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Utility-Scale Concentrating Solar Power and Photovoltaics Projects: A Technology and Market Overview

Michael Mendelsohn, Travis Lowder, and Brendan Canavan

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List of Acronyms

AC	alternating current
a-Si	amorphous silicon
b	bar
Bell	Bell Solar Thermal
BLM	Bureau of Land Management
CEC	California Energy Commission
CdTe	cadmium telluride
CIGS	copper indium gallium selenide
CPV	concentrating photovoltaic
c-Si	crystalline silicon
CSP	concentrating solar power
DC	direct current
DOE	Department of Energy
FPL	Florida Power and Light
ft	foot
HTF	heat transfer fluid
ISO	independent system operator
IOU	investor-owned utility
MW	megawatt
NERC	North American Energy Reliability Corporation
PEIS	Programmatic Environmental Impact Statement
PG&E	Pacific Gas and Electric
PPA	power purchase agreement
PV	photovoltaic
RPS	renewable portfolio standard
SCE	Southern California Edison
SDG&E	San Diego Gas and Electric
SEGS	Solar Energy Generating System
SGIP	small generator interconnection process
TEP	Tucson Electric Power
TES	thermal energy system

Executive Summary

Solar energy technologies continue to be deployed at unprecedented levels, aided significantly by the advent of large-scale projects that sell their power directly to electric utilities. Such utility-scale systems can deploy solar technologies far faster than traditional "behind-the-meter" projects designed to offset retail load. These systems achieve significant economies of scale during construction and operation, and in attracting financial capital, which can in turn reduce the delivered cost of power.

This is the first in a series of three reports on utility-scale solar installation in the United States. This report serves as: (1) a primer on utility-scale solar technologies and (2) a summary of the current state of the U.S. utility-scale solar market. The second report overviews policies and financing of utility-scale solar systems; the third report assesses the impact of financial structures on the cost of energy from utility-scale systems.

Utility-scale solar projects are generally categorized in one of two basic groups: concentrating solar power (CSP) and photovoltaic (PV). CSP systems generally include four commercially available technologies: CSP trough, CSP tower, parabolic dish, and linear Fresnel reflector, although only CSP trough and CSP tower projects are currently being deployed. CSP systems can also be categorized as hybrid systems, which combine a solar-based system and a fossil fuel energy system to produce electricity or steam.

PV systems usually include either crystalline silicon (c-Si) or thin-film technologies. Thin film includes an array of advanced materials, but only one—cadmium telluride (CdTe)—has had significant success in utility-scale solar development. Additionally, this report covers concentrating photovoltaic (CPV) systems,[1] which only recently have gained traction in the utility-scale market with several signed contracts.

According to a database maintained by the National Renewable Energy Laboratory (NREL),[2] there are approximately 16,043 megawatts (MW) of utility-scale solar resources under development[3] in the United States as of January 2012 (see Figure ES-1). PV projects make up the overwhelming majority (about 72%) of facilities under development. While many developers have specified that their projects will use PV (e.g., c-Si or CdTe), in some cases the technology will be selected just prior to construction. This selection will likely depend on module pricing at the time of order placement once all necessary permits have been obtained and pre-construction activities completed. It is not uncommon, especially given the recent drop in c-Si module prices, for developers to switch technologies in the planning phase.

According to NREL's internal database, CdTe thin-film technology represents about one-fifth of the total inventory of planned utility-scale solar projects and nearly one-third of total planned PV

[1] This report categorizes CPV as a PV technology, though some analysts group it under CSP.
[2] This database was corroborated by similar databases maintained by the Solar Energy Industries Association (SEIA 2011a) and SNL Financial.
[3] For this paper, "utility-scale" is defined as projects 5 MW or larger. These projects were either publicly announced and hold a long-term power purchase agreement or were announced directly by a utility. Public announcements are made via press releases.

projects[4]. First Solar was once considered the sole or joint developer of all utility-scale CdTe projects under development in the United States, though this is changing with the entrance of General Electric into the CdTe market. GE is currently contracted to supply panels to the 20 MW Illinois Solar plant being developed by Invenergy.

Approximately 8,224 MW of developing projects are utilizing c-Si modules or have not indicated final technology selection. The majority of these projects are expected to select c-Si-based modules. Per NREL's criteria—5 MW or larger and holding a long-term contract—approximately 11,500 MW of total PV capacity is under development in the United States, including c-Si, CdTe, copper-indium-selenide (CIS) [5] modules, and CPV technologies.

Among CSP projects, tower systems have a slight market penetration edge over parabolic troughs (about 16% versus 9% of all utility-scale solar systems under development). NREL's project announcements database indicates that the tower market is dominated by one developer, BrightSource Energy, who holds over 2.2 GW of PPAs with California utilities. Solar Millennium was the principal developer in the trough space, but the company's announced switch to PV and subsequent sale of all proposed projects[6] to solarhybrid has left only six trough developers and no clear market front-runners.

Figure ES-1 provides an overview of the U.S. utility-scale solar market. Two cutting-edge solar technologies, Enviromission's solar chimney and Solaren's space solar project, are indicated as "Other" because they hold PPAs and constitute significant additions to the total capacity under development, but they are not categorized as traditional CSP or PV technologies. Two solar/fossil hybrid plants representing a combined 100 MW of solar capacity are included as a separate category to note their distinct approach; both plants will use solar power to supplement natural gas-fired generation. Finally, CIS is included because of the recent announcement that Solar Frontier, the Japanese CIS manufacturer, will supply up to 150 MW of panels to energy developer enXco for use in their PPA contracts with San Diego Gas and Electric (SDG&E).

[4] In the energy industry, some, if not many, planned projects will not reach completion. Therefore, we assume this figure to be greater than what will be delivered by the current pipeline of projects.
[5] Copper-indium-gallium-selenide (CIGS) is perhaps the more common version of this thin-film technology. Solar Frontier, the sole supplier of CIS/CIGS thin-film modules to the utility-scale market (as of January 2012), does not use gallium in their semi-conductor blend.
[6] Solar Millennium also filed for insolvency in December 2011 (Wesoff and Prior 2011).

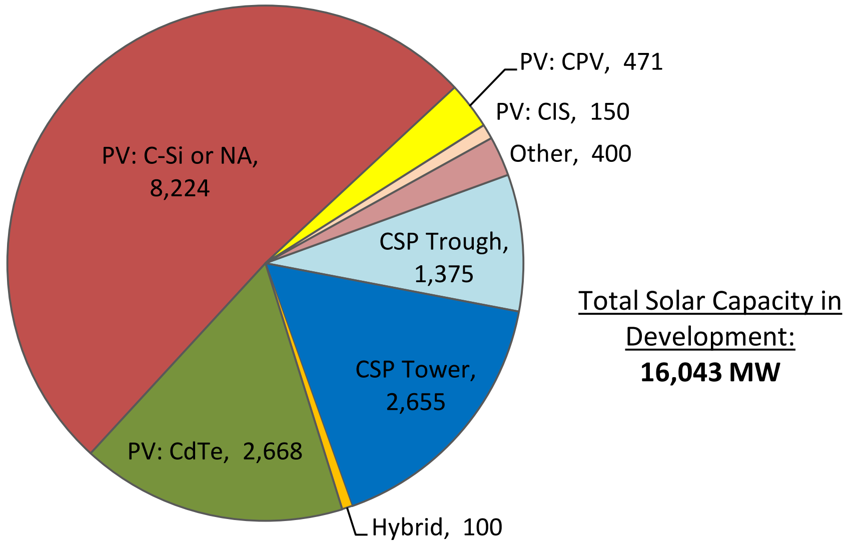

Figure ES-1. Total U.S. utility-scale solar capacity under development (all numbers in MW)

Currently, multiple utility-scale systems are producing power on a consistent basis. The nine solar trough CSP plants that comprise the solar energy generating system (SEGS) in California's Mojave Desert constitute the majority of CSP. The SEGS units commenced commercial operation from 1984–1991 with several additional utility-scale CSP projects coming online recently (EIA 2008). In 2007, the 64 MW Nevada Solar One project, a CSP trough plant developed by Acciona Solar Power, became operational (Acciona 2010). Two 5-MW demonstration facilities developed by Ausra and eSolar also became operational in 2008 and 2009, respectively (Ausra 2008; eSolar 2009). There are over 40 utility-scale PV facilities currently operational in the United States, amounting to some 673 MW of capacity. See Appendix Table A-1 for a full list of operating utility-scale PV plants.

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1 Introduction

Drivers ranging from energy security and cleaner air to global economic competitiveness and rapidly falling costs are sparking a significant shift in energy generation policy and planning. Electric utilities in the United States and the regulatory agencies that oversee them are increasing renewable energy use to meet electric load. Technological advances in materials and components and heightened experience among market entities are leading the way to more cost-effective renewable power production. Renewables have also significantly benefitted from a raft of support policies and incentives at the municipal, state, and federal levels. These include federal tax credits, cash grants, loan guarantee programs, feed-in tariffs, and state renewable portfolio standards (RPS),[7] which are discussed in detail in the second utility-scale solar report. For example, California's RPS, the most robust in the United States, with a required 33% of renewable generation from its investor-owned utilities (IOUs), has touched off a spate of solar procurement in the last two years. Today, California's three IOUs hold PPAs with nearly 72% of the total solar capacity under development in the United States (see Appendix C).

Supportive policies, financial innovations, and plummeting technology costs have spurred utility-scale[8] solar market development in the United States. This report introduces that growing market. It has two objectives: (1) to summarize solar technologies deployed at utility-scale installations, and (2) to provide a market overview of U.S. deployment activities. The report is divided by technology type: Section 2 deals with CSP technologies, and Section 3 deals with PV solar power technologies. Market overviews for each technology are provided at the conclusion of each subsection. This report only considers projects already contracted to sell power [typically in the form of a power purchase agreement (PPA)].

1.1 Utility-Scale Market Overview

Approximately 1,176 MW of utility-scale solar power was operational as of January 2012 (see Figure 1). About 43% (503 MW) of this capacity is furnished by CSP facilities, all but 10 MW of which utilize trough technology; the remaining 57% of this capacity comes from PV installations. Crystalline silicon (C-Si) and cadmium telluride (CdTe) comprise the majority of technologies deployed at these installations with 58.0% and 34.5% representation, respectively. Amorphous silicon (a-Si), another thin-film technology, represents about 7.0% of total PV installations, and concentrating photovoltaic (CPV) about 0.5%.

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[7] RPS policies are essentially mandated quotas for renewable energy generation as a proportion of total electricity production.

[8] For this paper, "utility-scale" is defined as any solar electric system with a capacity of 5 MW and above. Such utility-scale installations can deploy solar technologies far faster than traditional "behind-the-meter" projects designed to offset retail load. These systems employ significant economies of scale during construction, operation, and financial capital attraction, which can reduce the delivered cost of power.

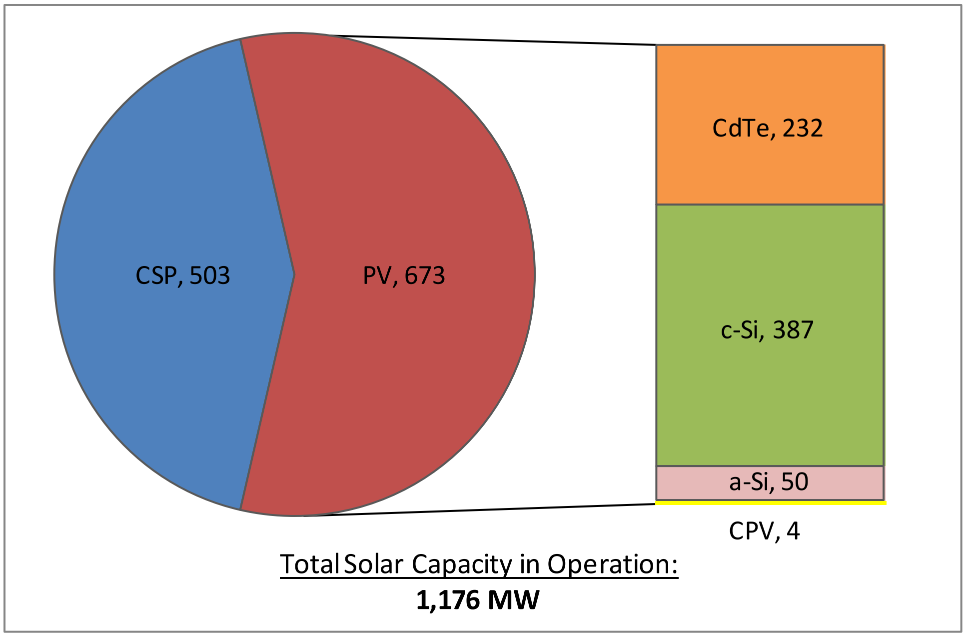

Figure 1. Total U.S. utility-scale solar capacity in operation as of January 2012 (all numbers in MW)

Figure 2 illustrates that PV capacity will continue to outpace CSP in the United States as more developing projects come online. Nearly all utility-scale CSP plants today use troughs; however, most planned CSP capacity will not use troughs. Instead, CSP towers have become the preferred technology, with over 2,655 MW of projects under contract. CSP tower developer BrightSource holds the majority of the PPAs, with about 2.2 GW of capacity (82% of the total planned CSP capacity). Recent CSP trough market contraction was largely the result of developer Solar Millennium's technology swap for their Blythe, Amargosa, and Palen facilities. At least 2 GW of CSP troughs were scrapped for PV because of what Solar Millennium described as more "favorable conditions in the PV and commercial bank markets" (PV Magazine 2011).

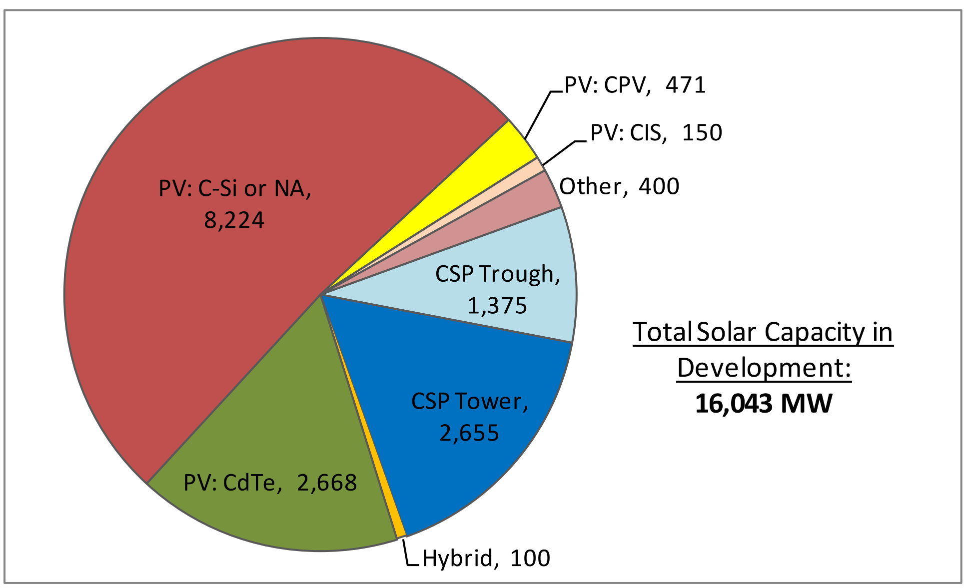

Figure 2. Total U.S. utility-scale solar capacity under development (all numbers in MW)

2 Concentrating Solar Power

CSP systems produce electricity by focusing sunlight to heat a fluid. The fluid then boils water to create steam that spins a conventional turbine and generates electricity or it powers an engine that produces electricity (Richter et al. 2009). CSP plants consist of three major subsystems: one that collects solar energy and converts it to thermal energy; a second that converts the thermal energy to electricity; and a third that stores thermal energy collected from the solar field and subsequently dispatches the energy to the power block.

There are currently 503 MW of utility-scale CSP facilities operating domestically.

Table 1. Operating Utility-Scale CSP Projects in the United States

Plant	Capacity (MW)	Developer	Technology	Location	PPA With
Kimberlina	5	Areva	Linear Fresnel	Bakersfield, California	Pacific Gas & Electric (PG&E)
Martin Next Generation Solar	75	Florida Power & Light	CSP Trough	Martin County, Florida	Florida Power and Light (FPL)
Nevada Solar One	64	Acciona	CSP Trough	Boulder City, Nevada	PG&E
Sierra SunTower	5	eSolar	CSP Tower	Lancaster, California	Southern California Edison (SCE)
SEGS 1-9	354	Luz International	CSP Trough	Mojave Desert, California	SCE
Total	**503**				

The first large-scale, commercial CSP stations were the solar energy generating systems (SEGS) built by Luz International, Ltd. from 1984–1991 (DOE 2010c). Nine plants were built in three separate locations for a total of 354 MW. Figure 3 shows SEGS 4, located in Kramer Junction, California, which has a peak output of 150 MW. SEGS 1 and 2 have a combined maximum output of 44 MW and are located in Daggett, California. SEGS 8 and 9 have a combined maximum output of 160 MW and are located in Harper Lake, California. NextEra operates and partially owns SEGS 3–9, with a combined maximum output of 310 MW (NextEra 2010).

The latest CSP plant to be developed was the 75 MW Martin Next Generation Solar Energy Center developed by and for NextEra subsidiary Florida Power and Light (FPL). The plant was completed in 2010 (FPL 2010). This facility uses CSP trough technology to supplement the 3,705 MW gas- and oil-fired Martin Generation facility and is considered in this report to be a solar/fossil hybrid plant.

Figure 3. SEGS 4, Kramer Junction, California

Source: PIX 14955

CSP systems are unique in the renewable energy sector in that they can integrate large-scale thermal energy storage (TES). The first utility-scale plants with storage are now operating in Spain (Andasol 1–3) and were developed by Solar Millennium (Solar Millennium 2010). At least six plants with TES are currently in development in the United States—the 250 MW Solana Solar plant by Abengoa Solar (6 hours of dispatchable storage), the 110 MW Crescent Dunes plant by Solar Reserve (10 hours of dispatchable storage), the 5 MW Bell Solar Thermal by Bell Energy (storage capacity unknown), and three BrightSource projects whose locations and storage capacities are yet undisclosed (Wesoff 2010; Wesoff 2011; Environmental Leader 2010; BrightSource Energy 2011a). Solana and Crescent Dunes finalized loan guarantees from the U.S. Department of Energy (DOE) for $1.45 billion and $737 million, respectively, to support project development (DOE 2011c).

CSP plants can be functionally integrated with fossil fuel plants to create hybrid CSP-fossil power plants that can offer peak and base-load power capability. Fossil hybrid plants, also known as integrated solar combined cycle, are under construction in the United States (Florida) and North Africa, including Egypt, Algeria, and Morocco (Richter et al. 2009).

Solar thermal power requires approximately 3–8 acres/MW, depending on the technology and amount of TES. For example, SEGS 3–9 (with a combined capacity of 310 MW) cover more than 1,500 acres, averaging 4.84 acres/MW of gross maximum output (NextEra 2010). In contrast, the Solana station with 6 hours of dispatchable storage will cover approximately 3 square miles, or 6.86 acres/MW of gross maximum output (Solana Solar 2009).

Like other steam-based technologies, CSP (other than parabolic dish) utilizes steam to spin a turbine. Water consumption is a primary consideration for these facilities and can vary from

700–900 gal/MWh, although alternative cooling methods, such as air cooling, can drastically reduce this value at the expense of some efficiency loss and increased cost (Stoddard 2008).

CSP systems are generally classified by the process in which each device collects solar energy. Sections 2.1–2.4 illustrate and compare four primary technologies—CSP trough, CSP tower, parabolic dish, and linear Fresnel reflector. Although only the first two are currently in utility-scale development in the United States, information on CSP-related thermal storage and cooling technologies is also provided.

2.1 CSP Trough

2.1.1 Technology Overview

CSP trough (also referred to as parabolic trough) systems use curved mirrors and single-axis tracking to follow the sun throughout the day, concentrating sunlight on thermally efficient receiver tubes or heat collection elements. A heat transfer fluid (HTF)—typically synthetic oil, molten salt, or steam—circulates in the tubes absorbing the sun's heat before passing through multiple heat exchangers to produce steam. The steam spins a conventional steam cycle turbine to generate electricity or it is integrated into a combined steam and gas turbine cycle when used in hybrid configurations. Utility-scale collector fields are made up of many parallel rows of troughs connected by receiver tubes in series. Rows are typically aligned on a north-south formation axis to track the sun from east to west. Site requirements for a solar trough system include relatively level land, although the solar fields can be divided into two or more terraces. Figure 4 provides a schematic of a CSP trough plant.

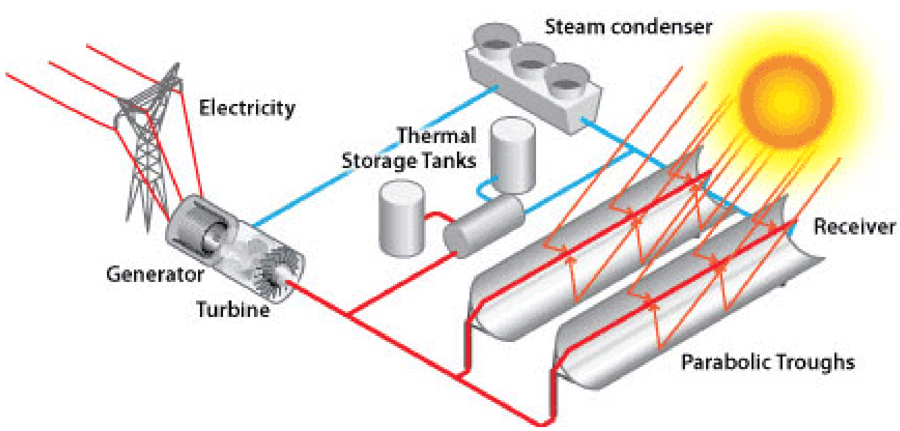

Figure 4. CSP trough schematic

Source: Department of Energy 2011b

Solar troughs are considered the most mature and commercially proven of the CSP technologies. In utility settings, solar trough power plants have shown consistent performance when connected to the electric grid.[9] Improved operating flexibility and dispatchability has been achieved through integration with hybrid fossil systems as well as through demonstrated TES capabilities.

[9] Beyond SEGS and Nevada Solar One, applications exist in Israel, Algeria, and Spain.

There are advantages and disadvantages of different HTFs. Synthetic fuels remain viscous at lower temperatures during the night and on cloudy days but lose efficiency in the heat transfer process (Herrmann et al. 2002). Molten salt, on the other hand, is a highly efficient heat transfer medium that solidifies at lower temperatures. Neither synthetic fuels nor molten salts can directly drive a turbine and therefore must use heat exchangers to boil water and spin a steam turbine. Using steam directly as an HTF is advantageous because it does not require heat exchange equipment; however, it is not very efficient relative to other transfer fluids because it cannot reach high enough temperatures. Further discussion of TES is provided in Section 2.6.

Figure 5. The Nevada Solar One CSP trough system came online in 2007

Source: PIX 16603

2.1.2 CSP Trough Market Overview

At present, roughly 1,375 MW of utility-scale CSP trough plants are in development with PPAs[10] in place (Table 2). This figure excludes the 100 MW of solar/fossil hybrid plants currently in development. Pacific Gas and Electric (PG&E) holds the majority of trough PPAs, totaling 530 MW.

[10] PPAs are contracts between power producers and power purchasers for the long-term sale of electricity. See Appendix B for more information.

Table 2. U.S. Utility-Scale CSP Trough Plants in Development

Plant	MW	Developer	Location	PPA With
Bell Solar Thermal	5	Bell Energy	Tucson, Arizona	Tucson Electric Power
Bethel Energy	50	Bethel Energy, LLC	Imperial Valley, California	San Diego Gas & Electric
Ft. Irwin Solar Power Project	500	Acciona Solar Power	Ft. Irwin, California	U.S. Army
Genesis Solar Energy Project	250	NextEra	Riverside County, California	PG&E
Mojave Solar Power Project	280	Abengoa	San Bernardino County, California	PG&E
Solana Generating Plant	280	Abengoa	Gila Bend, Arizona	Arizona Public Service
Westside Solar Project	10	Pacific Light & Power	Kaua'I, Hawaii	Kaua'I Island Utility Coop.
Total	**1,375**			

Sources: Solar Thermal Magazine 2010; NASDAQ QMS 2006; NREL 2009; CEC 2010b; Solana Solar 2009; Bloomberg 2009; CEC 2010b

Solar Millennium made headlines in 2011 when it decided to change its Blythe (1 GW), Amargosa (500 MW), and Palen (500 MW) projects from CSP troughs to PV (PV Magazine 2011; Wesoff and Prior 2011). In doing so, Solar Millennium forfeited a DOE loan guarantee that was acquired to assist development of the Blythe project. Solar Millennium's technology switch was reportedly due to shifting economics as PV modules and other costs have come down in price significantly over the past several years (Clean Energy Authority 2011a). Solar Millennium is currently in insolvency proceedings and has sold its U.S. project pipeline to German developer solarhybrid.[11]

2.2 CSP Tower

2.2.1 Technology Overview

CSP tower systems, often referred to as power towers or central receivers, use a field of mirrors called heliostats that individually track the sun on two axes and redirect sunlight to a receiver at the top of a tower. Sunlight is concentrated 600–1,000 times, making it possible to achieve working fluid temperatures of 500°–800°C (930°–1,470°F) (Australian National University 2010).

[11]In March, 2012, solarhybrid began its own insolvency proceeding due to concerns of illiquidity (i.e., not enough cash to pay bills) (PV Magazine 2012).

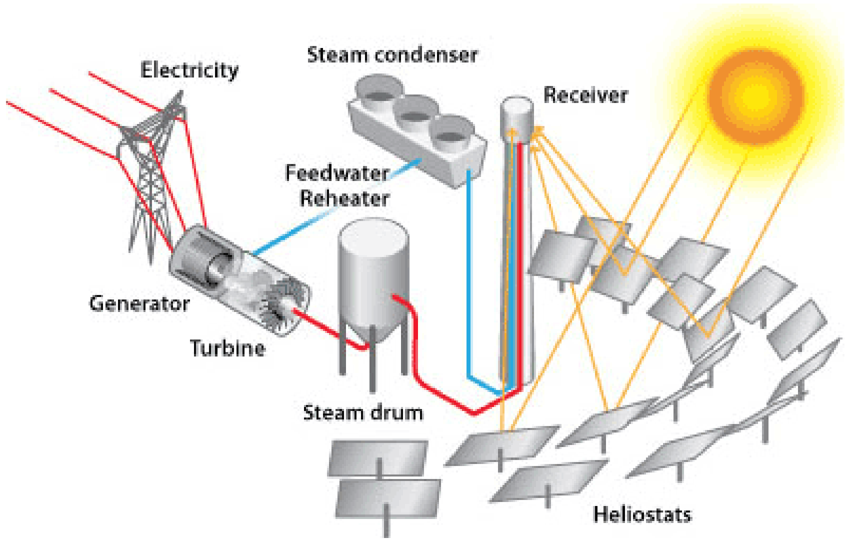

Figure 6. CSP tower schematic

Source: U.S. Department of Energy 2011c

Pilot CSP tower plants have proven the technical feasibility of using various HTFs including steam, air, and molten nitrate salts. Early CSP tower systems generated steam directly in the receiver; however, current designs use both steam and molten salt as HTFs. When integrating storage, CSP tower systems have an advantage over CSP troughs since they are able to obtain higher operating temperatures, resulting in a lower required salt inventory for the storage system (Richter et al. 2009).

Figure 7. The Solar One facility in California employed CSP tower technology

Source: PIX 00036

The largest CSP tower system currently in operation is the PS20 station, designed by Abengoa Solar in Seville, Spain (LaMonica 2009). The 20 MW facility, which began operation in April 2009, features a 531 foot (ft) solar tower and 1,255 heliostats. The PS20 is adjacent to the world's first commercial CSP tower, the PS10, also designed by Abengoa Solar.

In Israel, BrightSource is operating the 4–6 MW Solar Energy Development Center (BrightSource Energy 2011b). According to BrightSource, the facility generates the highest quality steam of any operational solar thermal plant at a temperature of 550°C (1,022°F) and 140 bar (b) pressure.

Also worth noting, the 23 MW Coalinga solar project in central California, recently commissioned in the San Joaquin Valley, utilizes a 327 ft tower system to produce steam (but no electricity) and improve output from an aging nearby oil field. Chevron owns the Coalinga field and the development company that installed the system, Chevron Technology Ventures (IBM 2011).

2.2.2 CSP Tower Market Overview

Some 2,655 MW of proposed CSP tower systems are currently under contract with U.S. utilities. BrightSource Energy has the most megawatts under contract. In April 2011, BrightSource closed on a $1.6 billion DOE loan guarantee for its Ivanpah, California, facility (DOE 2011c). Of BrightSource's 2.2 GW portfolio under contract, Ivanpah represents 392 MW, which allocated about evenly between PG&E and SCE. Many of BrightSource's other projects are at undisclosed locations. In October 2010, BrightSource broke ground on the Ivanpah project and received a $300 million investment from NRG Energy. With this investment, NRG Energy will hold a majority equity stake in the project (Murray 2010).

One small utility-scale CSP tower system operates in the United States—eSolar's 5 MW Sierra Suntower. The facility became operational in 2009 and sells power to SCE (NREL 2010b). In co-development with NRG Energy, eSolar has two proposed facilities, the Gaskell Sun Tower phases 1 and 2, under long-term contracts with IOUs for a total of 245 MW. To help lower costs, eSolar deploys a modular design surrounding a conventional turbine (eSolar 2010).

SolarReserve has two CSP tower facilities under development—Crescent Dunes and Rice Solar Energy Project—totaling 260 MW and 25-year contracts with PG&E and NV Energy (Reuters 2009). SolarReserve was founded by United Technologies Corp., whose Rocketdyne subsidiary demonstrated the solar tower technology at the Solar One and Solar Two power plants in southern California. However, both facilities were demonstration projects and are no longer operating (Solar Reserve 2010). U.S. Renewables Group, a large private equity firm exclusively focused on clean fuel projects, supports SolarReserve (SolarReserve 2011).

Table 3. U.S. Utility-Scale Central Receiver Projects in Development

Plant	MW	Developer	Location	PPA With
BrightSource, PG&E PPA	108	BrightSource	California	PG&E
Coyote Springs 1 & 2	400	BrightSource	Coyote Springs, Nevada	PG&E
Crescent Dunes	110	SolarReserve	Nye County, Nevada	NV Energy
Gaskell Sun Tower (Phases 1 & 2)	245	NRG/eSolar	Kern County, California	SCE
Hidden Hills 1 & 2	500	BrightSource	Inyo County, California	PG&E
Ivanpah Phases 1–3	392	BrightSource	Ivanpah, California	PG&E
Rice Solar Energy Project	150	SolarReserve	Blythe, California	PG&E
Rio Mesa 1–3	750	BrightSource	Riverside County, California	SCE
Total	**2,655**			

2.3 Parabolic Dish

2.3.1 Technology Overview

Parabolic dish, or dish engine, systems are individual units comprised of a solar concentrator, a receiver, and an engine or generator. The concentrator typically consists of multiple mirror facets that form a parabolic dish, which tracks the sun on two axes and redirects solar radiation to a receiver (Richter et al. 2009). The receiver is mounted on an arm at the focal point of the reflectors and contains a motor-generator combination that operates using either a Stirling engine or a small gas turbine. Dish systems are generally between 10 kilowatts (kW) and 25 kW in size. Compared with other CSP technologies, parabolic dish conversion efficiencies are the highest, reaching over 30% (SolarPACES 2010).

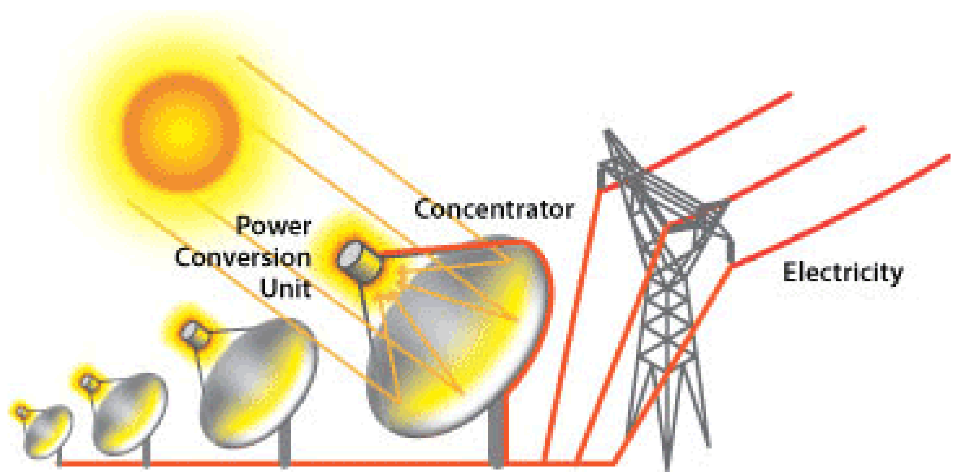

Figure 8. Schematic of a parabolic dish system

Source: DOE 2011d

Parabolic dish systems are considered highly modular, allowing individual deployment for remote applications or groupings for small-grid or large-scale utility applications (SolarPACES 2010). Individual placement also enables greater flexibility than other CSP systems since dish systems can be placed on varied terrain with grades up to 5% (TEEIC 2010). In addition, parabolic dish technology only uses small quantities of water, mostly for washing concentrators free of dust. However, due to current economies of scale, dish systems are generally only proposed in utility-scale projects.

2.3.2 Parabolic Dish Market Overview

At present, there are no utility-scale parabolic dish projects in development.[12] Through 2010, one company—Tessera Solar—held at least three contracts with western U.S. utilities, representing more than 1,600 MW. Tessera was the development affiliate to Stirling Energy Systems, which was a manufacturer of parabolic dishes and Stirling solar engines before filing for Chapter 7 bankruptcy in 2011 (Wesoff 2011).

In May 2011, Tessera lost its last contract when the developer that bought the project, AES, decided to replace the parabolic dish technology with PV. Greentech Media reported that Tessera could not secure a DOE loan guarantee and was thus unable to fulfill the contract (Wesoff 2011).

2.4 Linear Fresnel Reflector

2.4.1 Technology Overview

Linear Fresnel reflector, also referred to as compact or concentrating linear Fresnel reflector, systems are made up of flat or nearly flat mirror arrays that reflect solar radiation onto elevated linear absorbers or receiver tubes. Water, the typical thermal fluid, flows through the tubes and is converted into steam. Steam can also be generated directly in the solar field, eliminating the need for costly heat exchangers (DOE 2010b). The system is similar to a CSP trough in that the sunlight is concentrated in a linear fashion. However, instead of a single curved mirror, linear Fresnel systems concentrate the insolation of many slightly curved mirrors onto a receiver. The receiver is stationary and does not move with the mirrors as in the CSP trough systems, so it does not require rotating couplings between the receivers and the field header piping, thus providing additional design flexibility.

[12] In March 2011, the Export-Import Bank of the United States supplied a direct loan of $30 million to develop a 10 MW solar dish project in Rajasthan, India. U.S.-based dish manufacturer Infina Corporation will supply the modules for this project (Export-Import Bank 2011).

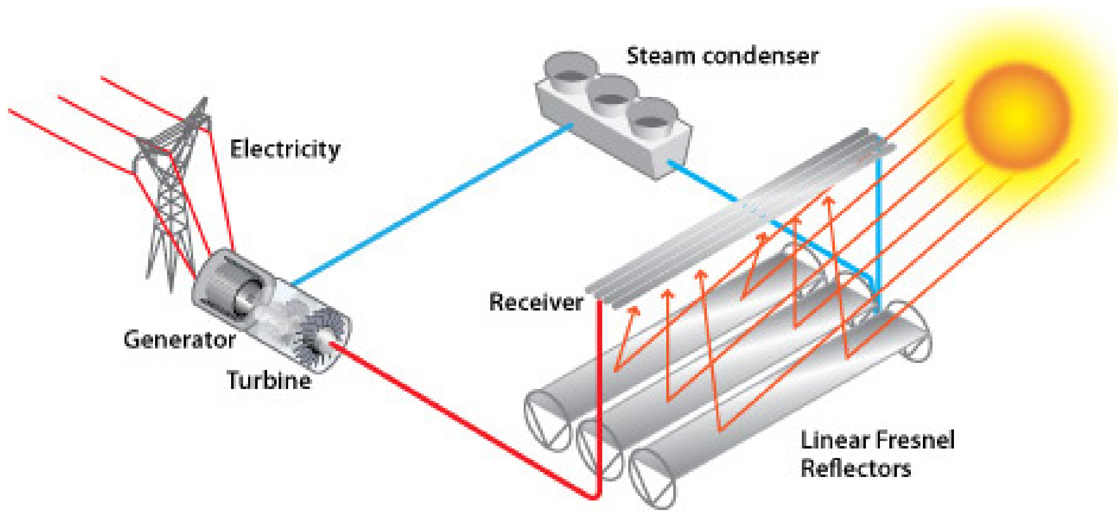

Figure 9. Linear Fresnel reflector schematic

Source: DOE 2011c

2.4.2 Linear Fresnel Reflector Market Overview

In 2010, Ausra—the sole developer of linear Fresnel projects in the United States—sold its technology and development pipeline to the French company Areva (Baker 2010). To date, Areva's 5 MW Kimberlina project in Bakersfield, California (previously developed and owned by Ausra), is the only utility-scale linear Fresnel reflector project in the United States. Prior to the Areva sale, Ausra was developing the Carrizo Energy Solar Farm, a 177 MW project, but that project was suspended.

2.5 Solar-Fossil Hybrid Power

2.5.1 Technology Overview

Hybrid power plants incorporate both solar collector fields and fossil fuel combustion to generate power, often relying on a common steam cycle and allowing for power production during sunlight fluctuations and nighttime hours.[13] There are many variations of hybrid plants, including simple natural gas backup, integrated solar combined cycle plants, and solar plants providing thermal input to existing or newly designed coal-fired plants. To produce steam in hybrid plants, CSP trough, CSP tower, and linear Fresnel collector devices may be used. Figure 10 is a rendering of a solar-fossil (gas turbine/CSP trough) hybrid facility.

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[13] For purposes of this report, in NREL's database projects are designated as hybrid if at least 50% of the energy is expected to be derived from fossil fuels. Many CSP systems utilize a small quantity of fossil fuel but are not classified as hybrid systems. For example, the BrightSource Ivanpah project will utilize a small auxiliary boiler, which is expected to provide 2% of its output.

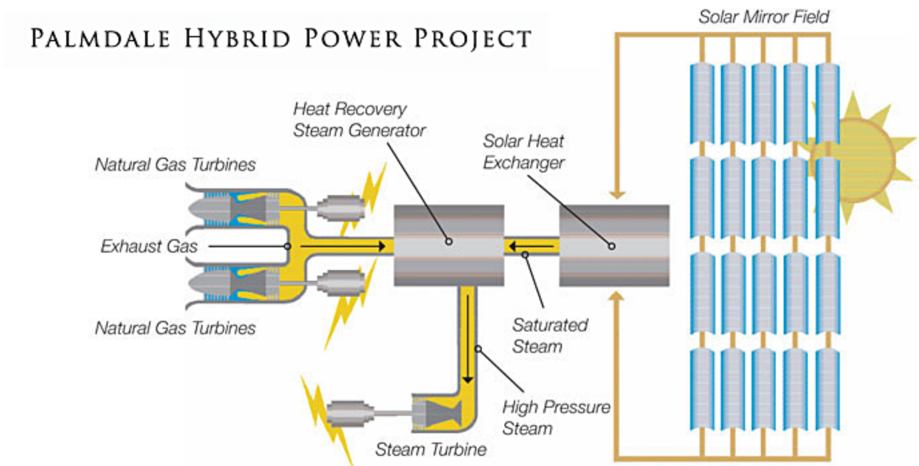

Figure 10. Rendering of a solar/fossil hybrid facility

Source: Inland Energy 2011

Combining CSP and fossil fuel power is not a new concept. In fact, many CSP plants use natural gas as a backup energy source. Assuming space requirements are adequate, it is possible to retrofit existing power plants with solar thermal technology, an option that may be advantageous for utilities looking to increase the efficiency of their fleets. By combining the components of technologically proven fossil fuel plants with the environmental benefits of CSP, there could be an increase in market opportunities and competition with conventional power plants.

2.5.2 Solar/Fossil Hybrid Market Overview

One solar/fossil electric generating plant, as defined by NREL, is currently in operation—the Martin Next Generation Solar Energy Center. The plant combines 75 MW of CSP trough with a 3,705 MW natural gas- and oil-fired generation facility.

As shown in Table 4, two utility-scale solar/fossil hybrid plants are currently in development, the Palmdale and Victorville 2 projects. These two plants feature similar hybrid designs including CSP trough and combined cycle technology designed and constructed as a combined facility (Inland Energy 2011). In each project, the solar field will provide approximately 10% of the thermal input. Both projects are also proposed to be constructed and owned by municipalities. The Victorville 2 project was approved by the California Energy Commission (CEC) in 2008 (City of Victorville 2008). In August 2011, the CEC formally approved development of the Palmdale project (CEC 2011).

Table 4. U.S. Utility-Scale Solar-Fossil Hybrid Projects Under Development

Plant	Solar/ Total MW	Developer	CSP and Fossil Technology	PPA With
Palmdale Hybrid Power Project	50/570	Contractor not selected yet	CSP trough/natural gas combined cycle	City of Palmdale
Victorville 2 Hybrid Power Project	50/513	Contractor not selected yet	CSP trough/natural gas combined cycle	City of Victorville
Solar Total	**100/1,083**			

A large solar hybrid project, the San Joaquin 1 and 2 facilities, was recently cancelled due to "issues regarding project economics" and other aspects of the project (Martifer Renewables 2010). Additionally, the 4 MW Cameo hybrid demonstration project in Grand Junction, Colorado, was recently decommissioned and dismantled. Cameo was the first power plant to hybridize solar troughs and coal-fired generation.

2.6 Thermal Energy Storage

TES provides the ability of a system to store thermal energy collected by a solar field in a reservoir for conversion to electricity at another time. For CSP technologies, storage can be used to balance energy demand between day and night or during times of intermittent sunlight. By oversizing the solar fields and pulling the excess heat to the thermal storage component, the turbine can operate at a fairly constant rate. Figure 11 illustrates this process.

A storage system enables CSP plants to (1) negate the variability in system output due to sudden shifts in the weather and (2) extend the range of operation of a CSP system beyond daylight hours (Biello 2009). The power produced throughout the day can be more effectively matched with energy demand, therefore increasing the value of the power as well as the total useful power output of the plant at a given maximum turbine capacity.

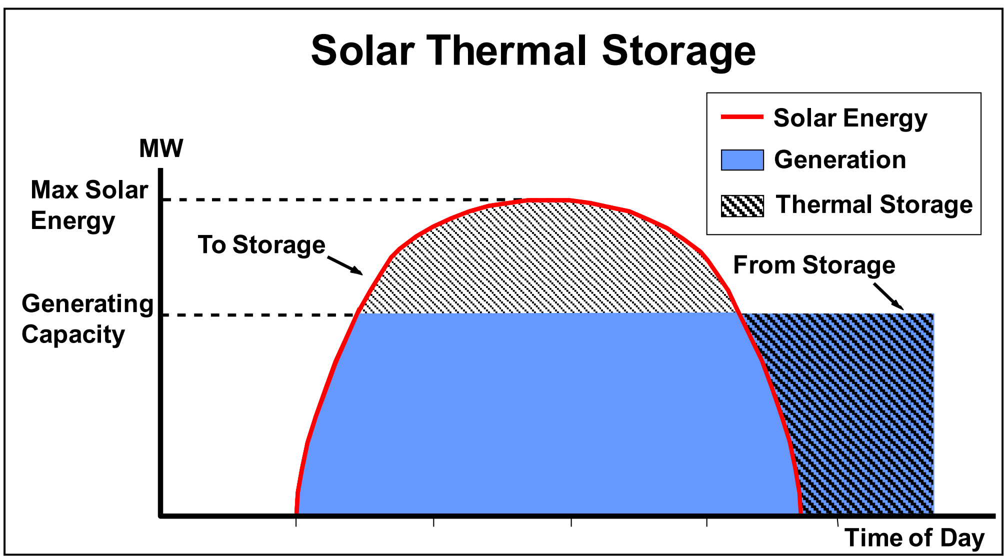

Figure 11. Solar thermal storage extends the power production period

A well-located CSP trough plant with no fossil backup or thermal storage should be able to achieve a 25% annual capacity factor (NREL 2011a). CSP with storage is theoretically capable of capacity factors around 75%, although economic application of storage limits the capacity factor to approximately 50% given current available technology.[14] CSP generation facilities supported through the DOE loan guarantee program have capacity factors that range from 26%–28% for projects without thermal storage to 43%–52% for projects with thermal storage (DOE 2011c).

[14] Capacity factor represents the delivered energy production divided by the theoretic energy production if the plant operated at full output all the time.

2.6.1 Technology Overview

Storage mechanisms are classified as either direct or indirect based on how the storage medium is heated by the solar concentrators. Indirect systems, such as most CSP trough plants, use a separate HTF, such as synthetic oil, that passes through a heat exchanger to heat the storage medium. Direct systems use the same fluid, such as steam, for both the HTF and the storage fluid eliminating the need for expensive heat exchangers.

Figure 12. The Solar Two system in California included a thermal energy storage system

Source: PIX 02185

Molten salt storage systems, which can be used in direct or indirect storage systems, seem to hold the greatest promise of economic commercialization (Price 2009). Molten salt systems allow the solar field to operate at higher temperatures relative to other fluids or storage media, reducing the cost of the system. Because salts melt at very high temperatures (e.g., ordinary table salt melts at around 1,472°F), they can hold significant quantities of heat without vaporizing (Biello 2009). A mixture of sodium nitrate and potassium nitrate, the salts can efficiently return as much as 93% of the energy sent into storage.

However, a technical disadvantage of molten salts is that they freeze at relatively high temperatures, from 120°–220°C (250°–430°F). Sandia National Laboratories is currently developing new salt mixtures with the potential for lower freezing points below 100°C (212°F) to help solve this challenge (Biello 2010).

2.6.2 Thermal Energy Storage Market Overview

TES offers potential long-term cost advantages for CSP plants by amortizing the fixed cost of the power block over greater electricity generation. However, a lack of development and operational experience has limited technology use to date.

The Andasol plant in Spain, developed by Solar Millennium, utilizes 28,500 metric tons of molten salt to provide 7.5 hours of backup generation at full output (Solar Millennium 2010). The salt utilized in the plant is 60% sodium nitrate and 40% potassium nitrate, both commonly found in fertilizers and other materials.

In the United States, no operating CSP plants utilize thermal storage, although several are in development. Abengoa Solar's Solana power station is expected to store 6 hours of thermal energy (NREL 2010a). Located outside Gila Bend, Arizona, the 250 MW (net)[15] facility is projected to cost $2.00 billion, $1.45 billion of which will be paid for with debt financing covered under a DOE loan guarantee (Prior 2010). In late 2011, BrightSource announced that it will add storage capability to three of its PPAs with SCE (BrightSource Energy 2011a).[16]

Bell Independent Power Corporation (Bell) is also developing a CSP and combined thermal storage facility. The 5 MW plant will be part of the new Tech Park in Tucson, Arizona (Environmental Leader 2010), and was the result of Bell's request for proposal submission to Tucson Electric Power (TEP). Bell and TEP signed a 20-year contract, which is currently awaiting approval from the Arizona Corporation Commission (Solar Thermal Magazine 2010). The facility is expected to begin operating in 2012.

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[15] Because the generator size will be smaller than actual capacity after the application of storage, these 250 MW are a "net" figure.

[16] According to a BrightSource press release, "Under the original power purchase agreements with Southern California Edison, BrightSource would provide approximately four million megawatt-hours of electricity annually across seven power plants. Due to higher efficiencies and capacity factors associated with energy storage, the new set of agreements will provide approximately the same amount of energy annually but with one less plant, reducing the land impacts of delivering this energy and avoiding transactional costs that ultimately impact California's ratepayers" (BrightSource Energy 2011a, p. 2).

A Discussion on Capacity Factors

Capacity factor is the ratio of actual output of power over a period of time compared to the output of full nameplate capacity operation. Solar technologies have relatively low capacity factors because they only produce power when the sun is shining. Other technologies, such as coal or natural gas, can produce power at a relatively constant rate or as dictated by demand.

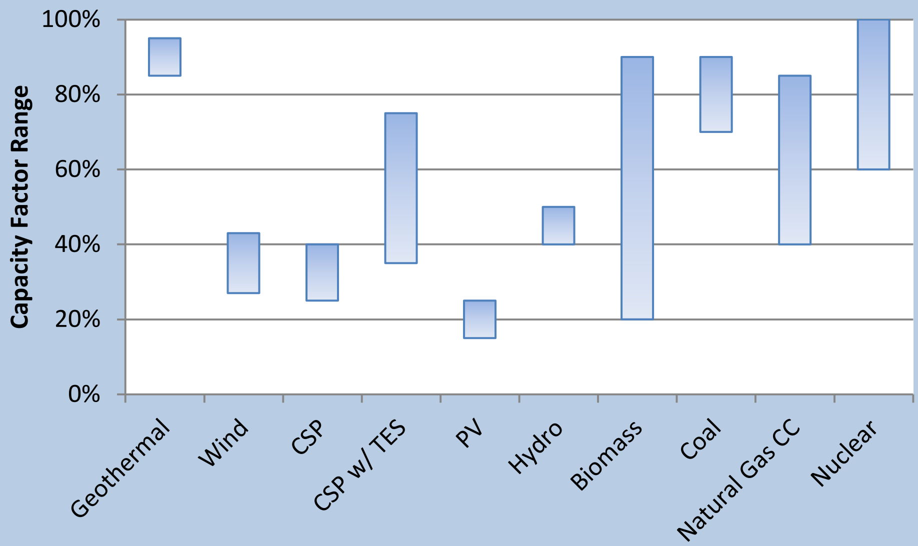

Figure 13. Comparison of capacity factor by technologies

The capacity factor for PV technologies ranges from 14%–18% for thin-film systems and 20%–24% for crystalline installations. Thermal storage can significantly increase the capacity factor of eligible CSP plants from 25% without storage to approximately 75% with storage.

Source: Renewable Energy Research Laboratory 2011

2.7 Cooling Systems

Steam-driven power plants, such as CSP facilities, require a consistent source of fresh water, which can be difficult to obtain in the desert where the solar resource is plentiful. Water consumption is primarily connected to the cooling system. There are three primary types of cooling systems: open loop, closed loop, and dry. Open loop, or once-through, cooling systems pull heat from the power plant by withdrawing large quantities of water from rivers and other sources and returning the now-warmer water to its source. As most of the water used in an open loop system is returned to its source, these systems actually consume (via evaporation) very small quantities of water (DOE 2008).

Due to environmental concerns associated with increasing the temperature of river water, open loop systems were disallowed in new power generation facilities in the early 1970s (California Environmental Protection Agency 2008). Nonetheless, open loop cooling systems grandfathered into the new law are still widely used throughout the United States. According to the DOE, more than half of the existing fleet of thermal generating plants in the United States are estimated to be equipped with once-through cooling systems (DOE 2008). The U.S. Environmental Protection Agency is in the process of developing new rules associated with Section 316(b) of the Clean Water Act that will help determine when open loop cooling will be allowed. Recent revisions to the draft rules gave power developers more flexibility in water cooling, although some may still need to switch from open to closed loop systems.

Table 5. Water Usage Requirements for Electric Generation Technologies

Cooling System	Power Plant Technology	Water Usage (Gallons/MWh)	
		Withdrawal	Consumption
Open loop	Fossil/biomass waste/nuclear steam	20,000–60,000	100–400
	Natural gas combined cycle	7,500–20,000	50–100
Closed loop	Fossil/biomass waste steam	300–600	300–1,100
	Nuclear	500–1,100	700–850
	Geothermal	2,000	1,400
	Solar trough	760–920	720–1,050
	Solar tower	750	740–850
Dry	Various technologies	0	0–80
Hybrid	Various technologies	50–650	100–600

Source: DOE 2008; Macknick et al. 2011

Closed loop cooling systems cool and recirculate water within the power plant and thus withdraw far less water than open loop systems. However, during the cooling process, water is lost via evaporation. Closed loop systems negate thermal pollution of water sources and withdraw far less water but lower plant efficiency by approximately 0.8%–1.4% (DOE 2008).

Dry cooling, or air cooled, systems use air to condense heat and cool power plants. These systems have minimal water requirements—either in withdrawal or consumptive modes—and can generally be used in all steam cycle power plant technologies, including CSP trough and CSP tower facilities (DOE 2008). However, dry cooling systems are more expensive to build and can lower the efficiency and output of the power plant, especially on very hot days.

To help balance cost, plant output, efficiency, and water use, some power plants are being designed with hybrid cooling systems that combine closed loop wet and dry cooling systems (DOE 2006). Air cooling dissipates heat directly into the air, using water only for general plant uses and steam cycle blowdown, which eliminates dissolved solids in the steam. Hybrid cooling systems can reduce water use by 50%–85% with only a 1%–3% drop in power output (DOE 2010a).

3 Photovoltaic Solar Power

In the last several years, solar PV has achieved unprecedented scales of deployment. A range of factors have contributed to this development, including a rapid decline in solar module prices, increased requirements on utility procurement of renewable energy via state RPS programs, and financial incentives available through the federal government. Total installed PV capacity has increased from 22 MW in 2000 to nearly 3.1 GW as of the third quarter of 2011 (SEIA 2011b). Over 1 GW of grid-tied PV was added in the first three quarters of 2011 alone.

Utility-scale installations have seen the greatest growth in the last two years, increasing from 70 MW installed in 2009 to over 700 MW installed in 2011 (SEIA 2011b; SEIA 2012). In 2011 alone, utility installations were up 185% from the previous year. Going forward, NREL estimates that there are more than 11 GW of utility-scale PV projects in the pipeline with signed PPAs as of January 2012.

Figure 14. SunEdison's 8.2 MW Alamosa plant

Source: PIX 15558

3.1 Traditional PV

3.1.1 Technology Overview

PV systems consist of c-Si or thin-film solar modules. c-Si materials include monocrystalline or polycrystalline cells. Thin-film PV includes an array of materials including CdTe, copper indium gallium selenide (CIGS), and a-Si. These materials are generally less expensive to produce than c-Si but have lower conversion efficiencies.[17] Although many thin-film materials have been introduced over the past several years, steep price reductions in c-Si modules have overridden the technology's cost advantage.

[17] Solar panel efficiency is the ratio of electric power produced by a PV module to the power of the sunlight striking the module.

The majority of PV modules—about 80%–90%—currently installed in the United States are based on c-Si wafers (Solarbuzz 2010).[18] Silicon wafers are produced either by slicing sections of bulk silicon or growing thin ribbons that are sectioned into wafers (Bates 2000). Since silicon has a high melting point, the production process is energy intensive. In addition, much of the bulk material is lost when cutting the wafers.

Several companies have attempted to innovate on the process of silicon production to eliminate this waste and hasten the production process as well. For example, 1366 Technologies, a solar cell manufacturer based in North Lexington, Massachusetts, has devised a continuous process that uses a molten silicon bath to form wafers instead of the traditional ingots and boules. The company secured a $150 million loan guarantee from the DOE in September 2011 to scale up manufacturing and had secured two prior DOE grants to pioneer the technology. The molten silicon process is estimated to achieve production cost reductions of 50%, energy use reductions of 90%, and the generation of silicon wafers in a fraction of the time of current production standards (DOE 2011a).

Before the end of 2008, the demand for crystalline solar panels outpaced the industry's ability to produce them, a trend that opened the door for other solar module alternatives, such as thin films (Wang 2009b). Manufacturing c-Si has since ramped up, and as of 2011 it appears to have outpaced demand.

PV arrays require inverters to convert direct current (DC) power produced by the modules into alternating current (AC), which can then be connected to the electrical grid. Throughout the components of the system there are electrical losses, which derate the conversion from nameplate DC power rating to AC power rating (as explained in Table 6).

[18] This includes installations at the residential, commercial, and utility scale. If only utility-scale installations (as defined by this report) are considered, then the figure is approximately 58%, according to NREL's internal databases.

Derate Factors for Photovoltaic System Components

Table 6. PVWatts Default Derate Values

Component Derate Factors	PVWatts Default	Range
PV module nameplate DC rating	95%	0.80–1.05
Inverter and transformer	92%	0.88–0.98
Mismatch	98%	0.97–0.995
Diodes and connections	100%	0.99–0.997
DC wiring	98%	0.97–0.99
AC wiring	99%	0.98–0.993
Soiling	95%	0.30–0.995
System availability	98%	0.00–0.995
Shading	100%	0.00–1.00
Sun-tracking	100%	0.95–1.00
Age	100%	0.70–1.00
Overall DC-to-AC derate factor	77%	0.09999–0.96001

The overall DC-to-AC derate factor varies for different PV systems and applications. NREL's PVWatts tool incorporates a standard derate factor of 0.77 (or a 23% loss in output from nameplate DC rating to actual AC energy produced).

Source: NREL 2011b

Row spacing is very important in order to maximize power density (kW/acre) and minimize panel shading. If only a portion of a cell, panel, or array is shaded, the power output can fall—sometimes dramatically.[19] In contrast to CSP technologies, which require direct sunlight to operate properly, PV systems utilize both direct and indirect (diffuse) radiation (Pitz-Paal 2009). For this reason, PV systems can be more widely deployed and can even operate on cloudy days (albeit at a lower capacity). Under cloudy weather and dawn and dusk conditions, thin-film solar panels convert low and diffuse sunlight to electricity more efficiently than crystalline-based panels.

Current PV conversion efficiencies vary by technology and manufacturer, though generally speaking, thin-film materials have lower efficiencies than silicon wafers. First Solar, who deals

[19] The installation of micro-inverters on each module can recover 10%–30% of annual performance loss due to shading. This has proven a more efficient approach to DC/AC conversion than the installation of one central inverter (Deline et al. 2011).

exclusively in CdTe modules, reported an average efficiency of 11.7% in 2011 (up from 11.4% in 2010) and recently announced a record-setting 14.4% for their highest efficiency module (First Solar 2012). Modules in the c-Si space run between 14% and almost 20%[20] efficiency in the field, with 23% efficiency achieved in controlled laboratory testing (referred to "champion-production" efficiency) (Green et al. 2011).

PV systems do not require water to operate. However, a small amount of water is needed to clean the panels and is recommended in areas that have little rain. Operation and maintenance costs are minimal for these systems because there are few moving parts and no need to service turbines or generators (see Figure 17). The largest cost of PV technology is for the modules, approximately 50% of the total, followed by the installation materials, labor, and the inverters. Inverter replacement can be a significant expense. PV module warranties are generally 20–25 years long; however, inverter warranties are typically 10–15 years long (Russell 2010). Technological improvements are occurring rapidly in many subsectors. For example, microinverters can be paired with each PV module, in contrast to centralized inverters, which are paired with a bank of modules. Therefore, if a single microinverter fails, only the module paired to the failed inverter is affected (Russell 2010).

There is concern about the life of both microinverters and centralized inverters. Improvements are being made in this area, too. For instance, in October 2010, SolarBridge Technologies announced a 25-year warranty on its new microinverter, the SolarBridge AC Module System (SolarBridge 2010).

[20] SunPower's E19/425 solar panel has a reported conversion efficiency of 19.7%, one of the highest in the PV market today (SunPower 2010).

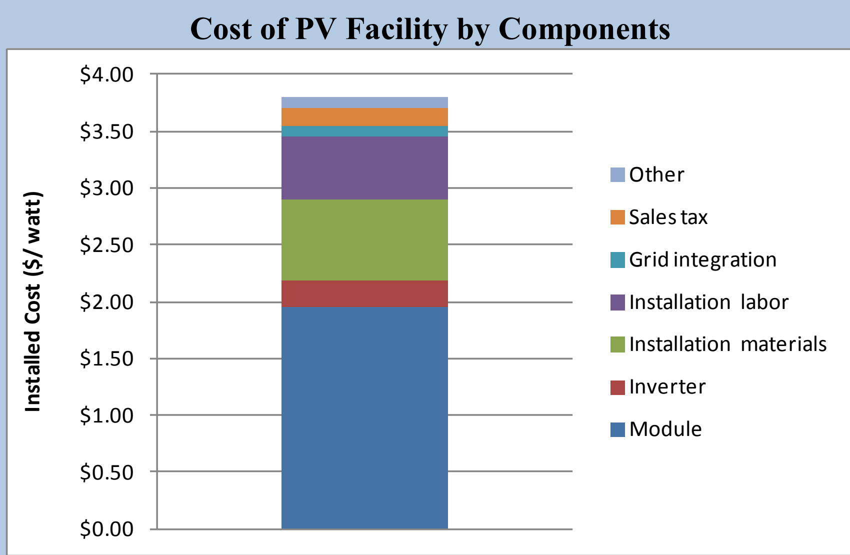

Figure 15. Utility-scale PV facility by cost component

Source: Goodrich et al. 2012

Figure 15 shows the cost breakdown for a fixed-tilt utility-scale PV system utilizing c-Si modules. Lower efficiency thin-film modules generally cost less but can have higher balance of plant (or non-module) expenses. This includes costs for supporting structures, DC cabling, and inverters.

3.1.2 PV Market Overview

The PV industry's extraordinary growth has not been without challenges. From the overheating and contraction of the Spanish market in 2007 and 2008 (the result of miscalculations in their feed-in tariff program) to plummeting module prices, the solar industry has proven a very dynamic market. Many companies have downsized or withdrawn completely from the market. Between late 2008 and 2011, several PV manufacturers and developers, including OptiSolar, SunPower, SunTech Power Holdings, Energy Conversion Devices, Solyndra, and SunEdison, laid off workers or shuttered operations (Baker 2009; Fehrenbacher 2009; Wang 2010).

Despite this challenging landscape, solar industry job growth in the United States has been significant over the last several years. The most recent *Solar Jobs Census* estimates that as of August 2011, there were 100,237 solar employees (workers who spend over 50% of their time supporting solar-related activity), which is up 6.8% from August 2010 (Solar Foundation 2010).

To analyze the utility-scale market, this report segments PV into three general project sizes. Systems smaller than 20 MW are commonly referred to as "distributed" systems, as they often tie into distribution level voltages.[21] Systems 20–49 MW are referred to as "mid-sized," and those 50 MW and larger are referred to as "large-sized."

3.1.2.1 Distributed Utility-Scale PV Systems

Distributed systems are often integrated into the distribution grid interconnecting below 69 kilovolts, which is generally considered the level at which transmission service begins (Wisconsin Public Service Commission 2009). However, for several reasons these systems are applicable for consideration as utility-scale systems and were therefore included in this analysis. At this project size, power is almost exclusively sold to utilities. Most customers do not have the load to support 5 MW or more of on-site PV.[22] In addition, in order for solar projects to access relatively low-cost capital, the PPA contract must be signed with a counterparty that has an excellent credit rating (Feo and Tracy 2009). Utilities are generally considered excellent counterparties due to their bonding capability and regulatory mission to provide power to their customers.[23] Appendix Table B-1 represents all distributed utility-scale (5.0–19.9 MW) projects currently under development that hold PPAs.

PV project development at the distributed utility-scale has many advantages. Environmental permitting, grid integration, and site control can be less burdensome at this project size. Certain companies are also considering development at brownfield sites, including former mining operations and other disturbed lands, which can further reduce environmental oversight of project development (Mendelsohn 2010).

In California, generators up to 20 MW are subject to the Small Generator Interconnection Procedures (SGIP), which avoids the need to be grouped into a "cluster" for a time-consuming, grid-wide system impact study. However, this shortcut has attracted a lot of projects just under the threshold, requiring the California independent system operator (ISO) to reassess the SGIP (Mendelsohn 2010).

According to NREL's internal database, approximately 65 distributed projects totaling 589.2 MW of capacity are currently under development and hold PPAs. See Appendix Table B-1 for information on these projects.

3.1.2.2 Mid-Sized Utility-Scale PV Systems

In the past few years, many announcements regarding PV systems in the 20–49 MW range have been made. The first two systems in this size range were completed in 2009: the 25 MW DeSoto and the 21 MW Blythe projects. Prior to these projects, the largest system in the United States was the 14 MW Nellis Air Force Base system. As shown in Appendix Table B-2, there are currently 57 mid-sized projects in advanced development (i.e., with PPAs in place) totaling

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[21] For more information, visit www.recurrentenergy.com/solar/.

[22] Further, large customers pay for power primarily through demand charges tied to their peak demand during the month (and often with a "ratchet" mechanism tied to the peak demand in the prior 12-month period). Accordingly, due to the variable output of a solar field, utility charges may not decline proportionately with solar production, although the energy component of the utility bill should decline proportionately with solar production.

[23] Regulatory decisions to limit rate increases can negatively impact bond ratings and the utility's ability to counter-sign renewable energy contracts or develop renewable energy projects. The importance of a utility's creditworthiness is discussed in greater length in the second report, *Finance and Government Initiatives* (Mendelsohn et al. 2011).

1,329.5 MW of capacity. SCE leads all utilities in this size category with 18 contracts totaling 384 MW. See Table B-2 for more information on these projects.

According to NREL's database of project announcements, First Solar deploys its own CdTe thin-film panels in its projects. First Solar CdTe modules have been selected for other projects, including juwi solar's BlueWing facility in Texas (Vo 2010). Most other projects are expected to utilize c-Si panels, although the panel manufacturer and even the PV material are not always disclosed as part of the project announcement. In part, this may be because developers wait to procure the lowest-cost components available until just prior to installation.

3.1.2.3 Large-Sized Utility-Scale Systems

According to NREL's utility-scale projects, there are currently 9,425 MW of large-sized (greater than 50 MW) PV projects currently holding a PPA with a utility purchaser (see Table B-3). None are currently operating. First Solar is the clear leader among developers with 1,920 MW of capacity in the development or construction phase. This amounts to about one-fifth of the total capacity of large-sized projects under development. First Solar also has one of the largest projects under current development, the 550 MW Topaz Solar Farm, which will sell its energy to PG&E (Wang 2009). For purposes of comparison, the Topaz project is 10 times larger than the largest PV project completed in the United States: the recently completed 55 MW Copper Mountain Solar Facility in Nevada (which also uses First Solar's CdTe panels).

SunPower is another player with a significant stake in the large-sized solar project space. The developer signed three PPAs with SCE in 2011 for the sale of 711 MW of power from three facilities. These three projects represent all of SunPower's plays in the large-sized category.

Energy developer enXco recently signed an agreement with Japanese manufacturer Solar Frontier to deliver up to 150 MW of CIS[24] panels for use in enXco's PPAs with SDG&E. These will be the first CIS modules deployed at utility scale in the United States.

Many more utility-scale solar projects than those listed here have been proposed but do not necessarily have a PPA contract in place. California alone has tabulated over 70,000 MW of proposed renewable energy projects for the state, over 90% of which are projected to be 200 MW and larger (CEC 2010b).

[24] CIS is a variant of copper-indium-gallium-diselenide, often referred to as CIGS.

Development on Public Lands

Many large-scale solar projects, including those without PPA contracts, have been proposed for development on federal land administered by the U.S. Department of the Interior's Bureau of Land Management (BLM). Interior Secretary Ken Salazar announced several initiatives to improve the speed of BLM application review. In 2009, there were 470 applications, with 158 of those being solar, to develop 97,000 MW of renewable energy projects on BLM land (U.S. Department of the Interior 2009). Federal agencies were to work with western leaders to designate tracts of BLM land as suitable for large-scale solar energy development, fund environmental studies, open new solar energy permitting offices, and speed reviews of industry proposals (U.S. Department of the Interior 2009).

For several years, the BLM has been involved in a wide-scale environmental evaluation of solar energy development across BLM lands. The process, referred to as the Solar Programmatic Environmental Impact Statement (PEIS), was expanded to review 24 solar energy study areas. In October 2009, the BLM issued over 1,100 pages of comments that will be considered when developing the draft PEIS (BLM 2010).

In June 2010, the BLM issued a guidance document on the rental fees to be applied to solar facilities for use of BLM land. The BLM will apply two separate rental fees: (1) base rent, which is applied on a per-acre basis to specific counties and ranges from $15.70/acre/year to $313.88/acre/year; and (2) megawatt capacity fee, which is applied on a per-megawatt basis and ranges from $5,256/MW/year for PV projects to $7,884/MW/year for CSP with 3 hours or more of thermal storage (BLM 2010). In January 2011, BLM issued a solar energy plan of development, which provides guidance on submitting solar applications to the agency, including outlining expected information with respect to facility engineering, project construction, and transmission interconnection (BLM 2011).

One project of note on BLM land is BrightSource Energy's Ivanpah Solar Project. The Ivanpah site is home to the desert tortoise, classified as "threatened" on the endangered species list (Wesoff 2011b). Construction at the Ivanpah site was halted in April 2011, and after further analysis, was allowed to resume in June 2011. According to a report submitted to the BLM and the CEC, 20 live tortoises were observed to be living within the project boundary (Solar Power Partners 2010). BrightSource was required to mitigate the environmental impact of the project by significantly reducing the overall footprint. Environmental oversight will remain over the project's life and, likely, beyond.

3.2 Concentrating PV

3.2.1 Technology Overview

CPV systems use optic lenses to focus sunlight onto high-efficiency solar cells. Due to the integration of lenses, CPV systems require direct sunlight to operate, so most systems employ single- or dual-axis trackers to follow the sun across the sky (BLM 2010).

CPV technologies combine two components to generate electricity: concentrators, which can be either lenses or mirrors, and a semiconducting material based on the array of available PV technologies. Depending on a selected strategy, a manufacturer will employ a combination of concentrators and semiconducting material to achieve the lowest cost of energy.

The potential cost advantage of CPV over traditional PV is the use of less semiconducting material that comprises the cell. Lower efficiency CPV technologies may employ silicon (CdTe and CIGS can also be used), but the highest efficiencies are achieved with multi-junction cells using materials other than silicon. Field efficiencies for these cells are in the 30% range and laboratory tests have achieved upwards of 40% efficiency (Kurtz 2011).

Current concentration intensities range from as low as 2x (or 2 "suns") to as high as 500x. Some emerging technologies are anticipated to reach up to 1,000x. CPV concentrations are often distinguished as low, medium, and high as roughly outlined in Table 7. Because of the high temperatures inherent to light concentration, CPV systems often require integration of heat sinks to dissipate heat and prevent damage to the solar cells.

Table 7. CPV Concentration Classes

Class of CPV	Typical Concentration Ratio	Type of Converter
High-concentration	>400X	Multi-junction
Medium-concentration	~3X–100X	Silicon or other cells
Low-concentration	<3X	Silicon modules

CPV systems function similarly to PV systems in that they utilize inverters to convert the DC generated by the solar cells to AC, which can then be delivered to the electrical grid. These systems have low water requirements and, due to their high power density, have lower land requirements than other solar technologies. In addition, CPV technologies have the potential to significantly reduce costs because the majority of the system expense is in the lenses, mirrors, and tracking equipment—components that are highly susceptible to economies of scale.

3.2.2 CPV Market Overview

CPV systems are the least commercially deployed of the PV technologies. The only utility-scale plant currently in operation is a 5 MW project located in Hatch, New Mexico, commissioned in June 2011. NextEra Energy Resources owns the project, which uses Amonix modules—high-efficiency, multi-junction gallium indium PV cells covered with Fresnel lenses (Clean Energy Authority 2011b). Amonix is one of two manufacturers currently supplying technology to the utility-scale CPV market in the United States; the other is French semiconductor company Soitec.[25] All systems are considered high concentration.[26]

[25] Another CPV manufacturer, Solfocus, has installations in the United States, but none are utility scale as defined in this report.

[26] Low and medium concentrating systems may soon be competitive as well. For example, in late 2011 SunPower entered the CPV market with the rollout of their C7 Tracker system. This technology uses parabolic mirrors instead of lenses to concentrate sunlight, and monocrystalline silicon cells instead of multi-junction cells. The company has not yet contracted this technology for any utility-scale projects, though a 1 MW installation is planned at Arizona State University's Polytechnic campus (Clean Energy Authority 2012).

The limited commercial success of CPV to date is partly due to the fact that these systems are more complex than PV systems. During 2008, as silicon prices were reaching new market highs, CPV systems appeared ready for a commercial breakthrough (Barron 2008). Prices have since collapsed, however, and this has changed the economics of several alternative technologies, including CPV (Hamberg 2011).

Despite the dramatic decreases in silicon and conventional module pricing, the CPV market looks to be entering a tentative growth stage. According to NREL's database, at least 10 utility-scale CPV projects representing about 471 MW are currently in development and hold long-term PPAs with utilities. San Diego Gas and Electric (SDG&E) holds the majority of these PPAs, both in terms of megawatts (410 MW, or 86% of total) and absolute numbers (6).

One CPV project, the 30 MW Alamosa Solar Generating Project in Colorado, will be the largest CPV installation in the world when completed in 2012 (Pankratz 2011).[27] Project developer Cogentrix received a DOE loan guarantee of $90.6 million in September 2011; this was the only loan guarantee awarded to a CPV project.

Continued market growth for CPV will be the most important factor in keeping its costs competitive with traditional PV and with fossil fuels. Without manufacturing in the tens of megawatts per year, it is unlikely that CPV will achieve the cost reductions necessary to make it an economic technology, despite its high efficiencies (Kurtz 2011).

Figure 16. CPV modules at the SolarTAC testing facility in Aurora, Colorado

Source: PIX 19186

[27] There are larger CPV projects in development, but none are expected to be completed as soon as the Alamosa Project.

Table 8. CPV Systems Under Development

Facility Name	Capacity (MW)	Developed By	Location	Power Sold To
Alamosa Solar Generating Project	30	Amonix/Cogentrix	Near Alamosa, Colorado	Xcel Energy
Desert Green Solar Farm	6.5	Soitec	Borrego Springs, California	SDG&E
Imperial Solar Energy Center West	250	Tenaska Solar Ventures	Imperial County, California	SDG&E
LanEast Solar Farm	22	Soitec	Boulevard, California	SDG&E
LanWest Solar Farm	6.5	Soitec	Boulevard, California	SDG&E
Littlerock Solar Power Generation Station	5	Amonix	Torrance, California	SCE
Lucerne Solar Power Generation Station	14	Amonix	Lucerne Valley, California	SCE
Rugged	80	Soitec	Boulevard, California	SDG&E
South Swan Solar Project	12	Amonix	Swan Road Quarry, Arizona	TEP
Total	**471 MW**			

4 Summary of Market Highlights

Utility-scale solar capacity additions have grown exponentially in the last several years, and the development pipeline ensures that significant growth will maintain through the near-term. Plunging PV costs have altered the competitive landscape amongst technologies but have generally improved project economics enabling large-scale solar deployment. Key observations from this report include:

- PV leads the utility-scale solar market for projects under development with approximately 72% of the capacity under long-term contract. In contrast, only about 57% of the current operational capacity in the United States derives from PV technologies. About 71% of PV projects under development have indicated or are expected to utilize c-Si modules made from a wide variety of manufacturers; approximately 23% are contracted to use CdTe modules, most of which will be manufactured by First Solar.
- California utilities are priming the market by signing large PPA contracts with utility-scale developers. Combined, California's three IOUs represent 72% of the total utility-scale market in the United States.
- Though CSP trough plants dominate the CSP market today, there is nearly half as much CSP trough capacity in development as that for CSP tower. The contraction of the CSP market is largely due to the exit of Solar Millennium, who announced in late 2011 that they would be switching the technology for their Blyth and Palen facilities from troughs to PV.
- Conversely, CSP tower technologies have risen to prominence in the U.S. development pipeline, representing approximately 2,655 MW, or 16% of planned utility-scale solar capacity. One company, BrightSource, dominates this space, with about 2.2 GW of projects contracted with two of California's IOUs (SCE and PG&E).
- Currently, there are no utility-scale linear Fresnel or parabolic dish systems contracted for development. The principal developers of both technologies, Ausra and Stirling Engine Systems, respectively, have met financial troubles that have disrupted their development pipelines. Ausra sold its linear Fresnel technology to French conglomerate Areva in 2010, and Stirling declared bankruptcy in September 2011.
- CPV technologies have made big gains in the development market, with nine projects totaling 471 MW currently under contract. This is notable for a technology that has only enjoyed a few years of commercialization.

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Appendix A: Operating Utility-Scale Solar Plants

Table A-1. Operating Utility-Scale PV Plants

Plant	MW	Developer	Operating Year	Solar Tech	Location	PPA With
Aerojet	5	Solar Power Inc.	2010	c-Si	Sacramento, California	Aerojet Superfund Site
Agua Calliente (partial output)	30	First Solar	2012	CdTe	Yuma County, Arizona	MidAmerican Energy Holdings (Buffett)
Air Force Academy	5	SunPower	2011	c-Si	Colorado Springs, Colorado	
Alamogordo Solar Energy Center	5	First Solar	2011	CdTe	Deming, New Mexico	PNM
Alamosa Solar Plant	7	SunEdison	2007	c-Si	Hooper, Colorado	Xcel Energy
Avenal Solar Generating Facility	45	NRG	2011	a-Si	Avenal, California	PG&E
Blue Wing Solar Project	14	juwi	2010	CdTe	San Antonio, Texas	CPS Energy
Blythe Generating Facility	21	First Solar/NRG	2009	CdTe	Blythe, California	SCE
CalRenew-1	5	Meridian Energy	2010	a-Si	Mendota, California	PG&E
Cimarron I	30	First Solar	2010	CdTe	Cimarron, New Mexico	Tristate Generation and Transmission
Copper Mountain	48	Sempra Generation	2010	CdTe	Boulder City, Nevada	PG&E
Cotton Center Solar Plant	17	Solon	2011	c-Si	Gila Bend, Arizona	APS
Davidson County Solar	16	Sun Edison	2011	c-Si	Cotton Grove Township, North Carolina	Duke Energy
Deming Solar Energy Center	5	First Solar	2011	CdTe	Deming, New Mexico	PNM
Desoto Solar Energy	25	SunPower	2009	c-Si	Arcadia, Florida	FPL
Dover SUN Park	10	SunPower/LS Power	2011	c-Si	Dover, Deleware	Delmarva Power

Plant	MW	Developer	Operating Year	Solar Tech	Location	PPA With
El Dorado Energy Solar	10	First Solar/Sempra	2008	CdTe	Boulder City, Nevada	PG&E
Exelon City Solar	8	SunPower	2010	c-Si	Chicago, Illinois	Exelon Corp.
Five Points Station	15	Solon	2011	c-Si	Five Points, California	PG&E
FRV Webberville Plant	30	Fotowatio Renewable Ventures	2011	c-Si	Webberville, Texas	Austin Energy
Greater Sandhill I	18	SunPower	2010	c-Si	Mosca, Colorado	Xcel Energy
Hatch Solar Energy Center	5	NextEra/Amonix	2011	CPV	Hatch, New Mexico	El Paso Energy
Jacksonville Solar	12	juwi	2010	CdTe	Jacksonville, Florida	Jacksonville Electric Authority
Las Vegas Solar Energy Center	5	First Solar	2011	CdTe	Las Vegas, New Mexico	PNM
Long Island Solar Farm LLC	32	BP Solar	2011	c-Si	Upton, New York	Long Island Power Authority
Los Lunas Solar Energy Center	5	First Solar	2011	CdTe	Los Lunas, New Mexico	PNM
Mesquite Solar 1	42	Sempra Generation	2011	c-Si	Arlington, Arizona	PG&E
Nellis Solar	12	MMA Renewable Ventures	2007	c-Si	Nellis AFB, Nevada	Nellis AFB
Paloma Solar Plant	17	First Solar	2011	CdTe	Gila Bend, Arizona	APS
Paradise Solar Energy Center	5	NextEra Energy Resources	2010	c-Si	West Deptford, New Jersey	
Porterville	5	Cupertino Electric	2011	c-Si	Porterville, California	SCE
Road Runner Solar Electric Facility	20	NRG Energy	2011	CdTe	Santa Teresa, New Mexico	El Paso Electric
San Luis Valley Solar Ranch	30	Iberdrola	2011	c-Si	Alamosa County, Colorado	Xcel
SFPUC Sunset Reservoir	4	Recurrent Energy	2010	c-Si	San Francisco, California	Sunset Reservoir
Space Coast Solar Energy	10	SunPower	2010	c-Si	Titusville, Florida	FPL
SPS - Dollarhide	10	SunEdison	2011	c-Si	Dollarhide, New Mexico	SPS
SPS - Hopi	10	SundEdison	2011	c-Si	Hopi, New Mexico	SPS
SPS - Jal	10	SunEdison	2011	c-Si	Jal, New Mexico	SPS

Plant	MW	Developer	Operating Year	Solar Tech	Location	PPA With
Stanton Solar Farm	5	Regenesis Power	2011	c-Si	Orange County, Florida	PG&E
Stroud Solar Station	20	Cupertino Electric	2011	c-Si	Helm, California	PG&E
Westside Solar Station	15	Constellation Energy	2011	c-Si	Five Points, California	PG&E
Wyandot Solar	10	juwi	2010	CdTe	Upper Sandusky, Ohio	American Electric Power Co.
Total	**673**					

Appendix B: Utility-Scale Solar PV Projects Under Development[28]

Table B-1. Distributed Utility-Scale PV Systems in Development (< 20 MW)

Plant	MW	Developer or Owner	Solar Tech	Location	PPA With
Austin Energy PV	5		PV	Texas	Austin Energy
Boron Solar Plant	15	Boron Solar, LLC	PV	California	SCE
Campbell Industrial Park Solar Project	5	Axio Power Inc.	PV	Hawaii	Hawaiian Electric Company, Inc.
Canton Landfill Solar Facility	5.6		PV	Massachusetts	NSTAR
Cascade Solar Project	18.5	Axio Power Inc.	PV	California	SCE
Catawba County Solar Project	5	Strata Solar LLC	PV	North Carolina	Duke Energy Carolinas, LLC
Celina Renewable Energy Center	5	SolarVision LLC	PV	Ohio	City of Celina
Central Antelope Dry Ranch B Solar Plant	5	Silverado Power LLC	PV	California	SCE
China Lake	14		PV	California	Naval Air Weapons Station
Concord Solar Farm	5	Shoe Show, Inc	PV	North Carolina	Duke Energy Corporation
Desert Green Solar Farm	6.5	Soitec USA Inc	CPV	California	SDG&E
Dos Rios Solar Project - I	10	SunEdison LLC	PV	Texas	CPS Energy
Dos Rios Solar Project - II	10	SunEdison LLC	PV	Texas	CPS Energy
East Lyme Solar Park Facility	5	GRE 214 East Lyme LLC	PV	Connecticut	United Illuminating Company
Foresight Solar PV Project	5	Foresight Renewables, LLC	PV	Arizona	Tucson Electric Power Company
Grundman Solar Project (Bruceville Road)	18	Constellation Energy Group, Inc.	PV	California	Sacramento Municipal Utility District
Heber Solar PV Project	10	Ormat Technologies, Inc.	PV	California	Imperial Irrigation District
Holiday Solar Array	8.5	Clear Peak	PV	California	SCE

[28] Denoting "PV" in the "Tech" column indicates that the panels to be selected will most likely (but not certainly) be c-Si.

Plant	MW	Developer or Owner	Solar Tech	Location	PPA With
Facility		Energy, Inc			
Hyder Solar Plant	16		PV	Arizona	Arizona Public Service Company
Kalaeloa Renewable Energy Park (Solar)	5.9	Multi-Owned	PV	Hawaii	Hawaiian Electric Company, Inc.
Kalaeloa Solar II	5	SunPower Corporation	PV	Hawaii	Hawaiian Electric Company, Inc.
Kauai Solar Plant	6	Alexander & Baldwin, Incorporated	PV	Hawaii	Kauai Island Utility Cooperative
Keystone Solar Project	6	Community Energy Solar LLC	PV	Pennsylvania	Exelon Generation Company, LLC
Lakeland Linder Regional Airport Solar Project	5.5	SunEdison LLC	PV	Florida	City of Lakeland
Lancaster Dry Farm Ranch B Solar PV Plant	5	Silverado Power LLC	PV	California	SCE
Lancaster WAD B Solar PV Plant	5	Silverado Power LLC	PV	California	SCE
LanWest Solar Farm	6.5	Soitec USA Inc.	CPV	California	SDG&E
Littlerock Solar Power Generation Station	5	Amonix, Inc.	CPV	California	SCE
Lucerne Solar Power Generation Station	14	Amonix, Inc.	CPV	California	SCE
Luke Air Force Base Solar Project	15		PV	Arizona	Arizona Public Service Company
McDowell Technical Community College Solar Plant	5	McDowell Green Energy LLC	PV	North Carolina	Duke Energy Corporation
Middlesex Apple Orchard Complex	6.7	KDC Solar LLC	PV	New Jersey	County of Middlesex
Mitchell County Solar Project (Solar DD)	14	Solar Design & Development LLC	PV	Georgia	Georgia Power Company
Mohave County Solar Project	10	SOLON Corporation	PV	Arizona	UniSource Energy Services, Inc.
Mount St. Mary's PV Park	16	Constellation Energy Group, Inc.	CdTe	Maryland	State of Maryland
Murfreesboro Solar Project	6.5	Duke Energy Renewables	PV	North Carolina	North Carolina Electric Membership Corporation

Plant	MW	Developer or Owner	Solar Tech	Location	PPA With
Napoleon Solar I Project	10	BNB Napoleon Solar LLC	PV	Ohio	Campbell Soup Company
NJ Oak Solar Farm	10		PV	New Jersey	Atlantic City Electric
Orion Solar Project	12	Fotowatio Renewable Ventures Inc.	PV	California	PG&E
Palm Springs Solar PV Project-II	5	Multi-Owned	PV	California	SCE
PLP Kauai 1 Solar Thermal	10	Pacific Light & Power	PV	Hawaii	Kauai Island Utility Cooperative
Prescott Solar Facility	10	SunEdison LLC	PV	Arizona	Arizona Public Service Company
Queen Creek Solar Plant	19	PSEG Solar Source LLC	PV	Arizona	Salt River Project
RE Columbia 3 Solar Facility	10	Recurrent Energy Inc.	PV	California	SCE
REDCO Solar 1	5	Renewable Energy Development Corp.	PV	California	City of Needles
Rinehart Solar Farm Project - Stage I	10	BlueChip Energy, LLC	PV	Florida	Florida Power Corporation
Rio Grande Solar Plant	5	Recurrent Energy Inc.	PV	California	SCE
Ronkonkoma LIRR Station	5.5	enXco, Inc.	PV	New York	Long Island Power Authority
Sierra View Solar IV Plant	19	Juwi Solar Inc.	PV	California	SCE
Sierra View Solar V Plant	19	Juwi Solar Inc.	PV	California	SCE
Somers Solar Center Facility	5	HelioSage Energy, LLC	PV	Connecticut	United Illuminating Company
Somerset Solar Project	10	SunEdison LLC	PV	Texas	CPS Energy
South Robeson Solar Farm	5	Strata Solar LLC	PV	North Carolina	Carolina Power & Light Company
South Swan Solar PV Project	12	Amonix, Inc	CPV	Arizona	Tucson Electric Power Company
SunEdison NM Solar 4	10	SunEdison LLC	PV	New Mexico	Southwestern Public Service Company
SunEdison NM Solar 5	10	SunEdison LLC	PV	New Mexico	Southwestern Public Service Company
Tropico Solar PV Plant	14	Foresight Renewables,	PV	California	SCE

Plant	MW	Developer or Owner	Solar Tech	Location	PPA With
		LLC			
UA Tech CTC Solar PV Project	5	CTC Solar	PV	Arizona	Tucson Electric Power Company
Victor Dry Farm Ranch A Solar PV Plant	5	Silverado Power LLC	PV	California	SCE
Victor Dry Farm Ranch B Solar Plant	5	Silverado Power LLC	PV	California	SCE
Vineland Solar One Expansion	12		PV	New Jersey	Vineland Municipal Electric Utility
West Tennessee Solar Farm	5	University of Tennessee	PV	Tennessee	Tennessee Valley Authority
Westford Solar Project	4.5	Multi-Owned	PV	Massachusetts	National Grid USA
Wharton Generating Station	10		PV	Texas	City of Houston
Westlands Solar Farms PV1	18	Westland Solar Farms, LLC	PV	California	PG&E
Total	**589.2**				

Table B-2. Mid-Sized PV Projects Currently in Development (20–50 MW)

Project	MW	Developer or Owner	Solar Tech	Location	PPA With
Adobe Solar Project	20	Fotowatio Renewable Ventures Inc.	PV	California	SCE
Alamosa Solar Generating Project	30	Cogentrix Energy, LLC	CPV	Colorado	Xcel
Alpaugh North Solar Plant	20	Solar Project Solutions, LLC	PV	California	PG&E
Antelope Solar Farm (Mojave Solar 4)	20	Fotowatio Renewable Ventures Inc.	PV	California	SCE
Antelope Solar Project - Tuusso	20	Multi-Owned	PV	California	SCE
Apex Solar Power Project	20	Fotowatio Renewable Ventures Inc.	PV	Nevada	NV Energy
Atwell Island Solar Plant	20	Solar Project Solutions, LLC	PV	California	PG&E
Avra Valley Solar Project	25	NRG Energy, Inc.	PV	Arizona	TEP
Borrego Springs Project	26	NRG Solar LLC	PV	California	SDG&E
Central Antelope Dry Ranch C Solar Plant	20	Silverado Power LLC	PV	California	SCE
Chicago Rockford Solar Project	20	Multi-Owned	PV	Illinois	Ameren Illinois Company
Corcoran Solar Plant	20	Solar Project Solutions, LLC	PV	California	PG&E
Cygnus Solar Project	25	Fotowatio Renewable Ventures Inc.	PV	California	SCE
Del Sur Solar Power Plant	38	Beautiful Earth Group, LLC	PV	California	SCE
First Solar/PNM PPA	22	First Solar	CdTe	New Mexico	PNM
Florida Solar 1	25		PV	Florida	Tampa Electric
Holly Hill Grove 1	20	National Solar Power, LLC	PV	Florida	FPL
Holly Hill Grove 2	20	National Solar Power, LLC	PV	Florida	FPL
Holly Hill Grove 3	20	National Solar Power, LLC	PV	Florida	FPL
Holly Hill Grove 4	20	National Solar Power, LLC	PV	Florida	FPL
Holly Hill Grove 5	20	National Solar Power, LLC	PV	Florida	FPL
Holly Hill Grove 6	20	National Solar Power, LLC	PV	Florida	FPL
Holly Hill Grove 7	20	National Solar Power, LLC	PV	Florida	FPL
Holly Hill Grove 8	20	National Solar Power, LLC	PV	Florida	FPL

Holly Hill Grove 9	20	National Solar Power, LLC	PV	Florida	FPL
Holly Hill Grove 10	20	National Solar Power, LLC	PV	Florida	FPL
Illinois Solar	20		CdTe	Illinois	ComEd
La Salle Solar Farm (Invenergy)	20	Invenergy LLC	CdTe	Illinois	Commonwealth Edison Company
LanEast Solar Farm	22	Soitec USA Inc	CPV	California	SDG&E
LSR Kramer South Solar	20	LSR Kramer South, LLC	PV	California	SCE
Marana Solar PV Project	35	Avalon Solar LLC	PV	Arizona	TEP
Maryland Solar Project	20	Maryland Solar LLC	PV	Maryland	FirstEnergy Solutions Corporation
McHenry Solar Farm	25	SunPower Corporation	PV	California	Modesto Irrigation District
Mililani Solar Park Project	20	Castle & Cooke Incorporation	PV	Hawaii	Hawaiian Electric Company, Inc.
Mojave Solar Project - Mojave	20	Fotowatio Renewable Ventures Inc.	PV	California	SCE
Mountain View Solar Plant	20	NextEra Energy Resources LLC	PV	Nevada	NV Energy
Murphy Flats Solar Project	20	Interconnect Solar Development, LLC	PV	Idaho	Idaho Power Co.
Nevada Solar Project	20	Fotowatio Renewable Ventures Inc.	PV	Nevada	NV Energy
Nicolis Solar PV Plant	20	Foresight Renewables, LLC	PV	California	SCE
Niland Solar Project	23	SunPeak Solar, LLC	PV	California	Imperial Irrigation District
North Edwards Solar	20	North Edwards Solar, LLC	PV	California	SCE
North Lancaster Ranch Solar PV Plant	20	Silverado Power LLC	PV	California	SCE
RE Columbia 2 Solar Facility	20	Recurrent Energy Inc.	PV	California	SCE
RE Rosamond Solar Plant	20	Recurrent Energy Inc.	PV	California	SCE
San Luis Valley Solar Ranch Project	30	Iberdrola Renewables, Inc.	PV	Colorado	Xcel
Searchlight Solar I	20	American Capital Energy, Inc	PV	Nevada	NV Energy
Sierra Solar Greenworks Solar PV Plant	20	Silverado Power LLC	PV	California	SCE
Simon Solar Farm (Social Circle)	30	Private Investor- Steve Ivey	PV	Georgia	Georgia Power Company
Sorrento Eagle Dunes	40	BlueChip	PV	Florida	Progress Energy, Inc.
Spectrum Solar	38	Fotowatio Renewable	PV	Nevada	NV Energy

Power Plant		Ventures Inc.			
TA High Desert Solar Plant	20	Multi-Owned	PV	California	SCE
Tierra Del Sol Solar Farm	45	Soitec USA Inc	CPV	California	SDG&E
Turning Point Solar	49.9	Agile Energy	PV	Ohio	Columbus Southern Power Co.
Victor Phelan Solar One Plant	20	Recurrent Energy Inc.	PV	California	SCE
Victorville Landfill Solar Project	21	Axio Power Inc.	PV	California	SCE
Weldon Solar	20		PV	California	SCE
White River Solar Plant	20	Solar Project Solutions, LLC	PV	California	PG&E
Total	**1,329.9**				

Table B-3. Large-Sized PV Projects Currently in Development (> 50 MW)

Project	MW	Developer or Owner	Solar Tech	Location	PPA With
Agua Caliente	290	First Solar	CdTe	California	PG&E
Alhambra Solar Project	50	SolarGen2	PV	California	SDG&E
Alpaugh Solar	50	Solar Project Solutions, LLC	PV	California	PG&E
Alpine Solar	66	Alpine SunTower LLC	PV	California	PG&E
Amargosa Farm Road Solar Power Project	500	Multi-Owned	PV	Nevada	NV Energy
Amargosa North Solar Plant	150	Pacific Solar Investments Inc.	PV	Nevada	NV Energy
Antelope Valley Solar Ranch One	230	First Solar, Inc.	CdTe	California	PG&E
Arlington Valley Solar Energy Project II	125	LS Power Group	PV	California	SDG&E
AVSP I Solar Project	325	SunPower Corporation	PV	California	SCE
AVSP II Solar Project	276	SunPower Corporation	PV	California	SCE
California Valley Solar Ranch	250	NRG	PV	California	SCE
Catalina Solar Project	110	enXco Inc.	PV	California	SDG&E
Centinela Solar Project	130	LS Power Group	PV	California	SDG&E
Copper Mountain Solar II	150	Sempra Generation	CdTe	California	PG&E
Desert Sunlight Project	550	First Solar Inc.	CdTe	California	PG&E
Estancia Solar Farm	50	Silverado Power	PV	New Mexico	PNM
FRV Regulus Solar Project	75	Fotowatio Renewable Ventures	PV	California	SCE
Gadsden Solar Farm	400	National Solar Power	PV	Florida	Progress Energy, Inc.
Hardee Solar Farm	200	National Solar Power	PV	Florida	Progress Energy, Inc.
Imperial Solar Energy Center South	130	Tenaska Solar Ventures	CdTe	California	SDG&E
Imperial Solar Energy Center West	250	Tenaska Solar Ventures	CPV	California	SDG&E
Mayflower Solar Project (SolarGen)	50	SolarGen2	PV	California	SDG&E

Project	MW	Developer or Owner	Solar Tech	Location	PPA With
McCoy Solar Energy Project	750	NextEra Energy Resources LLC	PV	California	SCE
Mesquite Solar I	170	Sempra Generation	PV	Arizona	PG&E
Mount Signal Solar Project	50	US Solar Holdings	PV	California	SDG&E
National Solar Power Project	400	National Solar Power, LLC	PV	Florida	FPL
North Star Solar I Project	60	Multi-Owned	PV	California	PG&E
Pearl Harbor Solar Project	300	Sempra Generation	PV	Hawaii	Hawaiian Electric Industries, Inc.
Quinto Solar Project	110	SunPower Corporation	PV	California	SCE
Rugged Solar Farm	80	Soitec USA Inc	CPV	California	SDG&E
Sacramento/Recurrent PPA	88	Recurrent Energy, Inc.	PV	California	Sacramento Municipal Utility District
Silver State North	140	NextLight Renewable Power, LLC	CdTe	Nevada	NV Energy
Silver State South	250	NextLight Renewable Power, LLC	CdTe	California	SCE
Solar Millennium Blythe Power Project (Photovoltaic)	1,000	Multi-Owned	PV	California	SCE
Solar Millennium Palen Power Project (CA Solar 10)	500	Multi-Owned	PV	California	SCE
Sonora Solar Project (SolarGen)	50	SolarGen2	PV	California	SDG&E
Sorrento Solar Farm	120	BlueChip Energy, LLC	PV	Florida	FPL
Stateline Solar Project	300	First Solar, Inc.	CdTe	California	SCE
Topaz Solar Farm	550	MidAmerican Energy	CdTe	California	PG&E
Wonder Valley Solar Farm	100	Sustainable Energy Capital Partners	PV	California	SCE
Total	**9,425**				

Appendix C: Utility-Scale Solar and Power Purchase Agreements

Electric utilities, including investor-owned, municipal, and public, provide nearly all the electricity consumed by homes, businesses, and industries in the United States. Accordingly, their adoption of renewable energy systems is critical to the success of the technologies. In response to RPS requirements and customer demand for more renewable energy, electric utilities throughout the country have signed long-term contracts for the output of large-scale renewable energy generating facilities in recent years. These long-term contracts, known as power purchase agreements (PPAs), guarantee a steady and predictable revenue stream from the project, which lowers its risk profile and facilitates investment.

Due to stringent RPSs and other initiatives, California's three IOUs— PG&E, SCE, and SDG&E —lead in contracting with or developing solar projects. Figure 1 illustrates the significant gap between these utilities (particularly PG&E and SCE) in contracted solar megawatts relative to the other leading IOUs.

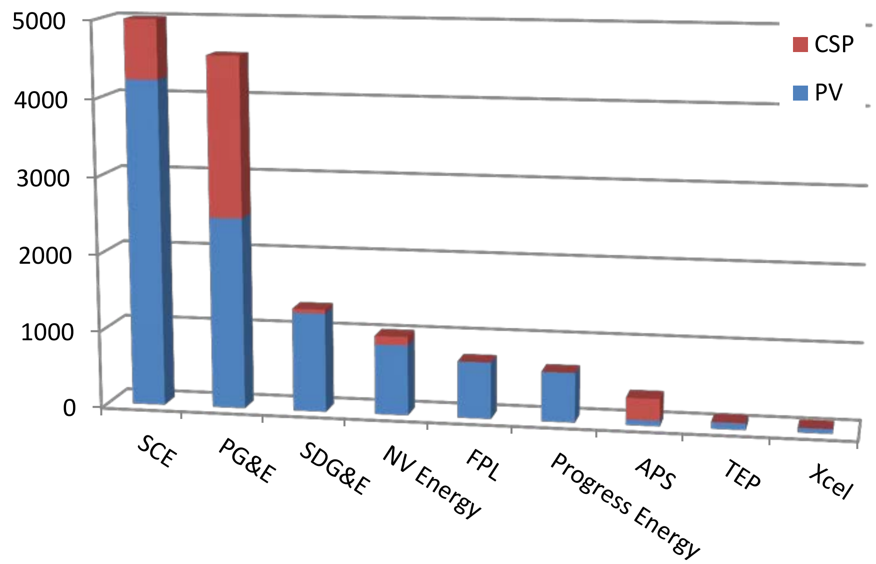

Figure C-1. Leading utilities with utility-scale solar in development (under contract or planned)

Appendix D: The Solar Resource

The solar resource, or quantity of sunlight, of the United States is significant. Total annual U.S. energy demand could theoretically be met with PV systems covering less than 1% of the nation's land area (Denholm and Margolis 2008). The southwest United States—comprising California, Arizona, Nevada, Utah, New Mexico, Colorado, and western Texas—has some of the best solar resources in the world. In fact, Arizona, California, Nevada, and New Mexico are estimated to have the solar resources to produce 4.1 million MW of electricity, almost four times the electric-generating capacity of the entire United States (DOE 2003; EIA 2008). The CSP and PV solar resource for the United States are shown in Figure D-1.

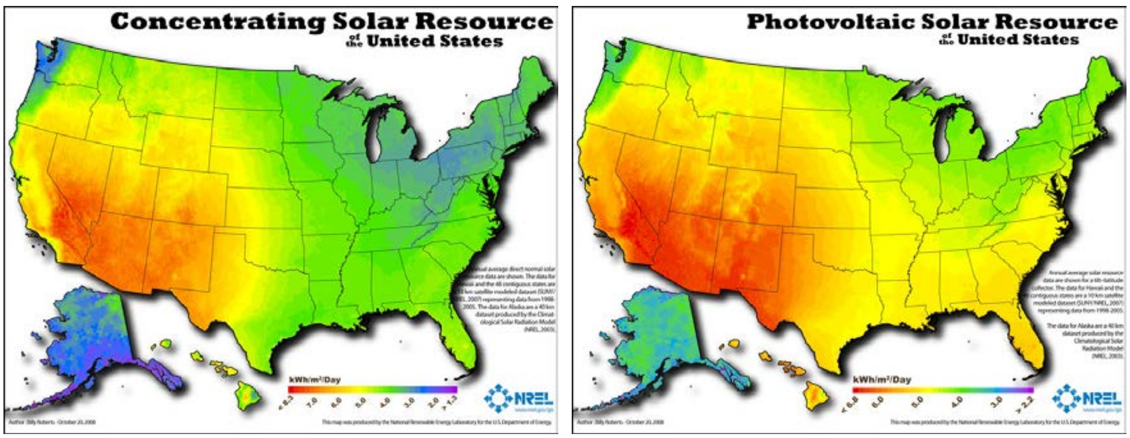

Figure D-1. Concentrating and PV solar resources in the United States

Source: NREL 2010c

Despite abundant solar resources, significant economic barriers to widespread adoption remain. In particular, it is challenging to serve regions with modest solar resources, including arranging and underwriting the capital, building and maintaining the necessary transmission pathways, and assigning cost recovery through long-term contracts with utilities.

Furthermore, even in areas of high insolation (the measure of solar radiation striking a given area at a given time), finding suitable sites for large-scale solar installations can be difficult. Figure D-2 compares the availability of solar resource in the southern California and Nevada region—one of the best solar resource locations nationally—before and after considering various development factors. The left image depicts the regional resource with no "filters" or limitations to access. The right image depicts the same resource but with the following set of access limitations:

- Only premium solar resource (6.75 kWh/m^2/day and greater)
- No use of environmentally-sensitive or restricted land (e.g., excludes land controlled by the U.S. Department of Defense)
- No use of land with grades of 1% or greater.

As readily seen in the side-by-side graphics, applying the access filters greatly reduces the potential resource.

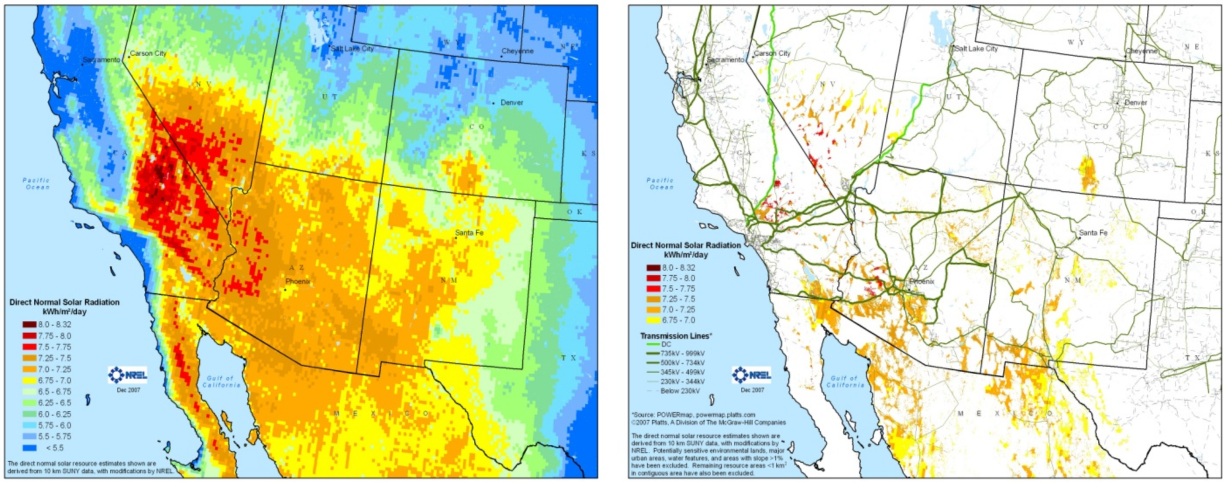

Figure D-2. Solar resource rear southern California without a filter (left) and with multiple filters applied (right)