renewable energy portfolio standard due to faster-than-expected wind power development by IPPs. And a strong response from the U.S. wind energy industry to a request for proposals by the Bonneville Power Administration seeking 1,000 MW of new wind power in the Pacific Northwest resulted in 25 proposals, totaling about 2,600 MW. Further, the proposals included room for expansion of the projects to a total of 4,000 MW.

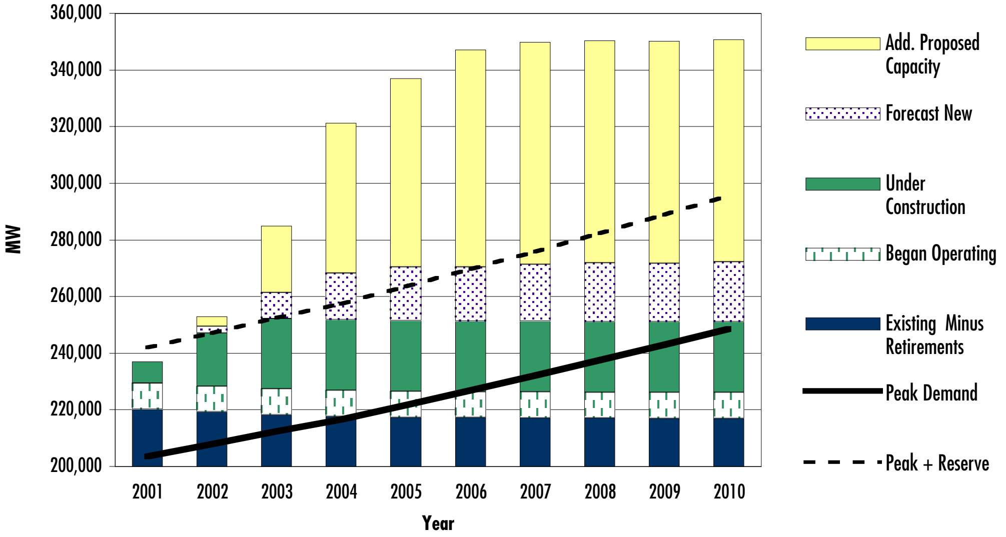
It is our view that IPPs are competent and innovative developers who can, and will, play an active role in the deployment of renewable energy projects, such as wind and solar. If economic incentives can be properly structured, IPPs could provide enormous momentum for renewables deployment. The western states must provide tax or other economic incentives and ensure a stable regulatory environment for renewables, in order to enable IPPs to build wind and solar projects, if the policy goal of a more diversified energy portfolio with a greater use of non-hydro renewables is to be met.

New Plants to Meet Future Demand

RDI's NEWGen database, which tracks power plant development, reveals an explosion of new projects in the West totaling 133,747 MW by 2010. Clearly, not all of these proposed power plants will actually reach completion. In order to arrive at a forecast of expected power plant additions, RDI Consulting built a detailed probability-based forecast model, which applies probabilities to specific units based on the unit's status (proposed, early development, advanced development, sure development, or under construction), region, and technology. For example, projects in the advanced development stage receive a higher probability of completion than those in early development. Similarly, projects in a region with a great number of competing projects receive lower probabilities than those in a region with few competing projects. Furthermore, based on our understanding of construction timelines, delay periods based on technology type are included in the model. Dates of successful projects slip according to the delay period probability distribution. The model also accounts for projects with more than one phase—subsequent project phases that depend on a prior phase can only occur if the model determines that the prior phase is successful.

Exhibit 11 shows the year 2001 and future demand and supply balance in the West. In summer 2001, 9,201 MW of new plants commenced operation in the West and 24,915 were under construction. An

Exhibit 11: New Generating Capacity Required to Meet Future Demand in the West, 2001-2010



additional 99,631 MW of capacity is proposed and our model forecasts that, of this, 21,161 MW will eventually be built. How much of the additional proposed capacity will come on-line depends in great measure on the retirements of existing generation and overall wholesale market prices.

Some areas, in particular California, have an aging fleet of power plants that are approaching the end of their operating lives. The power plant sites on which they sit are quite valuable, and in many cases repowering of these power plants has been considered, or in fact, undertaken. Retirements or repowering will be driven by both economic and environmental considerations. Exhibit 11 includes a number of retirements that have been announced, but more retirements during the next decade are likely. Incremental opportunities for cogeneration projects and tax incentives for certain power projects, particularly renewables, could result in capacity additions beyond our forecast.

Nevertheless, under our base case scenario, by 2010 an additional 23,000 MW of generating capacity beyond the 55,277 MW expected[13] by RDI Consulting to come on-line by 2005 (see Exhibit 9) has to be built to meet expected demand growth.

It is, however, clear from Exhibit 11 that developers, marketers, and capital markets have responded to power shortage conditions and are rapidly building new plants that will provide customers with a reliable supply of electricity. New power plants are getting built in markets with regulated reserve requirements (such as the installed capacity, or ICAP, obligations in the NERC reliability regions New York or PJM) and in markets with no required reserve requirements (such as California). They are getting built in regions with independent system operators (ISOs) and in regions without ISOs. New power plants are even getting built in markets with significant regulatory risks and significant permitting and environmental hurdles. Developers are responding to the needs of the power markets, whatever the structure.

Nevertheless, a minimum of regulatory certainty must be in place. For example, unless California recovers quickly from the debacle of spring 2001 and begins attracting power infrastructure investments through a predictable regulatory framework, the state could be headed into another crisis just a few years down the road. In our work with developers we are seeing companies hesitating to enter the California market because of the looming uncertainty. This is becoming a bigger factor relative to local opposition and environmental constraints as the real reason why capacity does not get built.

Residential Users Affected by Rising Demand

Residential customers that use natural gas will be increasingly confronted by rising and more volatile gas prices due, in large measure, to the growing demand for natural gas by electric power generation. In 2000, of the total U.S. consumption of 22.7 trillion cubic feet (Tcf) of natural gas, about one-fifth, or 4.9 Tcf, was attributable to residential use. Power generation accounted for 9.3 Tcf. Natural gas use by power plants has accelerated significantly since 1950.

In 1950, power generation accounted for a little over 10% of natural gas consumption, but by the end of 2000 it had quadrupled to 40%, while the share of residential use held constant. Natural gas consumption by IPPs grew from 2.5 Tcf in 1999 to 3.0 Tcf by the end of 2000 and is poised for a significant increase in the coming years when over 80,000 MW of new gas-fired IPP generation is expected to come on-line in the U.S.

It is clear that power generation is competing for an increasing share of North America's natural gas supply. Coupled with a pipeline infrastructure that is old and out of capacity, a tug-of-war between power generation and traditional gas users is unavoidable. We predict that this will result in greater market volatility and the potential for upwardly spiraling gas prices. It appears that the greatest price volatility will not come from increasing wellhead prices, but from high transportation costs on pipelines. However, transportation costs are a point where a regulatory commission could exact control in an effort to mitigate gas price volatility.

Changes in the way the natural gas market operates, and how fast and efficiently market participants embrace such changes, will determine the level of price and attendant volatility that residential customers could see on their energy bills in the future. An important factor in the California energy crisis was the limit on natural gas pipeline capacity and how that limit allowed natural gas prices to spiral out of control.

Energy Conservation Can Help

The enormous electricity savings achieved in California this summer have shown that energy conservation is indeed real and that it can amount to much more than good will. Corporate and private measures to conserve energy reduced both energy and peak demand in the state: During the months of June through August 2001 peak demand was on average 11% below the year 2000 levels and energy consumption was 8% lower. If these data are adjusted for growth and weather, the savings are even bigger. While the beginning of the summer was relatively cool, August 2001 was warmer than average and California's energy conservation measures were put to the test: the Golden State passed.

California has now proven that the call of society and policy makers for reductions in electric energy consumption will be answered if it is loud and clear enough and if consumers understand that forgoing the use of electricity will yield significant results and no blackouts. Savings in electricity consumption can relate to both savings in energy and reductions in peak demand. Both have very positive impacts on reliability and the price of electricity. In the next sections we will discuss energy efficiency and reductions in peak demand.

Energy Efficiency

In 1998, the residential sector used 1,122,000 GWh of electricity, or 35% of all the electricity consumed in the United States. Sixty percent of that consumption was due to appliances, such

Exhibit 12: Household Appliances Certified with the Energy Star Significantly Reduce Residential Energy Consumption

Appliance	Existing U.S. Avg. (KWh/year)	New Energy Star (KWh/year)	Annual Energy Savings (%)
Refrigerator	1,141	620	46%
Clothes Washer	1,018	416	59%
Dishwasher	611	555	9%
Computer	262	115	56%
Television	307	154	50%
VCR	60	46	23%
Rack Stereo System	87	67	23%

SOURCE: *End-Use Data and Market Trends*, E SOURCE, 2001, and National Renewable Energy Laboratory, private communication.

as refrigerators, washers, dryers, and televisions. Although the penetration of most appliances in U.S. households is very high (for example, over 90% of all households have a microwave) or saturated (every household has at least one refrigerator), population growth and a shift to smaller households will increase the overall number of appliances. This increase in the number of appliances can be expected to result in greater energy consumption. However, this does not necessarily have to be so, as the example, below, of refrigerators and freezers shows.

Driven by federal standards, the efficiency of the U.S. stock of refrigerators and freezers is improving so dramatically that, despite population growth and a modest increase in penetration (more than one refrigerator or freezer per household), the Energy Information Administration projects a reduction in refrigerator and freezer electricity consumption to 25% below 1998 levels by 2010 and 30% by 2020. Energy efficiency can make a contribution to meeting our energy needs.

In Exhibit 12 we show the estimated average annual energy consumption of selected U.S. household appliances and compare their consumption to energy use of products labeled with the Energy Star, denoting the products are designed for energy efficiency. Exhibit 12 shows that large energy efficiency gains are possible for nearly every common household appliance.

Price-Responsive Demand

As the Governors' Energy Policy Roundtable on February 2, 2001, concluded, sending more timely and accurate price signals to consumers is key to realizing energy efficiency's potential, managing peak load, encouraging distributed generation, and lowering the overall cost of electricity.

Over the last two decades, energy and peak demand growth have grown approximately in proportion. In the late 1990s, however, peak demand growth accelerated over energy demand, which some believed was caused by changes in electricity usage. Evidence to support this theory is weak, and higher-than-normal temperatures in many regions of the country at the time appear to be the more likely reason why peak demand reached unprecedented levels. The most recent demand figures reflecting more moderate weather have confirmed our view that peak and energy demand still grow essentially in parallel.

During the few hours of peak demand each year when electricity demand reaches its highest levels, and wholesale power price spikes have become fairly common, utilities have curtailed their interruptible customers and issued more notifications to consumers to reduce their electricity consumption. With the changing market, especially the wholesale power price spikes, utilities are more concerned than ever before about reducing the peak demand levels.

With the advent of the Internet, and other new technology, voluntary load reduction (VLR) programs are becoming increasingly efficient to implement and administer. Participants in VLR programs, which have been in existence for well over 20 years, are financially rewarded for forgoing power consumption during high-demand periods. However, many interruptible customers who were turned off for the first time in 2000 or 2001 are finding that they preferred the days when their service was not interrupted.

If VLR programs can penetrate energy markets to the point that they have a sizeable effect on peak demand, the traditional relationship between peak and energy demand growth could be severed. This would result in higher load factors for the electric system. Higher load factors in turn could allow the level of reserve capacity to decline from current levels.

Resource Options for the Future

Technological advances, availability of equipment, low capital and production costs, and favorable environmental performance currently make natural gas-fired combined cycle power plants the leading generating technology of choice for utilities and IPPs. Even with higher natural gas prices forecast over the next decade, gas-fired generation appears to remain competitive against its direct rival, coal. Only significantly higher than forecast natural gas prices, an inadequate building of needed pipelines, issues about fuel diversity, and concerns about reliability of supply could threaten gas' dominance.

Policy makers and regulators will want to influence the selection of future energy resources. Environmental considerations, including regional haze, ground level ozone, or particulate matter (such as at 2.5 microns, $PM_{2.5}$) are concerns, as well as an energy supply that hedges against fuel price volatility and improves national security by using domestic sources of energy. Providing adequate energy resources for western states is good public policy, as important as public health or clean water. To make good choices, legislators must understand the full range of western energy resource options.

The West is approaching a point where the limits of its natural resources become visible. This is certainly already true for western water. While coal and natural gas reserves remain large, and somewhat of a moving target, we estimate that, at current consumption of 7,968 billion cubic feet per year, proven and likely western gas reserves will be depleted in 70 years, unless better development and production technologies can increase the yield of wells or natural gas is imported by pipeline from Alaska, Canada or Mexico or as liquefied natural gas (LNG) from other countries. Oil resources in the Lower 48 states are beginning to show signs of declining production and new deep-water natural gas wells in the Gulf of Mexico are depleting faster than historically had been the case, which may require increased drilling activity. This is in the face of an ever-increasing demand for energy.

In the first half of the 20th century western states were faced with a different resource challenge: how to supply adequate amounts of water. The result was the Colorado River Project, which culminated in the construction of the Hoover and Glen Canyon dams. Today, western states are assessing how to meet the West's future energy needs. The President's National Energy Policy[14] has provided some ideas in this regard, but western states will need to find a solution that reflects their resources, geography, and the expectations of their people. In this section we will provide an overview of western energy resource options, which will be discussed in greater detail in Chapter 7, "A Closer Look at Energy Resource Options."

In Exhibit 13 we provide estimates of the energy potential of the five most important future western energy resources: coal, gas, hydro, wind, and solar. We have not included nuclear generation in this summary table, because it is our view that in the near and intermediate term no nuclear facilities will be built in the West. We further believe that biomass will only play a small role in meeting future western energy supply, because resources appear to be insufficient in relation to western energy needs. For geothermal generation, RDI Consulting found no adequate information that would allow an estimate of the geothermal energy potential and for that reason could not quantify this renewable energy. Nevertheless, where available, geothermal energy is an excellent source of power, because of its relatively low cost and high value in the market due to

Exhibit 13: An Overview of Western Electric Resource Options and Their Energy Potential

	2001 Demand/Emissions	Maximum Use of Resource				
		Natural Gas	Coal	Hydro	Wind	Solar
Proven and Likely Economic Reserve		577,222 Billion Ft3	123,479 Million tons	N/A	N/A	N/A
Peak Demand/ Capacity (MW)	203,428	203,428 (1)	203,428 (1)	50,870 (2)	282,506 (3)	1,040,248 (4)
Heat Rate (HHV) mmBtu/kWh		7,100	9,500	N/A	N/A	N/A
Capacity Factor %, Min-Max (5)		61.3-80	61.3-85	44.8	25-45	20-25
Energy (GWh)	1,092,160	1,092,160	1,092,160	199,400	930,455	2,098,433
Depletion at 2001 Demand (years)		42 (6)	215	Indefinite	Indefinite	Indefinite
Air emissions (000) tons/year	Actual	Using Best Available Control Technologies (BACT) (7)				
NO_x	1,045	115	830	None	None	None
SO_x	1,283	5	882	None	None	None
CO_2	658,000	453,246	1,054,153	None	None	None

SOURCE: RDI Consulting

NOTE: Assumes current technologies for resource recovery and energy production.

(1) Capped at 2001 western peak demand of 203,428 MW.

(2) There is little additional hydro generating potential in the western states above current levels.

(3) Source: RDI Consulting analysis, see section, "Wind"

(4) Source: RDI Consulting analysis, see section, " The Solar Energy Potential."

(5) For fossil fuels, the minimum capacity factor is based on 2001 energy demand. For typical capacity factors of generating technologies, see Exhibit 36.

(6) Accounts for natural gas used for residential and industrial at 2001 consumption.

(7) For details, see Exhibit 15

the ability to dispatch the plants. Hydro generation was included in the exhibit, because it is currently the only important renewable source of energy in the West, and it is interesting to compare its capacity and energy production to that of solar and wind.

The idea behind Exhibit 13 is to show how much energy demand each energy resource could meet if it were used exclusively to produce all the electricity in the West. For natural gas and coal, we have also calculated the number of years this resource would last until it was depleted based on current resource estimates. Further, for both fossil fuels, we show the air emissions impact the full use of this resource would have compared to actual 2001 emissions from western power plants. Even though this exercise is hypothetical, it is nevertheless insightful.

Fossil Fuels

With oil production almost exclusively reserved for transportation and the chemical industry, natural gas and coal remain the only fossil fuel resources available for electric power generation in the West. Natural gas is mainly found in Texas and along the Rockies. Coal, the most abundant fossil fuel, is found in many western states. The most important coal region is the Powder River Basin, which straddles Wyoming and Montana.

According to our hypothetical estimate, 42 years of gas would be available if all western gas (base on the aforementioned estimate and reduced by the percentage currently used for industry and residential use) were used for power generation. Using the best available control technology (BACT), actual air emissions in the West would drop significantly because of the displacement of coal generation.

BACT would also reduce western emissions of sulfur dioxide (SO_2) and nitrogen oxides (NO_x) if all generation were to come from coal, but carbon dioxide (CO_2) emissions, a greenhouse gas, would increase by 60%. (See Exhibit 13.) In light of current climate talks, generation from coal is not likely to increase its share as a source of western energy, unless CO_2 emissions can be sequestered. According to our resource estimate, if all western electricity were generated from coal there are enough reserves to provide for 215 years of coal-fired generation until proven and likely economic reserves are depleted.

Hydro, Wind, and Solar

Hydro, wind, and solar are the important renewable energy resources in the West. Hydro's generating potential is fully developed and is thus limited to the current generation of 199,400 GWh, or one-fifth of western electric energy needs. Because the source of water in the West is primarily snowpack that melts in the spring, hydro generation exhibits an uneven pattern of generation over the course of a year, being highest in the spring and early summer. To meet one-fifth of western energy requires almost complete use of western hydro potential and comes with significant environmental costs. There may be opportunities for small hydro generation development, but those projects would add only minimal amounts of capacity to western generating capacity.

For both solar and wind, RDI Consulting conducted a detailed resource assessment that is described in the sections, "Wind" and "The Solar Energy Potential." Data from the National Renewable Energy Laboratory (NREL) and a geographic information systems (GIS) were used to estimate the western wind and solar potential. The GIS analysis discounted 90% to 99% of potentially available wind and solar resources, which already excludes urbanized areas, national parks and other areas not available for wind or solar power plants. We find that wind could provide, ideally, 85% of western energy needs, while solar has the potential to produce twice the amount of electricity consumed in the West in 2001. This surprising result supports the view that solar power may be the preferred renewable energy source in the Southwest, where, based on our analysis, wind resources are much smaller than the solar resources.

Western solar resources are potentially the best in the world and are almost exclusively found in the Southwest—with Arizona being the hot spot of solar power. Western solar resources are enormous. According to our analysis, 1,051,466 GWh could be generated by premium solar resources alone and would be commensurate with total western energy demand of 1,092,160 GWh (see Exhibit 24). Premium solar resource areas have the potential of over 480,000 MW of power, yet would occupy only about 0.2 % of western lands.

Wind potential in the West is also very large. Paradoxically, of all western states, California, the birthplace of wind power, has few wind energy resources available for development compared to other western states. Wind generating technologies were developed in the U.S. in the 1980s, but it was in Europe that wind emerged from a niche technology to become today's fastest growing generating technology. The U.S., including the West, is currently seeing an explosion of new wind farms. According to our analysis, there appear to be 282,506 MW of Class 4 and higher wind resources in the West, which could generate 930,455 GWh of electricity.

Nuclear

Nuclear energy from fission is an enormous source of energy. Fission, the process that we know as nuclear power today, is also the source of enormous controversy due to the inherent dangers in operating with and storing nuclear material. Given the current environment, we do not believe that new nuclear power plants will be built in the West in the next several years. Nevertheless, we believe that existing nuclear plants will extend their operating licenses where economically and technically feasible. If nuclear fusion could ever be used for power generation (the technology is still in its infancy), it would provide unlimited amounts of energy with little environmental impact. That day, however, is far off in the future.

Geothermal

Geothermal generation is another resource option for western energy supply. Unfortunately, geothermal resources are not as easily accessible as wind and solar, and questions about the resource potential remain. In the West, 3,276 MW of geothermal power plants operate, though new geothermal power plants are not currently being actively pursued. However, modern oil drilling techniques may soon be used to unlock more of the Earth's heat for power generation. Searching for economic geothermal resources could be a worthwhile energy policy goal.

Biomass

Generation from biomass remains a possibility for a sustainable energy future, but in reality the generation potential from biomass is likely to be limited. Unless biomass is a waste product from farming or forestry, the growth of "energy crops" would require large resources of arable land and water. Finally, while biomass generation is "carbon-neutral," it still causes emissions. For the above reasons, biomass will likely not play a large role for western energy.

If the western states want to increase the percentage of renewable energy sources, wind and solar power and, where available, geothermal generation are the only real choices. According to our analysis, solar power's resource potential is nearly three times that of wind. Further, as we show in this report, solar resources are located where electricity is consumed, while wind resources are much farther from metropolitan areas. The intermittence of these resources can be greatly overcome by a robust transmission system. And finally, the intermittence issue of solar generation can further be greatly mitigated using heat storage or fossil fuel hybridization, both of which are described in detail in the section "Using Supplemental Off-Sun Power." Western states are therefore encouraged to take a look at solar energy as a significantly promising renewable energy technology.

After this overview of western energy resource options, we will now look at emissions of existing power plants and the expected changes in emissions levels in our base case scenario.

Air Emissions from Existing and New Power Plants

Sixty-eight percent of western electricity needs are met with fossil fuel generation. In 2001, an estimated 44%, or 482,226 GWh of electricity were generated from coal, and 24%, or 259,604 GWh, were generated from natural gas or oil. Emissions from coal, natural gas, and oil-fired power plants are the main source of air pollutants from power plants in the West. Geothermal[15] and biomass generation contribute the rest, but only account for a small amount. In Exhibit 14 we show the projected NO_x and SO_2 emissions from western power plants in 2001 and 2010.

Exhibit 14: Air Emissions from Western Power Plants, 2001-2010, Base Case Forecast

Region	2001		2010					
	Total (000) Tons		Total (000) Tons		Change over 2001			
					(000) Tons		Percent	
	NO_x	SO_2	NO_x	SO_2	NO_x	SO_2	NO_x	SO_2
Northwest	69	114	66	63	-3	-51	-4%	-45%
CO and WY	149	165	145	186	-4	21	-3%	13%
California	18	–	9	12	-9	12	-50%	N/A
Southwest	272	191	258	150	-14	-41	-5%	-21%
Prairie States	210	270	230	294	20	24	10%	9%
Texas	327	543	175	384	-152	-159	-46%	-29%
TOTAL/AVERAGE	**1,045**	**1,283**	**883**	**1,089**	**-162**	**-194**	**-16%**	**-15%**

SOURCE: RDI Consulting
NOTE: Emissions based on RDI Consulting's base case demand and supply forecast.

Emissions for 2001 were based on the capacity mix during 2001 and were calculated using a plant dispatch model, called the Interregional Electric Market Model (IREMM). IREMM is a computer model that simulates electricity markets nationwide and dispatches generation to load on an hourly basis. Using plant-by-plant generation results and reported data on unit-specific emissions, it calculates the total emissions of NO_x, SO_2, and CO_2. From the data in Exhibit 14 we can see that in 2001 western power plants emitted an estimated 1.05 million tons of NO_x and 1.28 million tons of SO_2.

For the year 2010 we find that under our business-as-usual base case scenario, pollutant levels will decrease by about 15% for both NO_x and SO_2—despite the fact that power generation will increase by 23% over the same time period (see Exhibit 5). By 2010 western energy demand is expected to grow from 1,092,160 GWh in 2001 to 1,333,945 GWh.

The main reason for this trend is the replacement of older, less efficient generation by modern gas-fired power plants, as well as the installation of scrubbers, or the switching to lower sulfur coals, at coal-fired power plants in order to be compliant with regional haze reduction targets under the Western Regional Air Partnership (WRAP), especially in national parks (Class 1 areas). In addition, economic displacement of Gulf lignite in Texas with Powder River Basin coal may result in even lower emissions than forecast here.

Base Case Forecast

In our forecast, we have assumed a business-as-usual scenario, which is our base case. Under this scenario, we include all announced power plant additions and retirements that we believe are likely to occur, retirements of uneconomical units based on model results, as well as automatic additions of new capacity by plant type based on load shape, capital cost, and forecast fuel prices. Therefore, our base case scenario pictures an energy future that continues to rely heavily on natural gas and coal. We believe that this business-as-usual scenario provides a good reference point.

In the base case forecast, the retirement of less efficient units, the penetration of more natural gas-fired power plants, and further implementations of air regulations show that western air will receive less pollution (with the exception of CO_2) from power plants in 2010 than today. If renewable energy sources, such as wind and solar, were given an opportunity to make a substantial contribution to western energy, skies could be even clearer.

A Comparison of Emissions and Water Use

Most generation technologies require large amounts of water for cooling and plant processes. The exceptions are wind, photovoltaics (PV), and dish Stirling power plants, which are the only generating technologies that can produce electricity while using practically no water. Biomass and fossil fuel combustion produce air emissions, while hydro, solar, wind, and nuclear generations are emission free; geothermal generation releases small amounts of emissions. Supplying power puts great strain on our water resources and pollutes our air. The next two sections on air pollutants and water use compare the environmental impact of various power generation technologies on these resources.

Air Pollutants

Power generation from fossil fuels is one of the biggest sources of air pollution in the western states. In 2001, western power plants emitted an estimated 1,045,000 tons of NO_x and 1,283,000 tons of SO_2. 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.[16]

In addition, generation from fossil fuels is the major source of CO_2 emissions in the West. Nationwide, 40% of all CO_2 emissions are estimated to originate from power plants; the percentage for western states is similar. The Kyoto Protocol, to which the U.S. has decided not to become a party, would have required the U.S. to reduce CO_2 (or equivalent pollutants) by 7% below 1990 levels by 2010. If the power generation sector were to meet this goal on its own, today's CO_2 emissions of 658 million tons would have to be reduced by 143 million tons, or 22%.

In Exhibit 15 we show the air emissions of NO_x, SO_2, CO_2, and particulates by generating technology. This table makes it clear that coal-fired power plants, even when using the most efficient boilers and BACT, are still the biggest polluters. A gas-fired combined cycle plant, for example, emits less than one-half the amount of CO_2 than a state-of-the-art coal plant does. This is because of the lower efficiency of the steam cycle of a coal plant in comparison to a combined cycle and the chemistry of the coal combustion process, which contains more carbon atoms per unit of heat. Gas boilers and combustion turbines are less efficient methods of producing electricity from natural gas than combined cycle technology, as indicated by their higher heat rates.

Nuclear, hydro, wind and solar power produce no air pollution and geothermal generation produces very little. Replacing coal-fired power plants with gas-fired generation can already provide a great deal of emission reductions. In our base case we assume that such a displacement of coal with natural gas and the construction of more efficient coal plants will reduce western NO_x and SO_2 by about 15% over the next decade. However, this trend would still result in a net increase of CO_2 emissions by 13.4% (See Exhibit 15).

Only if gas-fired combined cycle plants were to displace even greater amounts of coal-fired power generation in the West, as forecast by our business-as-usual base case, could western power plants on their own meet the goals of the Kyoto Protocol. Today, western coal plants emit up to three times the carbon of a new combined cycle plant, and replacing 1 MW of coal with 1 MW of combined cycle would reduce carbon emissions by about one-third (assuming the two plants would operate at the same capacity factor). However, it is not certain that enough natural gas could be produced at a price competitive with coal to make such a displacement scenario possible.

In addition, with increasing demand for natural gas by power generators, gas prices will likely become more volatile, thus resulting in unstable power prices. This market instability may tilt the scale more toward renewables, which provide a hedge against volatile fuel prices. The California energy crisis has shown the value of such hedges, where, for example, the parabolic trough solar plants in the Mojave Desert continued solar electric generation at the contracted, fixed cost despite the high natural gas prices in California at the time.

Nuclear and renewables emit neither CO_2 nor other air or water pollutants. As discussed elsewhere, new capacity from nuclear and hydro is unlikely in the current environment. Solar, wind, and geothermal are therefore the only realistic alternatives for zero-emissions technologies.[17] Given the easy access to solar and wind, and the vast amounts of resources, these types of renewable generation emerge as the West's best alternative to drastically reduce air pollution and, in particular, CO_2. While natural gas can also make a great contribution in this regard, renewables may be preferred toward the end of the decade. Given the current boom in natural

Exhibit 15: Air Emissions of Major Pollutants by Generating Technology per MWh Using Best Available Control Technology (BACT)

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 RDI Consulting analysis. Biomass not included in this table due to difficulties in finding reliable information.

(1) Based on 2000 average sulfur content in western coal plants of 1.3 lbs/mmBtu.

gas-fired power plants and the forecast of natural gas prices in the 2.75-3.25 $/mmBtu range over the next few years, natural gas is the fuel of choice for the time being.

Water Requirements

With the exception of wind and PV solar power, all generating technologies are based on a thermodynamic process, in which heat is converted into electricity. Immutable laws of physics dictate that the efficiency of this process depends on the difference between the temperature of the heat source, for example, the boiler or turbine, and the "exhaust" temperature of the process. Therefore, only thermal generating technologies, like solar dish Stirling, that operate at very high temperatures can reach high efficiencies even with simple air cooling. For all other thermal generating technologies, water cooling is required, unless alternative cooling techniques are used, which, however, decrease the efficiency of the plant.

In Exhibit 16 we show the amount of cooling water required to produce one MWh of electricity. In addition to cooling water, power plants require process water that is used for steam cycles or the washing of solar mirrors. The amount is usually small compared to the cooling water requirements.

Estimating cooling water use by power plants is difficult because the amount of water required is very location dependent. The amount of water needed for evaporative cooling in a cooling tower depends mainly on the average temperature and humidity at the plant's site, and the quality of the water. Water quality determines how often the reservoir of cooling water needs to be discharged because it condenses into brine, which jeopardizes plant equipment as well as the environment. Therefore, not every drop of cooling water can be used for cooling. In Exhibit 15 we have considered the total cooling water requirements, and not just cooling water net of discharged water, for evaporative cooling in a cooling tower.

Data in Exhibit 16 are based on RDI research with the exception of cooling water requirements for coal, oil, steam, and nuclear. In particular the data on combined cycle (CC) plants was derived by analyzing the cooling water procurement of dozens of new natural gas-fired CCs in the West. These data came from RDI's NEWGen data and analysis service. In addition, the Kramer Junction Co. (KJC), which operates 165 MW of parabolic trough capacity near Kramer Junction, California, provided Platts/RDI Consulting with cooling water data on parabolic trough plants.

The key conclusion from Exhibit 16 is that all thermal power stations, including parabolic troughs, use hundreds of gallons of cooling water per megawatt-hour of electricity. CCs use the least amount of water because of their high firing temperature in the combustion turbine portion of the combined cycle and the combustion of two different thermal cycles. Stand-alone combustion turbines do not use cooling water, but also operate at the lowest efficiency.

Of renewable generating technologies, wind power, dish Stirling, and PV are the true water misers and use only one hundredth of the water required by other generating technologies. Only

Exhibit 16: Cooling Water and Process Water Requirements by Plant Type, per MWh

Plant Type		Water (Gallons/MWh)	
		Cooling	Process
Coal		670 (a)	– (1)
Combined Cycle		250-300 (b)	– (1)
Combustion Turbine		None	Variable (2)
Nuclear		620 (c)	– (1)
Solar	Power Tower	750 (d)	8.0 (d)
	Parabolic Trough	764 (e)	8 (e)
	Dish Stirling	None	4.4
	Flat Panel PV	N/A	4.4 (3)
	Concentrating PV	N/A	4.4 (3)
Wind		N/A	1.0 (c)
Hydro		N/A	N/A

SOURCE: (a) MWH Consulting, (b) RDI Consulting and NEWGen, (c) American Wind Energy Association (AWEA), (d) RDI Consulting estimate and (e) KJC Operating Co

NOTE: Evaporative Cooling. Process water includes that used for make-up water for steam turbines, combustion turbine wash, air inlet fogging, solar mirror wash, wind turbine blade wash, etc.

(1) Included in cooling water.

(2) The amount of process water for turbine washes and inlet air fogging depends on location and application of turbine.

(3) RDI Consulting estimates based on dish Stirling.

process water is used for turbine blade or glass and mirror washing. Therefore, these generating technologies should be of greatest interest to southwestern states where water is a precious resource and where an ever-growing population and associated water demand have put water supply reliability in the public eye.

Global Warming Policies Could Restrain Fossil Generation

Ninety percent of human energy needs are derived either by burning fossil fuels, such as coal, oil, or natural gas, or by burning wood, dung, and other types of biomass. In the combustion process, CO_2 is formed and discharged into the atmosphere. Part of this CO_2 is converted by photosynthesis (that is, plants) or absorbed by the oceans, with the remainder increasing the CO_2 concentration in the atmosphere.

From pre-industrial times to the present, the CO_2 concentration in the atmosphere has risen from 280 parts per million (ppm) to close to 360 ppm. Its concentration is currently increasing at an accelerating rate, which is now about 3 to 5 ppm per year. Although the physics and chemistry of the Earth's atmosphere are not understood well enough to draw precise conclusions about the effects of an increase in CO_2 on the world's climate, a large part of the scientific community concludes from atmospheric data and theoretical models that manmade CO_2 emissions will result in an increase of the global surface temperature. (See also section, "Solar Power Insurance Against Kyoto Protocol.")

According to these scientists, such an increase in temperature would result in dramatic climate changes, which in turn may have a negative impact on the planet's ecosystem (including agriculture). The changes might be dramatic, in particular, because they would occur over a time scale that is too fast for either humans or nature to adapt. Therefore, if research in the next years confirms global climate change from CO_2 emissions, then the U.S. power industry, which currently produces 40% of U.S. CO_2 emissions, may experience pressure to reduce its reliance on fossil fuels, and, in particular, coal.

It has been argued that the U.S. could also use carbon "sinks" to, at least in part, meet its emission reduction goals. Carbon sinks are ecosystems that naturally sequester certain amounts of carbon, for example, a newly planted forest, in the U.S. or elsewhere. In 1999, the United States released about 5.6 billion tons of CO_2 into the air, of which 1.7 billion came from coal-fired power plants.[18] According to an article in *The New York Times,* in order to offset all of its domestic carbon emissions, the U.S. would have to plant a forest the size of the surface area of Jupiter, which has a surface area 120 times that of Earth.[19]

Certainly, even under the current draft of the Kyoto Protocol, not all CO_2 emissions have to be curtailed; rather, the U.S. emissions level is targeted to be reduced to 7% below its level in 1990 by 2010. In addition, RDI Consulting calculated the area of a forest needed to sequester all U.S. carbon emissions "only" to be the size of Earth.[20] Despite the differing estimates, the message is the same: Using carbon sinks alone is unlikely enough to stem potential global warming.

Today, coal-fired generation contributes about 52% of all electricity produced in the U.S. and 44% of the electricity in the West. Despite uncertain profit margins, criticism from environmental groups for its mining practices, significant problems related to air emissions from coal-fired power plants, and a stagnation of its business in the current natural gas-fired generation boom, the coal industry is charged with keeping our economy humming. No other industry would be hit harder by a demand for reduction in CO_2 emissions than the coal industry. Its uneasiness in the face of the Kyoto Protocol is more than understandable.

Nevertheless, if the link between CO_2 and climate change is further corroborated, the U.S. may need to drastically reduce carbon emissions. While carbon mitigation techniques such as sequestration of CO_2 are mentioned as possible solutions, these are more long-term remedies. At this point, it is also not clear whether planting trees or sequestering carbon dioxide in geological formations is either significant or practical. In Exhibit 17 we show the CO_2 emissions from western power plants in 2001, 2005, and 2010. Under RDI Consulting's base case scenario (under which the future mix of generating sources occurs according to the economics of the plant type, which is dictated by the regional fuel price, the cost of the technology, current emissions cost, and regional electric market dynamics) carbon emissions increase by 13% from 658 million tons in 2001 to 746 million tons in 2010.

By 2010, this increase would cause western states to miss the goals of the Kyto Protocol by an estimated 231 million tons. If western power plants were voluntarily to meet these emissions reductions on their own, RDI Consulting estimates that emissions would have to be reduced to about 515 million tons in order to be in compliance. However, under our business-as-usual scenario, CO_2 emissions actually increase by 88 million tons.

In 2001, only 1.5% of western energy was produced with non-hydro renewable energy. Most of this renewable energy is geothermal and wind—including 1,229 MW of new wind capacity that came on-line that year. In order to see what impact a rapid renewable energy deployment could do to curb carbon emissions, RDI Consulting hypothesized that, by 2005, 5% of electricity was generated from non-hydro renewables, and 10% in 2010. We assumed that hydro continued to produce about 199,400 GWh, the level of generation at 2001 installed hydro capacity and normal hydro conditions. We further assumed that the capacity factor of the new non-renewable energy source was about 33%, which is a reasonable value when both wind and solar are averaged together.

Under these assumptions, we find that, by 2005, 16,202 MW of new renewable capacity would have to be built, increasing to 40,551 MW by 2010. While such renewable capacity additions are not impossible, they would require a rapid renewable energy deployment.

In order to see the impact of these renewables on carbon emissions, we assumed for each GWh of electricity 1,000 tons of CO_2 would be saved by avoiding generation of 1 GWh from coal. (However, if those renewables were to displace energy from natural gas, the CO_2 emissions reductions would only be about half as big.) By 2010 this rapid renewable energy deployment of wind and solar, the most abundant western renewable energy resources, would more than compensate for the expected growth in emissions by 88 million tons under our business-as-usual base case scenario. Nevertheless, in 2010, western states would still emit 113.6 million tons more CO_2 from their power plants than targeted by the Kyoto Protocol.

Exhibit 17: Carbon Dioxide Emissions from Western Power Plants, 2000-2010

Scenario		Year		
	Kyoto Target (1)	2001	2005	2010
Base case Forecast				
CO_2 (Million Tons)	515	658	683	746
Change over 2001	Million Tons	N/A	25	88
	Percent	N/A	3.80%	13.40%
Required Change under Kyoto	Million Tons	-143	-168	-231
Rapid Renewables Deployment				
Non-hydro Renewables	as % of Electric Energy	1.50%	5%	10%
	New Capacity (MW) (2)	1,229	16,202	40,551
Saved CO_2 (3)	Million Tons	N/A (4)	43.3	117.2
CO_2 short of Kyoto		-143	-124.6	-113.6

SOURCE: RDI Consulting

(1) Assumes that electric generation independently meets the required percentage reductions of carbon dioxide proposed by the Kyoto Protocol.

(2) Assumes a capacity factor of 33%.

(3) Assumes CO_2 savings of 1,000 tons/GWh.

(4) Included in base case forecast for 2001.

The only solutions for western states to be in compliance under this “what-if” scenario, where power plants try meet the Kyoto goals independently, would be to either further deploy renewables, reduce emissions through greater use of natural gas or nuclear, sequester carbon underground or in new forests, or trade emissions with other states or countries.

Emissions trading would seek to lower global CO_2 emissions where this can be done most cost-effectively. For example, it may be cheaper to retire an inefficient steam plant in another state or country and to buy emissions credits from a new, highly efficient power plant, which produces significantly lower CO_2 emissions and which is built to replace the retiring capacity, instead of trying to lower carbon emissions from western plants. Because carbon emissions are a global rather than a local problem, this approach produces the same result. The U.S. under the Clinton administration had sought such a trade program as a condition of signing the Kyoto Protocol. Indeed, in the summer of 2001, the protocol was amended to allow for some form of emissions trading.

The other alternatives to lowering CO_2 emissions from power plants and still meeting the goals of the Kyoto Protocol would be for the West to reduce its electricity use or to seek offsets in other areas of energy consumption. The magnitude of the required energy savings would be significant, but consumers may now be willing to undertake such energy conservation efforts based on their experiences with the California energy crisis. The problem with seeking offsets in other areas of western energy consumption is that other large sources of CO_2, will have an even harder time lowering their emissions. For example, for transportation, no real alternative to gasoline exists at this point.

Europe and Japan have decided to go forward with an amended version of the Kyoto Protocol. The U.S., which produces a quarter of the world's manmade output of greenhouse gases, including CO_2, has decided to stand outside the agreement.[21] This has created considerable uncertainty for the U.S. industry and coal generators, which must factor possible CO_2 regulations into their business and generation planning decisions.

Carbon sequestration in geological formation appears to be an interesting idea, but it remains to be seen how practical and how expensive it is. It is unproven and may only be possible in certain situations. Sole reliance on carbon “sinks” seems a rather outlandish idea given the fact that the U.S. alone would have to plant a forest of planetary proportions. The West, in particular, would not even have the water that such forests would require.

With fusion only a distant possibility and fission a political hot potato with questionable economics for new plants, renewable energy is the only alternative for western states to aim for the targets of the Kyoto Protocol in the power generation arena. While natural gas-fired power plants could replace coal-fired generation and thus greatly reduce carbon emissions, there are probably not adequate reserves of economically competitive natural gas to satisfy the power generation requirements.

Endnotes

[1] Detailed analyses on demand and supply balances would preferably follow NERC region boundaries. Nevertheless, we believe that the regions as defined herein provide information directly applicable to state-level concerns.

[2] Edison Electric Institute, *Electric Reliability: Potential Problems and Possible Solutions*, Washington, D.C., May 2000, available at www.ehirst.com .

[3] Economists, transmission planners, regulators and policy makers are grappling with the question of how to structure a business model around transmission systems: Who should control it? How are decisions for transmission expansions made? And how are costs allocated between buyers and sellers of power? The Western Governors' Association also took up these questions at its annual meeting in August 2001 and continues to evaluate options. (Western Governors' Association, Conceptual Plans for Electricity Transmission in the West, August 2001, available at www.westgov.org .)

[4] Edison Electric Institute, *Transmission Planning for a Restructuring U.S. Electricity Industry*, Washington, D.C., June 2001, www.ehirst.com .

[5] NEWGen data and analysis service, August 2001, RDI/Platts.

[6] Denmark, where wind generates 10% of the country's electricity, has mitigated reliability concerns through geographic diversity of its wind farms and improved wind forecasting abilities.

[7] The average annual demand is the total annual energy divided by the 8,760 hours in a year.

[8] In the Pacific Northwest, rain and snowfall patterns limit hydro generation in all months except a few months during years with above average snowpack and precipitation. Therefore, reliability in this region is based on energy rather than peak demand.

[9] Peak demand numbers are reported on a NERC region level. In order to develop peak demand numbers for the regions of this study, RDI Consulting has estimated peak demand using state-by-state energy demand and regional load factors. Load factors are the ratio of average demand divided by peak demand.

[10] Mark P. Mills, *The Internet Begins with Coal*, The Greening Earth Society, May 1999.

[11] K. Kawamoto, J. Koomey, M. Ting, B. Nordman, RE. Brown, M. Piette, and A. Meier, *Electricity Used by Office Equipment and Network Equipment in the U.S.: Detailed Report and Appendices*, Lawrence Berkeley National Laboratory Berkeley, California, LBNL-45917, February 2001.

[12] Total nameplate capacity in the West is higher than 237,078 MW, but the large amounts of hydro generation need to be derated from the nameplate capacity to account for the significant variations in rain and snowfall experienced from one year to the next.

[13] Includes 9,201 MW operating, 24,915 MW under construction, and 21,161 MW forecast.

[14] National Energy Policy, Report of the National Energy Policy Group, The White House, May 2001.

[15] Geothermal generation results in small amounts of air pollutions due to volatile compounds that are naturally diluted in the brine from geothermal fields.

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

[17] Geothermal steam sometimes contains pollutants and is, therefore, strictly speaking not a zero-pollutant generation source, but emissions are very low.

[18] U.S. Environmental Protection Agency (EPA). "Recent trends in U.S. Greenhouse Gas Emissions," Tables ES-1 and ES-5, www.epa.gov/globalwarming/emissions/national/trends.html.

[19] Jeff Goodbell, "Blasts from the Past," *The New York Times Magazine*, July 22, 2001, p. 31.

[20] Assumes a CO2 sequestration rate of a forest of 5 tons of per acre per year.

[21] "Kyoto Rescued?," *The Economist*, July 28, 2001

Chapter 2

Electricity from Solar Power

A Clean and Abundant Energy Resource

Flat panel photovoltaic (PV) solar cells, typically made of silicon and ubiquitous on calculators and roadside call boxes, are the best-known form of solar generating technology. Generally, the public associates flat panel PV with future solar energy production.

However, flat panel PV is not the way solar energy will be harnessed in the near term for large-scale power generation. While it is the most visible of all solar technologies and for that reason attracts the attention and support of the public and policy makers, concentrating solar power (CSP) is positioned to be the true leader in solar power generation technology today.

In CSP, mirrors or lenses first focus and amplify the sun's energy. The concentrated sunlight is then converted to electricity through the photovoltaic process or a thermodynamic heat cycle, which uses a motor or turbine. In all CSP technologies, mirrors or lenses follow the trajectory of the sun through the sky and thus optimize energy collection. The four prominent CSP technologies are concentrating PV (CPV), parabolic trough, dish Stirling, and power tower; the latter three use a heat cycle to produce energy.

Currently, CSP is the most efficient and cost-effective way to generate electricity from the sun. In addition, hundreds of megawatts of CSP generating capacity could be brought on-line within a few years and make a meaningful contribution to our energy needs. Exhibit 18 provides an overview of solar power cost of flat panel PV and CSP technologies.

Exhibit 18: Solar Power Cost and Performance Overview

Technology	Capital Cost $/kW (1)	Power Cost Cents/kWh (2)
Flat Panel PV (3)	7,500–8,500	51.0
CSP Technologies		
Concentrating PV	TBD	TBD
Dish Stirling	2,650	16.7
Parabolic Trough	2,877	13.4
Power Tower	2,713	9.0

SOURCE: National Renewable Energy Laboratory, Stirling Energy Systems, RDI Consulting financial model

(1) Based on current technology, standard plant size, and assumed installation levels. See sections, "The True Cost of Using Solar Power" and "A Primer on Solar Generating Technologies."

(2) Power cost based on capital cost, variable and fixed O&M cost, and certain financial assumptions. See "The Price of Solar Power."

(3) Crystalline silicon.

A cursory review of Exhibit 18 shows why CSP is the leading technology. The combination of low capital costs and high efficiencies results in the lowest cost of power.[1] The capital and power cost numbers in Exhibit 18 are based on annual installation levels of about 100 MW for each technology and current technology and production processes. All CSP technologies, and in particular parabolic trough, power tower, and dish Stirling, have great promise for significant cost reductions. This could result in a much lower cost than shown in Exhibit 18, if these technologies are more widely adopted.

Of all CSP technologies, parabolic trough, power towers, and dish Stirling are the most ready to bring on-line large amounts of capacity in the Southwest. The penetration potential of CPV is not as clear at this point, because more research and development is required before it is possible to determine the technology's cost curve and, hence, market potential.

Parabolic trough and dish Stirling are the CSP technologies with the largest number of system hours. Existing parabolic trough plants have decades of operational history, and one dish Stirling system has been operating, albeit with interruptions, for the last 17 years. Two power tower systems (Solar One and Two) operated as demonstration projects in the 1980s and 1990s, but are now decommissioned. During the demonstration project, the units operated for about 2,000 hours. System experience with CPV is still low compared to dish Stirling, which targets a similar niche in the power market, but a few CPV systems are currently in operation, mainly by Arizona Public Service, and are accumulating more system hours.

In this study, we will use the cost and performance of parabolic trough and dish Stirling as proxy technologies to demonstrate the contribution that CSP could make to western energy and to evaluate the economics surrounding CSP. Parabolic troughs and dish Stirling technologies are similar, respectively, to power towers and CPV. Much of the analysis performed specifically for parabolic troughs and dish Stirling can be applied to power towers and CPV. Because of similar performance characteristics and economies of scale, generally power towers compete with parabolic troughs, and CPV is a competitor with dish Stirling.

The choice of parabolic troughs and dish Stirling as proxy technologies was influenced by the fact that these technologies have longer track records and are better known than power towers and CPV, respectively. In 2001, the developers of parabolic trough and dish Stirling plants were interested in developing domestic projects and were in negotiation with power purchasers in the Southwest to build new capacity. No power tower project was being pursued in the U.S, but a consortium of companies, including those involved in the Solar Two power tower project, is pursuing a project in Spain (Solar Tres) and is interested in bringing the technology to the U.S. market.

The cost and performance of all solar-generating technologies are discussed in detail in the chapter, "A Primer on Solar Generating Technologies," which also provides a detailed discussion of the cost data summarized in Exhibit 18. Power towers show the lowest solar power cost, but capital and O&M cost assumptions used in Exhibit 18 rely on industry information. While these figures represent good faith estimates, the industry admits great uncertainty in providing cost information on its own technologies until new projects are built. The cost and performance of parabolic trough plants and dish Stirling systems are further discussed in detail in the section, "Capital and Production Costs of Solar Power." In this section we will mark the technology to market; that is, we determine how well these plants would do in a competitive power market today, using some of the most advanced modeling tools in the industry. This mark-to-market analysis allows valuing the power delivered by CSP technologies for a power aggregator or utility.

Next, leading to the economic analysis is a thorough discussion of the western solar generating potential and how the profiles of solar radiation, regional load shapes, and the intermittence of sunshine all affect the ability to provide electricity from solar power. These sections are crucial for understanding the potential of solar power for western energy supply and, in our view, contain some of the most interesting findings of our study.

The Solar Generating Potential

In order to assess the role that solar power can play in western energy supply, it is important to know how much solar resource is available. Why invest time and effort in a renewable energy technology if it can only provide a small fraction of our energy needs? Geothermal power plants are an important source of renewable energy, but the potential exists in only a few places. So, how much solar energy falls on a patch of western land, and is there enough land for large-scale solar generation?

The answer to this last question is: Yes. Solar energy is an abundant and underutilized energy source in the West. Solar resources are optimal in the Desert Southwest and—given the geographic and climatic conditions—potentially the best in the world. Not only are there hundreds of square miles that could be used for solar generation, this land is also close to some major western metropolitan areas where large quantities of electricity are consumed. Our analysis shows that western solar energy resources are commensurate with current electricity demand in the West.

Amount of Power Contained in Solar Radiation

The intensity of solar radiation outside the atmosphere is about 1,300 watts per square meter (W/m^2). When sunlight passes through the Earth's atmosphere, a portion is scattered or absorbed—by haze, particles, or clouds. On a clear day in the Desert Southwest about 80% to 90% of the solar radiation entering the atmosphere reaches the ground. The U.S. has some of the best solar resources in the world, and the intensity of solar radiation at ground level in areas such as Las Vegas, Nevada, can reach values as high as 1,100 W/m^2.

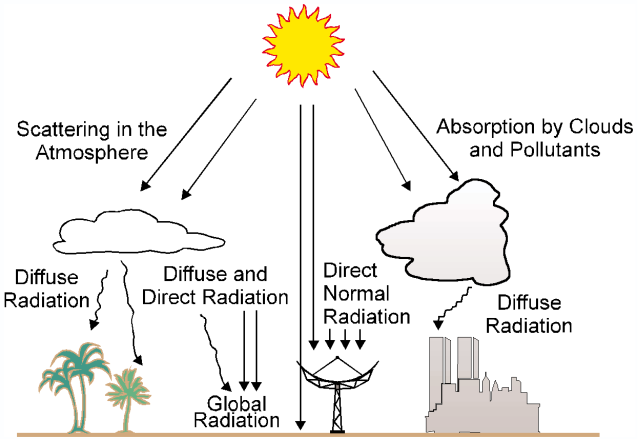
Even on a clear day, sunshine is composed of diffuse (scattered) light and rays that come undisturbed from the sun (direct normal radiation). Exhibit 19 illustrates the definitions of diffuse, direct normal, and global radiation. Global radiation is the sum of direct and diffuse radiation. Haze increases the amount of diffuse radiation while at the same time the amount of direct normal radiation decreases. Haze also results in reflection and absorption of sunlight, which reduces the overall amount of global radiation. On an overcast day, essentially all radiation that reaches the ground is diffuse, while on a clear day 93% to 95% of all radiation is direct normal.

While flat panel PV power plants use both diffuse and direct radiation, CSP power plants (CPV, dish Stirling, power tower, and parabolic trough) can only use the direct component of the sunlight. This makes CSP unsuitable for areas with high humidity and frequent cloud cover, both of which result in scattering. However, this imposes little limitation on CSP power plants, because for the western U.S., areas of highest total (global) radiation are also areas with low humidity and few clouds.

Radiation levels are affected by both 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 Desert Southwest, toward the fall and winter, cloud cover increases and often shields the sun.

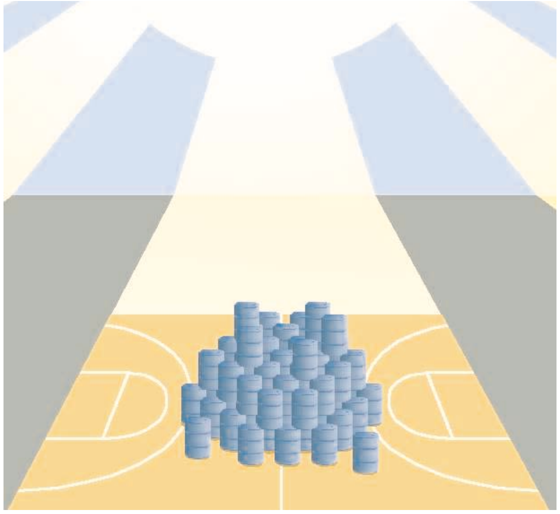
For solar power generation using CSP, the annual average amount of solar energy reaching the ground needs to be 6.0 kilowatt-hours per square meter per day (kWh/m^2/day) or higher. This is the case in many regions of the West (see "The Solar Energy Potential"). In premium solar resource areas, the average annual solar radiation exceeds 7.0 kWh/m^2/day. Using the most efficient solar generating technology (dish Stirling), an area the size of an NBA basketball court located in a premium solar resource would generate 60,740 kWh of electricity a year. To generate the same amount of electric energy, natural gas equivalent to 60 barrels of oil would have to be burned in a combined cycle power plant. Exhibit 20 displays this energy and shows that solar radiation is a concentrated form of power. Current technology can capture large amounts of this energy and convert it to electricity—indefinitely, domestically, and with no pollution or price volatility.

Exhibit 19: Direct Normal, Diffuse, and Global Solar Radiation



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

Exhibit 20: As Much as 60 Barrels of Oil Are "Saved" by a Solar Power Plant the Size of an NBA Basketball Court (437 m^2) per Year



NOTE: Dish Stirling system in premium solar resource area.

The Amount of Sunshine in the West

According to a report by EPRI, the southwestern U.S. is likely to have some of the best solar resources in the world.[2] This is due to a combination of factors, including the latitude, low cloud cover and humidity, and the high altitude of the Colorado plateau.

At noon, on a clear day in Las Vegas, the sun is so intense that, at that time of day, a square patch of land three feet on each side could power an average household. Certainly, not all of that energy can be converted into electricity and the sun does not shine at night and not with the same intensity all day and year around, yet this example provides an indication of the amount of energy the sun sends to the ground in the southwestern U.S.

Large areas of the West receive average sunshine of between 6 and 7.5 kWh/m^2/day, making solar power plant development possible in many states of the WGA. Surprisingly, good solar resource areas, which are suitable for solar power plants, can be found as far north as Idaho and Wyoming.

However, in order to assess the feasibility of meeting large amounts of western electricity with solar power, the following questions need to be answered:

- How much land do solar power plants require and how does that compare to the total land requirements of other generating technologies?
- How much land is available in the western U.S. that is suitable for solar power plant development and how much of this land is in good, excellent, or premium solar resource areas?
- How much energy could be generated on this land?

For this purpose, RDI Consulting estimated the land requirements in solar resources areas based on the typical performance of CSP technologies.

Land Requirements

With noontime direct normal radiation levels as high as 1,050 W/m^2 in many areas of the Desert Southwest, solar radiation can be very strong during midday. Nevertheless, the sun does not shine year round with the same intensity, and, during its path across the sky, the sun's intensity changes. In addition, weather conditions, such as clouds or haze, can change the level of direct normal solar radiation received by the collectors of a solar power plant.

The amount of solar energy that a solar power plant can convert to electricity depends on the technology. For example, dish Stirling systems produce more energy per acre than power tower plants. Here, for the purpose of comparing the land requirements of solar power plants to conventional plants, we used typical performance values of CSP plants. In order to estimate the energy production, we used engineering data and hourly annual solar radiation data from Las Vegas, a premium solar resource area—defined as an area that has radiation levels in excess of 7.0 kWh/m^2/day.

Not all areas of the Desert Southwest are premium solar resource areas. But, initial development of large-scale solar power plants would likely occur in premium resource areas and, as we will show later, premium solar resources are abundant in the Desert Southwest.

In Exhibit 21 we show the amount of land a CSP power plant would require in order to produce the same amount of annual energy as an equivalent conventional or other renewable energy source. For example, a nuclear plant with a capacity of 1,000 MW is expected to operate at a capacity factor of 85% per year and will thus produce 7,446 GWh of electricity. In order to provide the same amount of energy, a solar power plant would occupy a square of land with sides of 5.2 miles. Equally, a solar power plant would require a 3.6 x 3.6-mile plot to substitute for a 525-MW natural gas-fired combined cycle plant or a 500-MW coal plant.

Exhibit 21: Land Requirements of a Concentrating Solar Power Plant Compared to Conventional Power Plants, by Annual Energy Production

Conventional Plant					Solar Plant (1)		
					Plant Footprint		
Plant Type	Capacity (MW)	Capacity Factor	Generation (GWh)	Plant Footprint (Acres)	Acres	Miles x Miles	Solar/Plant Type
Nuclear	1,000	85%	7,446	TBD	13,227	5.2 x 5.2	TBD
Coal	500	85%	3,723	TBD	6,613	3.6 x 3.6	TBD
Combined Cycle	525	80%	3,679	TBD	6,536	3.6 x 3.6	TBD
Wind	30	45% (2)	118	960 (2)	210	0.6 x 0.6	22%
Lake Powell (Hydro)	1,300	48% (3)	5,466	161,280	9,710	3.9 x 3.9	6%

SOURCE: POWERdat and RDI Consulting

(1) Typical concentrating solar power plant in premium solar resource area (average radiation ≥ 7.0 kWh/m2/day).

(2) In Wind Power Class 7.

(3) 1995-2000 average.

Given the vast expanses of unused land in the West, especially in the desert, such areas are easy to find and could produce solar energy indefinitely. Beyond that, no additional land is needed for other uses such as resource extraction, that is, mining or drilling. And, by using heat storage, solar power could provide pure solar energy around the clock. In fact, a detailed load shape analysis for Nevada Power indicates that as little as 3.5 hours of solar energy storage at a specific capacity could displace almost equivalent amounts of conventional capacity (see "Heat Storage") in that market.

Solar power generation compares favorably with other renewables such as wind. A solar power plant in a premium resource area would only require one-fifth of the land that a wind farm would need if it were located in a top wind energy resource area (Power Class 7). While the construction of a solar power plant practically excludes other land uses, the small footprint of the wind turbine towers permits farming or ranching to continue almost undisturbed. This is a great advantage of wind power and will continue to provide a driver for its deployment. Solar's advantage, conversely, is that most land on which solar power plants could be built are deserts. Premium solar resource areas, for example, are typically hot plains with little or no vegetation.

Compared to the hydro projects of the Colorado River Project, solar power compares especially well. A CSP plant could produce the same annual energy as the Glen Canyon Dam on only 6% of the land now inundated by the waters of Lake Powell. Although Lake Powell has become a favorite vacation spot and contributes greatly to western water management, its electric power generation capabilities could not be justified today in terms of the associated environmental impacts.

The Solar Energy Potential

Critical to evaluating solar power's potential for western energy supply are the questions of how much land is available in the western U.S. for solar power plant development and what is the quality of the solar resources. To answer these questions, RDI Consulting performed a detailed analysis using solar radiation data[3] from NREL and RDI's POWERmap geographic information system (GIS).

Using these solar radiation data, we created three solar resource classifications based on the annual average solar energy, expressed in kWh/m^2/day as shown in Exhibit 22.

These solar data are for direct normal radiation as received by a two-axis tracking concentrator and can be used directly for dish Stirling systems, CPV, or power towers. The data also provide a good estimate for parabolic trough plants, which have only single-axis tracking. Solar power plant development is justified in an area that has at least good solar resources. Large areas in the Desert Southwest have good, excellent, or premium solar resources.

Even though the West has vast expanses of open land, some of this is already being used or is not suitable for solar power plant development. The White Sands missile range in New Mexico, for example, is off limits, as are the national parks. Other sunny areas of the West are too moun-

Exhibit 22: Solar Resource Class Definitions

Resource Class	Average Annual Solar Energy (kWh/m2/day)
Good	6.0-6.5
Excellent	6.5-7.0
Premium	more than 7.0

SOURCE: RDI Consulting

tainous. And finally, some areas of the West have seen a dramatic loss of open space, because of the growth of the western population and the development of large suburban areas.

We used GIS to map and calculate land potentially available for solar power plants and to classify it by its resource class. For this purpose, we excluded all areas we deemed unavailable (including buffer zones), terrain that is too rugged to allow the construction of solar plants, or areas otherwise unsuitable. In particular, we used the following algorithm in our GIS analysis. We excluded:

- 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.

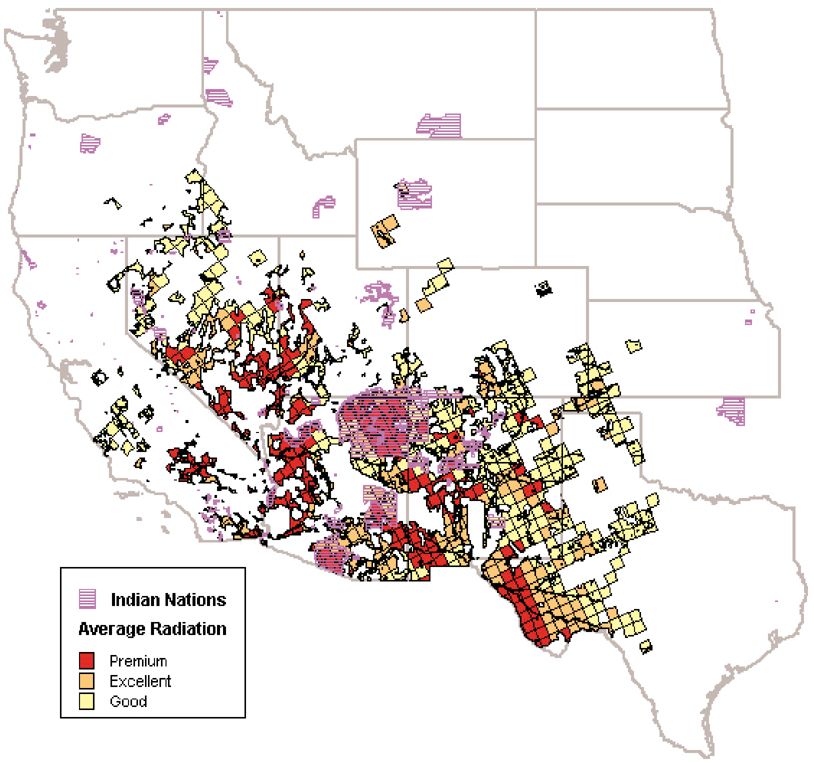
Indian lands were not excluded from our resource assessment, because of tribes' interest in the development of solar resources on reservation land. This interest was evident at the first Indian energy conference in San Jose, California, in August 2001.[4]

The results of this GIS analysis are shown in Exhibit 23. In 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 and Indian lands are shown as overlays.

Exhibit 23 shows that the majority of the available premium solar resource areas are in the states of Nevada, Utah, Arizona, and New Mexico as well as in western Texas. California has the least potentially available solar resources of all southwestern states, a reflection of the state's high population density, the influence of coastal clouds, and the fact that much of the remaining open space is protected. In addition, California has large military ranges, such as Edwards Air Force Base. Even in the Mojave Desert, a world-class solar resource area and home of the largest solar power plant in the world (see section, "The 354-MW SEGS Power Plants"), land for solar power plant development is becoming scarce.

In order to estimate the amount of land likely to be available for solar power plant development in the West, we first calculated the areas associated with solar resources as shown in Exhibit 23. Thus, land that is generally unavailable or unsuitable was excluded. Of the potential land, we kept only 3% in premium areas, 2% in excellent areas, and only 1% in good solar resource areas in our analysis. By considering only this small percentage of the potentially available land, we hope to account for land that is further excluded because of ownership, ranching, ruggedness of

Exhibit 23: Potentially Available Land with Premium, Excellent, and Good Solar Resources in the Western United States



NOTE: Solar resources ≥ 7.0 kWh/m2/day are considered premium, 6.5-7.0 excellent, and 6.0-6.5 good.

terrain, or other reasons. Premium resource areas were assigned the highest percentage of availability to reflect the great interest of solar power plant developers in those areas and the fact that these areas are usually deserts.

In order to calculate the potential solar generation that could come from this land, we used the following values for the land requirements and efficiencies of a thermal solar power plant. In the analysis of Exhibit 24 we assume that 1 MW of solar power requires five acres of land and that the solar fields of these plants would have the following capacity factors: 25% in premium, 22.5% in excellent, and 20% in good solar resource areas. These figures are a reasonable estimate for assessing the generating potential and are typical for CSP technologies.

It is important to note that these capacity factors are the capacity factors of the solar field—the right quantity for assessing the solar resource potential—and not the electric capacity factors of the power island of a solar plant. For example, a plant with a 1-MW solar field and a 1-MW power island would have an electric capacity factor of 25% in a premium resource area. However, if the solar field were oversized by a factor of two and the surplus heat stored, then the 2-MW solar field would still only yield a capacity factor of 25%, yet the electric capacity factor of the 1-MW power island would roughly double to 50%. This is because the electric generator could continue to produce power on stored heat when the sun does not shine.

Exhibit 24: Estimated Solar Resources in the West

Region		Solar Resources			
		Premium	Excellent	Good	Land as % of Region
Northwest	MW	–	1,791	15,408	0.03
	GWh	–	3,529	26,995	
	Acres (000)	–	9	77	
CO & WY	MW	2,513	18,423	24,194	0.20
	GWh	5,504	36,313	42,388	
	Acres (000)	13	92	121	
California	MW	61,617	14,809	21,743	0.50
	GWh	134,942	29,189	38,093	
	Acres (000)	308	74	109	
Southwest	MW	377,149	211,872	156,128	1.40
	GWh	825,956	417,600	273,536	
	Acres (000)	1,886	1,059	781	
Prairie States	MW	–	2,082	4,731	0.02
	GWh	–	4,105	8,288	
	Acres (000)	–	10	24	
Texas	MW	38,842	50,681	38,264	0.04
	GWh	85,064	99,892	67,039	
	Acres (000)	194	253	191	
TOTAL	GWh	1,051,466	590,627	456,340	0.50
2001 Demand	GWh	1,092,160			N/A

SOURCE: POWERmap and RDI Consulting

NOTE: Estimate for electric generation assumes 5 acres/MW and capacity factors of 25% for premium, 22.5% for excellent, and 20% for good.

As can be seen in Exhibit 24, at 1,052,000 GWh, premium solar resources alone are capable of producing nearly all of the estimated 1,092,000 GWh of western electricity consumed in 2001. If excellent and good solar resources are included, the western solar generating potential is twice the current electric energy demand, but would only require one-half of 1% of western lands. Although solar energy resources are not evenly distributed, large solar resources are found in many areas of the West and are often located close to load centers.

In order to get a better understanding of the size of the land that would be required to meet western electricity demands with solar power, we show in Exhibit 25 the area required to replace existing generation by fuel type. For example, in 2001, western coal plants generated about 482,226 GWh of electricity, or 44% of western electricity. To provide the same electricity from solar power plants located in premium resource areas, 46% of premium solar resources would be required, which is equal to one-tenth of 1% of the area of Lower-48 western states. This area would be equivalent in size to a square of 41.5 x 41.5 miles.

For the purpose of solar power plant development, five areas in the West stand out. To estimate the amount of available premium solar resources in these areas we used the same methodology as in Exhibit 24. Given the solar resources and proximity to load centers, the following regions are likely to be the focus of solar power plant development:

- **Mojave Desert** This area—despite its dwindling size—is still a top solar resource development area, because of world-class solar resources, access to transmission, and the proximity to the major load centers of Los Angeles and San Diego. Estimated available premium solar resource area is 213 square miles. Near Harper Lake, California, an estimated 2,200 acres (3.4 square miles) of fallow agricultural land were previously zoned for solar power plant development and would allow construction of new solar power in proximity to the existing SEGS parabolic trough units VIII and IX, which occupy some of this land.

- **Nevada Triangle** Close to one of the fastest growing and most power hungry cities in the nation, Las Vegas, the southern "triangle" of Nevada provides plenty of premium

Exhibit 25: Premium Solar Resources Required to Replace Existing Generation, by Fuel

2001 Generation by Fuel	GWh	Solar Resources Required		
		% of Premium Resources	(Miles x Miles)	Land as % of Western States
Coal	482,226	46	41.5 x 41.5	0.10
Oil and Gas	259,604	25	30.4 x 30.4	0.05
Nuclear	124,306	12	21.1 x 21.1	0.03
Hydro	199,400	19	26.7 x 26.7	0.04
Other	26,625	3	9.7 x 9.7	0.01

SOURCE: RDI Consulting
NOTE: 2001 generation by fuel type was renormalized to normal hydro and weather conditions.

solar resources. Estimated available premium resource is 520 square miles. In the Nevada triangle 24 square miles of land have already been designated as solar enterprise zones. In the section, "Heat Storage," we show that 1,250 MW of solar capacity, which would occupy 7.8 square miles, using 3.5 hours of storage, would be able to meet one-third of Nevada Power's energy needs reliably.

- **West of Phoenix** Large areas of lands are potentially available west of Phoenix. Estimated available premium solar resource is 520 square miles.

- **Navajo and Hopi Nations** The Navajo and Hopi nations appear to have the largest contiguous premium solar resource area in the West. The land is mainly flat and ideal for solar power plant development. To export the power, transmission line upgrades or construction is needed. Tax advantages for developments on tribal lands could make the Navajo and Hopi nations a preferred solar development area. Estimated available premium solar resource is 424 square miles.

- **Tucson** Around Tucson, Arizona, and reaching into southern New Mexico are large amounts of premium solar resources that could serve this rapidly growing metropolitan area. We estimate that 472 square miles of premium solar resource areas are available.

A strip of west Texas along the Mexican border also contains large amounts of premium solar resources and is located inside the ERCOT transmission system. Texas consumes more power than any other western region and the interconnection rules of the ERCOT system operator allow for easy interconnection within the region. However, a large amount of new generating capacity recently came on-line in the state. This and the fact that Texas' Renewable Energy Portfolio Standard is already oversubscribed could make it hard for solar plant developers to count on regulators to mandate more renewable energy.

Intermittence of Sun a Challenge

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 western states causes solar radiation to go to zero within an hour across the entire region. While local weather conditions can vary across an area as large as the West, the nightly setting of the sun occurs nearly at the same time.

Solar's intermittence due to weather conditions can be dealt with by dispersing solar power plants across the West. Premium solar resource areas are found in six western states, and excellent and good solar resources areas are found in 11 states. A robust transmission grid would allow the transfer of solar power across the West—transmitting electricity from where the sun shines to where it does not. To a limited degree, the existing transmission grid of the Western Systems Coordinating Council (WSCC) can already perform this function.

Research in Denmark on wind, which faces similar weather-related intermittence problems, has shown that a penetration of wind power as high as 10% poses few problems to the reliability of the bulk power supply, even if wind capacity is not backed up by conventional power sources. And the better the wind forecast, the smaller the problem—which is why the Danish system operator is investing in its wind forecasting abilities. For solar power, weather-related intermittence is even less of a problem, because sunshine is easier to forecast than wind. Further, sunshine in top solar resource areas is very consistent. The challenges stemming from the weather-related intermittence of wind and solar resources may often be overstated.

While geographic diversity can address weather-related intermittence, the nightly setting of the sun requires some form of off-sun generation. For thermal solar power plants, heat storage or fossil fuel hybridization provides means to produce power even after the sun has set or when clouds move in. In the Desert Southwest, the problem of the daily cycle is further reduced by the fact that during the summer—when power is needed the most—nights are short and only about one-third of the electricity is consumed between dusk and dawn. At the same time, however, 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.

In this section, we will explain the off-sun generating technologies that allow thermal solar power plants to produce power even when the sun does not shine. In principle, both heat storage and fossil fuel hybridization allow around-the-clock generation. These technologies are inherent to thermal solar power plants, which include all CSP technologies with the exception of CPV. Currently, heat storage is much more efficient and economical than energy storage in batteries, flywheels, or through hydrogen production. Whether and to what extent off-sun generating capabilities will be used will be determined by the economics of the market in which the solar plant operates.

Dealing with the Nightly Outage

Thermal solar generating technologies can provide electricity even when the sun does not shine because, unlike PV cells, which convert sunlight directly into electricity, thermal solar technologies first convert the light into heat and then use a thermodynamic cycle to produce electricity. For the power cycle, however, it does not matter whether the heat comes directly from the sun, from heat energy storage, or even a boiler.

Currently only parabolic trough plants and power towers allow for off-sun generation by using either heat storage or fossil fuel hybridization. While fossil fuel hybridization is easily incorporated into parabolic trough and power towers and has been demonstrated for dish Stirling systems, in all instances it suffers from low efficiencies compared to combined cycle systems. Heat storage for dish Stirling systems has been proposed, but has not yet been attempted.

While around-the-clock generation may be desirable from an operator's point of view and appears to preselect parabolic trough plants and power towers, in reality economic, siting, and environmental considerations will likely call for a mix of concentrating solar generation technologies—with and without off-sun generation. Ultimately, power markets will determine the winning technologies and the solar generation mix. The purpose of this section is to show how off-sun generation works and that it could provide reliable power.

Using Supplemental Off-Sun Power

Heat Storage

A distinct advantage of power tower and parabolic trough solar thermal power plants is the availability of a relatively inexpensive way of storing energy in the form of heat,[5] especially compared with other intermittent renewable energies, such as PV and wind.

Solar power plants with heat storage collect thermal energy during the day by increasing the temperature of a large heat reservoir. At one of the parabolic trough plants near Kramer Junction, California, heat storage utilized oil (see "The 354-MW SEGS Power Plants"). However, the power tower demonstration project, Solar Two, used a more effective and safer molten-salt storage system. In future applications, the heat reservoir will, therefore, likely be a large tank of molten salt rather than oil. The heat capacity of these storage systems is very large. For example, six-hour full-load heat storage of a 100-MW parabolic trough contains enough energy to power a home for nearly 70 years.[6]

Molten-salt heat storage is technologically ready, safe, and the most economic of all thermal energy storage technologies. It allows thermal energy to be collected during the day and to be saved for use at night or it can be used to keep the plant at full output when clouds pass over the plant location. The effectiveness of heat storage increases with the operating temperature of the thermal solar power plant. The high temperatures of the power cycle in power towers make this technology particular attractive for heat energy storage

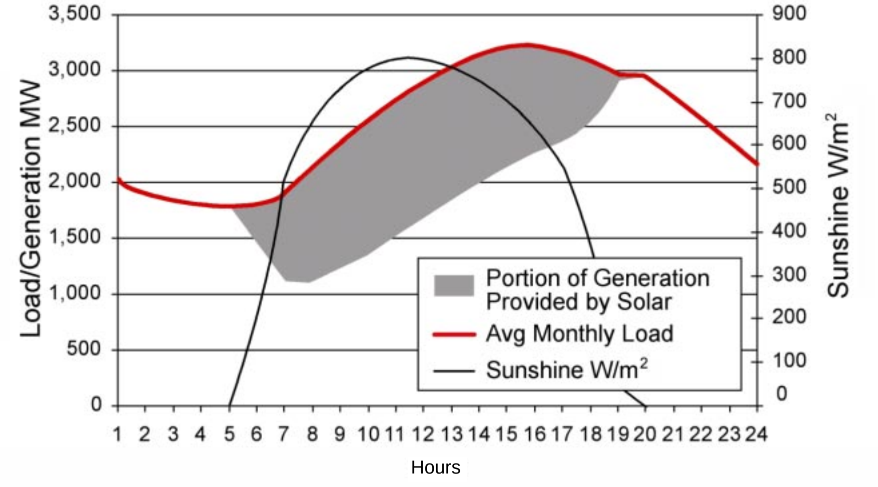
In a competitive market, energy storage also allows the operator to maximize profits. For example, during periods of low hourly power prices, the operator could forgo generation and dump heat into storage. At times of high prices, the plant could run at full capacity even if the solar field was not receiving full sun, or no sun at all. 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. Therefore, additional revenues from the energy market may justify the cost of adding storage.

Additional flexibility in the operation of a thermal solar plant with storage comes from oversizing the solar field, that is, the collectors generate more heat than required by the steam turbine of the plant. For example, a 100-MW thermal solar plant could have a solar field that has a nominal energy output of 150 MW of thermal energy. At times during the day, for example around noon, the solar field will produce enough heat for 150 MW of electricity. Of this, 100 MW are used to generate electric power while the other 50 MW go into storage for later use. Such a plant would have a solar-to-electric capacity ratio of 1.5 (150 MW/100 MW = 1.5). Local solar resources and the electricity market in which the thermal solar plant dispatches determine the optimal configuration of storage hours and solar-to-electric capacity ratio.

Using heat storage, solar power plants can displace installed capacity in the market. To demonstrate this point, consider a 1,250-MW solar power plant[7] with 3.5 hours of full-load storage in the Nevada Power market area. For simplicity of this illustration of the effectiveness of heat storage for meeting power needs, we assume that the solar-to-electric capacity ratio remains at 1.0. (In reality the solar field would likely be oversize to capture additional operational and cost advantages.) Over a recent four-year period, the Nevada Power market area had an average peak load of 3,215 MW during the peak month of August.[8] In Exhibit 26 we show the average load in August together with the average solar generation,[9] which a 1,250-MW solar plant with no storage located outside Las Vegas could displace from other generators. The electric energy supplied by the plant is the grey area below the load.

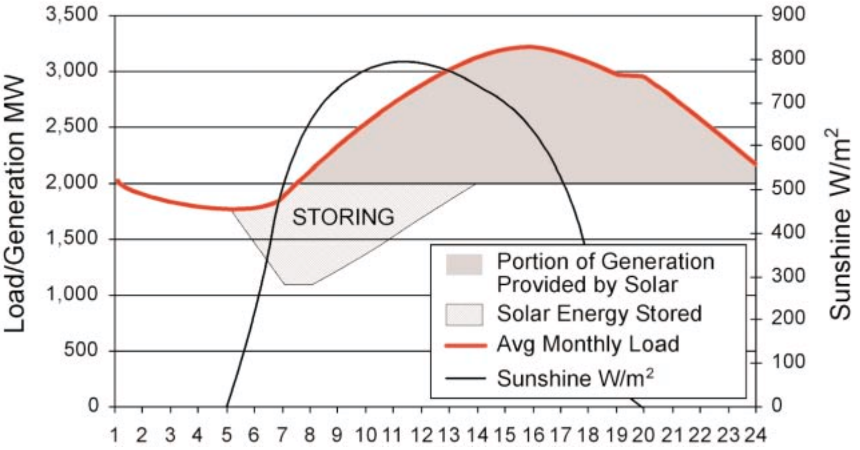
While this power plant makes a substantial contribution to the electricity supply during the day, the output from the solar plant goes to zero at nightfall, which occurs around 8 p.m. in August. At that time, Nevada Power's load is still nearly 3,000 MW, down from its peak of 3,125 MW. Therefore, at least 3,000 MW of conventional generation capacity is still needed to meet demand after sunset. Despite a summer rating of 1,250 MW, without heat storage this solar capacity could only displace about 125 MW of other generating capacity in the market.

Exhibit 26: Generation of 1,250 MW of Solar with No Storage during Nevada Power's Summer Peak Month (August)



Source: RDI Consulting

Exhibit 27: Generation of 1,250 MW of Solar with 3.5 Hours of Storage During Nevada Power's Summer Peak Month (August)



Source: RDI Consulting

If we now add 3.5 hours of full-load heat storage to the 1,250-MW solar power plant, the picture changes dramatically. In Exhibit 27, we show the same 1,250-MW plant but now with storage. From sunrise until around 7:30 a.m. the plant stores all the energy collected by the solar field and then slowly ramps up to full load, which it reaches by 1 p.m. (13:00 hours). At this point, no energy is stored, instead the heat storage is filled with 3.5 hours of full-load energy and the plant begins to tap into its reservoir. With hours of full-load storage available, the plant can now continue to run (with decreasing output) until midnight.

The solar plant still delivered the same amount of energy to the market as earlier. However, the important difference is that the plant now produces electricity until midnight, at which time Nevada Power's load has dropped to 2,000 MW. The load will not reach a level as high as 2,000 MW again until the next morning. By that time, the solar power plant will begin to dispatch again.

Therefore, 1,250 MW of solar generating capacity with 3.5 hours of full-load storage is able to displace over 1,000 MW of conventional capacity in the 3,000-MW Nevada Power market.

Outside the peak month of August, the 1,250-MW solar plant with 3.5 hours of heat storage continues to provide a similar level of functionality, because, while the daily energy production of the solar power plant is lower outside of the summer season, so is the average load, as a large portion of Nevada Power's load is due to air conditioning. For most months outside the summer, Nevada Power's demand falls off more rapidly than solar output. This will be described in more detail in the section, "Seasonality."

RDI Consulting performed a similar analysis for Southern California Edison's (SCE) load for a hypothetical solar power plant with storage located in the Mojave Desert. Again, the results are similar. Only a few hours of storage are needed before the solar plant can dramatically reduce the need for back-up capacity in the market.

The purpose of this analysis is to show that the nightly outage is not a great limitation to the large-scale deployment of solar power plants, even if all the generation is “pure solar.” Heat storage could provide off-sun generation as needed.

Fossil Fuel Hybridization

All thermal solar power plants have the option of hybridization with fossil fuels, because heat is what generates electricity in dish Stirling systems, parabolic trough plants, and power towers. Hybridization is possible for all three technologies. The ease of hybridization for trough and tower plants stems from the fact that the boiler is an entirely separate component, while for dish Stirling systems the hybridization needs to be an integral part of the design—and that has proven to be more difficult to design and implement.

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, a parabolic trough plant or power tower becomes an ordinary steam plant. The heat rate (efficiency) in this operating mode can, in theory, approach 9,000 Btu/kWh at best, which is 30% less efficient than a modern combined cycle plant. Despite the poor efficiency, operating on natural gas remains a reasonable economic choice for the plant, because it increases the dispatch of the plant, provided the cost of producing power with natural gas is lower than what the plant can earn in the wholesale market.

A parabolic trough plant in hybrid mode running on natural gas produces power at higher emissions and at a higher fuel cost than a combined cycle plant, because of its lower efficiency and poorer environmental controls. Despite the higher fuel consumption compared to a combined cycle plant, the levelized cost of hybridization is reasonable because hybridization uses equipment that otherwise would be idle (except for the boiler, which is only built for use in hybridization mode). The reason for considering hybridization for off-sun generation is that it is less capital intensive than heat storage. However, it forgoes the advantages of zero emissions and continues to expose a portion of the plant's energy production to the price volatility of natural gas.

Fossil fuel hybridization muddles the character of a solar plant and, for that reason solar power plant developers seem to distance themselves from using natural gas other than for operational purposes, for example, keeping the heat transfer fluids liquid during cold weather or outages.

Nevertheless, if new solar power plants are built, some of them may still feature fossil fuel hybridization as a means of producing power when the sun does not shine. Eight out of nine operating parabolic trough units near Kramer Junction use hybridization for off-sun generation.

Accounting for Cloud Cover

In top solar resource areas, cloud cover is relatively rare, especially in the summer, but it is possible to forecast cloud formation. According to the operators of the parabolic trough solar plants near Kramer Junction, next-hour sunshine can be forecast with near certainty. While solar power is an intermittent resource, its availability is much more predictable than wind power. Still, research in Denmark on wind has shown that electric supply remains reliable even at a 10% penetration of wind due to the geographic diversity of the turbines. The very good predictability of solar generation on an hour-ahead, or even day-ahead basis, further simplifies the task of managing this intermittent resource.[10]

Despite this ability to forecast cloud formation, clouds can still be trouble for the operation of solar plants. For example, this is the case, when clouds move as bands or are highly scattered and the large solar field receives sun in spotty and interruptible ways—and if such a weather pattern persists for more than a few hours. This is because, while the overall reduction in average solar radiation may not be that high, the frequently changing heat production of the solar field could make operation of the plant difficult. Unless a parabolic trough or power tower plant has energy in heat storage or hybridization with natural gas is used, the output of the plant could be below expected levels. Because dish Stirling units can ramp to full power within seconds after being hit by the sun, and because of their small size—the entire dish Stirling system is either in the shade or in the sun—this average output of a dish Stirling unit tracks average radiation levels very well. At the same time, of course, dish Stirling[11] units are intermittent sources of electricity and cannot levelize short periods of shading like power towers or parabolic trough plants can.

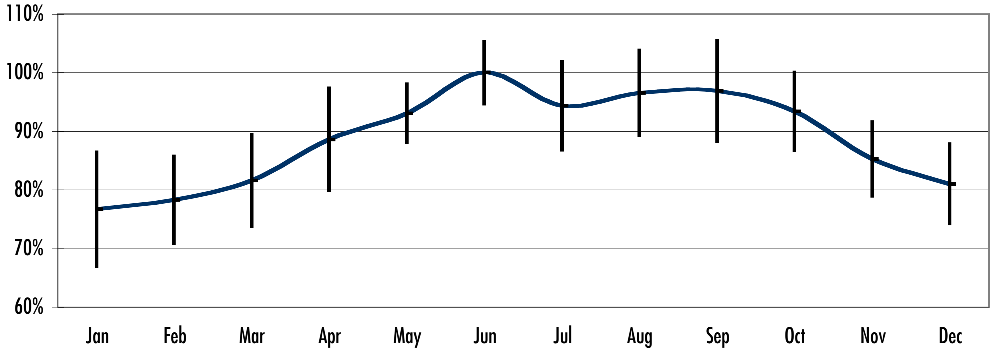
Still, on occasion a solar power plant may fail to deliver energy into the market. In our economic analysis we have included intermittence cost and we will present our methodology for calculating this cost in the section, "Putting a Cost on Intermittence."

So, how big is the impact of weather on solar generation? In order to answer this question, we analyzed 30 years of hourly solar radiation for premium and excellent solar resource areas in the Desert Southwest. In Exhibit 28 we show the influence of weather on solar radiation in Daggett, California, a premium solar area, and Phoenix, Arizona, which has excellent solar resources. The solar radiation data in these areas were already adjusted for the changing hours of daylight with the season and only show the effects of clouds and haze.

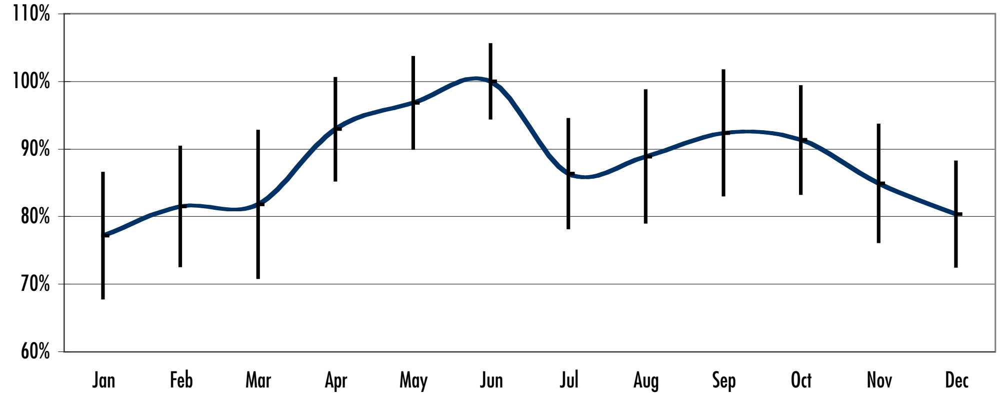
In both areas, the average solar radiation is highest in June than for any other month of the year.[12] This is the time when a solar plant would operate on average at 100% of its rating. The black stock-chart type bars in Exhibit 28 show that during certain years the solar radiation during that month was more or less than the average. The length of the bar represents the standard deviation around the average. For example, the graphs show that in both areas solar generation during June may vary from 95% to 105% of the average from one year to another.

Exhibit 28: Variation of Sunshine in Premium and Excellent Solar Resource Areas due to Clouds and Haze

Daggett, CA—Premium Solar



Phoenix, AZ—Excellent Solar



100% = Maximum of Average Monthly Solar Energy Adjusted for Seasonality

Source: RDI Consulting

A look at Exhibit 28 shows the variability of solar generation with the seasons and the differences between a premium and an excellent solar resource area. In both areas, energy production from the solar power plant due to clouds and haze reduces output by about 20% in December and January. The summer monsoon season in July adversely impacts the solar resource in the Phoenix area when, on average, the output of a solar plant drops to 86% of the plant's nominal rating. In Daggett, the output drops to the middle of the 90th percentile. In early fall, the expected solar output would be expected to be in the low 90th percentile in Phoenix but in the high 90th percentile in Daggett.

For the amount of energy that can be generated from a solar power plant in a month, the season, clouds, and shorter days affect the output. In the following section we will look at the combined effects and how the seasonal changes in solar energy production relate to seasonal changes in electric loads in the regions.

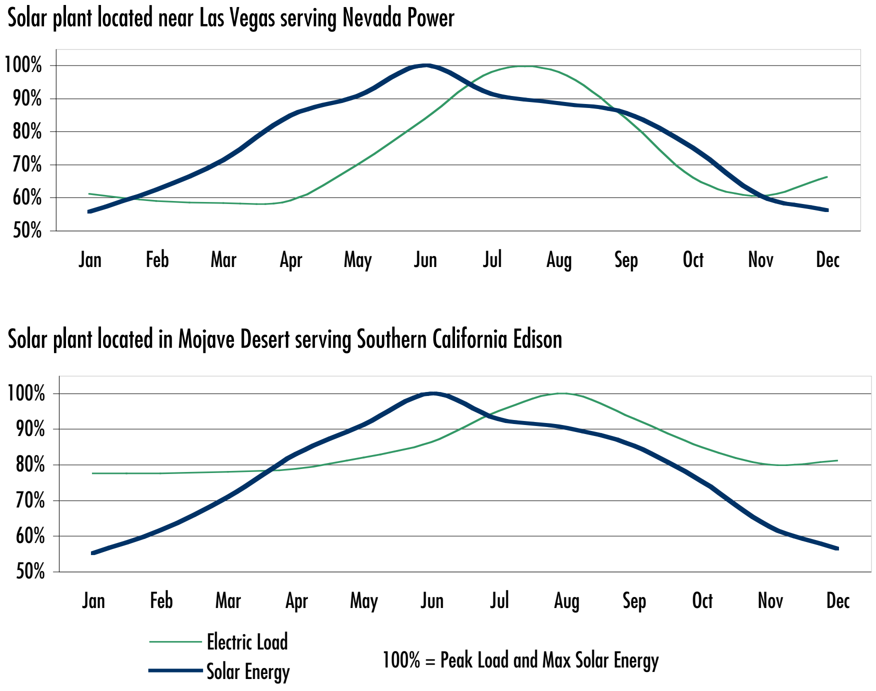
Seasonality

Unless a solar power plant is located at the equator, its monthly energy production is greatly influenced by the seasonal changes of the sun's position in the sky. In the northern hemisphere, days are shorter in the winter and the sun is lower on the horizon, which reduces the solar energy that reaches the surface.

In Exhibit 29 we show the seasonal variations of solar energy, which account for the effects of shorter days and weather, in two premium solar resource areas, as well as the electric loads that solar power plants located in these areas would serve. The shape of the total seasonal variation of solar energy is similar in both areas and would correspond well to the seasonal energy production of a two-axis solar power plant, such as a dish Stirling system or power tower. Parabolic trough plants are more greatly affected by the low position of the sun on the horizon during the fall and winter, and expected energy production from this technology during those seasons would be lower than shown in Exhibit 29.

In the Desert Southwest and California, air-conditioning loads result in a summer peak demand.

Exhibit 29: Seasonal Solar Energy and Load in Nevada and Southern California



Source: RDI Consulting

These loads are associated with summer heat waves, which typically hit both areas in August. It should be noted that the month of highest temperature, humidity and load occurs two months after solar energy has peaked.[13] Though solar radiation reaches its highest levels in June, southwestern energy demand does not peak until August. This is because local temperatures are greatly influenced by larger weather patterns and it takes about two months before the warming of the northern hemisphere brings the dog days of summer to the Desert Southwest.

Nevertheless, solar energy production is well correlated with load—increasing in the summer, when electricity is needed the most. In contrast, output from conventional thermal power plants, such as natural gas-fired combined cycle, coal, or even nuclear plants, drops by about 10% in the summer months due to less efficient thermal cycles. Therefore, solar and conventional thermal power plant output complement each other well. This situation would be especially true in the Southwest and Texas, which both rely heavily on coal, nuclear, and natural gas for power generation (see Exhibit 7). But, even for California, which has considerable amounts of hydro energy, a similar argument holds. This is because after the spring, runoff for hydro generation drops off considerably.

Exhibit 29 shows, however, significant differences in the relationship between solar energy and load. Most of SCE's load is located in Los Angeles, which has a moderate climate year round due to the strong influence of the ocean and coastal clouds. We have assumed that a solar power plant serving SCE would be located in the Mojave Desert, where solar energy production in January or February would be lower by about 40% than the maximum solar output in June, while the load would only be about 20% lower. This means that solar output falls off faster than load in this example.

Fortunately, the situation in the Las Vegas area is different. Here air-conditioning loads result in a seasonal load profile that is similar to solar energy production. The solar energy profile falls below the load profile only during the months of July and August. This means solar energy production in this market follows electricity load very well, and solar power can provide enough energy despite the seasonal variation in sunshine.

In many other areas of the Desert Southwest, the relationship between load and solar radiation is likely to be similar to the situation in Nevada. Phoenix and Tucson have a load shape similar to Nevada. In these regions, solar energy is also expected to be a good match to the load profile.

The True Cost of Using Solar Power

In order to provide an estimate of the cost of using solar power for western energy supply, we have taken an approach that marks the solar power plant to market and then calculates the cost of power. We undertook the following steps:

First, we created an hourly plant dispatch model, which simulates the operation of a solar power plant in the southwestern wholesale market and determines the revenues the plant would receive. For this we created an "artificial" sun that simulates hourly sunshine in the West. In addition, we developed hourly power price streams with forecast power prices and the volatility observed in the southwestern markets prior to the California energy crisis. Both simulations were conducted for 100 years.

Next, in order to estimate the intermittence cost, we took a market-based approach. We assumed that the market will operate as a one-hour-ahead market and that the penalty for not delivering 1 MWh of power is equal to the hourly market price of power. That is, if a solar power plant fails to deliver the MWh to which it is committed, it will have to buy replacement power at market price.

Fossil fuel-fired power plants are significant sources of air pollution. These emissions can be associated with significant health problems and can be harmful to forests, water bodies, and crops. Except in a few circumstances and only to a limited degree, the cost of electricity from conventional sources does not account for these external costs.[14] Instead of trying to estimate external costs, we use the premium that society attaches to renewable energy as a proxy for the external costs of other forms of energy. For example, the premium for renewable energy is the sum of tax credits and green energy premiums (the amount of money consumers are willing to pay for green power above their usual electricity bills). This premium results in a revenue increase to the utility and a cost reduction to the developer for renewables.

In estimating today's cost of power from solar technology, we took the following approach. We defined today's cost as the cost of building and operating a solar power plant with current technology and where the project is not one-of-a-kind. At the same time, we assumed the industry would not yet take advantage of cost reductions through investments in production capacity, but would instead satisfy its equipment needs through outsourcing. Such a situation would be one where short-term financial incentives allowed the development of hundreds of megawatts of solar capacity, while a long-term sustainable market for solar power was not in place.[15] For estimating today's cost we did, however, take into account discounts from volume purchases in the outsourcing. Specifically, we assumed that about 250 MW of parabolic trough or power tower mirrors and about 100 MW of dish Stirling systems were ordered annually.

We are aware that the 100 MW annual production volumes for dish Stirling are not likely with the start of incentives such as tax credits or buydowns, which could provide a market for this and other CSP technologies, because dish Stirling technology may require a slower ramp-up to overcome concerns over technology risk. However, the cost of dishes greatly depends on volume—to a much greater degree than parabolic trough or power tower technology. Therefore, in order to better compare the cost of the technologies, we assumed the dish Stirling systems proved reliable and could deploy large amounts of capacity.

We have done this mark-to-market analysis for four proxy plants: two differently sized dish Stirling plants and two parabolic trough plants, one with heat storage and the other with fossil fuel hybridization. All plants were located in the Mojave Desert and received the forecast wholesale power price in the southwestern U.S. The key results of this analysis for parabolic troughs can be applied to power towers, while the results for dish Stirling systems can be used to understand the economics of CPV, because of the similarities of the respective technologies. Such a detailed analysis of the other two CSP technologies, especially power towers, would have been desirable as well, but was outside the scope of this study.

In the next sections, we will describe our methodology and the results of our financial analysis in detail. Before we begin our discussion, however, we want to note that no correlation apparently exists between the instantaneous production of energy from solar power and the price of power in the Southwest. This observation is important for understanding the role solar power can play in western power markets.

Solar Energy Production and Electricity Prices

In a competitive energy market, the price of power depends on the demand and supply balance. During summer peak demand, the price for power is usually significantly higher than during the lowest demand of the year. Therefore, generating technologies that produce power primarily or solely during the periods of peak prices, and especially during times of price spikes, can produce power that is more expensive than cycling or baseload power plants. This is why a simple cycle combustion turbine is economic to install despite its high variable production cost, because its sole purpose is to run during peak demand when prices are high.

One of the positive features of solar power is that its output increases during the summer, when regionally electricity is needed the most, and that it's available during the day, when demand is higher than at night. However, on average, daily solar production peaks a few hours before the demand reaches its maximum (see Exhibits 26 and 27, in section, "Heat Storage"). Further, during the year, southwestern monthly load peaks in August, while solar energy reaches its highest level in June, two months earlier (see Exhibit 29, in section, "Seasonality").

Peak energy prices occur during the times of highest demand. Our discussion suggests that—on average—maximum output from solar power plants with no heat storage or fossil fuel hybridization is shifted from the daily peak demand by a few hours (depending on the season and location) each day and from the annual peak by about two months. This means that solar power plants do not operate like a "peaking" plant, which is understood to (primarily) dispatch during hours of peak demand.

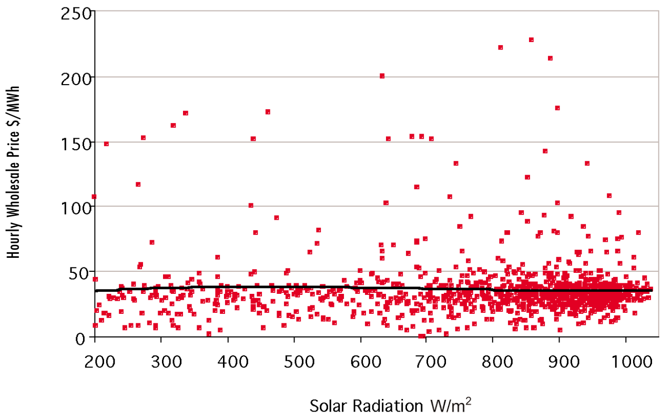
To examine the issue further, we looked at the correlation between hourly power prices and solar radiation in the Desert Southwest. The only year for which such real-time data were available was 1999. Hourly prices are for SCE prior to the California energy crisis. The extensive transmission interconnections in the Southwest result in small price differentials across the entire region. It is for this reason that SCE hourly prices can be used as a proxy in this analysis. In Exhibit 30 we show a scatter plot of hourly power prices versus solar radiation during the southwestern electric peak demand months of July, August, and September.

If sunshine and demand were correlated, that is, if a solar power plant were indeed a peaking plant, then the trend line in the scatter plot in Exhibit 30 would have a positive slope (that is, it would climb from the lower left corner to the upper right corner). However, the trend line is flat. This shows that instantaneous solar energy production and wholesale prices during peak months are not correlated. Therefore, solar power plants that produce power proportional to the instantaneous solar radiation do not target peak prices in the Desert Southwest.

Some correlation between local load and local solar radiation may exist, but this is unlikely given the daily and monthly offset of average load and solar radiation. In addition, as long as a regional wholesale market exists, the economics of power will be governed by the regional price.

The result of this analysis greatly simplifies our dispatch model, since it was unnecessary to correlate the hourly radiation of our artificial sun to the hourly electricity price stream.

Exhibit 30: Hourly Wholesale Prices in Southern California Edison versus Solar Radiation in Daggett, Mojave Desert, July 1–September 30, 1999



Source: RDI Consulting

Putting a Cost on Intermittence

The wind power industry is engaged in a discussion with regulators and utilities about the cost of intermittence. What is the additional cost incurred by purchasing energy from intermittent energy sources? For example, wind cannot produce power on demand—that is, be "dispatched"—unless the wind happens to blow. And what is the cost of the capacity necessary to back up intermittent generation?

In order to estimate the cost of intermittence associated with solar plants, we took a market-based approach. In our dispatch model we assumed a one-hour-ahead energy market. Next, we assessed no penalty for over-generation from renewables, but if a generator fails to deliver the capacity committed in the hour-ahead market, the generator must buy replacement power at the current hourly wholesale price. Additional penalties may be imposed on the plant for failure to deliver, such as a "capacity" penalty, but the level of such penalties and whether such penalties would extend to renewables is not clear and we thus assumed that the purchase of replacement power was the only intermittence cost.

Based on our research, next-hour sunshine in premium solar energy resource areas can be predicted well (even the next-day forecast tends to be reliable). We believe that the following assumptions about the ability to forecast solar radiation in the next hour is representative of the actual forecast abilities in premium solar resource areas: The probability is 95% that the output in the next hour will be equal or larger than expected; 2% that the output will be 20% lower; 2% that it will be half; and 1% of the time the plant fails to deliver at all.

Using these assumptions, and the above market-based approach, we calculated the intermittence cost for dish Stirling systems. The two parabolic trough plants have either four-hour heat storage or fossil fuel hybridization, and thus intermittence in a one-hour-ahead model is not an issue.

Capital and Production Costs of Solar Power

RDI Consulting relied on company information and data from NREL as well as discussions with relevant parties for its estimates of the capital and production costs of solar generating technologies. We believe that the cost estimates given in this report for dish Stirling, parabolic trough, and power towers are reasonable, but the actual cost of construction and operation of new solar power plants may be different.

Today's capital and production costs of dish Stirling and parabolic trough are based on company information, provided by Stirling Energy Systems (SES), and NREL (shown in Exhibit 40). The actual cost of new solar power plants may be different than the good-faith estimates in Exhibit 31 for the following reasons:

Exhibit 31: Today's Capital and Production Costs of Dish Stirling, Parabolic Trough, and Power Tower

	Dish Stirling (1) 2.5 MW/100 MW	Parabolic Trough100 MW	Power Tower 100 MW
Capital Cost			
Basic Plant $/kW	2,650	1,956	2,065
Heat Storage $/kWh	N/A	103	27
Additional Solar Field $/kW	N/A	510	540
Fossil Fuel Hybridization $/kW	Not commercial	196	196
Fossil Heat Rate (HHV) (2)	TBD	10,800	10,000
Fixed O&M $/kW-year	40/2.5 (1)	37	30
Variable non-fuel O&M $/MWh			
Basic	16.8/15 (1)	2	2
Heat Storage	N/A	– (3)	– (3)
Fossil Fuel Hybridization	TBD	– (3)	– (3)

SOURCE: Stirling Energy Systems and National Renewable Energy Laboratory

NOTE: Based on current technology, standard plant size, assumed production capacity, and company information.

(1) Based on 2.5-MW plant size (100 units) for "distributed" generation and 100-MW plant size (4,000 units) for a central power station.

(2) Based on natural gas.

(3) Negligible compared to basic variable non-fuel O&M.

While the O&M values for parabolic trough plants are based on over 10 years of operating experience at the SEGS solar power plants (see "The 354-MW SEGS Power Plants"), no new parabolic trough plant has been built in over a decade. On the other hand, the ongoing purchases of replacement mirrors at SEGS provide a good idea of the capital cost of the collector field. And there are few questions about the cost of the steam-plant portion, which is no different from any other conventional steam unit.

For both parabolic trough and power towers, there is uncertainty with regard to the capital cost of molten-salt heat storage, which has been used in only one power tower demonstration project. Also, the cost estimates of power towers are based only on the relatively small Solar One and Solar Two power tower units and the current development activities on Solar Tres in Spain. Until a new power tower project the size of 100 MW is built and operated, both capital and operating costs for power towers remain somewhat uncertain.

Our cost estimates for dish Stirling reflect uncertainties over capital and O&M costs—possibly in both directions—because only a few demonstration units were built by SES, SAIC/STM Power, and others. The SES systems, on which our cost assumptions are based, are over a decade old. SES has conducted significant research on its systems and has received quotes from third-party manufacturers for building new units.

The critical component of the dish Stirling system is the Stirling engine. This engine can be produced by the automotive industry, taking advantage of that industry's enormous economies of scale and technical sophistication. Therefore, it appears that projected cost estimates are possible. Yet, there remains some concern as to whether new motors, at the cost quoted by the automotive industry, will be as reliable as previous ones. This question cannot be answered until new units are built.

Another company that is actively engaged in developing dish Stirling units is Science Applications International Corp. (SAIC) and STM Power. SAIC/STM Power developed its own dish Stirling system using an entirely different engine, built by STM Power, and collector system than SES. These systems are much younger than the dish Stirling units that SES acquired from Southern California Edison (SCE) (and which were originally built by McDonnell Douglas). Because SAIC/STM Power has less experience with its units than SES, we relied on cost information from SES and used it as a proxy for all dish Stirling systems. However, SES' cost estimates are commensurate with that of other Stirling engine and concentrating dish manufacturers.

We make no long-term forecast for the cost of solar power plants. However, we point to the success of wind power as an example of the enormous cost reductions possible when a technology moves from an experimental and demonstration phase into commercialization. The levelized cost of wind power has come down by 70% in the last 15 years and is now approaching $40/MWh (4 cents/kWh). Cost continues to decline and is likely to accelerate given the current growth in wind project development (see section, "Wind").

Every new technology requires an incubation period. During this time the technology matures and the cost declines. There is no reason to believe that thermal CSP technologies, including parabolic trough, power towers, and dish Stirling, will be any different, especially because of the similarity in engineering between wind and thermal solar power plants. Just like wind power, thermal CSP technologies use ordinary technology in an extraordinary way. Cost reductions are expected to come overwhelmingly from learning, volume production and economies of scale rather than engineering advances.

Cost reductions in thermal solar power plant equipment appear likely and, with all caveats, the numbers presented in Exhibit 31 are a reasonable place to start. Future responses to requests for proposals will show the actual costs.

All estimates in Exhibit 31 represent incremental capital costs. For example, a basic parabolic trough plant with a solar field, whose peak thermal output is sized to match the capacity of the steam turbine, costs 1,956 $/kWh. Additions to the solar field would increase the cost $510 per kilowatt. One hour of full load energy storage for a 100-MW plant would add 1 hour x 100 MW x 103 $/kWh = $10.3 million to the project cost.

Revenues and Costs of Thermal Solar Power Plants

In the previous sections we provided information on solar radiation, electric load shapes, solar generating technologies, and cost. This should help make clear the issues that determine the reliability and cost of electricity generated from solar power. In this section we will take the analysis a step further and estimate the revenues of four proxy solar power plants (two dish

Stirling systems and two parabolic trough) by simulating these plants in the energy market. To do this, we created hourly electricity and natural gas prices and an hourly sunshine model. In our analysis we "dispatch" these four proxy solar plants against the hourly price and solar data in order to determine their capacity factors, revenues, and costs. This allows us to see how well these plants would do in a competitive market today; that is, we mark the plants to market.

The dispatch model takes into consideration the engineering parameters of the solar technologies and the availability of sunshine. The plants are then operated to maximize their revenues in the energy market. Each plant is dispatched against 100 different annual price and solar data sets. We used proprietary computer models to develop these data sets based on historical price volatilities and variations in sunshine. The mean values of the price data are equal to 2002 forecast prices provided by RDI Consulting's forecasting group. By operating the plants for 100 years, this approach allows us to see the variation in annual revenues that a solar plant could experience in an energy market due to price volatility and variations in sunshine.

The wholesale price of power is RDI Consulting's forecast price in the Southwest for the year[16] 2002, which we chose because we expect that by that time electricity prices should return to normal and 2002 would be the earliest on-line date for a solar power plant. By creating volatility, the price streams differ greatly in their exact shape from year to year, while their statistical characteristics, such as averages and standard deviations, remain the same.

The Solar Power Plant Proxies

In Exhibit 32 we show the cost and performance assumptions of four dish Stirling and parabolic trough proxy solar power plants. The cost data are based on Exhibit 31 and the chapter, "A Primer on Solar Generating Technologies."

Exhibit 32: Performance and Cost Assumptions of Proxy Solar Power Plants

	Proxy Technology			
	"Distributed" Dish Stirling	100-MW Dish Stirling	Parabolic Trough w/ Heat Storage	Parabolic Trough w/ Fossil Hybrid
Electric Capacity (MW)	2.5 MW (100 units)	100 MW (4,000 units)	100 MW	100 MW
Solar to Electric Capacity Ratio	1	1	1.8	1.25
Off-sun Generation	None	None	4 hours	24 hours
Cost				
Capital Cost ($/kW)	2,650	2,650	2,877	2,152
Fixed Cost ($/kW-year)	40	2.5	37	33
Non-fuel Variable O&M ($/MWh)	16.8	15	2	2
Fuel Cost ($/mmBtu) (1)	N/A	N/A	N/A	3.87
Fossil Heat Rate (HHV) (Btu/KWh)	N/A	N/A	N/A	10,800
Project Life	30 years	30 years	30 years	30 years

SOURCE: Stirling Energy Systems and National Renewable Energy Laboratory (NREL)
NOTE: For details see Exhibit 40.
(1) Annual average gas price, please see text for details.

Two proxy plants are dish Stirling plants. One is a "distributed" plant of 2.5 MW composed of 100 25-kW units, and the other is a 100-MW plant using 4,000 units. Capital cost assumptions on a $/kW basis are the same for both, based on a total unit manufacturing of 4,000 units per year. However, the economies of scale of a large plant allow for lower O&M costs. Considering a 100-MW dish Stirling plant allows us to compare on equal footing dish Stirling to parabolic trough plants with a unit size of 100 MW. The reason for including distributed dish Stirling systems is because we believe this is a niche market for dish Stirling (and concentrating PV), as described later.

The two 100-MW parabolic trough plants include one that uses molten-salt heat storage and can operate four hours at full load during cloud cover or after dark. The solar field of this plant is oversized by 80% and thus allows it to store energy while the plant could still operate at full capacity. It also allows for operation at full capacity when solar radiation would not be high enough otherwise. The solar-to-electricity ratio at this unit is therefore 1.8 (180 MW solar/100 MW electric = 1.8). Naturally, the electric output of this plant, and hence its capacity factor, is higher than it would be without oversizing the solar field and including thermal storage. Of course, this 100-MW plant would also occupy about twice the area of a 100-MW dish Stirling plant. The optimal heat storage and solar-to-electricity configuration were determined by economic optimization done by NREL based on power prices provided by RDI Consulting.

The second parabolic trough plant is a fossil fuel hybrid. This means that a fossil fuel-fired boiler can produce heat for the steam cycle during cloud cover or at night. Of course, power from this off-sun generation will produce air emissions. Neither the efficiency nor the emissions control on such a boiler unit compares favorably to a combined cycle natural gas-fired plant. In addition, power generated in hybridization mode will not receive any production tax credits or green energy premiums.

For more details on the technology and performance of dish Stirling or parabolic trough plants, please refer to the section, "Thermal Solar Power."

Revenues and Production Cost

The *true* cost of power is determined not only by its production cost, but also by the value that the power has in the market. A perfect example of this is the power generated by a simple cycle combustion turbine. Its power cost can be two to three times more than the average price of power in the wholesale market, but because it only operates when prices spike—and such price spikes occur with sufficient frequency—it still produces enough revenue to be economic.

Similarly, the values of the four proxy solar generating technologies in this analysis differ not only by their production costs, but also by how much money they can make in the market. The best way to see this is by estimating the revenues of the four solar proxy plants in the proxy market. For this mark-to-market approach, we created hourly price streams for electricity and natural gas, as well as hourly sunshine data sets. We then operated the plants in this market with the goal of maximizing the plants' net revenues.

For electricity prices, we used SCE hourly market prices forecast for 2002, developed by RDI Consulting's forecasting group. Because of the strong electrical interconnections between Southern California and the rest of the Southwest, price differentials in the regional wholesale markets are small. It is for this reason that the SCE prices in our model can be used to determine the revenues of a solar power plant in any location in the Southwest.

While these forecast prices show hourly variations, they do not display the volatility observed historically in the market. In order to introduce volatility we used econometric models to simulate electricity price volatility observed in 1999—prior to the California energy crisis. In this way, 100 annual hourly price data sets were generated, with the same statistical characteristics as the mean of the 2002 forecast prices and the 1999 volatility. In order to account for some of the regulatory intervention in California, we capped hourly prices at 100 $/MWh. This also makes the revenue estimates more conservative.

We also created 100 annual hourly natural gas prices in the same way as the electricity prices. Electricity prices and gas prices were correlated. The mean natural gas used in this model is $3.87/mmBtu, and the level of the SCE power prices and the cost of power produced by the parabolic trough hybrid both depend on this forecast natural gas price level.

Exhibit 33: Revenues and Production Cost of Proxy Solar Power Plants, Base Case

Base Case		Proxy			
		Distributed Dish Stirling	100-MW Dish Stirling	Parabolic Trough w/ 4-Hr Storage	Parabolic Trough w/ Fossil Hybrid
Electric Capacity (MW)		2.5	100	100	100
Capacity Factor (1)	Solar	25.2	25.2	34.1	25.2
	Fossil	N/A	N/A	N/A	25.4
Average Market Price ($/MWh) (2)		41.17	41.17	41.17	41.17
Average Revenue Received by Plant ($/MWh) (2)		48.50	48.50	53.40	56.17
Intermittence Cost ($/MWh) (3)		1.41	1.41	N/A	N/A
Fuel Cost ($/MWh) (4)		N/A	N/A	N/A	40.13
Non-Fuel O&M (Variable and Fixed) ($/MWh)		35.96	16.20	14.65	9.62

SOURCE: RDI Consulting

NOTE: Revenues and costs are expressed in $2001.

(1) Net of parasitic loads.

(2) Subject to a $100/MWh price cap.

(3) Intermittence cost is incurred when the generator cannot dispatch committed capacity into an hour-ahead energy market.

(4) For electricity generated with natural gas.

NOTE: Because of the varying land requirements and different efficiencies, the capacity factors should not be used to determine which technology produces the most energy per area. For example, the heat-storage parabolic trough plant has a capacity factor of 34.1% with an 80%-oversized solar field that occupies at least 5 acres per MW. The dish Stirling plant has a 25.2% capacity factor but 1 MW of power requires 4 acres. Comparing apples to apples, the same area occupied by a dish Stirling plant produces 60% more solar electricity than a parabolic trough plant.

Hourly sunshine data were developed from 30 years of solar radiation data in Daggett, California, provided by NREL. One hundred years of hourly sunshine data were generated from historic data by adapting our proprietary volatility simulation models. It was not necessary to correlate solar radiation and power prices on an hourly basis, because no such correlation exists. It is well known in the power industry that load is correlated to temperature and humidity (not sunshine). In addition, research in California has shown that the correlation is strongest with regard to a 3-day moving average, rather than same-day or hourly.[17]

In Exhibit 33 we show the results of our dispatch analysis, where we dispatched the four proxy plants to optimize net revenues while considering the available sunshine and engineering constraints of the respective technologies. For the dish Stirling plants, we used our in-house dispatch model and entered the engineering parameters such as minimum threshold and part-load efficiency. Because dish Stirling units can ramp up to full load within 20 seconds, ramp rates were ignored.

For the parabolic trough plants, RDI used NREL's parabolic trough dispatch model. This detailed model accounts for heat loss in storage, ramp rates, conversion of two-axis-tracking solar data to single-axis-tracking parabolic collectors, and so forth. We provided NREL with 100 years of solar data and natural gas and power prices. The parabolic trough with heat storage changed its dispatch strategy monthly based on the mean-forecast hourly power price, while the dispatch of the natural gas boiler was determined hourly based on the market price of power and the marginal production cost of the unit.

Exhibit 33 shows the dish Stirling plants operated at a capacity factor of 25.2%. The heat-storage parabolic trough plant operated at 34.1% capacity factor, because of its 80%-oversized collector field. The capacity factor of the solar portion of the generation for the parabolic trough fossil fuel hybrid with a 25% oversized solar field was 25.2%, while the gas-generation accounted for 25.4%. Over the 100 years, the standard deviation of annual solar energy was ±2%. Such consistency in solar radiation can be found in premium solar resource areas, such as the Mojave Desert. The impacts on revenues of these changes in solar radiation differ with the generation technology and are described below.

Exhibit 33 shows that, at an average annual gas price of 3.87 $/mmBtu, the average wholesale price of power during all hours of the year was 41.17 $/MWh (subject to a 100 $/MWh price cap). The average price that dish Stirling was able to capture was 48.5 $/MWh, or 18% more than the average market price. Revenues varied by ±5.8% on an annual basis for the 100 years of dispatch in our model.

The parabolic trough plants, which can dispatch power, were able to target hours of higher power prices. This is why the average price received by the parabolic trough with heat storage was 53.40 $/kWh. The plant can hold generation in the morning and can dispatch the stored energy later in the day when prices are higher. The year-to-year changes in solar energy resulted in variations in annual revenues of 6% (standard deviation).

The fossil fuel hybrid parabolic trough plant was able to receive the highest average price in the market—56.17 $/MWh—because the gas-fired boiler can be dispatched based on next-hour prices. The solar portion of the generation, however, received a price similar to the dish Stirling plants. Of course, the higher revenues also come with a higher production cost—24.5% of the dispatch was due to natural gas, which increased the production cost by 40.13 $/MWh (from 9.62 $/MWh) for electricity generated when burning gas. However, because of the ability to switch to natural gas as a backup fuel, earnings from the parabolic trough hybrid varied the least from year to year. Over the 100 years of simulation, revenues had a standard deviation of 3.2%.

The Price of Solar Power

Even though we have to this point marked solar power plants to market as if they were merchant plants, in the near term no solar power plant will operate this way. This is because, at the current cost of solar power and forecast wholesale prices, these plants are not financially viable. In our financial modeling, we assume that these solar power plants are built with independent power producer (IPP) financing after securing a power purchase agreement (PPA) for at least 10 years for the entire output of the plant. The price paid under such a PPA will allow adequate debt service and will provide investors with an internal rate of return (IRR) based on the perceived risk of the technology. Exhibit 34 shows the key financial assumptions of the discounted cash flow model.

In Exhibit 35 we show the power prices of our four solar power plant proxies from the discounted cash-flow model. The base case includes a 10% solar investment tax credit currently in place. On the production side, we reduced output proportionally to the equivalent forced outage rate (EFOR), which was assumed to be 5% for all technologies.

The power price for the proxies is also affected by the different IRR, which increases with the perceived risk of the technology. The technology risk of a parabolic trough plant with fossil fuel hybridization is very low and comparable to conventional power generating technologies, because hundreds of megawatts of this technology have operated successfully for over a decade in California. An IRR of 15% appears reasonable. For parabolic trough with molten-salt heat storage, we increased the IRR to 18% to reflect the fact that molten-salt storage has not yet been used commercially. But this level of IRR seemed adequate, since the remainder of the plant is similar to the existing parabolic trough units.

Exhibit 34: Key Financial Assumptions

Item	Value
Debt to Equity Ratio	70/30
Debt Maturity	15 years
Debt Interest Rate	7.50%
Average Debt Service Coverage Ratio	1.5
Minimum Debt Service Coverage Ratio	1.3

Target IRR	
Dish Stirling	20%
Parabolic Trough w/ Heat Storage	18%
Parabolic Trough Fossil Hybrid	15%

NOTE: Assumes IPP financing with long-term PPA of at least 10 years.

Exhibit 35: Power Cost of Thermal Solar Power Plant Proxies

Power Price $/MWh		Proxy			
		Distributed Dish Stirling	100-MW Dish Stirling	Parabolic Trough w/ Heat Storage	Parabolic Trough Fossil Hybrid
Base case		187	167	134	93
+	Solar Property Tax Exemption	174	154	124	88
+	2 ¢/kWh Green Energy Premium	154	134	104	78

For dish Stirling, we increased the IRR to 20%, because of the technology risk associated with the Stirling motor. In our view, this IRR is very favorable. Investors could perceive a greater risk for this technology and expect an IRR of 25% percent or more. In reality, for the first dish Stirling plants, performance guarantees may be required in addition to a high IRR to draw investments, because dish Stirling technology is still pre-commercial at this point. However, as described earlier, our financial analysis assumes installation levels of about 100 MW. We have thus assumed that dish Stirling technology has proven reliable during the initial deployment and that the target IRR here only needs to address long-term risk associated with this new technology

With these financial assumptions, and the capital and O&M numbers from Exhibit 32, the power cost of distributed dish Stirling plants with a 2.5-MW plant size is 187 $/MWh, and 167 $/MWh for a 100-MW dish Stirling plant. This compares to the 134 $/MWh of parabolic trough with heat storage and the 93 $/MWh of parabolic trough with fossil fuel hybridization. The high capital cost of dish Stirling and the 25.2% capacity factor are the reasons that, at today's cost, dish Stirling is the most expensive thermal solar generating technology.

Power generated from a parabolic trough plant with fossil fuel hybridization, where about half of the plant's output is derived from operation on natural gas, had the lowest cost of power of 93 $/MWh and is able to obtain the highest price in the market of 56.17 $/MWh. This hybrid solar generation technology thus provides the greatest value to its owners. However, while the operation on fossil fuels increases overall plant utilization and reduces cost, this energy relies on fossil fuel, produces emissions, and continues to expose the price of power to volatility in natural gas prices.

In addition to our base case, in Exhibit 35 we also assess the impacts of a property tax exemption and a 2 ¢/kWh green energy premium on power cost for generation from pure solar. We believe that solar power plants are likely to receive a property tax exemption for the portion of land occupied by the solar collectors. Such property tax exemptions were granted to the SEGS plants in California (see "The Circumstances That Made It Happen") and we anticipate that other states or counties will provide similar tax incentives. With such a property tax exemption, the power cost is reduced by about 5% to 8% for all solar technologies.

It is our view that, in the near term, energy from solar power plants could be marketed into green energy programs, which already exist in many parts of the country and are popular. Individual customers can purchase energy from renewables through a surcharge on their electricity bills. Today, the renewable energy in these programs typically comes from wind. Customers appear willing to pay 2 to 3 cents more for every kWh produced by a renewable, non-polluting energy source. After accounting for the cost of administering these programs, we assumed that solar plants could receive an additional 2 ¢/kWh (20 $/MWh) for their solar-electric energy. We applied this green energy premium over the entire life of the project, which reduces the power cost of all solar technologies by a flat 20 $/MWh, except for the parabolic trough hybrid—where only half the output qualifies as green energy and the cost reduction is thus only half that—10 $/MWh. After applying these incentives, an electric power service provider would view the cost of power for a 100-MW dish Stirling as 134 $/MWh and for the lowest cost parabolic trough plant as 78 $/MWh.

However, whether such a green energy premium can be obtained for the entire 15 years of the project life is not certain because wind power is becoming so cost effective that it will soon be able to provide cost-competitive green energy without the premium (and possibly without the production tax credit [PTC] as well). This puts solar energy at a disadvantage in a green energy portfolio offering. The development of solar power, it appears, will require a mandated percentage in a green power portfolio or renewable energy standard.

Even with a property tax exemption and a 2 ¢/kWh green energy premium, with today's cost of technology, solar power is still not competitive and would require additional financial incentives to be able to enter the market, including, for example, a PTC. While today's cost of solar power already makes optimistic assumptions about the level of annual installations, it does not reflect the long-run cost of these technologies. What these technologies will cost, after hundreds or even thousands of megawatts have been installed, is not known at this point. At best, the successful cost reductions of wind power can be used as an example for possible cost reductions for thermal solar generating technologies.

It is difficult to tell if, and how quickly, these cost reductions will be possible. It is our view that performance improvements for dish Stirling and parabolic trough plants are imminent and only moderate research and development is required to achieve them (see sections, "Improvement in Heat Collector Efficiency" and "Dish Stirling to Set New Efficiency Record"). In contrast, efficiency improvements in PV systems are contingent on overcoming significant material sciences challenges. When, if, and at what cost these PV efficiency improvements can be reached is not clear.

A significant portion of a parabolic trough plant is the steam plant, and no cost reductions are likely there. But for heat collecting elements, mirrors, truss structures, Stirling motors, and heat storage, cost reductions through volume manufacturing, better design, increases in unit capacity (especially for dish Stirling), and efficiency improvements are likely.

Wind power's cost of power, which has dropped by over 70% over the last 15 years (see Exhibit 44) is still falling and is soon likely to be the lowest of all generating technologies, including conventional and renewables. Turbine sizes have increased from 55 kW in 1980 to 2.5 MW today, an increase in unit size of a factor of 45! Therefore, it can be expected that economies of scale in unit size and production volume will result in considerable cost reductions of CSP technologies as well.

How Solar Power Compares to Other Generating Technologies

Our analysis shows that today's cost of CSP solar power is between 134 and 187 $/MWh. (The levelized cost of the parabolic trough fossil fuel hybrid is not included, because its cost is determined by a combination of electricity from solar and natural gas.)

Decisions on new generation capacity are based on capital and production costs in today's deregulated electricity market, as has been the case for years in the electric utility industry. At current natural gas prices, the combined cycle plant is the cheapest form of energy. Because it is clean burning and can be built quickly, combined cycle is the power plant of choice for independent power producers. A natural gas-fired combined cycle plant can deliver energy between 45 and 48 $/MWh at a natural gas price of 3.87 $/mmBtu. Lower natural gas prices—as seen in the fall of 2001—result in a significantly lower cost of power from natural gas-fired power plants. According to research by our coal consulting group, coal-fired generation would only be able to compete with natural gas if gas prices were between 3.50 and 4.00 $/mmBtu and if these new coal plants operated at high capacity factors.

Solar power's direct competitor is wind power. The power cost of wind has fallen from 150 $/MWh in 1984 to about 40 $/MWh in 2000. New "Stateline" wind farms at the Oregon/Washington border that came on-line in December 2001 have an estimated power cost of 40 $/MWh and report a power cost of 25 $/MWh after considering the PTC. Power cost (before the PTC) is expected to drop to as low as 25 $/MWh in the not-too-distant future.[18]

Other generating technologies include nuclear, geothermal, and biomass. However, we do not believe that any new nuclear power plants will be built due to the high capital cost of the technology (estimated at around 2,000 $/kW) and its associated environmental and political concerns, including spent fuel storage. In addition, nuclear generating technologies, such as the pebble-bed modular reactor (PBMR), that may be acceptable to the public are still in the research and development phase.

The cost of geothermal power critically depends on the type of geothermal resource and the cost of drilling. The capital cost of a new geothermal plant is comparable to that of a steam plant plus the additional costs associated with geothermal resource recovery, such as drilling and steam production. According to an analysis performed by NREL, given the right steam resources, geothermal would be cost-competitive if it received a PTC commensurate to that awarded to wind.[19]

The cost of biomass generation depends on the fuel source. It appears that biomass generation may increasingly occur through co-firing in coal plants. Until the cost of fuel for biomass facilities

Exhibit 36: Capital and Production Cost of Electric Generation Technologies

Plant Type	Power Cost $/MWh	Capital Cost $/kW	Heat Rate (HHV) Btu/kWh	Fuel Cost $/mmBtu	Capacity Factor
Coal	26–33	900–1,200	8,500–10,000	1.20	85%
Combined Cycle	45–48	525–600	7,100	3.87	80%
Combustion Turbine	110–135	325–450	10,900	3.87	8–10%
Wind	40	850	N/A	0	35–45%
Solar (1)	Dish Stirling	187	2,650	NA	25.2%
	Power Tower	90	2,713	8 hrs, 1.8x	48%
	Parabolic Trough	134	2,877	4 hrs, 1.8x	34.1%

SOURCE: RDI Consulting.
NOTE: All costs are expressed in $2001 for currently available technology

decreases significantly, new capacity from biomass will be small and biomass generation will not play an important role in future energy markets.

We provide a brief summary of the capital and production costs of electric generating technologies in Exhibit 36.

How to Account for External Costs

Exhibit 36 provides a comparison of generating technologies based on their costs. But environmentalists and the developers of renewable energy sources have repeatedly argued that a fair comparison of the cost of electricity should include the external costs of using coal, oil, nuclear, or hydropower. For example, the fossil fuel industry does not pay the cost of treating respiratory illnesses stemming from air pollution; instead, the health care system does. Yet, the fossil fuel industry would argue that it makes royalty payments to the government, which in turn fund the healthcare system. An endless number of examples can be found and any billions, or even trillions, of dollars in external cost can be argued over—or away.

It is our view that the external costs of various fuels and generating technologies are indeed significant. Nevertheless, they cannot be "calculated." The public knows about many of these externalities, and in this report we have discussed some of them. Legislators and regulators increasingly acknowledge these costs and have begun to reward—with tax incentives or buydowns—those who do not burden our society with waste or pollution. Especially in Europe, external costs are widely recognized, and many have been priced higher than in the U.S.

Society values, via tax breaks or green energy premiums, clean sources of energy. And we have considered this premium, and thus to a certain extent externality costs, in our financial model.

Our market-based approach accounts for the external costs of other forms of energy by assuming tax credits and price premiums for solar energy that appear likely, have occurred in the past, or are awarded now. Our base case financial assumptions, for example, include an investment tax credit. Such an investment tax credit is an implicit acknowledgment of the external costs of other sources of power.

Endnotes

[1] RDI Consulting did not provide cost data for concentrating PV, because we were not able to find dependable data.

[2] EPRI and U.S. Department of Energy, *Renewable Energy Technology Characterization,* TR-109496, Topical Report, December 1997.

[3] Available at http://www.nrel.gov/gis/.

[4] Indian Energy 2001 organized by the Council of Energy Resources Tribes (CERT), http://www.certredearth.com/.

[5] Every thermal power generating station, whether coal, nuclear, or other, could in principle store energy as heat, but this is not necessary as the energy is already "stored" in the fuels, such as coal, processed uranium, or natural gas.

[6] Assumed average consumption of 1 kilowatt.

[7] This would be the summer capacity of the plant. The solar intensity used for this rating was 826 W/m^2.

[8] The all-time peak occurred on July 1999 at 3,993 MW.

[9] Average expected solar radiation was determined from 30 years of data.

[10] We anticipate that real-time satellite images of cloud formation will be an integral part of a solar power plant's dispatch strategy in the future.

[11] In this report we assume that hybridization of dish Stirling units with natural gas is generally not used.

[12] This is true even if the solar energy is not adjusted for seasonality.

[13] Air-conditioning loads are the primary reason for the summer peak demand.

[14] Some of the external cost is accounted for by emission credits for fossil fuel plants or the decommissioning charge for nuclear plants.

[15] This was indeed the situation in the 1980s and 1990s when the 354-MW SEGS solar power plants were built near Barstow, California.

[16] The forecast used in this study was produced in August 2001. Since then, power market economics have changed and RDI Consulting's current forecast differs from the one used here, but not in a way that would be material for this solar power analysis.

[17] California Energy Commission Staff, *High Temperatures & Electricity Demand: An Assessment of Supply Adequacy in California Trends & Outlook*, July 1999, available at http://38.144.192.166/electricity/1999-07-23_HEAT_RPT.PDF (size 704.2K).

[18] NEWGen and Tom Gray, “Wind Energy’s Cost Hit New Low,” American Wind Energy Association, accessed March 6, 2001 at www.awea.org.

[19] Brandon Ownes, “An Economic Valuation of a Geothermal Production Tax Credit,” NREL, working paper (2001).

Chapter 3

A Primer on Solar Generating Technologies

Whereas the public often associates flat panel photovoltaic (PV) with solar power, it is in fact thermal solar power plants, such as parabolic trough, power towers, and dish Stirling, that can provide economic large-scale power generation today. With PV, electric power is produced by light directly in a semiconductor, while in thermal solar generation the heat of the sun is used to power an engine or turbine.

The 354-MW parabolic trough solar thermal power plants in California's Mojave Desert (see "The 354-MW SEGS Power Plants") contribute more than 70% of the worldwide production of solar electric energy. The capacity of these plants is 140 times greater than the 2.5 MW of utility PV installed in the West as of October 2000. And, it is 2.5 times larger than the cumulative capacity of all PV cells—from calculators to the international space station—ever sold in the U.S. since the solar cell was first invented.

Thermal solar power plants, such as dish Stirling, power towers, and parabolic trough, are cost-effective means of generating electric power from solar energy. They are simple, well understood, and already achieve efficiencies currently out of the reach of commercial PV cells. Though both PV and thermal solar generating technologies have risks, the type of risk is different. Thermal solar power plants are simply new applications of technologies originally developed for fossil fuel power generation, the chemical industry, and the military. Solutions for most of the technical challenges they would expect to face have probably already been devised, whereas advances in PV will require advances in materials.

In the following sections we provide a primer on solar generating technologies from flat panel PV to solar towers.

Photovoltaic Electric Power

At the heart of any PV cell, commonly known as a "solar cell," is a semiconductor junction, which absorbs light within a certain frequency range and creates an electric potential. PV cells with only one such junction, the typical PV cell, can only utilize a portion of the light spectrum. This is one of the reasons that the efficiency of even the best single-junction cell does not exceed 16%. Inherent losses due to imperfections in the semiconductor and losses related to the semiconductor's operating temperature are other reasons.

Multi-junction PV cells are able to use a wider spectrum of light and thus achieve higher efficiencies. However, these devices are difficult to manufacture and so expensive that their use is limited to special applications, such as in space or for concentrating PV. Flat panel PV cells, typically made from silicon, are used for small solar power applications, from solar cells on rooftops to modules on traffic signals, and are easily recognized by their bluish panels.

In the last five years, the worldwide PV industry has seen growth of about 20% annually and the industry is bullish about the future, especially after the California energy crisis. Domestic shipments of PV cells increased 74% during the two-year period ending in 2000, reaching approximately 75 MW of peak power.[1] It is doubtful, though, that this kind of growth is sustainable, because the projected penetration levels of distributed generation, such as rooftop PV, appear too optimistic in the face of near-term forecast power prices. The crisis mentality of the California energy crisis is already subsiding, and the public is taking a more strategic approach to meeting western energy supply needs.

Flat Panel PV

Flat panel PV is the best-known application of PV modules. Many semiconductor materials can produce electricity, but today crystalline and amorphous silicon solar cells are still the only commercially available flat panel PV cells. The high production cost of PV cells remains the technology's biggest impediment to larger market penetration and large-scale power generation. It is for that reason that PV research in the last decade focused on using alternative semiconductor materials with the goal of achieving lower cost.[2] While progress has been made on that front, it is unclear at this point whether and when exotic PV materials will be able to compete with silicon-based cells.

A unique characteristic of flat panel PV is the fact that it can use both diffused and direct normal radiation. This makes PV most attractive in areas with clouds and haze. But overall radiation levels are likely to be low in such areas as well, and it is questionable whether utilizing a marginal energy resource makes sense in the first place.

Exhibit 37 provides an overview of today's cost and performance of flat panel PV based on data from an ongoing program to install flat panel PV units in the 70-100 kW range.[3] The program has seen module costs drop significantly in recent installations, but the structures necessary to support and connect the modules (balance-of-plant) will continue to comprise a considerable portion of the unit cost. The cost reductions in the program were mainly due to better module-buying strategy rather than module production cost reductions. Even at current annual production volumes, which are already approaching 100 MW, the capital cost of flat panel PV is still very high.

Exhibit 37: Cost and Performance of Flat Panel PV and Concentrating PV

	Flat Panel Photovoltaic (1)		Concentrating PV
	Crystalline Silicon	Amorphous Silicon	
Unit Size	50 x 2 kW =100 kW	50 x 2 kW =100 kW	22–28 kW
Max Conversion Efficiency % (2)	13	6.5	18–19
Generation Threshold W/m^2	≥50 (3)	≥50 (3)	50
Annual Average Efficiency % (4)	11	6	TBD
Annual Avg. Capacity Factor % (4)	24	24	30–32
Equiv. Forced Outage Rate (EFOR)	TBD	TBD	1–3
Off-sun Generation	None	None	None
Acres/MW	3.8	7.6	8–10
Construction Time	2 weeks	4 weeks	3–4 days per unit
Capital Cost $/kW	7,500–8,500		TBD
Fixed O&M $/kW-year	10	TBD	10
Variable Non-fuel O&M $/MWh	10	TBD	10
Production Capacity for U.S. Market MW/year	68	6.5	TBD
Cumulative U.S. Sales	140 MW		0.5 MW
Largest Unit in the U.S.	1 MW		TBD
Demonstrated System Hours	Unknown	Unknown	TBD

SOURCE: National Renewable Energy Laboratory (NREL); Golden, Colorado, private communication; see reference in endnote 3.

(1) Commercially available technologies only. Crystalline silicon modules account for about 90% of the flat panel PV market, while amorphous silicon modules account for the remaining 10%.

(2) At 1,000 W/m^2.

(3) Direct normal and diffuse radiation.

(4) Premium solar resource area. Flat panel PV tilted to latitude.

Concentrating PV

PV cells using multiple semiconductor junctions are capable of converting a much larger spectrum of sunlight to electricity than the single-junction cells used in conventional flat panel PV and thus have much higher efficiencies—up to 30%.[4] Nevertheless, multi-junction cells can be used more cost effectively if sunlight is concentrated first. The same solar module then produces more power than under normal light conditions. For example, if mirrors or lenses concentrate light on multi-junction cells and increase the sunlight concentration by a factor of 10, that cell will produce about 10 times more power than under direct sunlight. Concentrating PV (CPV) uses mirrors or lenses to focus sunlight on high-efficiency cells. The concentrating optics, as in all concentrating solar power technologies, can only focus direct normal radiation, but not diffuse light.

The idea behind CPV is that a few high-performance (and high-cost) PV cells are put to maximum use by concentrating light on them by using either mirrors or lenses. Because the concentrating optics is cheaper than PV modules, this approach is expected to result in an overall lower system cost. Currently, most CPV systems use lenses to concentrate sunlight and employ two-axis tracking mechanics to follow the sun as it makes its way across the sky. Exhibit 37 provides cost and performance data on CPV.

We believe that CPV is a promising form of PV power generation because it uses only one-tenth, or even less, semiconductor material than flat panel PV and it can thus employ more expensive and efficient PV cells. CPV uses cheap lenses to leverage the costly PV modules and is likely to reach a lower cost of power than flat panel PV. Due to the smaller size of the panel per kilowatt, the use of a two-axis tracking mechanism is possible, and worthwhile, which increases overall system efficiency and capacity factors.

While PV benefits from technology transfer from the semiconductor and computer chip industry, solutions to many of the challenges that will make PV economical are not known at this point. As the recent decade has shown, efficiency gains and cost reductions in commercial PV are hard to come by. Nevertheless, research in PV should continue. PV is reliable and requires little maintenance. And CPV has the potential to leverage PV cell performance.

There are inherent advantages to using PV. Besides being able to use both direct and scattered light, PV cells have no moving parts and, because PV uses the photoelectric effect, it can, in theory, reach efficiencies not possible with any practical thermodynamic cycle. Yet, we believe that in the near term PV, especially flat panel PV, will only play a small role in large-scale solar electric generation.

Thermal Solar Power

Thermal solar power plants use the heat of the sun to generate electricity. By itself, the sun's heat would not be enough to power engines or turbines. Therefore, in thermal solar power plants, the sunlight is first concentrated using mirrors either on a single point or on a tube. For this reason thermal solar power plants (and concentrating PV) are collectively referred to as concentrating solar power (CSP) technologies. There are three different thermal CSP technologies: power tower, parabolic trough, and dish Stirling.

The three systems differ in the way they concentrate and collect sunlight, but the final step of generating electricity is identical, in that an engine or turbine is used to convert heat to electric energy (similar to a conventional power plant). The solar collectors concentrate the sunlight, and the light then hits a heat collector, which contains a heat transfer fluid that powers an engine or steam turbine. Simply put, a solar thermal power plant is a conventional power plant using the sun's heat as the energy source. Therefore, thermal power plants can be hybridized with fossil fuels because it is heat, not light as in PV, that powers the plant, and that heat can come from any source.

Power Towers

Two systems were built in the 1980s and 1990s, as demonstration plants. The units operated successfully, but were decommissioned after the demonstration period. Though new power tower systems are not being actively pursued in the U.S., there is activity in Spain on a third power tower (Solar Tres). If successful abroad and if a solar power market develops in the U.S., the companies involved in projects abroad would likely bring the technology back to the U.S.

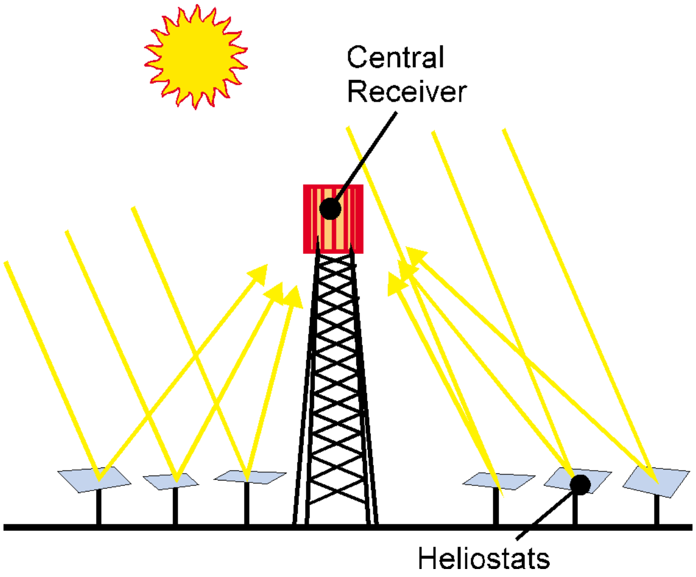
In the power tower concept, a large array of mirrors (called heliostats) tracks the sun in a way that reflects the sunlight onto a central receiver mounted on top of a tower. The sunlight is absorbed and turned into heat, which in turn powers a steam cycle. Exhibit 38 shows the design of a power tower. Parabolic trough plants and power towers can use molten-salt heat storage or fossil fuel hybridization to generate power when the sun does not shine. In molten-salt technology, salt is heated to a point at which it liquefies, hence the term molten salt.

Power towers have some general advantages over other solar generating technologies. Because an array of hundreds of mirrors focuses the light on one central receiver, the temperature of the thermal cycle is very high, resulting in good steam cycle efficiency. Molten salt, the heat transfer and energy storage medium, poses no threat to the environment. The high temperature of the working medium also results in better heat storage cycle efficiencies than is possible with parabolic trough plants.

When heat storage is used, the solar field is usually oversized so that heat can be dumped into storage while the remaining solar field continues to generate enough heat for the plant to continue to operate at its rated capacity. The ratio of solar field thermal capacity to electric capacity is called the solar-to-electric capacity ratio. A solar power plant with a ratio of 1.8 has a solar field that, under normal sun conditions, produces 80% more energy than the plant's electric power rating. A 100-MW plant with a solar-to-electric capacity ratio of 2.0 would have a 200-MW solar collector field.

The electric load shape and associated power prices in a market determine which solar-to-capacity ratio with how many hours of heat storage provides the greatest value to the plant owner. Optimization algorithms are used to determine the plant design. For the Desert

Exhibit 38: Design of a Solar Tower



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

Southwest, it appears that at today's cost for solar collectors and heat storage, a solar-to-electric capacity ratio of 1.8 with four hours of storage provides the greatest value.[5]

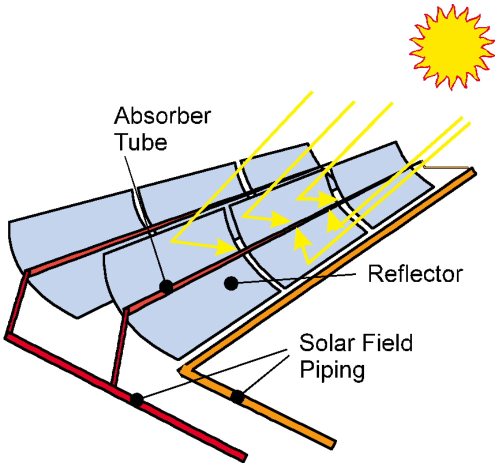
While the two power tower demonstration projects were successful, the units only operated for a limited time, and more long-term experience with the technology would be desirable. In particular, the reliability of the solar receiver at the top of the tower is unclear until longer-term operating experience can be obtained, even though the second receiver built for the Solar Two project verified the design expectations. In the receiver, thin-walled tubing and its joints are subject to considerable thermal stress, which could lead to cracks. However, Boeing Co., the maker of the solar receiver and the molten-salt storage system, has applied its experience from rocket engine nozzle technology, where comparable high heat transfer thin-wall tubing technology is employed, to solar towers, and it is confident that the receiver and storage technology will perform reliably.

On the downside, power towers must take advantage of economies of scale and can only cost-effectively be built in 50- or 100-MW units. Also, power towers require the largest amount of space per megawatt of energy produced of any CSP technology. Detailed cost and performance data are summarized in Exhibit 40.

Parabolic Troughs

The solar field of a parabolic trough plant consists of long parallel rows of trough-like reflectors—typically made of glass mirrors. 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 line (see Exhibit 39). A heat transfer fluid, typically oil at temperatures up to 400°C (750°F), is circulated through the pipes and then pumped to a central power block area, where it passes through a heat exchanger. The heat transfer fluid then generates steam in a heat exchanger, which is used in turn to drive a conventional steam turbine generator.

Exhibit 39: Design of a Parabolic Trough System



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

Beyond the heat exchanger, parabolic trough plants are just conventional steam plants. It is for this reason that parabolic trough plants, like power towers, can use heat storage with molten salt, or hybridization with fossil fuel, to generate electricity when the sun does not shine. The relatively low operating temperature of the parabolic trough steam cycle at 400°C (750°F) compared to conventional thermal power stations, or even power towers, limits the efficiency of the plant. This lower operating temperature also results in a lower heat storage cycling efficiency than what can be achieved with power towers.

Several commercial units with sizes up to 80 MW have been built and still operate today ("The 354-MW SEGS Power Plants"). Detailed cost and performance data for parabolic trough plants are summarized in Exhibit 40.

Heat storage for new parabolic trough plants will be accomplished using molten-salt storage. This technology, which was demonstrated with power towers, has not yet seen a commercial application, but it promises to be more economical and safer than the original technology employed at one of the SEGS parabolic trough plants. One of the first SEGS parabolic trough plants used Caloria, a mineral oil, for heat storage, which, like the heat transfer fluid in the collectors of the troughs, is a highly flammable liquid. This 13-MW plant provided three hours of heat storage, but an accident set the storage unit on fire and destroyed it.

This points to a general hazard at parabolic trough plants. The heat transfer fluid in the heat-collecting elements of the solar field is currently a highly flammable organic compound, which is also used in the petrochemical industry. Fires, therefore, pose a danger to parabolic trough plants. However, a similar fire hazard exists at many industrial facilities that handle flammable liquids, including refineries.

Like a conventional steam plant, parabolic trough plants require large amounts of cooling water, which may be difficult to obtain in the desert where solar power plants will be located. Power towers have similar cooling water requirements. Only dish Stirling and PV technologies do not require cooling water.

Improvement in Heat Collector Efficiency

During a site visit at Kramer Junction, California, RDI Consulting toured the SEGS parabolic trough plants. Sunray Energy operates units I and II, and the Kramer Junction Co. (KJC) operates units III through VII, while units VIII and IX, a few miles down the road, are operated by FPL Energy.

The KJC and the FPL units recently received a row of new heat collecting elements (HCE) from the manufacturer SOLEL, a vestige of the former LUZ development company. And at both plants, the plant operators confirmed that the new elements had increased the heat collection efficiency of the HCE by about 18%. This is a significant improvement in the performance of parabolic trough plants and equivalent to a capital cost reduction of the solar field.

Exhibit 40: Cost and Performance of Thermal Concentrating Solar Power Plants

	Dish Stirling	Parabolic Trough	Power Tower
Standard Plant Size	2.5 MW/100 MW	100 MW	100 MW
Max Conversion Efficiency % (1)	30%	24%	22%
Generation Threshold W/m^2	200	300	300
Annual Average Efficiency (2)	21.40%	13.70%	16.00%
Annual Avg. Capacity Factor (2)			
Basic Plant	25.20%	23%	29%
With Thermal Storage (3)	N/A	33% (4 hrs, 1.8 x)	48% (8 hrs, 1.8 x)
With Fossil Fuel Hybridization	N/A	23-95%	29-95%
Equiv. Forced Outage Rate (EFOR) %	5 (estimate)	5	5 (estimate)
Off-Sun Generation	Fossil Hybrid	Heat Storage/Fossil Hybrid	Heat Storage/Fossil Hybrid
Acres/MW of Collectors	4	5	8
Construction Time (4)	3-4 days per unit; 35 days/6 months	12 months	12 months
Incremental Capital Cost			
Basic Plant $/kW	2,650	1,956	2,065
Heat Storage $/kWh	N/A	103	27
Additional Solar Field $/kW	N/A	510	540
Fossil Fuel Hybridization $/kW	Not commercial	196	196
Fossil Heat Rate (HHV) (4)	TBD	10,800	10,000
Incremental Fixed O&M $/kW-year			
Basic	40/2.5	33	30
Heat Storage	N/A	2	1.5
Additional Solar Field Only	N/A	2	1.5
Fossil Fuel Hybridization	N/A	–	–
Incremental Variable Non-fuel O&M $/MWh			
Basic	16.80/15	2	2
Heat Storage	N/A	–	–
Fossil Fuel Hybridization	N/A	–	–
RDI estimated new Capacity (MW) that could be built (5)			
2002	0.7		–
2003	3.1	30	–
2004	27.5	100	50
2005	75	200	50
2006	100	300	150
Total	206.3	630	250
Cumulative U.S. Installations	118 kW	354 MW	10 MW
Largest Unit in the U.S.	25 kW	80 MW	10 MW (decommissioned)
Demonstrated System Hours	80,000	300,000	2,000

(1) At 1,000 W/m^2.

(2) Premium solar resource area.

(3) The number of hours of full-load heat storage and the solar-to-electricity ratio are given in parentheses, e.g. "(3 hrs, 1.6 x)" means three hours of full-load electric generation from heat storage and a solar field, which is oversized by 60% with regard to the electric capacity of the power island.

(4) Based on natural gas.

(5) Assumes sufficient tax or buydown incentives and private sector financing, but no government-backed programs, such as loan guarantees.

Dish Stirling

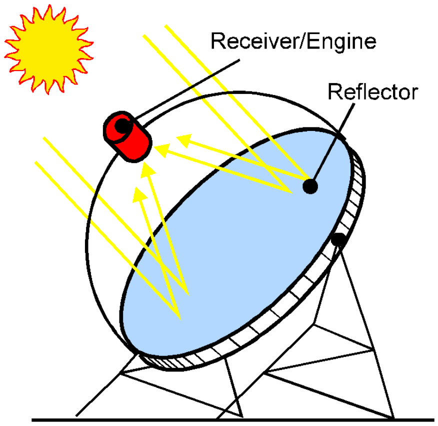
A dish Stirling system consists of a parabolic-shaped point focus concentrator in the form of a dish that reflects solar radiation onto a receiver mounted at the focal point. These concentrators are mounted on a pedestal and can pivot on two axes to follow the sun. This two-axis tracking mechanism allows the capture of the highest amount of solar energy at any time possible. A schematic of the dish Stirling principle is shown in Exhibit 41, and a photo of a dish Stirling system owned and operated by Stirling Energy Systems (SES) is shown in Exhibit 42.

The concentrated heat is utilized directly by a heat engine mounted on the receiver, which moves with the dish structure. Stirling cycle engines are currently favored for power conversion. All practical and commercial dish systems currently use Stirling engines. Dish Stirling systems achieve peak efficiencies of up to 30% (net). The typical value for a unit's peak electrical output is about 25 kW.

Conceptually, the dish Stirling system is the simplest of all thermal solar technologies, but the Stirling motor that converts the heat is a sophisticated closed-cycle motor that is highly specialized for this application. Stirling motors are not found in many applications. They are used as an ultra-quiet motor in attack submarines and for small power generation units (gen-sets). However, market penetration of Stirling gen-sets is marginal due to the dominance of the combustion motor (diesel gen-sets).

Stirling motors have accumulated tens of thousands of operating hours on dish Stirling systems; one dish Stirling unit owned and operated by SES is 17 years old and demonstrates that most of the materials that were used are durable. This system has operated, albeit with interruptions, for over a decade and a half. Newer units, manufactured for Science Applications International Corp. (SAIC) by STM Power, have not worked quite as reliably as expected, and this has raised questions about Stirling motor reliability. The motors used by SAIC and manufactured by STM Power are different from the motors used by SES but there are some concerns as to whether new units based on SES' design will work as well as its existing motors that were built over a decade ago.

Exhibit 41: Design of a Dish Stirling System



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

It is for that reason that both SES and STM Power have engaged in serious evaluations of their motors. Both companies are confident that new motors could be produced in large numbers at low cost and would be more reliable than current motors. However, doubts remain, because the performance of laboratory bench prototype Stirling motors, which are fired by natural gas, does not translate well into solar applications. This is because the solar flux that hits the heater head of a dish-mounted Stirling motor is less homogenous, resulting in thermal stress and pressure differentials in the pistons of the motor.

Aside from questions about the reliability of the Stirling motor, the dish Stirling is the quintessential thermal solar power plant:

- Its two-axis tracking mechanism allows it to maximize solar energy collection.
- The generation threshold is relatively low.
- The unit ramps to grid synchronization within a minute.
- It has the highest efficiency of any solar generating technology.
- It requires the least amount of land in relation to peak capacity and energy production.
- Its high engine-operating temperature allows air cooling, thus eliminating the need for cooling water.

Exhibit 42 shows SES' dish Stirling system.

Dish Stirling units share many characteristics with wind turbines. Like wind turbines, dish Stirling units are intermittent energy sources, have only a pedestal as footprint, can be built within days (actual assembly takes only a few hours), and come in small unit sizes and are thus modular. Tactics for marketing dish Stirling plants, therefore, could emulate some of the market penetration tactics used for wind turbines. They also allow for smaller solar farms that may fit better into renewable energy portfolios and can be expanded in modules. In contrast, a 100-MW parabolic trough plant requires an all-or-nothing investment decision of \$200 million to \$300 million.[6] The same is true for power towers.

Dish Stirling to Set New Efficiency Record

Both SES and STM power are currently aggressively pursuing the introduction of dish Stirling systems into the market and are engaged in the development and construction of new dish Stirling units. Research at SES' existing units has shown that the air-cooling system was originally over-engineered and that decreasing the cooling capacity can reduce parasitic loads. Additional changes to the motor design and the collector system will, in SES' view, improve (net) peak efficiency at its next units by 10% from currently near 30% to 33%. This would set a new

Exhibit 42: SES Dish Stirling System

SOURCE: Stirling Energy Systems. Used with permission.

world record for the efficiency of any solar power generating technology and would increase annual electric output by 6.3%.

Beyond the Economics

In this section we compare some of the characteristics of CPV, dish Stirling, power towers, and parabolic trough, because these technologies are very different from one another.

In this report we have presented both a "distributed" as well as a 100-MW dish Stirling solar power plant, because dish Stirling is modular. Currently, individual units have a capacity of only 25 kW. These units are designed to be eventually fully automated, contain only small amounts of hazardous coolant, and require no cooling water to operate. Further, they make very little noise[7] and have a relatively low profile. For these reasons, dish Stirling can be installed close to residential areas.

Their modularity and easy interconnection make dish Stirling systems attractive for small or mid-sized customers. Even though dish Stirling is more expensive than parabolic trough or power towers today, the amount of capital required to install the first unit is low—around $100,000. This makes dish Stirling systems similar to wind turbines, and their early entry into the market may come from small installations of one or a few dozen dishes.

Most of what we have said about dish Stirling systems also holds for CPV systems. Anticipated CPV unit size is 22-28 kW, similar to dish Stirling, making CPV a direct competitor with dish Stirling. CPV would even be more suitable for distributed installations because of its low O&M needs.

Parabolic trough plants and power towers, in contrast, are large industrial facilities. Economies of scale suggest that unit size should be about 100 MW (electrical). For a parabolic trough, the heat transfer fluid used in the heat-collecting elements of the solar field is currently a highly volatile organic compound and is hazardous. Because fires in parabolic trough plants are serious threats (and have occurred), these facilities must be built away from residential or industrial areas, with associated investments in transmission lines. Also, land below the solar collectors needs to be kept free of all vegetation in order to avoid grass or brush fires that would have the potential to destroy the solar plant. This weed control is currently done using herbicides, which may concern local environmental agencies as well as customers who are shopping for green power. Wind loading is also a greater problem for parabolic trough than for dish Stirling units.

Power towers avoid the hazardous heat transfer fluid by using molten salt. The salt is non-toxic and, in fact, is used as a plant fertilizer. Soil sterilization is not required because the focal point of the mirrors is at the top of the power towers—far off the ground—and no volatile heat transfer fluids are present. Of all CSP technologies, power towers are the most visible due to the tall receiver tower, and they occupy more land per megawatt-hour produced than any other CSP technology.

Parabolic trough plants and power towers also require large amounts of cooling water—commensurate with those of other steam plants, for example, coal. Only natural gas–fired combined cycle plants can achieve lower water requirements, and they only consume about one-half to one-third of the cooling water required by a steam plant. Solar resources are greatest in desert areas, but here water is a scarce and precious commodity. Therefore, the fact that cooling water is required for parabolic troughs and power towers is a big drawback for these technologies. Both power technologies could, however, address this issue by employing dry cooling or a mix of dry and wet cooling. However, these technologies, which are available to any thermal power plant—solar, coal, or nuclear—result in a higher parasitic load and thus in a lower net efficiency of the plant.

Parabolic trough plants and power towers can incorporate heat storage and fossil fuel hybridization, which allows them to displace existing capacity from the market, as we have shown in the section, "Using Supplemental Off-Sun Power." Their ability to dispatch power also allows them to earn a higher average price for power.

The monthly energy production of parabolic trough plants is more seasonal than for other CSP technologies. Parabolic troughs show a much greater drop in output toward the winter than dish Stirling, CPV, and power towers. This is because the latter three technologies use two-axis tracking systems while the solar fields of a parabolic trough plant are composed of rows of parabolic troughs that only pivot on one axis. This results in less efficient tracking of the sun in general and in particular during the winter months.

The efficiency of dish Stirling power plants is the highest of all solar technologies, and as little as four acres of land are required per megawatt of power. This means that a dish Stirling system can produce 60% more solar electric energy on the same plot of land than, for example, a parabolic trough plant.

It is our view that an emerging solar power market will shake out the mix of solar power generating technologies. Dish Stirling, CPV, parabolic trough, and power tower are such fundamentally different technologies that all could have a place in the market, at least initially. The optimal supply solution will be influenced by many factors, including economics, aesthetics, environmental concerns, availability of cooling water, practicality, safety, and funding. Nevertheless, CPV and dish Stirling will be in direct competition, as will power towers and parabolic troughs.

Existing Solar Power Plants in the West

While PV cells are often associated with solar power, only 2.5 MW of utility PV solar power operate in the West. The majority of this capacity has been built under the TEAM-UP program of the Solar Electric Power Association since 1996.[8] The largest facility is a 1-MW PV system owned and operated by the Sacramento (California) Municipal Utility District. In contrast, nine units of thermal solar plants using parabolic troughs located in the Mojave Desert near Kramer Junction, Daggett, and Harper Lake in California have been delivering 354 MW of power to Southern California Edison (SCE) for over a decade.

The parabolic trough plants are hybridized with natural gas and can deliver round-the-clock power. However, by U.S. federal law, the energy supplied by natural gas is limited to 25% of the total effective annual thermal plant energy output. During California's energy crisis in 2000 and 2001, these plants were able to forgo the use of natural gas and continue to deliver power to SCE, thus providing a hedge against volatile fuel prices.

The 354-MW SEGS Power Plants

The 354 MW of parabolic trough solar power plants, called Solar Electric Generation System (SEGS), in the California Mojave Desert in the vicinity of Barstow, were built over a seven-year period in the late 1980s and early 1990s. The plants were developed by LUZ International Ltd., a U.S. firm with strong ties to Israel, and each plant is owned by a separate limited partnership. Over the course of the project development, the unit size increased from 13.8 MW to 80 MW. The first unit had a capacity of 13.8 MW; six subsequent units were 30 MW each; and the last two units had a capacity of 80 MW each. SEGS I had two large (hot and cold) storage tanks for heat storage that allowed the plant to operate off-sun for nearly three hours at full load. Subsequent plants utilized a gas-fired boiler or heater to selectively supplement solar electricity production during peak demand periods.

In the 1980s, the state of California strongly encouraged renewable power production. As a reaction to the second oil price crisis, when the crude oil price rose to nearly US$40 per barrel, tax incentives were given to independent renewable power projects. Further, the California Energy

Commission required utilities to buy energy from so-called "qualifying facilities" (QF) under the federal Public Utilities Regulatory Policy Act (PURPA) at high fixed prices under long-term standard offer contracts. Between 1984 and 1991, first under private agreements and then with the help of the attractive standard offer long-term power purchase agreements plus federal and state tax incentives, LUZ erected the nine parabolic trough solar power plants in the Mojave Desert. To build these plants, $1.3 billion was raised—initially from private risk capital investors and next, with increasing confidence in the maturity of the technology, from institutional investors.

The first step occurred in 1983 when LUZ negotiated a 30-year contract with SCE to sell electricity from the first two plants—a 13.8-MW facility followed by a 30-MW plant. Subsequently, the standard offer 30-year power purchase agreements that were in place for the third to seventh units had fixed energy payments for the first 10 years and energy payments based on the avoided fuel cost of the electric utility for the remaining 20 years, which were initially linked to the price of fuel oil and later to natural gas. For the eight and ninth plants, the initial 10-year period of fixed energy payments was eliminated. However, the standard offer capacity payments were fixed for 30 years for the third through ninth plants. Given the expected high oil and gas prices in the early 1980s, the forecast revenue stream was very good.

However, several developments changed the economic environment that LUZ encountered by the time the seventh unit was completed.[9] First, additional new QF capacity with increasingly better heat rates had entered the market and thus lowered the avoided cost to utilities. Secondly, when oil and gas prices rapidly fell in the middle of the 1980s and remained at a low level, non-fixed energy payments dropped. Both effects significantly reduced the revenues projected for potential owners. These and other market factors translated to a higher return on investment being demanded by investors.

Up through the seventh plant, the capacity was artificially limited to 30 MW by FERC rules, but this limitation was then lifted, allowing much larger 80-MW plants. Other technical changes by LUZ, while beneficial, increased the perceived risk to investors, again raising the bar on the required return on investment. In 1985, the investment tax credit legislation expired, requiring year-to-year extensions to maintain this important incentive. During this time, LUZ also encountered difficulties with union labor issues, with premium payments to suppliers due to the tight schedules, high internal financing costs, and pressure from investors to offer even more attractive returns.

Despite these barriers, LUZ continued its development with two 80-MW units. Late approval to construct from the California Energy Commission, an early end date on the tax subsidy, and problems with construction management led to significant construction cost overruns by the completion of the ninth unit. While LUZ still achieved the construction of the plant, the company was financially weakened.

During the 1991 development of the 10th plant, another regulatory issue added further grief and accelerated the end of the parabolic trough success story. The state of California recognized the greater property requirements for solar plants in comparison to conventional fossil fuel-fired power stations and, therefore, exempted the solar system part of the plant from the state property tax. This exemption expired at the end of 1990 and was not renewed until May 15, 1991. This additional constraint, combined with the December 31, 1991, requirement for interconnection of the plant to benefit from the available tax credits, meant that the 10th plant had to be constructed in about seven months, a period that was not manageable without high added costs. This circumstance plus the other growing financial barriers resulted in the inability of LUZ to obtain construction financing. This situation, combined with a generally weak financial condition, forced LUZ to file for bankruptcy in mid-1991.

The bankruptcy of LUZ, however, did not result in closure of the nine parabolic trough plants, as each was owned by a limited partnership with a small LUZ involvement. The main need was to replace the LUZ entity that operated and maintained the plants under contract. Today, units I and II are operated by Sunray Energy; units III through VII are operated by KJC Operating Co.; and FPL Energy operates units VIII and IX. All units continue to operate with mixed success. Notably, the Kramer Junction site, with SEGS III-VII, has set performance records in recent years and has systematically lowered its O&M costs. All nine plants deliver reliable power to southern California.

The demise of LUZ teaches some important lessons. Consistency and stability of tax and energy policies are essential. Specifically, for highly capital-intensive new technologies, stable policies are a prerequisite in an early development stage. The unpredictable changes experienced in this particular case not only exhausted LUZ financially but put additional risk and insecurity on the investors.

Exhibit 43: Units III Through VII of the LUZ Parabolic Trough Solar Power Plant in the Mojave Desert, Kramer Junction, California

SOURCE: National Renewable Energy Laboratories (DOE). Used by permission.

Endnotes

[1] Associated Press, "Solar Gets Its Day in the Sun," NYTimes.com, accessed August 5, 2001.

[2] National Renewable Energy Laboratory, *Photovoltaics: Energy for the New Millennium*, January 2000.

[3] Solar Electric Power Association, *Large System Cost Report*, October 2000, Washington, D.C.

[4] National Renewable Energy Laboratory [2].

[5] This is, therefore, the design of the parabolic trough proxy plant with storage in our financial analysis (see "The True Cost of Using Solar Power").

[6] Smaller parabolic trough plants can be built, but these plants would forgo some of the lower costs that result from economies of scale.

[7] There is some noise from the fan of the cooling element, but it is comparable to the noise from a car fan.

[8] Solar Electric Power Association [3].

[9] For an excellent discussion of the LUZ story written at the time by a LUZ executive, see Michael Lotker, *Barriers to Commercialization of Large-Scale Solar Electricity: Lessons Learned from the LUZ Experience*, SAND91-7014, Sandia National Laboratories, November 1991.

Chapter 4

Benefits of Using Solar Power

An Untapped and Abundant Energy Source

Solar energy is the source of all energy on Earth with the exception of nuclear and geothermal energy. Yet, very little of our energy needs are met directly by tapping into this abundant resource. Only through the use of hydro, wind, and biomass have humans indirectly taken advantage of the solar energy that reaches the Earth every day. For the greater part of our energy needs, we rely on fossil fuels.[1]

Modern technology now allows harnessing solar energy directly for home heating or electric power generation. Solar power can be produced using the photovoltaic effect or by using the sun's heat to power engines or turbines.

The southwestern United States is home to world-class solar resources. The latitude, the low humidity, and the high altitude of the Colorado plateau make southwestern solar resources likely the best in the world.[2] In the scorching deserts of California, Nevada, and Arizona lie some of the greatest untapped domestic energy reserves.

As our analysis has shown, only 0.5% of western lands would have to be used to produce twice the energy consumed in 16 states (excluding Alaska) of the Western Governors' Association (WGA) using existing technology. This energy could be produced with no air emissions and indefinitely.

Fuel Diversity Hedges Against Fuel Cost

Today, the western states obtain 68% of their electric energy from fossil fuels. In 2001, this was equal to 741,830 GWh, which is equivalent to 727 million barrels of oil.[3] Of this portion, 24% was natural gas (and some oil) and 44% of this energy was derived from coal. Over two-thirds of western energy depends on the price of two fuels. In this report we have indicated that, in our view, future volatility of natural gas prices may be higher than has been experienced historically due to the increasing competition for natural gas to fuel generating units.

If western states want to hedge against fuel price volatility, then a diversification of energy sources is essential. Renewable energies with no fuel cost, such as wind and solar, can play a fundamental role in hedging against volatility. Portfolio theory clearly shows that even higher cost resources such as renewables can result in lower long-run energy costs at the same risk level.[4]

An energy policy with a long-term strategy of reducing dependence on fossil fuels should not tie the revenues of renewable electricity to current prices for fossil fuels. Instead, such a policy should provide incentives that will generate sufficient revenues for emerging renewable technologies, to ensure that such technologies can enter the marketplace regardless of the price levels of fossil fuels.

If an energy policy does not proactively work to encourage renewable technologies and instead relies on tying renewable revenues to fossil fuel prices, the price signals from fossil fuels will only attract investment in renewable power when it is too late. With low fossil fuel prices, the demand for fossil fuel will increase, which in turn might accelerate the fossil fuel price, in some cases rapidly. The time is then too short to construct renewable technology to use instead of the now expensive fossil fuel. An example is the low natural gas prices of the late 1990s, which attracted hundreds of thousands of megawatts of natural gas-fired generation, which then resulted in increased demand for this commodity, and finally the natural gas price spikes seen in 2001.

Solar Power Plants Meet Siting, Permitting Criteria

A fossil fuel-fired power plant sited in the countryside uses local water resources and emits pollutants into the air, whereas its power is often consumed far from the plant. It is understandable that local residents often object to a new power plant proposed in their county, in spite of its offer of jobs and a tax base, because a power plant in the hundreds of megawatts is a large industrial facility. In fact, a review of the development process of hundreds of power plants in the U.S. shows that local opposition is a big obstacle to the construction of a new and needed generator.

Developers have learned to factor local opposition—often described as NIMBY ("Not in my backyard") or BANANA ("Build absolutely nothing anywhere near anyone") syndrome—into their contingency plans. With the demographic shift from the cities to the countryside—the sub-urbanization of America—more people with incomes not derived from the local economy live in rural suburbs. These modern country folk moved from the city to escape the industrial face of America—and not to live next to a power plant.

At the same time, power plants light our homes and fuel our high-tech economy. Without sufficient and reliable electric generation, the comfort and convenience of today's world would simply not be possible. Given these observations, the ideal power plant is one that does not pollute the air; uses little or no water; and is located where people do not live yet is close to load centers. Solar power plants meet these criteria more than any other conventional or renewable generating technology.

Solar Farms Can Be Built in Deserts

All western solar resources are located in deserts. The Southwest has vast expanses of extremely arid land that host few animals and plants, mostly congregated along rivers, streams, and arroyos. The land in between these arteries of life is often barren. It is these hottest and most lifeless parts of America's landscape that are most suitable for solar power plant development. Much of this land is administered by the Bureau of Land Management (BLM) and, unless it contains mineral resources, may be of little economic value.

All power plants occupy land and have an environmental impact, including solar power plants, which require about 4 to 5 acres per megawatt. The desert ecology deserves protection, but the best locations for solar power plants are on land for which there might be few other uses.

Western Solar Resources Often Close to Load Centers

At the same time, this land is close to some of the fastest growing load centers. Two reasons explain this: one is the geography of California and the other is the migration of millions of Americans into the Desert Southwest. People like areas with a lot of sunshine.

In close proximity to Los Angeles lie the vast expanses of the Mojave Desert, a premium solar resource area. Often there will be clear skies over the desert while Los Angeles is cloudy. Large deserts surround Las Vegas, another premium solar resource area and one of the fastest growing cities in the country. El Paso, Texas, and Phoenix, Arizona, which both have excellent solar resources, are also surrounded by deserts.

The unique situation in the Desert Southwest and California offers an enormous potential for the development of solar power plants. Characterized by high load centers surrounded by vast deserts, this region likely offers the best solar power opportunities in the world.

Solar Popular with Residents

When people are asked to name a renewable energy source they usually reply "solar" or "wind." Yet the information citizens have about these energy sources is often marginal. Solar power is usually identified with PV cells, and the use of solar power for large-scale power production is considered a utopian dream. Virtually unknown is the fact that thermal solar power plants can produce large amounts of reliable power today.

Our research suggests that western policy makers are likely to find their citizens ready to embrace energy from solar power. Green energy programs, which sell power generated from renewable energies at a premium to customers, have been successful and in some areas up to 5% of consumers have switched to "green" energy.[5] Most of these programs are running short on green capacity and thus have had to cut back on their marketing. With better education of the public about the sources of power and the choices they have in today's deregulating energy markets, and with larger-scale deployment of renewables, the penetration of green energy programs is likely to be even higher.

Until recently, consumers paid little attention to the source of electricity. But the California energy crisis changed the public's understanding of the issue dramatically. If one good thing can be gleaned from the crisis, it is that Americans now know that power does not originate in the outlet but is produced by power plants. Difficult choices have to be made as to the future sources of electric power.

A recent poll conducted by eight utilities in Texas showed that 49% of retail customers prefer to obtain their power from renewable energy sources. Only 14% prefer fossil fuel—assuming the cost for conventional power and power from renewables is the same—and many customers indicated they would be willing to pay a premium for green energy.[6]

It is likely that citizens will become even more involved in issues surrounding power generation. We anticipate a cultural transformation in America's approach to energy issues, similar to what has already occurred in Europe. American society could demand renewable energy not just as a special product in a utility's energy offering, but as an important part of a comprehensive power supply strategy.

Chances are that solar power would be a popular, if not the preferred, choice of renewable energy by the citizens of the Southwest.

Zero Emissions from Solar Plants

Solar power plants, at least the ones that do not use hybridization with fossil fuel for off-sun generation during cloud cover or at night, produce no air emissions. Zero-emission solar generation after dark or during cloudy days can be achieved with heat storage.

Solar power plants emit no pollutants such as NO_x, which causes ozone. The "ozone season" spans May to September, a period when sunlight and heat convert NO_x and volatile organic compounds (VOCs) into ground-level ozone, which is harmful to humans and animals. It is for that reason that generation from fossil fuels in California is limited during this time period. At the same time, output from solar plants peaks.

The Environmental Protection Agency (EPA) considers SO_2 to be a precursor of haze, and haze compliance start dates are likely to be coordinated with those for $PM_{2.5}$—small pollutant emissions from fossil fuel power plants, mainly coal plants. SO_2 is also the primary source of acid rain. Coal combustion also releases mercury, a toxic heavy metal.

Energy from pure solar power produces no emissions, can improve local air quality, and can help western states meet the goals of the Western Regional Air Partnership (WRAP)[7] to reduce haze in our national parks and restore the acclaimed vistas of the West. In addition, solar technologies without fossil fuel hybridization produce no CO_2 and thus do not contribute to global climate change.

Solar Power Insurance Against Kyoto Protocol

Shortly after taking office, the Bush administration announced that it would not participate in the treaty that has become known as the Kyoto Protocol, which was negotiated in 1997 in Kyoto, Japan. The treaty intends to limit the emissions of CO_2 and other pollutants that are believed to be linked to the heating of the Earth's lower atmosphere—referred to as global climate change. As recently as February 2002, the Bush administration has affirmed its opposition to the Kyoto Protocol.

America is one of the world's largest emitters of these so-called greenhouse gases, and its rejection of the Kyoto Protocol puts the effectiveness of the entire agreement into question. The world climate is an exceptionally complex system and it is fair to question the existence of a warming trend of the atmosphere due to CO_2 emissions and other greenhouse gases such as methane. Nevertheless, a study performed by the National Academy of Sciences on behalf of the Bush administration and released in June 2001 reported to the president that there was overwhelming evidence that global climate change is real. In particular the academy advised the president that:

> *Greenhouse gases are accumulating in Earth's atmosphere as a result of human activities, causing surface air temperatures and subsurface ocean temperatures to rise. Temperatures are, in fact, rising. The changes observed over the last several decades are likely mostly due to human activities, but we cannot rule out that some significant part of these changes are also a reflection of natural variability. Human-induced warming and associated sea level rises are expected to continue through the 21st century.*

Regardless of the ultimate outcome of the discussion on global warming and the implementation of the Kyoto Protocol, there are numerous other reasons to pursue the large-scale deployment of renewable energy sources such as solar, including regional haze or hedging against fuel price volatility. Yet, at the same time, solar power plants will act as an insurance policy against global climate change and the possible implementation of the Kyoto Protocol, or its successor, by helping to reduce future compliance costs under a climate treaty.

PV, Dish Stirling Require No Cooling Water

Because of the high operating temperature and high efficiency of the Stirling motor, air cooling can be used with little compromise on overall solar-to-electric conversion efficiency. The only water requirements for PV and dish Stirling are for occasional washing of mirrors and glass surfaces. This accounts for less than five gallons of water per megawatt-hour of power produced.

This total water consumption is one-100th of the water requirements of conventional power plants and makes PV and dish Stirling true water misers. This is especially important in the Desert Southwest where water resources are scarce. Only wind power requires less water per megawatt-hour for the occasional turbine blade wash.

Project Lead Time Is Short

Solar power plants can be built quickly and can thus follow demand growth more closely than most conventional power projects. Capacity can be built within one to two years—start to finish. This is primarily because solar plants have short development and construction times. The long lead times of many types of conventional power projects, especially those of coal and nuclear plants, combined with their large size, which is dictated by economies of scale, causes significant lumpiness in supply additions.[8] During such a long lead time, market fundamentals that originally justified the investment may have changed substantially, putting the economic viability of the project into question. Therefore, fast permitting and construction times are key competitive factors for any power generator.

Pure solar power plants, such as dish Stirling systems, PV, and power towers and parabolic trough plants without fossil fuel hybridization, do not have to apply for air permits. This lengthy permitting process can take up considerable time in the development of a fossil fuel plant. Further, because dish Stirling systems and PV by design do not require cooling water, another regulatory hurdle can be bypassed.

Another advantage of PV, dish Stirling, and power tower plants is the fact that very little or no toxic or combustible chemicals are part of the plant design. This eliminates most local permitting issues related to fire hazards or surface water run-off containment requirements under the Clean Water Act. Also, dish systems or PV have a lower visual impact than wind power plants, which stand as tall as 300 feet.[9] The size of the wind turbines also requires a detailed geological study to guarantee the stability of the turbine foundation. For dishes, which are also mounted on a pedestal, such studies are simpler because of the much smaller size of the structure and because dishes avoid instead of seek wind loads, which wind turbines encounter by virtue of their location and operation.

And finally, because the ideal locations for solar power plants are desert areas, acquiring these lands, obtaining zoning, and performing environmental impact studies will typically be a more rapid process than with urban and suburban areas targeted by conventional plants. Nevertheless, because of fire hazards, the land on which the collectors of a parabolic trough plant are located needs to be kept clear of vegetation at all times; this may cause problems under the Endangered Species Act or state wildlife protection laws. The small footprints of PV and the pedestal of dish Stirling cause a small impact on the land.

Because of the aforementioned reasons, solar power plants should have one of the shortest permitting and development times of any power technology. Overall project lead time is further improved by the short construction time of solar plants. However, differences exist among the technologies in terms of manufacture and construction, as the example of parabolic trough and dish Stirling shows:

The power island of a parabolic trough plant is essentially a steam plant, which is connected to the solar field through a heat exchanger, where the heat transfer fluid of the collectors produces the steam for the turbine. Thus, the construction period of a parabolic trough plant is comparable to that of a simple steam plant, which is estimated to be 12 months for a 100-MW power island. The solar field can be built concurrently and, because of the modular nature of the collectors, as quickly as desired.

Dish Stirling systems are entirely prefabricated and, once the foundation is set, can be erected and electrically interconnected in less than four hours, assuming that the necessary transmission interconnection has been completed. Since the units are self-contained, a dish can, in principle, produce power immediately. Initially installed units can thus offset some of the interest during construction with energy sales. While hybridization with fossil fuels is possible, in the near term, dish Stirling systems will likely not use hybridization. For this reason, no fuel lines need to be constructed to the dishes, which further simplifies construction. Dish Stirling power plants can be built within weeks. An entire 100-MW dish Stirling solar plant comprising 4,000 units can be assembled in a few months.

The current power plant construction boom in the U.S., with over 48,000 MW of new power plants built in 2001 and 57,000 MW expected in 2002, has all but exhausted engineering, procurement, and construction (EPC) contractor capacity in North America. It is for this reason that the developers of new parabolic trough plants will face difficulties finding an EPC contractor in the near term. In addition, RDI Consulting's research shows that in 2001 almost every large power project was delayed by months. Large-scale dish Stirling power plants do not require an experienced EPC contractor; thus no delays or difficulties in the construction of these solar plants are expected.

Such fast construction times reduce the cost of financing and provide better matching of supply to demand growth.

Endnotes

[1] Ultimately, the energy of fossil fuels also has its origin in solar energy, which made ancient forests and organisms grow.

[2] Department of Energy and EPRI, *Renewable Energy Technology Characterization*, Topical Report TR-109496, December 1997, p. 5-4.

[3] Assumes a fossil fuel to 1997 electricity conversion efficiency of 60%.

[4] Shimon Awerbucher, "Getting It Right: The Real Cost Impacts of a Renewables Portfolio Standard," *Public Utilities Fortnighly*, February 15, 2001.

[5] E SOURCE, "Making Green Electricity Programs Work: The Experts Speak Out," report GE-5, September 2000.

[6] Kathleen McFall, "Green Supply: Opportunity amid Uncertainty," *Energy Insight*, August 3, 2001, www.einsight.com.

[7] www.wrapair.org

[8] Lumpiness means capacity being added in amounts larger than the increase in peak demand in that year and thus requiring load to "grow into" capacity additions.

[9] Based on 800-kW turbine, including rotor.

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.

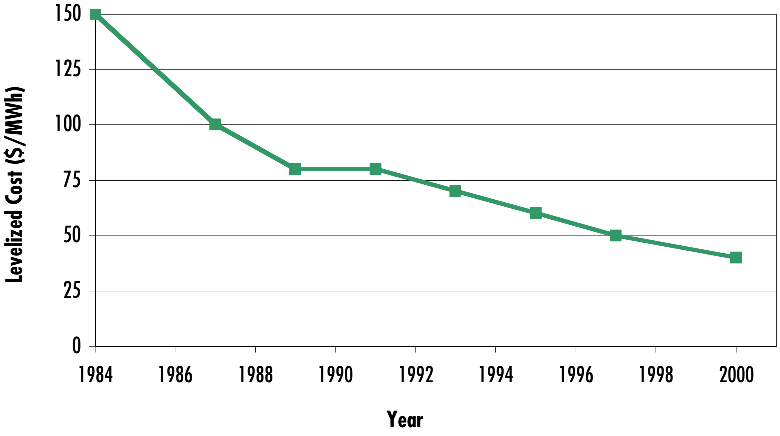
While the German and Danish governments provided the long-term financial stability and incentives that allowed high-price wind power to enter the market, the technology development was left to the wind companies themselves. The foundation of research and development had already been laid and had brought 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.

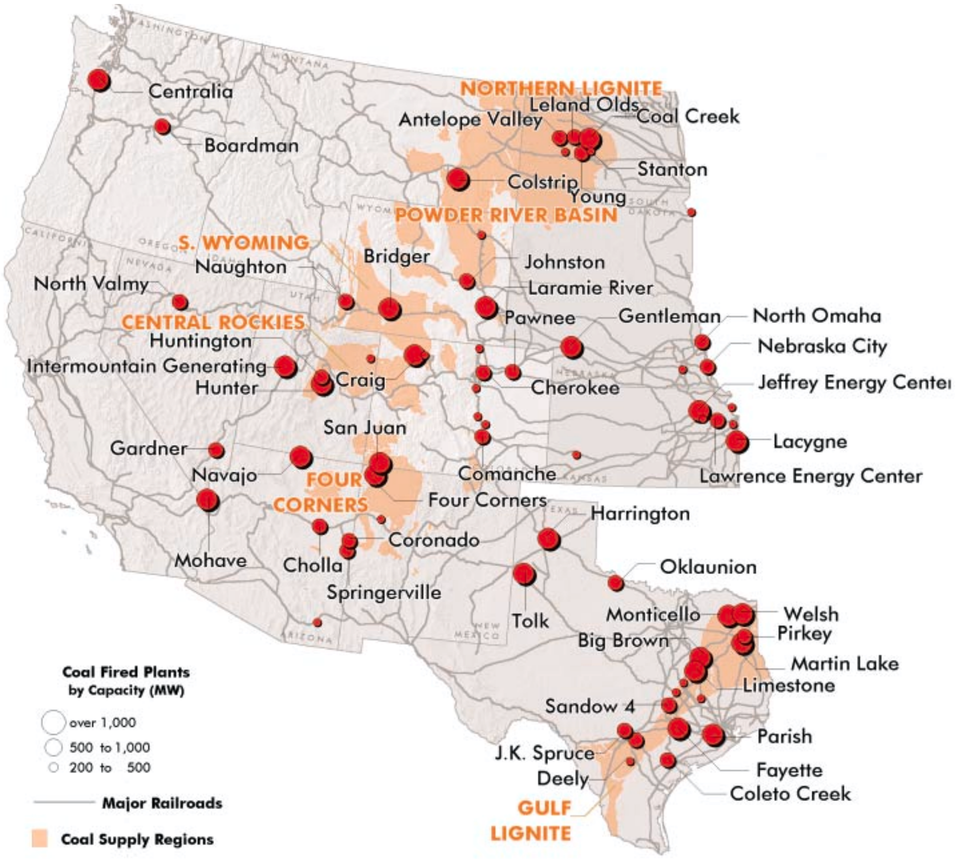
With the world's population growing, the use of fossil fuels will continue to grow in the near term and so will its impact. In the history of mankind, fossil fuels have played a key role in allowing the cultural and technological development of humankind. As long as other energy sources are not used 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 tenfold. 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.

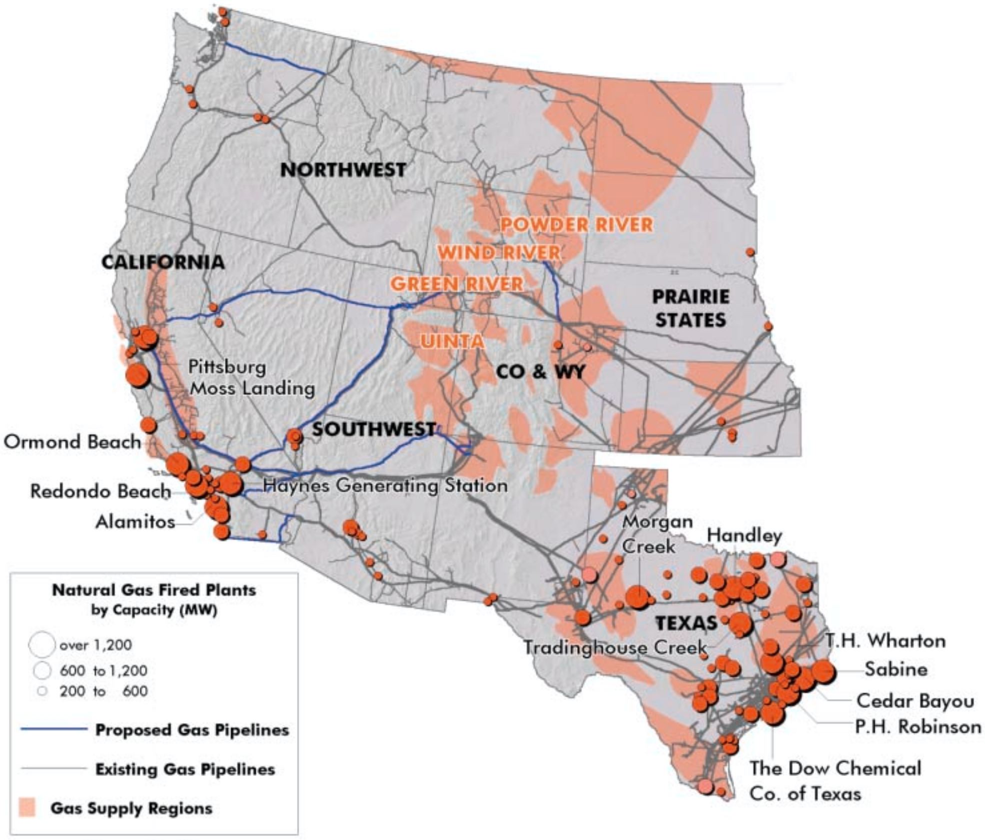
In Exhibit 47 we have labeled the four most important emerging natural gas supply regions, all located in the Central Rockies. These regions are the Uinta and Green River basins and the supply regions in the Wind River area and the Powder River Basin, which is also the West's biggest coal region.

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



*Plants over 200 MW shown.

Source: RDI Consulting, POWERmap

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

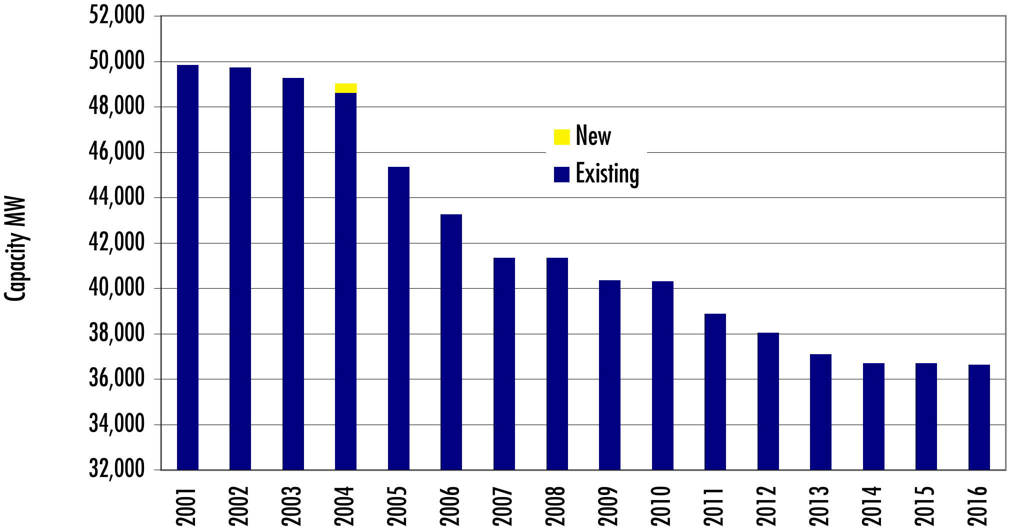
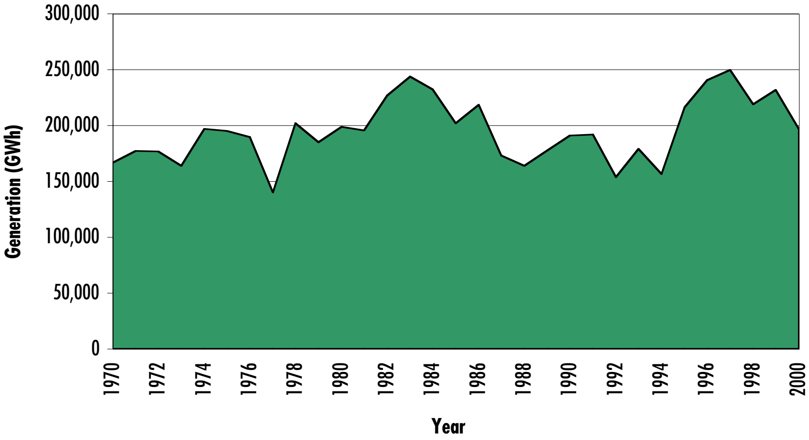


Exhibit 50: Hydro Generation in the West, 1970-2000



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.

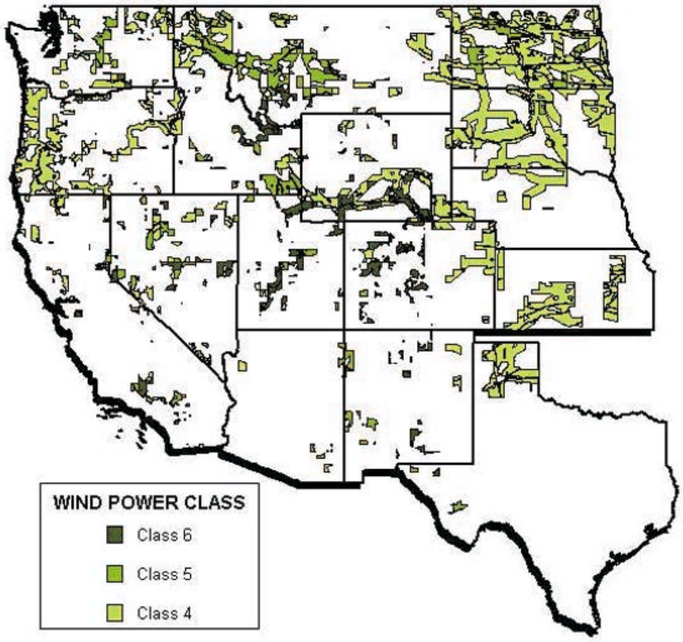
In our analysis we have excluded any wind resources on western land that is unavailable such as urbanized areas and national parks. This analysis is similar in methodology to that used for solar resources, which is presented in the section, "The Solar Energy Potential."

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		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.

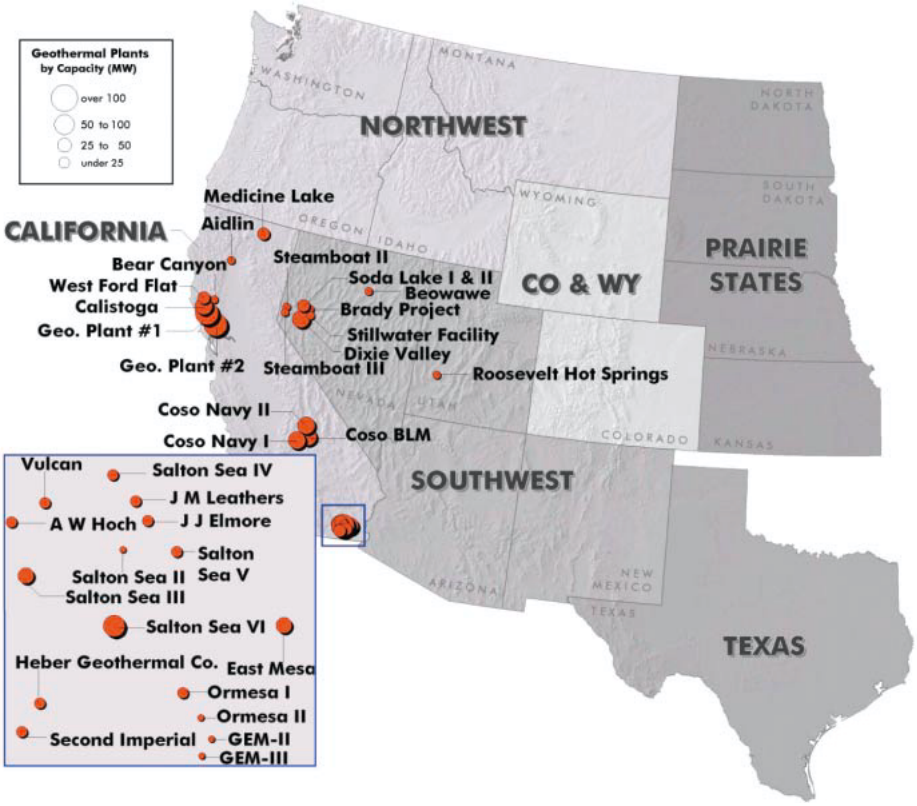
For all these reasons, energy from solar power appears to be the preferred renewable energy source in the Southwest. Western states that do not have good solar resources are fortuitously endowed with plenty of wind resources. Solar power and wind energy are found—except in a few fortunate places—in different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

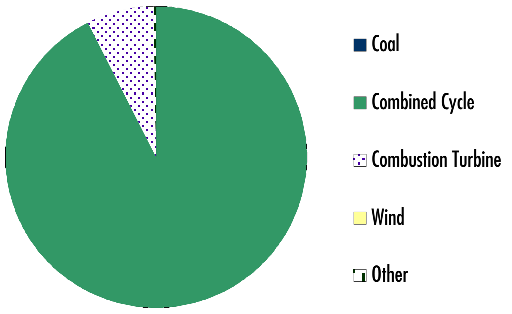
(1) RDI Consulting estimate
(2) RDI Consulting base case forecast.

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%

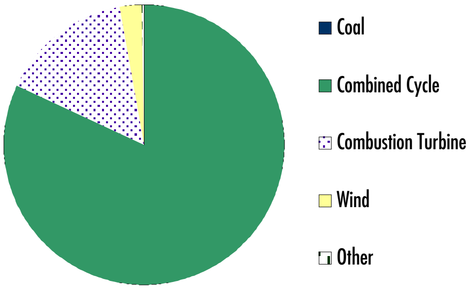
(1) RDI Consulting estimate
(2) RDI Consulting base case forecast.

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%

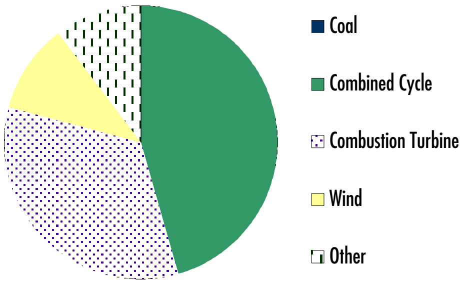
(1) RDI Consulting estimate
(2) RDI Consulting base case forecast.

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%

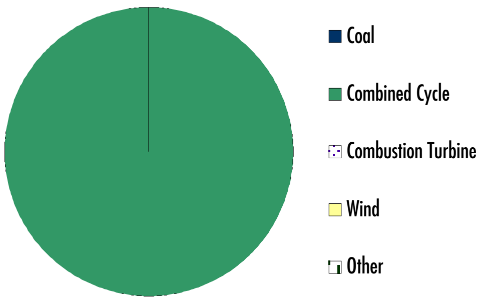
(1) RDI Consulting estimate
(2) RDI Consulting base case forecast.

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%

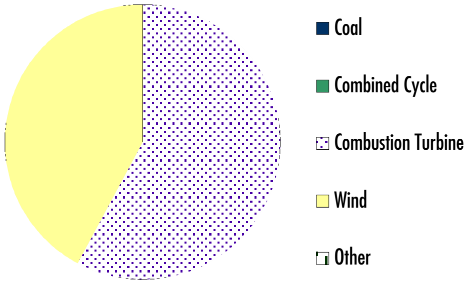
(1) RDI Consulting estimate
(2) RDI Consulting base case forecast.

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%

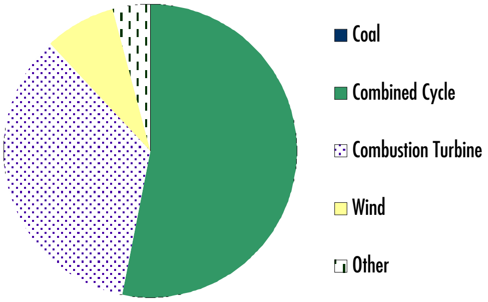
(1) RDI Consulting estimate
(2) RDI Consulting base case forecast.

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%

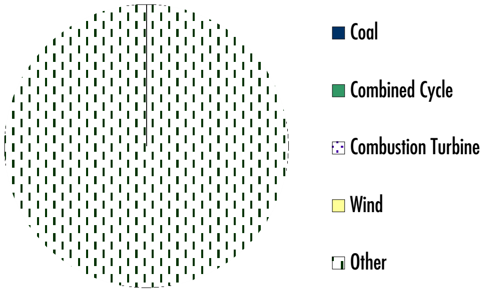
(1) RDI Consulting estimate
(2) RDI Consulting base case forecast.

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%

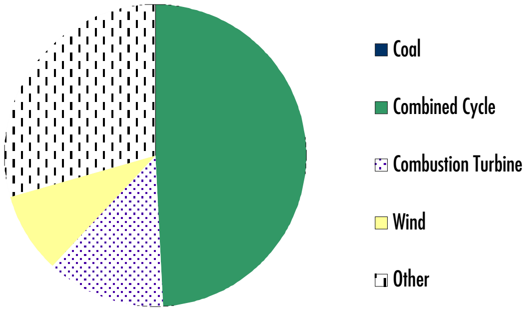
(1) RDI Consulting estimate
(2) RDI Consulting base case forecast.

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%

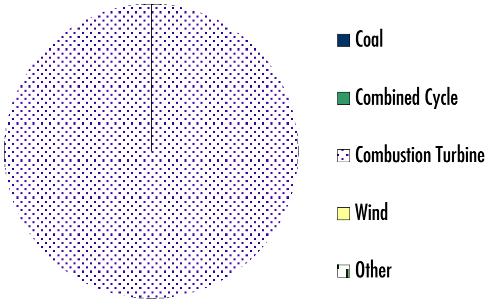
(1) RDI Consulting estimate
(2) RDI Consulting base case forecast.

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%

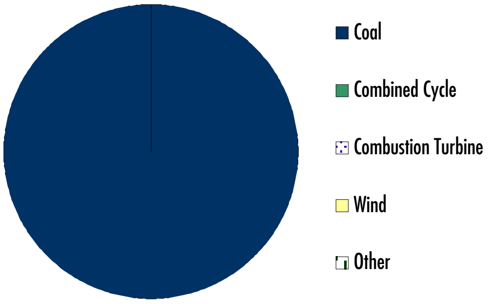
(1) RDI Consulting estimate
(2) RDI Consulting base case forecast.

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%

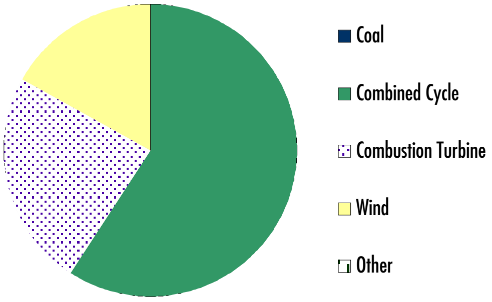
(1) RDI Consulting estimate
(2) RDI Consulting base case forecast.

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%

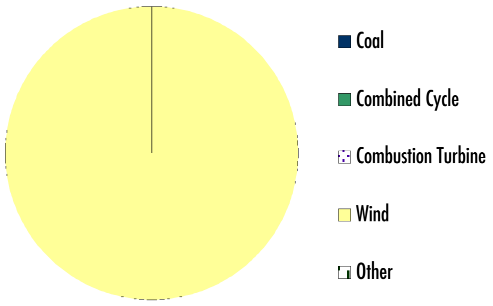
(1) RDI Consulting estimate
(2) RDI Consulting base case forecast.

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%

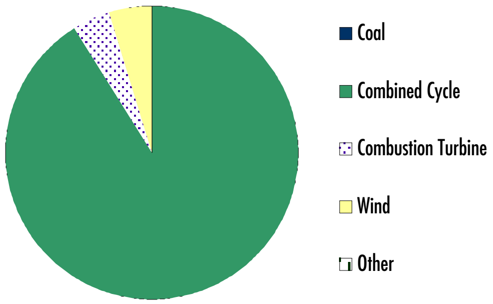
(1) RDI Consulting estimate
(2) RDI Consulting base case forecast.

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%

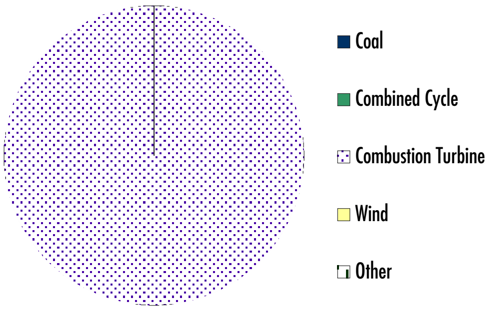
(1) RDI Consulting estimate
(2) RDI Consulting base case forecast.

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%

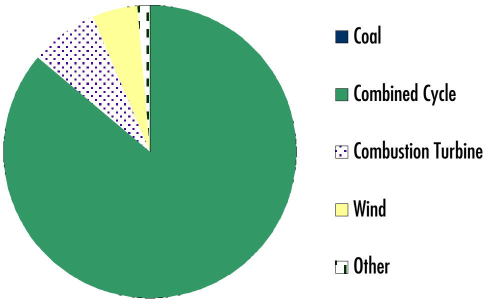
(1) RDI Consulting estimate
(2) RDI Consulting base case forecast.

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%

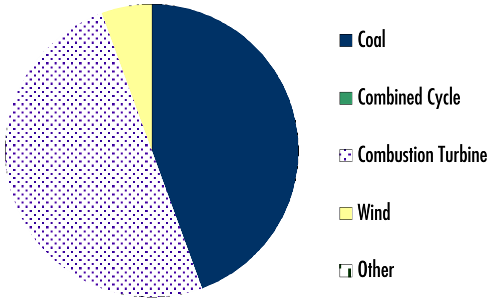
(1) RDI Consulting estimate
(2) RDI Consulting base case forecast.

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.

REPORT DOCUMENTATION PAGE

Form Approved
OMB NO. 0704-0188

1. AGENCY USE ONLY (Leave blank)

2. REPORT DATE
July 2002

3. REPORT TYPE AND DATES COVERED
Subcontract Report
August 1, 2001 to December 30, 2002

4. TITLE AND SUBTITLE
Fuel from the Sky: Solar Power's Potential for Western Energy Supply

5. FUNDING NUMBERS
CP02.4000

6. AUTHOR(S)
Dr. Arnold Leitner

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
RDI Consulting
3333 Walnut Street
Boulder, CO 80301

8. PERFORMING ORGANIZATION REPORT NUMBER
NAA-1-31470-01

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
National Renewable Energy Laboratory
1617 Cole Blvd.
Golden, CO 80401-3393

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
NREL/SR-550-32160

11. SUPPLEMENTARY NOTES
NREL Technical Monitor: M. Mehos

12a. DISTRIBUTION/AVAILABILITY STATEMENT
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

12b. DISTRIBUTION CODE

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.

14. SUBJECT TERMS
renewable energy; solar power; concentrating solar power; power towers; solar towers; parabolic trough; dish stirling; dish engine; dish systems; fuel from the sky; southwest; solar resources; photovoltaic; RDI consulting; western governors' association; western governor association; western governors association; energy and the environment; air emissions; visibility in scenic areas; energy independence; energy self-sufficiency; intermittent; intermittence; intermittency; wind and solar power; wind; solar; geothermal

15. NUMBER OF PAGES

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT
Unclassified

18. SECURITY CLASSIFICATION OF THIS PAGE
Unclassified

19. SECURITY CLASSIFICATION OF ABSTRACT
Unclassified

20. LIMITATION OF ABSTRACT
UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102