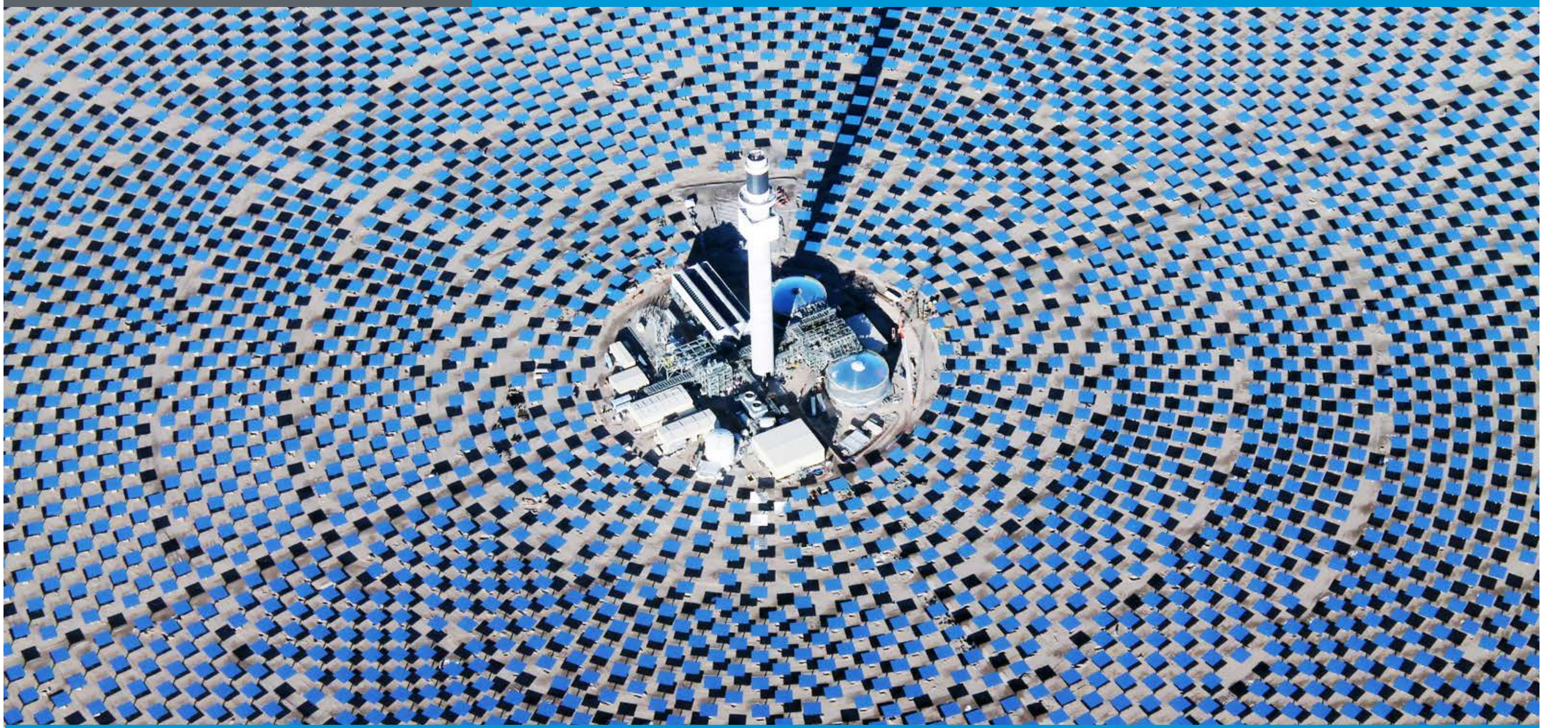
U.S. DEPARTMENT OF ENERGY

2014: The Year of Concentrating Solar Power

May 2014



Aerial view of the *Crescent Dunes* 540 foot power tower in Tonopah, Nevada. *Photo Credit: SolarReserve, LLC.*

2014: The Year of Concentrating Solar Power

Across the nation, solar energy is taking off, with more Americans "going solar" every day. And, it's not just solar panels popping up on the rooftops of homes; Americans are starting to adopt other forms of solar energy, as well. Concentrating solar power (CSP) is a technology that harnesses the sun's energy potential and has the capacity to provide hundreds of thousands of customers in the United States with reliable renewable energy—even when the sun isn't shining. The United States is particularly well suited for CSP because it leverages the nation's abundant solar energy resources, particularly in the sun-drenched southwestern states. Every day, more energy falls on the United States—in the form of sunshine—than the country uses in an entire year.

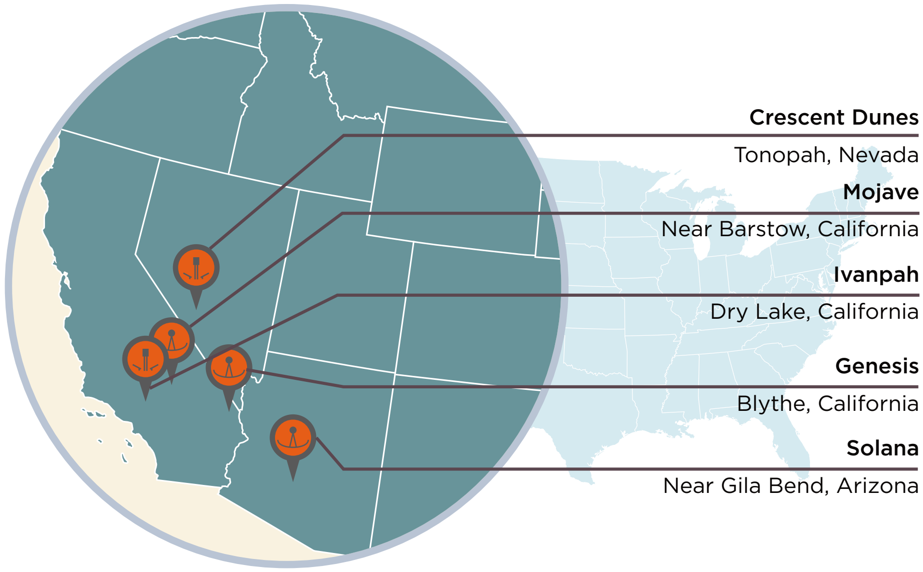
The year 2014 marks a significant milestone in the history of American solar energy. Through sustained, long-term investments by the United States Department of Energy (DOE) and committed industry partners, some of the most innovative CSP plants in the world connected to the United States electricity grid in 2013, and five plants of this kind are expected to be fully operational by the end of 2014. One of them is the largest CSP plant in the world; another represents a first-of-its-kind in energy storage technology at commercial scale in the United States. Collectively, these five CSP plants will nearly quadruple the preexisting capacity in the United States, creating a true CSP renaissance in America.

By many measures, the solar energy industry has been one of the fastest growing industries in the United States over the last five years. By the end of 2013, the United States had more than 13 gigawatts of installed solar capacity—nearly 15 times the amount installed in 2008 and enough to power more than 2 million average American homes.

DOE's SunShot Initiative—launched by the Office of Energy Efficiency and Renewable Energy's Solar Energy Technologies Office in 2011 as a national effort to make solar energy fully cost competitive with traditional energy sources by 2020—has played a critical role in solar energy's recent success. The SunShot Initiative's investments support innovation in solar energy technologies that are aimed at improving efficiency and reducing the cost of materials, as well as making it easier, faster, and cheaper for homeowners, businesses, and state, local, and tribal governments to "go solar."

Technology innovation is not the only area where DOE is contributing to the growth of solar in America. Through its Loan Programs Office (LPO), DOE is helping to finance the first deployments of innovative solar technologies, such as CSP, at a large scale. Projects employing technologies that are successfully demonstrated at a small scale with minimal large-scale applications often face difficulty securing the necessary capital for the initial commercial deployments. By providing loan guarantees for commercial-scale projects using these newer technologies, DOE reduced the projects' financial risk enabling new private investment in the CSP market.

In addition to helping meet utility demand for clean energy, the five LPO-supported CSP plants have created thousands of construction and operations jobs. The growth of CSP has built a far-reaching domestic supply chain that reaches 39 states according to the projects' sponsors. That supply chain includes international corporations that have invested in a U.S. solar market presence, as well as decades-old U.S. manufacturers that have been revived by this thriving new industry. All told, the United States solar industry employs more than 143,000 Americans, which is a jump of nearly 50,000 since 2010.



The five DOE-supported CSP projects are located in areas identified by the National Renewable Energy Laboratory as the most economically suitable lands available for deploying large-scale concentrating solar power plants in the southwest United States.

What Makes CSP Unique

A distinctive characteristic of CSP is that, when deployed with thermal energy storage, it can produce electricity on demand—providing a dispatchable source of renewable energy. Therefore, it can provide electricity whenever needed by an electric utility to meet consumer demand, performing like a traditional base-load power plant. CSP with thermal energy storage allows for more use of other renewable energy sources that provide variable or intermittent generation (such as wind and solar photovoltaic). Another distinction of CSP is its ability to integrate with fossil-based generation sources in "hybrid" configurations. Hybrid systems combine traditional fossil-fuel-powered plants with emissions-free CSP technology to improve the performance of both systems.

CSP is a key enabling technology in the "all-of-the-above" energy strategy for the United States. This report focuses on the current breakthroughs of CSP deployment in the United States and three key CSP technologies facilitating this shift to clean energy. It also highlights five commercial-scale United States CSP plants that demonstrate the capabilities of these cutting-edge technologies.

The three key technologies are

Parabolic Trough

Power Tower

Thermal Energy Storage

The five CSP projects profiled are

- **Crescent Dunes**—Tonopah, Nevada
- **Genesis**—Blythe, California
- **Ivanpah**—Dry Lake, California
- **Mojave**—near Barstow, California
- **Solana**—near Gila Bend, Arizona

Solana, Photo Credit: Abengoa Solar, Inc.

Genesis, Photo Credit: NextEra Energy Sources, LLC

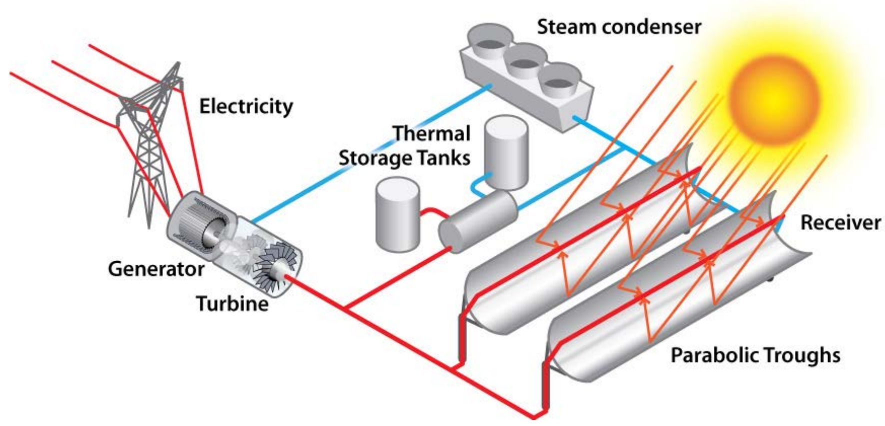
Mojave, Photo Credit: Abengoa Solar, Inc.

Three DOE-supported CSP Technologies

1. Parabolic Trough

How Parabolic Trough Works

Solar fields using trough systems capture the sun's energy using large mirrors shaped like a parabola, or a giant "U," that are connected together in long lines that track the sun's movement throughout the day. When the sun's heat is reflected off the mirror, the curved shape sends most of that reflected heat onto a receiver pipe that is filled with a specialized heat transfer fluid. The thermal energy from the heated fluid generates steam and electricity in a conventional steam turbine. Once the fluid transfers its heat, it is recirculated into the system for reuse. The steam is also cooled, condensed, and reused. Heated fluid in trough systems can also provide heat to thermal storage systems, which can be used to generate electricity at times when the sun is not shining.



Parabolic trough technology captures the sun's energy using giant "U" shaped mirrors to generate electricity.

How DOE Supports Parabolic Trough Technologies

DOE has supported research and development efforts on parabolic trough technology since the early 1980s. By the mid-1990s, all of the parabolic trough demonstration projects in California's Mojave Desert that used technology developed by DOE and its partners transitioned to private operation. They continue to operate more than 20 years later. These early demonstration projects were the foundation for three of the five CSP projects that received DOE loan guarantees and are connected or will be connected to the electricity grid by the end of 2014—*Solana, Mojave*, and *Genesis*. The DOE SunShot Initiative works closely with private industry partners from each of these three projects, as well as national laboratories and universities, to continue driving down costs toward the SunShot Initiative goal of cost competitiveness with conventional energy sources by 2020.

With six hours of storage, *Solana* can dispatch energy to customers during cloudy periods and after sunset.
Photo Credit: Abengoa Solar, Inc.

2. Power Tower

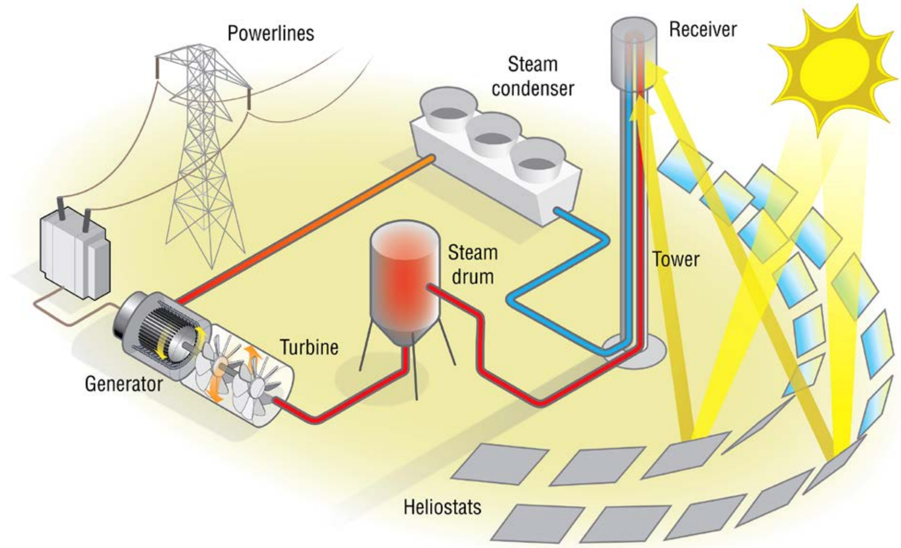
How Power Tower Works

Power towers use large, flat mirrors called heliostats to reflect sunlight onto a solar receiver at the top of a central tower. In a direct steam power tower, water is pumped up the tower to the receiver, where concentrated thermal energy heats it to around 1,000 degrees Fahrenheit. The hot steam then powers a conventional steam turbine. In this case, the medium that transfers heat from the receiver to the power block is steam. Some power towers use molten salt in place of the water and steam. That hot molten salt can be used immediately to generate steam and electricity, or it can be stored and used at a later time.

A large power tower plant can require thousands of computer-controlled heliostats that move to maintain point focus with the central tower from dawn to dusk. Because they typically constitute about 50% of the plant's cost, it is important to optimize heliostat design; size, weight, manufacturing volume, and performance are important design variables approached differently by developers to minimize cost.

How DOE Supports Power Tower Technologies

In the early 1980s, in partnership with industry and state government partners, and using American-developed technology, DOE built the first 10-megawatt power tower and refurbished it in the 1990s to utilize energy storage. Through the mid-1990s, the facility demonstrated that this technology could collect and store heat to generate utility-scale electricity 24 hours a day. Today, the SunShot Initiative works extensively with U.S. national laboratories, universities, and private industry to optimize the size, structure, reflective materials, and drives of the collectors, as well as the durability, absorptivity, and emissivity of tower-based central receivers. As a result of these efforts and subsequent advances in CSP technology, the CSP industry was prepared to develop and construct the two power tower facilities that will begin producing clean energy in 2014—*Ivanpah* and *Crescent Dunes*. Over the last 20 years, DOE has worked closely with its private partners in support of their components and power plant designs, and though LPO, DOE has provided financing to make the first two commercial-scale power towers in the nation a reality.



In power tower CSP systems, numerous large, flat, sun-tracking mirrors, known as *heliostats*, focus sunlight onto a receiver at the top of a tall tower. A heat-transfer fluid heated in the receiver is used to generate steam, which, in turn, is used in a conventional turbine generator to produce electricity.

Aerial view of one of the *Ivanpah* power towers in Ivanpah Dry Lake, California. *Photo Credit: BrightSource Energy*

3. Thermal Storage

How Thermal Storage Works

In a power tower that uses molten salt as the heat transfer medium, cold molten salt is pumped up the tower to the receiver, where it is heated, then flows to a hot storage tank. The hot salt then flows through a heat exchanger, where heat is transferred to water to produce the steam that spins the turbine. The molten salt then flows back to the cold storage tank. This hot molten salt retains its heat so well that it can be stored and used to generate electricity at later times.

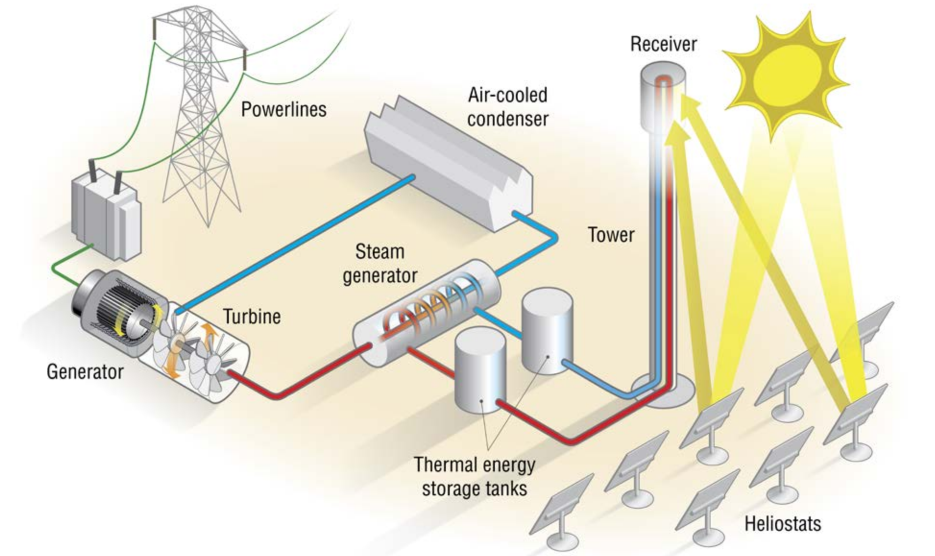
In a parabolic trough solar facility, the heat transfer fluid can be used not only to create steam, but also to heat molten salt stored in tanks near the power block. When the sun goes down, the hot molten salt (rather than the sun-heated fluid) generates steam and electricity.

By placing the storage between the receiver and the steam generator, solar energy collection is no longer directly coupled to electricity generation. The sun remains a necessary component of the system, but the molten salt thermal storage enables the plant to continue reliably generating electricity for hours when the sun is not immediately available, such as in the evenings or during cloudy days.

How DOE Supports Thermal Storage Technologies

DOE has worked to develop and improve thermal storage solutions since the 1980s. Research and development conducted over more than two decades has demonstrated 24/7 operations, proving that thermal storage CSP offers a flexible, dispatchable source of electricity. Two of the plants highlighted in this report—*Solana* and *Crescent Dunes*—utilize molten salt storage technology. In addition, studies have shown that CSP with thermal energy storage can enable greater incorporation of variable renewable generators, such as photovoltaics and wind, onto the electricity grid. This is due to the fact that CSP with storage is able to "fill in the gaps" left by intermittent renewable technologies so that as a package they can fully match the reliability of conventional power plants.

The SunShot Initiative's CSP program is working with partners across industry, national laboratories, and academia to develop and demonstrate advanced storage technologies, including phase-change materials and thermo chemical solutions. Continued technological breakthroughs will lower the cost of CSP and provide utilities and grids with a stable, reliable source of power.



In a CSP system with thermal energy storage, the heat transfer medium, such as molten salt, retains heat so well that it enables the plant to generate electricity for hours when the sun is not shining.

Solana molten salt storage tanks. *Photo Credit: Abengoa Solar, Inc*

DOE Loan Program Office CSP Portfolio Profile

LPO provides loan guarantees for projects that deploy innovative technologies that have been demonstrated but are not yet commercial. Early-stage technologies are often supported by the SunShot Initiative and other DOE research and development programs, with LPO and private market support after commercialization. DOE loan guarantees bridge a critical period of time between demonstration and commercial deployment of new technologies. The five projects highlighted below illustrate how loan guarantees were used to effectively reduce financial risk to a level that was acceptable to private market investors. CSP is a prime example of the types of technologies that DOE supports through its various programs, from inception to commercialization.

Solana (Abengoa Solar, Inc.)

The *Solana* parabolic trough plant was developed by Abengoa Solar, Inc. It is located near Gila Bend, Arizona, and uses parabolic trough and thermal storage technologies. With six hours of storage, *Solana* can dispatch energy to customers as needed during cloudy periods and after sunset. *Solana* generates electricity well into the evening to help meet the summer peak demand for air conditioning.

Solana created 1,700 construction jobs in Arizona and 60 jobs to operate and maintain the facility. This project catalyzed a robust solar energy technology domestic supply chain, which was demonstrated by Abengoa's contracts with 165 companies in 29 states across the country. Solana has the capacity to power more than 97,000 Arizona Public Service customers.

The project received a $1.4 billion loan guarantee from LPO, and leveraged more than $2 billion in total project investment.

Location	Near Gila Bend, Arizona
Technology	Trough; Thermal Storage
Size	1,920 acres
Power	250 MW
Customers	Arizona Public Service
Ground Break	December 2010
Start Date	October 2013

The *Solana* parabolic trough and thermal storage plant spans 1,920 acres near Gila Bend, Arizona.
Photo Credit: Abengoa Solar, Inc.

Genesis Solar (NextEra Energy Sources, LLC)

The *Genesis* solar energy project was developed by NextEra Energy in collaboration with solar technology and power block providers, Sener and Fluor. The plant is composed of two 125-megawatt parabolic trough technology units. *Genesis* expects to produce nearly 700 gigawatt-hours of renewable electricity annually from more than 500,000 parabolic mirrors.

Located in Blythe, California, *Genesis* created 800 construction jobs. Nearly 50 full-time jobs will be created to operate and maintain the facility. With both units online, Genesis will have the capacity to serve more than 60,000 average American homes.

Location	Blythe, California
Technology	Trough
Size	1,800 acres (Bureau of Land Management)
Power	250 MW
Customers	Pacific Gas & Electric
Partners	Sener, Fluor
Ground Break	December 2010
Start Date	April 2014

The project received an $852 million partial loan guarantee and leveraged more than $1.2 billion in total project investment.

The *Genesis* solar energy plant is composed of two 125 megawatt parabolic trough technology units.
Photo Credit: NextEra Energy Sources, LLC

Genesis is expected to produce nearly 700 gigawatt-hours of renewable electricity each year from more than 500,000 parabolic mirrors.
Photo Credit: NextEra Energy Sources, LLC

Ivanpah Solar Electric Generating System (NRG Energy, Inc.)

Ivanpah was developed by BrightSource Energy and constructed by Bechtel. Applying and improving upon DOE-supported power tower technology, Ivanpah uses over 300,000 software-controlled mirrors to track the sun across the sky and reflect the sunlight onto three towers. Ivanpah has the capacity to produce 392 megawatts of power and is expected to serve nearly 100,000 average American homes.

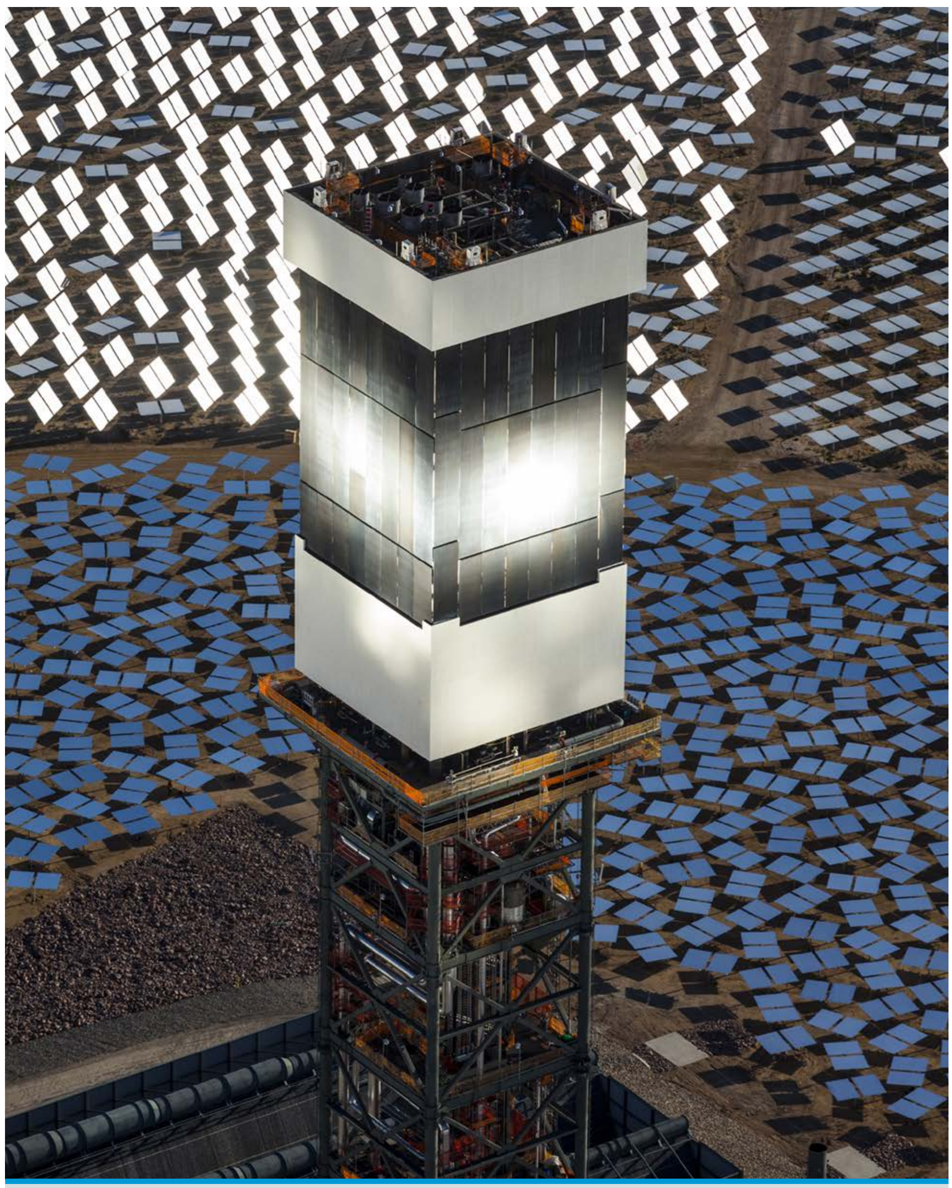
The construction phase employed more than 1,000 workers—installing the 173,500 heliostats and three power towers. Long term, Ivanpah created more than 80 permanent operations and maintenance jobs in the community.

Through LPO DOE also issued three loan guarantees, totaling $1.6 billion for the project—a partnership among NRG, Google, and BrightSource. Through the LPO support and private companies, the project leveraged $2.2 billion in total project investment, including Google's first tax equity investment in a renewable energy project.

The project received an $852 million partial loan guarantee and leveraged more than $1.2 billion in total project investment.

Ivanpah uses over 300,000 software-controlled mirrors to track the sun across the sky and reflect sunlight onto three power towers.
Photo Credit: BrightSource Energy

Location	Ivanpah Dry Lake, California
Technology	Power Tower
Size	3,500 acres (federal land)
Power	392 MW
Customers	Pacific Gas & Electric; Southern California Edison
Partners	NRG, Google, BrightSource
Ground Break	October 2010
Start Date	February 2014



Ivanpah's three power towers have the capacity to produce 392 MW of power. *Photo Credit: BrightSource Energy*

Crescent Dunes (SolarReserve, LLC)

The *Crescent Dunes* project was developed by SolarReserve, and ACS Cobra is working on the construction of the plant. The 540-foot power tower at *Crescent Dunes* was erected in fall of 2011 and completed in February 2012. The assembly of the 100-foot molten salt receiver atop the tower was completed in April 2013. The receiver panels are composed of alloy tubes through which molten salt flows to absorb energy once the plant is completed. After the energy is collected, the molten salt will flow back down the tower to the hot tank, where its energy will be stored until electricity is needed. Heliostats are assembled onsite and mounted on pedestals in the desert surrounding the tower. When completed in late 2014, approximately 10,000 heliostats will be installed, and *Crescent Dunes* will be the nation's first commercial-scale solar power tower facility with energy storage, as well as the largest power plant of its kind in the world.

During construction of *Crescent Dunes*, 600 jobs were created, and under the project's development agreement with Nye County, the project targets filling more than 90% of the construction workforce with Nevada residents. Equipment and services for the project were purchased from businesses located across 21 states. During peak performance, *Crescent Dunes* will have the capacity to serve nearly 43,000 average American homes.

The project received a $737 million loan guarantee and leveraged more than $1 billion in total project investment.

Location	Tonopah, Nevada
Technology	Power Tower; Thermal Storage
Size	~1,600 acres
Power	110 MW
Customers	Nevada Energy
Engineering, procurement, and construction (EPC) partner	ACS Cobra
Ground Break	September 2011
Estimated Start Date	December 2014

Crescent Dunes is the largest power plant of its kind in the world. *Photo Credit: SolarReserve, LLC*

During construction of *Crescent Dunes*, 600 jobs were created. *Photo Credit: SolarReserve, LLC*

Mojave Solar One (Abengoa Solar, Inc.)

The *Mojave* project was developed by Abengoa Solar, Inc. It is located in an unincorporated area of San Bernardino County, California, between Barstow and Kramer Junction. The plant sits on approximately 1,765 acres and is located about 100 miles northeast of Los Angeles. *Mojave* features DOE-supported parabolic trough technology to produce 250 megawatts of power and is one of the largest projects of its kind in the world.

During construction, *Mojave* has created approximately 830 American jobs and will employ 70 when completed. At full capacity, the CSP plant will be able to serve more than 60,000 average American homes.

The project received a $1.2 billion loan guarantee and leveraged nearly $1.7 billion in total project investment.

Location	Near Barstow, California
Technology	Trough
Size	1,765 acres
Power	250 MW
Customers	Pacific Gas & Electric
Suppliers	Rioglass, Schott
Ground Break	September 2011
Estimated Start Date	Late 2014

Mojave features DOE-supported parabolic trough technology to produce 250 megawatts of power. *Photo Credit: Abengoa Solar, Inc.*

During construction, *Mojave*, created approximately 830 jobs. *Photo Credit: Abengoa Solar, Inc.*

What's Next?

Just three years into the decade-long SunShot Initiative, DOE's investments at the national laboratories, industry, and universities are beginning to pay off. While initial innovations and cost reductions are impressive, we still have more work to do as we continue to work toward the goal of cost parity for CSP-generated electricity on the grid.

DOE's ongoing research and development efforts aim to help enable the deployment of transformative CSP technologies within the next 3-5 years. These technologies include highly efficient reflector materials integrated with low-cost collector structures, lean solar field manufacturing and assembly approaches, self-aligning and tracking controls, and cost-effective thermal energy and thermochemical energy storage technologies, among others.

The CSP industry continues to innovate to increase CSP grid compatibility, its use in hybrid power systems, and integration into advanced storage systems. These next-generation technologies may encounter obstacles similar to what the current generation faced in obtaining financing for initial deployments at the commercial scale. As the industry moves forward, LPO could help overcome those obstacles through two of its upcoming loan guarantee solicitations. First, LPO's advanced fossil energy solicitation could help to finance innovative uses of CSP in hybrid configurations with fossil-fired power plants to lower greenhouse gas emissions. Second, LPO's renewable energy and energy efficiency solicitation could help to finance projects that use CSP for innovative integration of renewables into the grid or for energy storage.

Conclusion

For decades, researchers and scientists have explored methods to convert the endless energy potential of the sun into usable electricity. Today, America is harnessing the sun's free and clean energy to power homes, businesses, and communities across the country. By deploying more solar energy capacity in the United States, we can reduce harmful carbon pollution and keep our air and water clean for future generations.

The United States is at the brink of shifting its energy economy from one that is dependent on conventional fossil fuels to one that is sustained on innovation and cleaner technologies. Creativity, research, and economies of scale continue to drive down component costs, while policies continue to be developed to address soft-cost obstacles. Meanwhile, developers, investors, and lenders are utilizing financing mechanisms to reduce barriers to obtain funding for solar projects at commercial scale—particularly for leading-edge projects that employ innovative technology. With help from DOE, the United States is becoming a global solar leader, developing and introducing innovative technologies into the marketplace to make clean energy affordable for all Americans.

Aerial view of one of the *Ivanpah* power towers in Ivanpah Dry Lake, California.
Photo Credit: BrightSource Energy

For more information, visit:

energy.gov
energy.gov/eere
energy.gov/sunshot
energy.gov/lpo

DOE/EE-1101 • May 2014

Printed with a renewable-source ink on paper containing at least 50% wastepaper, including 10% post-consumer waste.