CALIFORNIA SOLAR RESOURCES

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Abstract

California has enormous, although largely untapped solar resources. The state is also a leader in solar development with over 350 megawatts (MSW) of operating concentrating solar power (CSP) facilities and 100 MW of photovoltaic (PV) systems. Analyses of the state's solar resources show that PV can be deployed beneficially almost anywhere in California. Conversely, CSP facilities require higher concentrations of solar resources and may be more easily deployed in the southeastern part of the state. Ignoring economic constraints, the technical potential for PV in California exceeds 17 million MW of capacity. If applied to existing residential and commercial rooftops, the technical PV potential exceeds 74,000 MW of capacity. If CSP facilities are deployed only in those areas where the annual average direct-normal insolation exceeds 6 kilowatt-hours per day per square meter, the CSP technical potential exceeds 1,000 MW of capacity.

Keywords

Solar, solar resources, photovoltaics, concentrating solar power

California's Solar Resources

Purpose and Introduction

California has a tremendous supply of renewable resources that can be harnessed to provide clean and naturally replenishing electricity supplies for the state. Currently, renewable resources provide approximately eleven percent of the state's electricity mix.[1] California's Renewable Portfolio Standard (RPS) established in 2002 by Senate Bill 1078 (SB1078, Sher, Chapter 516, Statutes of 2002) requires electricity providers to procure at least one percent of their electricity supplies from renewable resources so as to achieve a twenty percent renewable mix by no later than 2017. More recently, the California Energy Commission, the California Public Utilities Commission and the California Power Authority approved the Energy Action Plan (EAP), accelerating the twenty- percent target date to 2010.[2]

The purpose of this white paper is to provide estimates of the solar resources located within California and potentially available for use in meeting the RPS and EAP goals. Estimates are provided on the "gross" potential (i.e., the potential unconstrained by technical, economic or environmental requirements) and the "technical" potential (i.e., unconstrained by economic or environmental requirements). This information updates and expands upon resource information provided in the Renewable Resources Development Report of 2003.[3]

Anyone who has walked through California's Central Valley during summer recognizes that the state has an abundance of sunlight. However, estimating the energy potential from sunlight requires knowing the available solar resource and the efficiency of the technology used to convert sunlight to energy.

As sunlight streams through the earth's atmosphere, some reaches the ground directly, some is reflected, some is absorbed and some is scattered. The amount of solar resource that actually reaches the ground depends on a number of factors including latitude, season, time of day, air quality and other atmospheric conditions (e.g., clouds, aerosol particles, etc.). Different methods are used to estimate the amount of solar resource that can be used for energy purposes.

Incident solar radiation (insolation) represents the amount of solar resource available per unit area and is usually expressed in terms of kilowatt-hours per square foot per day (or megajules per square meter per year). Insolation values summed over an area provide an estimate of the "gross" energy potential in that area. "Direct radiation" or "direct-beam" radiation refers to the light that hits the earth's surface directly and does not include any scattered or reflected sunlight. "Diffuse" radiation is scattered sunlight, while "albedo" radiation is light reflected off the earth's surface. "Global" radiation is the sum of direct, diffuse and albedo radiation.

Solar technologies that convert sunlight to electricity fall into two broad categories: concentrating solar power (CSP) systems and non-concentrating systems (primarily flat plate photovoltaic systems). CSP systems can use only direct-beam radiation to generate electricity. In contrast, non-concentrating photovoltaic (PV) solar systems such as flat plate collectors have the ability to use direct, scattered and reflected sunlight to generate electricity.

Solar Photovoltaics

Overview of Photovoltaic Technologies

PV cells (solar cells) are solid-state, semiconductor-based devices that convert radiant energy (light) directly into electricity. In contrast to most other power systems, PV systems do not rely on moving parts. As long as an adequate source of light is provided, PV systems will quietly generate electric current without emissions, conventional fuels, moving parts, and with minimal maintenance. These qualities make PV systems economical and technically ideal for portable or remote applications such as consumer products, electronic signs, call boxes on highways, and communication antennae. Zero emissions and quietness also make PV technologies likely candidates for use in urban areas.

PV cells consist of several layers of different materials. The primary layer is a semiconductor material where the photoelectric effect takes place. Semiconductors in today's commercial PV products are typically composed of silicon. The semiconductor is sandwiched between two metallic layers that provide a steady flow of electrons through the semiconductor and connect the cell to an external electrical circuit. These layers are sealed and protected from the environment by an encapsulant such as glass. An anti-reflective film is deposited between the encapsulant and the photoactive surface of the cell to maximize light absorption.

Today's commercially available solar cells consist of five basic materials, each with its own trade-offs between manufacturing costs and efficiency:

- Single-crystal, large-area planar silicon cells yield high efficiencies under normal light conditions;
- Single-crystal, small-area concentrator silicon cells yield higher efficiencies under concentrated light (from 20-1000 suns);
- Polycrystalline silicon cells are less expensive, but also less efficient than single-crystal cells;
- Various thin film semiconductor materials are available including amorphous silicon (a-Si), cadmium telluride (CdTe) and copper-indium-diselenide (CIS).

- Amorphous silicon modules are a commercial product, but are less efficient than polycrystalline materials. The severe performance degradation that plagued early versions of a-Si have been resolved, although they still suffer from an initial performance loss. CdTe also has stability and manufacturing challenges, in addition to potential environmental concerns over the use of cadmium. CIS technologies have potentially high efficiencies, but face manufacturing challenges.
- Multi-junction cells consisting of several layers of different semi-conducting materials are being produced primarily for space applications. These PV cells have achieved record-setting efficiencies as high as 35% under concentrated light, but are more complex to manufacture. Tandem-junction devices made of layers of amorphous silicon are currently available primarily for the terrestrial market.

PV systems are commonly made up of "flat-plate" collectors. Flat-plate collectors consist of large numbers of cells consolidated into modules that are grouped into an array, all mounted on a rigid, flat surface. PV systems can be built to provide power as dedicated central station power plants or distributed generating systems. Studies by Pacific Gas and Electric in the 1980's indicated the technical and economic challenges facing PV used in a central station approach.[4] More recently, flat-plate PV systems are being mounted on rooftops to help offset electricity demand at commercial buildings and homes. Since 1981, over 100 MW of rooftop PV systems have been installed in California.[5] Such distributed PV systems offer the potential of being an attractive power solution for congested urban areas where land premiums are too high to accommodate power plants with large footprints, and where the noise and emissions from a conventional fossil-fueled power plant might pose unacceptable impacts.[6]

In contrast to mounted rooftop PV systems, Building Integrated Photovoltaics (BIPV) systems made up of PV "shingles" and tiles are integrated into the structure of a building, thereby replacing or enhancing other building materials. BIPV has the potential for multiple savings by providing a combination of services such as weatherproofing, shading, insulation, and day lighting. Like mounted flat-plate systems, BIPV can be combined with battery back up to provide primary power, dispatchable peak power shaving and back-up power during power disruptions. In addition, PV/battery systems have an advantage over conventional backup generators because they produce power for the customer even when there is no emergency.

While PV systems have many advantages, they suffer from low overall efficiency. PV cell efficiencies range greatly depending on the cell material, and a significant amount of research work has been conducted to increase cell efficiencies. In general, the highest PV cell efficiencies achieved to date for small area cells are approximately 35 percent.[7] Efficiencies are significantly lower for PV modules. For example, polycrystalline and single crystalline PV modules have efficiencies ranging from 12 to 15 percent.[8] Amorphous silicon, CdTe and CIS modules have efficiencies ranging from 6 to 19 percent.

There is significant interest in incorporating PV systems into new home development due to the resulting possible societal benefits, including reduced electricity system costs, protection against price volatility and air quality improvements.[9] California's new home market is growing at approximately 200,000 homes per year.[10] When integrated into new home development, BIPV has the potential to significantly increase the market growth of PV systems in California. If just two percent of new homes are installed with 2.5 kilowatt-sized BIPV systems, this would result in a first year growth of nearly 10 megawatts (MW) of new PV capacity. If the number of new homes equipped with BIPV systems increased to 10 percent, the resulting contribution to California's electricity system at the end of ten years would be over 400 MW of PV generating capacity. Under an approach where fifty percent of new homes were equipped with PV systems, the total electricity contribution from PV could be as high as 1800 MW by 2017.[11]

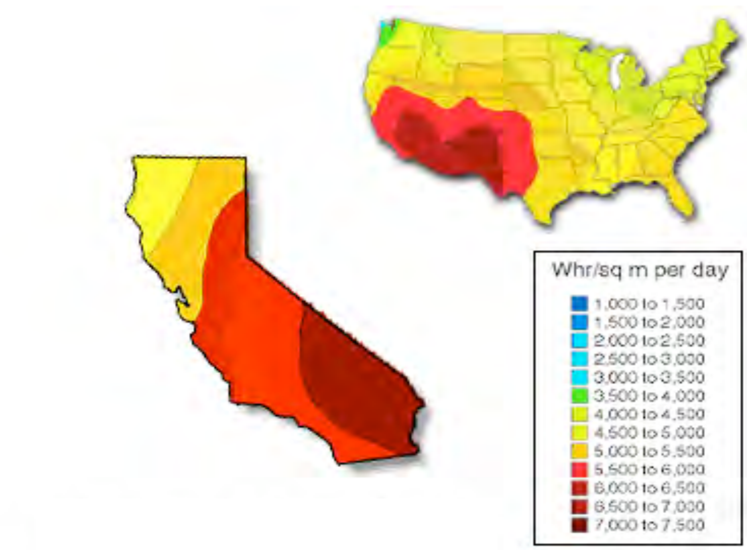
PV installed on homes and buildings represents a form of distributed generation (DG) that helps supply electricity directly at the demand source. In addition, PV systems may help eliminate or reduce the need to upgrade or build new transmission lines. In particular, by supplying electricity at the demand center, PV reduces the need to transfer electricity from the grid to the demand center. As the number of PV systems increase, the reducing need to transfer power can delay or eliminate upgrades in distribution lines and transformers.[4]

Currently, crystalline-silicon PV technologies continue to dominate PV sales, accounting for over 84% of worldwide shipments. Amorphous silicon thin-films account for another 11% of the market, with the remaining 4% coming from other thin-film products.[12] Thin films may play a more significant market role in the future, if they are able to reach cost and performance goals necessary to make the transition to larger scale, cost-effective manufacturing. A number of innovative non-conventional new technologies, such as dye-sensitized solar cells, are also under development.

Solar Photovoltaic Potential in California

Typically, insolation values are highest in summertime and in areas of lower latitudes, with dry climates and clear skies. As shown in Figure 1, the southwestern states of Nevada, Arizona and New Mexico tend to have very high insolation values from between 7 to 7.5 kilowatt-hours per square meters per day (kwhrs/m^2-day). However, much of California's Central Valley and the southern part of the state also have insolation values ranging from 5 to 7.5 kwhrs/m^2-day.

Figure 1: Solar Resources for California



California's solar potential was estimated using insolation values provided by the National Renewable Energy Laboratory's (NREL's) Climatological Radiation Model.[13] The model provides average daily total solar resource information on grid cell sizes of approximately 10 by 10-kilometer squares. Insolation values for the photovoltaic resource assessment represent the solar resource available to a flat plate collector oriented due south at an angle from horizontal equal to the latitude of the collector location. This is a typical configuration for a PV system.

Figure 2 shows the gross solar potential of flat plate PV systems in California. The values in figure 2 represent average annual estimates and show that most of California has a relatively good solar resource that could be harnessed using PV systems.

Figure 2: Gross PV Potential

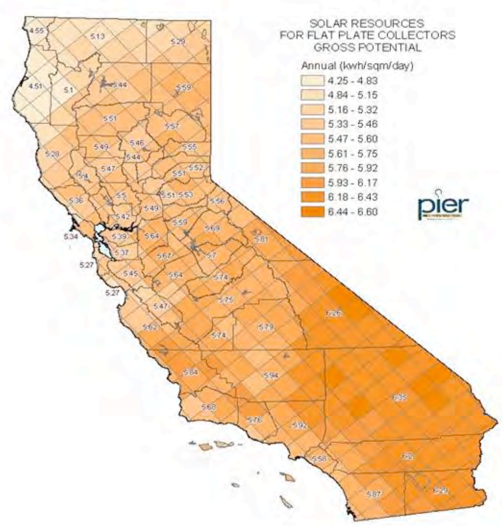
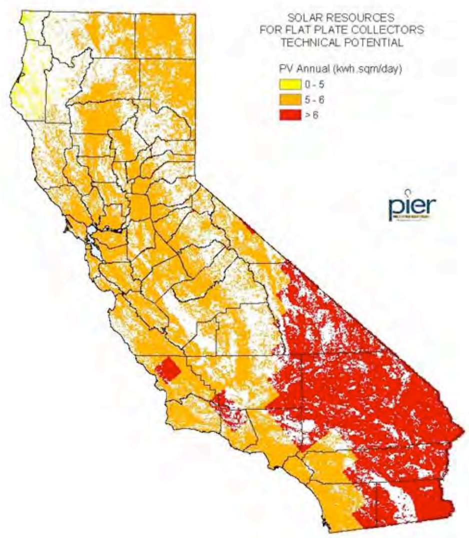


Figure 3: Technical PV Potential



Although a good indicator of solar resources, the gross potential tends to over-estimate actual electricity generation capacity. To estimate a more realistic technical potential, certain assumptions must be made. First, PV systems are assumed to have a typical 10 percent efficiency. In addition, the technical potential assumes PV systems are used only where practical. Consequently, the technical potential discounts or filters out locations where PV is impractical. For example, solar resources over large bodies of water or located in pristine areas of the state are assumed to be unavailable for use. Other areas excluded from the technical potential include forests (due to shading), agricultural lands, reserves, parks, areas with sensitive habitats (e.g., coastal sage scrub, wetlands, coastal zone and riparian management areas), and regions with north slopes greater than five percent.[14]

Figure 3 shows the PV technical potential in California based on the preceding assumptions. Comparison between the technical and gross PV potential maps shows a much higher technical potential exists in the southeastern part of the state than elsewhere. Table 1 provides a further breakout of the overall PV technical potential at the countywide level, showing that the technical potential for PV is extremely large at nearly 17 million MW statewide.

Given that PV manufacturing capacity worldwide is approximately 1000 MW per year, the technical potential far exceeds the PV capacity likely to be installed.[15] The technical potential also assumes PV systems can be installed as stand alone power plants or as rooftop applications. Due to economic considerations, we assumed that

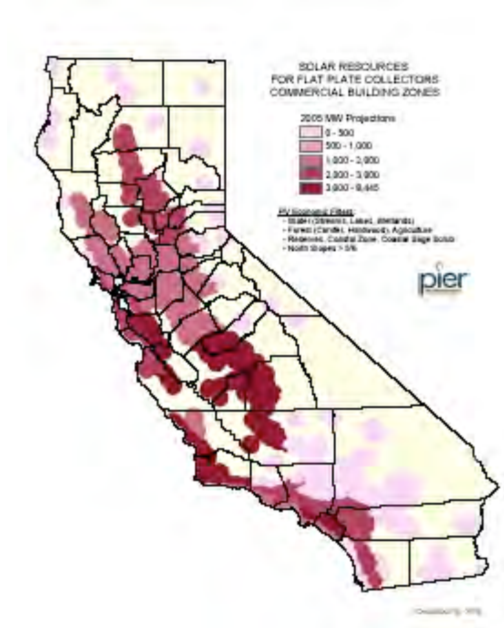
Table 1: PV Technical Potential by County

County	MWh/day	MW	County	MWh/day	MW
ALAMEDA	558,952	103,745	ORANGE	811,245	144,772
ALPINE	260,655	46,905	PLACER	439,756	80,747
AMADOR	214,149	38,754	PLUMAS	397,814	71,626
BUTTE	439,566	80,610	RIVERSIDE	7,811,694	1,253,372
CALAVERAS	378,300	67,423	SACRAMENTO	814,573	147,775
COLUSA	317,045	58,227	SAN BENITO	822,419	150,298
CONTRA COSTA	490,774	91,151	SAN BERNARDINO	25,338,276	3,981,405
DEL NORTE	91,916	20,329	SAN DIEGO	3,561,569	605,526
EL DORADO	373,269	67,806	SAN FRANCISCO	38,977	7,410
FRESNO	1,821,160	317,692	SAN JOAQUIN	513,946	91,113
GLENN	547,123	99,508	SAN LUIS OBISPO	2,450,572	418,263
HUMBOLDT	397,805	88,340	SAN MATEO	251,470	47,153
IMPERIAL	4,698,212	745,887	SANTA BARBARA	1,690,109	297,137
INYO	10,047,177	1,599,946	SANTA CLARA	861,570	158,437
KERN	6,300,316	1,043,071	SANTA CRUZ	157,093	29,776
KINGS	502,002	86,687	SHASTA	895,789	164,584
LAKE	529,442	98,033	SIERRA	193,077	34,794
LASSEN	2,754,941	492,190	SISKIYOU	1,345,782	261,615
LOS ANGELES	3,912,346	662,486	SOLANO	453,180	83,335
MADERA	799,540	140,005	SONOMA	576,430	106,940
MARIN	246,556	45,458	STANISLAUS	795,435	140,965
MARIPOSA	548,329	96,897	SUTTER	90,023	16,717
MENDOCINO	665,493	124,389	TEHAMA	1,316,667	239,196
MERCED	1,034,145	183,450	TRINITY	331,254	64,027
MODOC	2,237,536	423,331	TULARE	1,251,596	217,308
MONO	2,036,627	349,025	TUOLUMNE	668,673	117,463
MONTEREY	1,875,717	330,488	VENTURA	1,136,750	198,073
NAPA	330,271	60,168	YOLO	316,907	57,518
NEVADA	194,567	35,236	YUBA	202,601	37,602
			State Totals:	100,139,176	16,822,184

PV systems will be installed on rooftops rather than as stand alone power plants in the near term. Consequently, limiting PV system applications to residential and commercial building rooftops provides a smaller technical PV potential. Estimates of the number of commercial and residential units were developed using housing projections from Department of Finance and geographically located via zip codes.[16] Figure 4 shows the technical potential associated with locating PV systems on residential rooftops. The technical potential associated with installing PV systems on California's 15 million homes exceeds 38,000 MW. Figure 4 shows PV technical potential associated with residential housing to fall predominately around the Bay area, Los Angeles and San Diego metropolitan areas.

Figure 4: Residential PV Potential

Figure 5: Commercial Building PV



Another way to view PV potential is to examine the amount of PV capacity that could be installed on new homes. Based on the California Energy Commission's Emerging Renewables Program, the typical size of a PV system installed on a home is approximately 2.5 kilowatts.[17] Table 2 shows a countywide breakdown of the PV potential assuming PV systems of 2.5 kW are installed on all new homes. The statewide potential from this approach (for just the 2005 new housing stock) is over 430 MW of installed capacity.

Similarly, PV potential can be viewed in context of PV systems applied to commercial buildings. Roof top areas were estimated from Energy Commission Efficiency Division forecasting data. Figure 5 shows the PV potential associated with locating PV systems on commercial buildings (using 2005 commercial building numbers). Table 3 provides a countywide breakdown of the commercial PV technical potential. Under this approach, the 2005 PV potential statewide for commercial buildings is a little over 37,000 MW.

Table 2: New Residential PV Potential by County

County	PV Capacity (kw)	County	PV Capacity (kw)
ALAMEDA	8,088	PLACER	2,558
ALPINE	0	PLUMAS	8
AMADOR	50	RIVERSIDE	41,868
BUTTE	717	SACRAMENTO	11,877
CALAVERAS	266	SAN BENITO	80
COLUSA	35	SAN BERNARDINO	33,100
CONTRA COSTA	3,445	SAN DIEGO	37,796
DEL NORTE	10	SAN FRANCISCO	-338
EL DORADO	1,279	SAN JOAQUIN	3,800
FRESNO	4,944	SAN LUIS OBISPO	1,396
GLENN	53	SAN MATEO	1,678
HUMBOLDT	143	SANTA BARBARA	1,396
IMPERIAL	577	SANTA CLARA	12,145
INYO	1	SANTA CRUZ	923
KERN	6,042	SHASTA	471
KINGS	220	SIERRA	2
LAKE	321	SISKIYOU	37
LASSEN	20	SOLANO	1,048
LOS ANGELES	217,847	SONOMA	2,931
MADERA	359	STANISLAUS	2,518
MARIN	352	SUTTER	189
MARIPOSA	22	TEHAMA	112
MENDOCINO	160	TRINITY	0
MERCED	770	TULARE	2,108
MODOC	1	TUOLUMNE	137
MONO	10	VENTURA	3,073
MONTEREY	1,588	YOLO	335
NAPA	157	YUBA	109
NEVADA	186	Total (kW):	436,246
ORANGE	27,229	Total (MW)	436

Table 3: Commercial Building PV Technical Potential

County	PV Capacity (kw)	County	PV Capacity (kw)
ALAMEDA	377,922	PLACER	252,236
ALPINE	7,268	PLUMAS	23,486
AMADOR	65,339	RIVERSIDE	1,337,365
BUTTE	553,730	SACRAMENTO	162,052
CALAVERAS	106,604	SAN BENITO	838,844
COLUSA	225,158	SAN BERNARDINO	604,112
CONTRA COSTA	170,641	SAN DIEGO	1,378,654
DEL NORTE	64,031	SAN FRANCISCO	44,470
EL DORADO	138,096	SAN JOAQUIN	231,338
FRESNO	1,013,540	SAN LUIS OBISPO	3,045,804
GLENN	265,043	SAN MATEO	406,231
HUMBOLDT	276,242	SANTA BARBARA	3,258,365
IMPERIAL	28	SANTA CLARA	1,846,128
INYO	22,998	SANTA CRUZ	419,817
KERN	927,903	SHASTA	375,095
KINGS	371,712	SIERRA	7,637
LAKE	248,295	SISKIYOU	64,255
LASSEN	32,482	SOLANO	161,776
LOS ANGELES	4,478,579	SONOMA	374,731
MADERA	455,942	STANISLAUS	198,513
MARIN	275,934	SUTTER	225,417
MARIPOSA	19,355	TEHAMA	460,026
MENDOCINO	358,864	TRINITY	1,094
MERCED	255,528	TULARE	767,157
MODOC	24,050	TUOLUMNE	81,648
MONO	20,387	VENTURA	1,284,495
MONTEREY	1,843,157	YOLO	106,445
NAPA	168,419	YUBA	208,876
NEVADA	204,787	Total:	37,576,676
ORANGE	6,438,578	Total MW	37,577

In summary, California has a very significant and largely untapped PV potential. The technical potential associated with developing PV for central station applications and on residential and commercial rooftops exceeds 17 million MW of capacity. If PV is developed in the nearer term only as residential and commercial rooftop systems, the technical potential is still in excess of 75,000 MW of capacity. While not treated in this white paper, the actual amount of PV to be developed in California will be largely determined by economics and the special benefits that PV systems may provide to communities.

Concentrating Solar Power

Overview of CSP Technologies

Concentrating solar power (CSP) plants fall into three categories: parabolic troughs, power towers, and parabolic dish/heat engines (usually Stirling engines).

Power tower and parabolic trough solar systems typically produce steam to drive conventional steam MW-scale Rankine power cycles in either stand-alone systems or in the bottoming cycle of a combined gas turbine-steam turbine plant. Trough systems are also used to produce high temperature hot water to drive smaller (kW-scale or a few MW's) organic Rankine cycle units. Parabolic dish concentrators, on the other hand, provide high temperature thermal energy to drive small kW-scale engines located in the focal point of the dish. Development efforts are currently focused on Stirling engines, although air Brayton cycle engines are also of development interest.

Parabolic Trough Systems

Parabolic trough systems use single-axis tracking parabolic trough arrays to collect solar energy. The solar system is essentially a steam producer, using the collector field, high temperature oil heat transport system and an oil-to-water/steam heat exchanger set to generate superheated steam. The steam is then used in a conventional steam turbine power process to generate electricity.

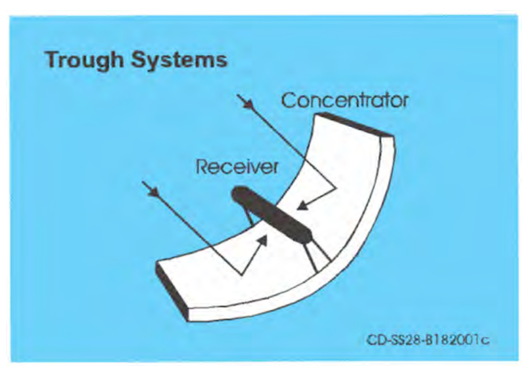
Figure 6 provides an overview of the five 30 MW parabolic trough plants at Kramer Junction, California. Figure 7 provides is a close-up photograph of a parabolic trough solar array, while Figure 8 illustrates the concept of the parabolic trough. Nine trough systems, built in the 1980's, are currently generating 354 MW peak in the high desert of Southern California. These systems, sized between 14 and 80 MW, are hybridized with up to 25 percent input from natural gas systems in order to provide dispatchable power when solar energy is not available. With up to 16 years of operating experience, continued technology improvements, and O&M cost reductions, troughs may represent the least expensive, most reliable CSP technology for near-term applications. [18]

Figure 6: Solar Trough Plant at Kramer Junction

Trough fields are typically sized for full power output during a clear midday in April or May. In the summer, the solar resource is at its maximum and power output could exceed the plant's design capacity. Consequently, a small portion of the solar field is stowed to maintain the design maximum capacity (i.e., to match the turbine steam input requirement). On a clear day, the plant will produce full power during most of the day. In arid or semi-arid areas the power output is fairly predictable.

Figure 7: Parabolic Trough Close Up

Figure 8: Parabolic Trough Concept



Thermal storage can be used to increase the operational flexibility of a solar thermal facility. By storing hot thermal energy delivered from the solar field, steam can be produced at will to meet later peak demands, such as during the evening. Also, thermal storage can be of use during intermittent disruptions in the solar resource, such as when clouds cover the sun, or can be used to provide a more uniform output over time. There is limited experience in California with thermal storage. The only thermal storage in California at the Solar Energy Generating Station (SEGS) plants was in SEGS I, located at Daggett, California, which employed a 2-tank (hot and cold) storage system utilizing the solar field working fluid. The tanks were approximately 950,000 gallons each and had an electrical capacity of about 43 megawatt-hours (MWhr).[18] Daytime solar energy was stored and used to produce electricity in the evening, initially during the winter evening period of peak demand. This storage system was destroyed by fire in 1999. Subsequent SEGS plants used solar/gas hybrid operation with supplemental boiler steam to provide dispatchable power.

Power Tower Facilities

Power tower facilities utilize power towers and two-axis tracking heliostat reflector fields to collect direct beam solar energy at high temperatures and generate steam for a conventional steam turbine. The system uses a circular array of heliostats (large individually tracking mirrors that can change orientation in order to track the sun's position) to focus sunlight onto a power tower mounted on top of a tower as shown in Figure 9. The technology is in a development stage, with no commercial projects in operation. The first power tower, Solar One, was constructed in the high deserts of Southern California, and operated in the mid-1980's. The project used a water/steam system to generate 10 MW of power.

In 1992, a consortium of U.S. Utilities banded together to retrofit Solar One to demonstrate a molten salt receiver and a thermal storage system. The 10 MW Solar Two Demonstration Project in Daggett, California, which is the retrofitted Solar One, is shown in Figure 10. This project completed testing in April 1999 and is the prototype for further U.S. development and commercialization.

Figure 9: Power Tower Concept

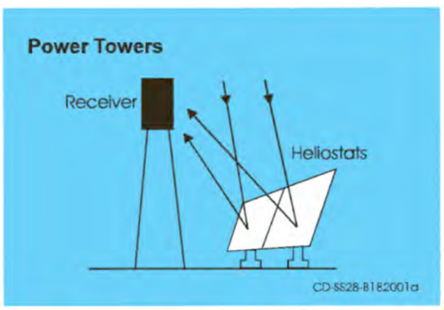
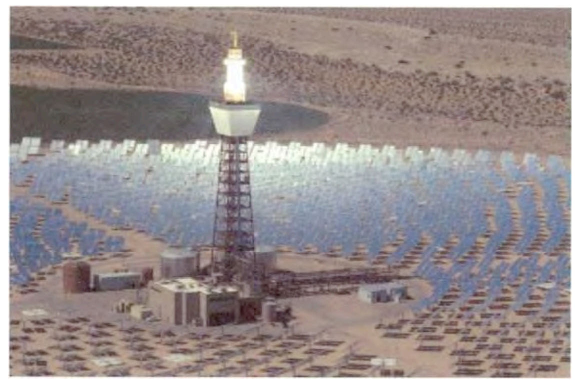


Figure 10: Solar Two Project



The power tower solar system is essentially a steam producer that supplies a steam turbine power plant, or augments the steam turbine side of a combined-cycle power plant. Flat mirror panels, or heliostats, track the sun by orientating along two axes and direct the sun's beams to a receiver on a central tower. Tower heights vary from 290 feet (88 m) for a 30 MW plant to 640 feet (195 m) for a 200 MW plant. In Solar Two, a molten nitrate eutectic salt flows through the receiver and into a hot storage tank. When steam generation is desired, the salt is pumped through a steam generator and returns to the cold tank. Because the heated salt is at such a high temperature, the steam can be produced at high pressures and temperatures, making the generation of electricity more efficient. Furthermore, the high temperature difference across the thermal storage system allows very cost effective storage of thermal energy, leading to plant capacity factors of over sixty percent using solar energy alone.

Power towers with both steam/water receivers and air receivers (for use with steam Rankine or air Brayton cycles) are currently being examined by other countries for various applications. Commercial plant capacities from 30 to 200 MW are anticipated.[18] While power tower systems could be configured as hybrid solar/fossil fuel plants similar to the parabolic-trough plants, a thermal storage system is most likely to be used to provide dispatchability with this technology.

The thermal storage would be provided by the molten-salt working fluid and is quite cost effective because of the operational parameters of these systems.

Parabolic Dish Engines

A parabolic-dish electric power unit converts direct-beam insolation to electricity by supplying thermal energy to power a heat engine located at the focal point. The dish is pointed directly at the sun by use of a dual-axis tracking system consisting of a drive motor, gearing and controls. The parabolic shape of the reflective surface, which can be mirrored glass, mirrored film, or a polished metal such as aluminum, focuses the radiation onto the receiver aperture at the engine. For a 25 kW unit a typical dish diameter would be 35-40 feet (10-12 m), focusing into a receiver aperture of approximately 1.5 feet (0.5 m) diameter, with a focal point about 24 feet (7.3 m) from the dish vertex (see Figure 11). Total unit height is on the order of 40-45 feet (12-14 m). Sun concentration ratios are 600 or more at the receiver, providing the ability to reach very high temperatures in the working fluid. The type of engine favored in current developments is a Stirling engine with hydrogen as the

Figure 11: Parabolic Dish Concept

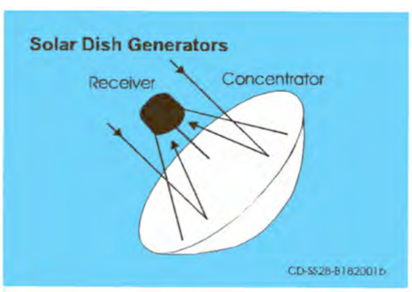


Figure 12: Parabolic Dish Units

internal working fluid. Thermal-to-electric efficiencies of Stirling engine-generator unit are on the order of 38-42 percent. Combined with two-axis solar tracking, overall unit solar-to-electric efficiencies assuming an insolation level of 1000 W/m^2 can approach at 29-30 percent, with future targets of 32-36 percent.

Power units utilizing two-axis tracking parabolic dishes with Stirling engine-driven generators are in a commercial prototype phase. Tracking in two axes is accomplished in one of two ways: (1) azimuth-elevation tracking or (2) polar tracking[19]. Two leading U.S. manufacturers are working on such systems: Stirling

Energy Systems (SES) in Phoenix and the Science Applications International Corporation (SAIC) / Stirling Thermal Motors team in San Diego, California and Ann Arbor, Michigan, respectively. SES is currently operating units at a Boeing facility in Huntington Beach, California. Both companies are anticipating future installations in California.

Unit capacities that have been under development range in electrical output from 5 kW to 25 kW though projects have also been started in the 1-2 kW range. Annual capacity factors (defined as the annual net electrical output in kWh normalized by the electrical production possible were the system to operate at design capacity for every hour of the year) in the mid-20 percent range are expected, depending on the solar resource at a given site. At a good solar site capacity factors should reach 26 percent or slightly higher.

Figure 12 shows the two parabolic-dish units operating at the Boeing/SES Huntington Beach site. The engine unit can be designed as a dual-fuel system, whereby thermal energy input to the working fluid can be supplied either by solar energy or a combustion fuel, either natural gas or biomass. In this type of operation full dispatchability of electrical output is possible. In the solar-only mode, the electrical output is dependent on the direct-normal insolation level. On a clear day, the unit will produce full power during mid day when the insolation peaks.

CSP Potential in California

Unlike PV systems, concentrating solar systems can use only direct normal insolation for electricity production. NREL supplied direct beam insolation values on a grid size of 10 kilometers by 10 kilometers using their Climatological Radiation Model. Figure 13 shows the distribution of direct beam solar insolation suitable for concentrating solar power (CSP) systems in California. Figure 13 shows that in general the best locations for CSP facilities tend to be in the southeastern portion of the state.

As with PV solar resources, the gross potential over estimates the actual amount of available resource. The approach to estimating CSP technical potential assumes that level locations with clear and high solar resources are the most technically appropriate location for employing CSP facilities. As a result, the CSP technical potential is estimated assuming locations with greater than an annual-average normal-beam solar radiation of 6 kilowatt-hours per day per square meter and no more than one percent slope. In addition, lands excluded or filtered from the technical potential include urban areas, forests, bodies of water, roads, and buildings, and any sensitive areas, pristine wilderness, National Parks, or State Parks. Other assumptions used in developing the CSP technical potential include area based performance characteristics of a packing factor of two (due to the tracking requirements of CSP systems that limit the degree to which they can be "packed" together), and a typical system efficiency of fifteen percent. Figure 14

Figure 13: Gross CSP Potential

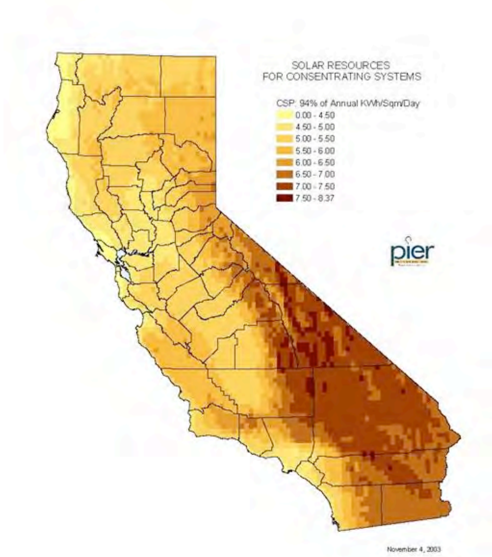
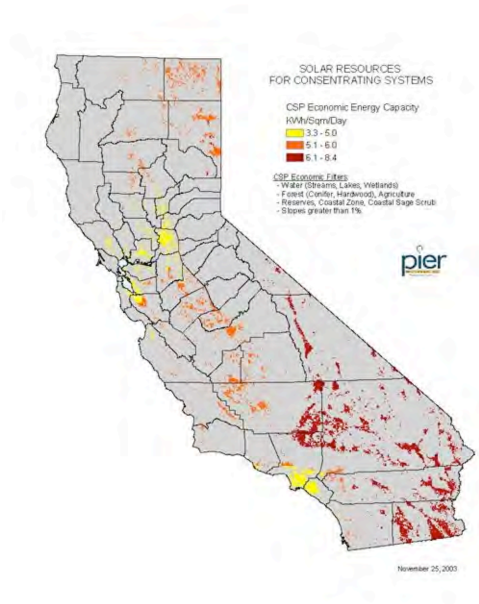


Figure 14: Technical CSP Potential



shows the equivalent geographical distribution of the CSP technical potential throughout the state. There are sixteen counties in California that meet the 6 kWh annual-average kWh per day per square meter direct normal solar radiation requirement. Table 4 provides a breakout of the CSP technical potential for these counties, and shows the statewide CSP technical potential to be approximately 1,000 MW of capacity.

Table 4: CSP Technical Potential by County

County	Acres	Total kW	Total MW	Total MWH
San Bernardino	1,256,034	381,158,658	381,159	988,016,559
Imperial	725,634	220,243,536	220,244	547,972,905
Riverside	419,267	127,160,811	127,161	318,998,213
Kern	418,639	127,029,235	127,029	330,488,517
Inyo	334,694	101,581,377	101,581	270,324,760
Los Angeles	244,572	74,232,750	74,233	189,442,262
Mono	39,716	12,054,750	12,055	30,997,196
San Diego	25,325	7,686,750	7,687	18,628,313
Lassen	24,302	7,376,250	7,376	16,377,260
Plumas	5,281	1,602,750	1,603	3,520,275
El Dorado	1,473	447,000	447	996,984
Santa Barbara	956	290,250	290	652,998
Sierra	638	193,500	194	437,858
Nevada	489	148,500	149	341,476
Placer	324	98,250	98	225,926
Modoc	185	56,250	56	123,393
Total	**3,497,530**	**1,061,360,617**	**1,061,361**	**2,717,544,893**

Endnotes

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[10] Department of Housing and Community Development, April 2005, *California's Deeping Housing Crisis*, Sacramento, CA, www.hcd.ca.gov/hpd/hc040805.pdf. Housing growth since 1997 was approximately 170,000 per year, but went up to 210,000 per year in 2004.

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[14] Regions with north slopes exceeding five percent were excluded due to the significant reduction in insolation with this orientation

[15] Navigant Consulting, June 2003, *The Changing Face of Renewable Energy: A Navigant Consulting Multi-Client Study,* June 5, 2003. Note that worldwide PV manufacturing capacity in 2002 was 560 MW (peak), and was expected to exceed 1000 MW by 2005.

[16] Mark Rosenberg, et.al, California Department of Forestry and Fire Protection, *Stratetgic Value Analysis:GIS Support and Analysis for Solving California's Electricity Generation, Transmission and Distribution Problems Economically Using Renewable Energy Resources, Draft Report,* August 2004

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[18] Electric Power Research Institute, December 2004, *Renewable Energy Technical Assessment Guide-TAG-RE:2004*, Report number 1008366

[19] In azimuth-elevation tracking, the dish rotates in a plane parallel to the earth (azimuth) and in another plane perpendicular to it (elevation). In the polar tracking method, the collector rotates about an axis parallel to the earth's axis of rotation. The other axis of rotation, the declination axis, is perpendicular to the polar axis.