



Concentrating Solar Power

MAIN POINTS

- Concentrating solar power (CSP) can achieve gigaton scale by 2020 for an investment of \$2.24 trillion.
- Solar resources are abundant in the U.S. and globally to meet new energy demand; CSP is ideally situated to remote, high-insolation desert areas, so new transmission build-out is needed to bring CSP to high-population areas.
- Solar thermal systems with storage can provide consistent power and thus are attractive relative to intermittent power sources, e.g., solar photovoltaics and wind.
- Tested technology has been supplying cost-competitive solar thermal power in southern California for the past 20 years.

Overview

Concentrating solar power (CSP) is a renewable generation technology that uses mirrors or lenses to concentrate the sun's rays to heat a fluid, e.g., water, which produces steam to drive turbines. CSP differs from solar photovoltaic (PV) technology, which directly converts the sun's ultraviolet radiation to electricity using semiconductors. The CSP technologies discussed here are utility scale although some rooftop CSP applications are being developed. Solar PV rooftop applications are common; however, utility-scale solar PV is also being deployed.

Because no input fuel is required, CSP plants release little or no carbon dioxide equivalent (CO_2e) emissions. CSP is a proven technology with more than 350 megawatts (MW) of installed capacity operating commercially in the Mojave desert since the 1980s and several smaller new plants brought on line since 2006. The current worldwide installed capacity is more than 500 MW, relying mostly on

the established line-focusing parabolic trough technology that provides peak demand generation. Several emerging technologies that promise higher conversion efficiencies and cost-competitive generation have been demonstrated on a smaller scale. These technologies, such as point-focusing power towers and line-focusing Fresnel reflectors, may extend the ability of CSP to provide shoulder or base-load power in addition to peak load.

There is a vast abundance of solar resources and qualified land for deployment of CSP. For example, in the southwestern U.S. alone, eligible land in proximity to transmission would readily allow for 200 gigawatts (GW) of potential CSP production. This would represent approximately $\frac{1}{5}$ of projected U.S. installed generating capacity in 2020. The ability to store thermal energy gives CSP technology an advantage over renewable sources such as PV and wind that have not yet developed on-site storage. Although thermal storage has yet to be proven financially viable at commercial



scale, plants with thermal heat storage facilities would be able to overcome solar power's intermittent nature, dispatch power on demand, shift generation to periods of peak demand, and achieve a higher capacity factor and thus reduce payback periods.

By the year 2020, an increase of approximately 492 GW of concentrating solar power capacity over today's installed base of 502 MW would reduce emissions by 1 gigaton of CO₂e per year. We estimate the total capital cost for such aggressive deployment to be approximately \$2.2 trillion, nominal, or \$4,546 per kilowatt (kW) of capacity. By 2020, we expect CSP plants to be cost competitive with today's natural gas plants at a levelized cost of electricity (LCOE) of approximately \$67 per MWh (in 2009 dollars), a 51% reduction over 2009 LCOE.

The scale-up would produce an estimated 460,000 permanent jobs and 8.7 million temporary jobs in construction. CSP is one of the many gigaton technologies that would increase U.S. energy security and independence by reducing dependence on foreign oil.

An aggressive CSP deployment schedule will encounter obstacles. Foremost, investment in and support for research efforts are required to bring emerging technologies, particularly storage media, to a commercializable, cost-competitive stage. Further, we expect a gigaton ramp-up would result in supply chain bottlenecks, mainly in turbine and storage media supply. While there is a large amount of land worldwide that is suitable for CSP projects, siting and permitting could slow down deployment.

A supportive, stable policy environment will catalyze aggressive deployment of solar

thermal generation. Technology-neutral policies, such as a price on carbon, as well as CSP-specific initiatives are required. A loan guarantee program would help overcome the high costs of financing emerging technologies. A streamlined approval process for plant siting and land-use permitting would expedite deployment. Lastly, significant investments in transmission infrastructure on the order of 10% to 20% of total plant capital cost are required; these can be triggered by revisions to rate-of-return regulation to attract private capital as well as federal oversight and a reorganized approval process.

Industry Background

The principles of concentrating direct sunlight into useful thermal energy are very basic, as a child with a magnifying glass on a sunny day can readily demonstrate. The basic engineering technologies for converting thermal energy into electricity have been commercially demonstrated for over 20 years, and CSP plants are used today to provide peak power.

Technology Overview

A CSP system employs mirrors or lenses (collectors) to concentrate sunlight on a receiver. Concentrated sunlight heats a heat-transfer fluid inside the receiver. The fluid is pumped to a central power block where it passes a heat exchanger and generates steam that drives a turbine or cycle engine to generate electricity. In general, the system beyond the heat exchanger is a conventional steam plant. There are four main CSP designs: parabolic trough, linear Fresnel reflector (LFR), tower, and dish systems. The technology most often used is parabolic trough mirrors; this is the

most established and commercially proven technology, accounting for more than 90% of installed capacity.

TROUGH

Trough systems use long parabolic mirrors curved around a single axis to concentrate solar power on a receiver that runs down the length of each trough. The receiver contains a heat-transfer fluid, typically a synthetic oil, which is heated to approximately 390°C; this, in turn, generates steam, which drives a turbine in a traditional Rankine cycle. The parabolic mirrors rotate along a single axis, tracking the sun's movement.¹ Trough systems can be fitted with heat storage facilities, typically using molten salt as storage medium, that allow electricity generation to shift to cloudy or non-daylight hours. Such a system is employed by Andasol 1 in Spain.²

LINEAR FRESNEL REFLECTOR (LFR)

LFR systems are an alternative to trough systems. Rather than using parabolic-shaped reflectors, LFR systems employ long parallel rows of flat or slightly curved reflectors. Each reflector is independently tracked on a single axis to reflect sunlight onto a receiver suspended and fixed in space above the reflectors. As with parabolic trough systems, a heat-transfer fluid can be used to boil water in a steam generator although some LFR systems are being designed to support direct steam generation within the receiver, which could improve performance and cost.³ Industry estimates that although LFR is less efficient than parabolic trough designs, it has an approximately 10% lower cost of electricity because solar field investment is less costly, operations and maintenance (O&M) material costs are lower because LFR has reduced breakage from



wind loads compared to trough designs, and LFR offers easier access to mirrors for cleaning.⁴

Compact LFR (CLFR) systems are a variation on the LFR design. CLFR systems use multiple horizontal receivers over the field of reflectors. By aiming adjacent reflectors at different receivers, CLFR systems can space reflectors more closely, reducing the coverage area of the solar field.⁵

TOWER

“Power tower” systems use a field of hundreds to thousands of mirrors (heliostats) that individually track the sun along two axes and focus sunlight on a central receiver placed at the top of a tower. Because of the high concentration of solar energy, operating temperatures can range much higher than in trough or LFR systems, 450°C to 550°C and above, which enables higher operating efficiencies in the Rankine cycle. The higher operating temperatures also allow molten-salt heat-transfer and storage capabilities, so the plants can deliver electricity during cloudy periods or at night.⁶

DISH AND OTHER

Dish systems use a mosaic of mirror facets distributed over a dish surface to concentrate sunlight on a receiver placed at the dish’s focal point. A working fluid such as hydrogen is heated in the receiver and used to drive either a turbine or a Stirling cycle engine (the latter is preferable due to its high efficiency). Because each dish rotates along two axes to track the sun, the size of the dish assembly is effectively limited, and a single dish typically generates only 10kW to 100 kW. For commercial-scale applications, a farm of several thousand dishes would need to be built.

A “solar chimney” is an experimental commercial-scale design that uses solar energy to heat air underneath an immense glass collector array and directs the airflow upward into a vertical chimney where it drives a turbine to generate electricity. An experimental plant built in Spain in the 1980s with a chimney 200m high and collection area of about 11 acres was capable of generating 50 kW of power.⁷ Significantly larger plants of 100 MW are currently envisioned although these would require collection areas of 20 square kilometers (km²) and chimneys 1 km high.⁸

CSP Industry

Commercial-scale CSP technology was first developed in the wake of the oil price peak of the 1970s. The largest plants constructed in this period were the nine Solar Electricity Generation Systems (SEGS) in the Mojave Desert in California, built from 1984 to 1991 by Luz International. Utilizing parabolic trough technology, the SEGS plants have a collective installed capacity of 354 MW and continue to operate today after having been acquired by several conglomerates in the wake of the Luz bankruptcy in 1991.

All other CSP projects during the post-1970s era remained relatively small pilot projects of 5 MW or less with the exception of the U.S. Department of Energy’s 10-MW Solar One pilot plant in the Mojave Desert. First operational from 1982 to 1986 and designed to demonstrate solar power tower technology, it was upgraded in 1995 and operated until 1999 as the Solar Two project to demonstrate the ability of solar molten-salt technology to provide long-term, cost-effective thermal energy storage for electricity generation.

The collapse of oil prices and removal of government subsidies stalled further development of commercial CSP technology in the 1990s. For nearly two decades no new large-scale, grid-tied CSP plants were built anywhere in the world. However, with increasing focus on renewable energy in recent years, interest and investment in CSP have renewed, in part because of its technological maturity relative to other alternative energy technologies. In 2006, the 1-MW Saguaro Solar Generating Station came on line outside of Tucson AZ, followed quickly by the much larger 64-MW Nevada Solar One station outside of Boulder City NV in 2007. In 2008, the first European commercial CSP plant, the 50-MW Andasol 1 project, was completed in Granada, Spain. All three use a parabolic trough design similar in concept to that used in the pioneering SEGS facilities.

INDUSTRY GROWTH

The current worldwide installed capacity of CSP is 502 MW, of which 419 MW are in the U.S.^{9,10,11} The vast majority of this global capacity (467 MW) is generated by line-focusing parabolic trough systems. Currently, there are only two power tower stations in commercial operation, both located in Spain near the city of Seville. Named PS10 and PS20, these power towers came on line in 2007 and 2009 and have capacities of 10 and 20 MW, respectively. Widespread power tower deployment might be delayed until proven to be financially viable.^{12,13}

In the U.S., a further 8,500 MW of CSP capacity is scheduled for installation by 2014.^{14,15} Approximately 40% of this capacity is expected to utilize parabolic trough technology, and the remainder is expected to use LFR,



power tower, and dish technologies.¹⁶ Among the companies developing CSP projects are: Brightsource, a power tower developer, that has signed power purchase agreements with both Southern California Edison and Pacific Gas & Electric Company (PG&E) for a total capacity of more 2,100 MW and Ausra which has announced a similar power purchase agreement with PGE&E for a 177-MW LFR plant at Carrizo CA. Other hybrid fossil fuel-trough installations are planned in California at the City of Palmdale (50 MW) and Victorville (the 50-MW 2 Hybrid Power Project).^{17,18}

Outside of the U.S., Spain is the leader in the CSP market with 1,037 MW of capacity currently under construction and an additional 6,000 MW of projects in the pipeline.¹⁹ Spain's attraction to CSP technology has been spurred by government incentives, including the Spanish Royal Degree, which calls for 500 MW of CSP by 2010. Of the planned CSP projects in Spain, 96% will utilize parabolic trough technology, with the technology choice linked to government incentives and subsidies (which cap the feed-in tariff at 50 MW, creating little incentive for higher output technologies.)²⁰

Other regions with plans for CSP development include the Middle East, North Africa, and Australia. In the Middle East, 325 MW of CSP capacity are being planned in countries such as Israel, Egypt, Algeria, Abu Dhabi, and Morocco.²¹ At the same time, the Mediterranean Solar Plan aims to install 10 to 12 GW of solar thermal power in North Africa and the Middle East to provide electricity to 35 million people in Europe by 2020.^{22,23}

Advantages of CSP

CSP technology has several advantages as

a renewable electricity generation source. First, 354 MW of trough plants have been in commercial operation for more than 20 years, proving the reliability of solar thermal generation. Second, like other renewable electricity generation technologies, solar thermal is immune to fuel-cost fluctuations because the fuel input is sunshine; this has both economic and energy security advantages for consumers. CSP has access to abundant resources, with a vast area of land that could host CSP plants.²⁴ In the southwestern U.S. alone, eligible land in proximity to transmission would allow for 200 GW of potential power production, equal to $\frac{1}{5}$ of existing U.S. electricity generation capacity.^{25,26}

The thermal energy generated by a CSP solar field does not need to be immediately used for power generation but can be stored for later use. Thermal energy can be stored much more efficiently than electrical energy, typically in the form of molten salt held in highly insulated storage tanks. Other alternative storage media, including concrete, water, synthetic oils, and phase-change materials, are being considered. Storage gives CSP technology several considerable advantages:

- Reliable operations during cloudy or nighttime conditions
- Near instantaneous dispatchable power to meet expected and unexpected peak demand
- The ability to shift electrical production from the natural peak of insolation to higher-priced peak demand, thereby increasing profitability and investment returns

- The ability of the solar field to be oversized relative to turbine capacity, thereby decreasing turbine costs, increasing the capacity factor, and reducing the payback period²⁷

Lastly, CSP plants can be easily hybridized with fossil-fuel heat sources (e.g., natural-gas-fired boilers), which increases plant reliability because the fossil-fuel back-up can bridge periods when sunlight is insufficient. Furthermore, the fossil-fuel heat sources can be used to boost operating temperatures to maximize plant efficiency and output.

Achieving Gigaton Scale

To abate 1 gigaton of CO₂e emissions globally, approximately 492 GW of CSP capacity, or roughly 4,900 plants of 100 MW capacity, would need to be added by 2020.²⁸ This would represent approximately 9% of global, or slightly more than 45% of U.S., projected electricity generation capacity in 2020.²⁹ If transmission constraints are set aside, land resources are more than ample to meet the gigaton goal.³⁰ Promising areas for CSP plants include the U.S., Spain, North Africa, the Middle East, India, Chile, Mexico, and Australia.

Scaling the Industry

In many respects, natural gas plants operate similarly to CSP and have similar construction periods, so they can be used as a reference for CSP plant potential.³¹ As a point of comparison, over 10 years starting in 1997, natural gas generation capacity expanded by 217 GW in the U.S. alone.^{32,33} This 113% expansion was spurred mainly by cheap natural gas prices, which suggests that a price on carbon or a



similar policy to achieve grid parity could spur the CSP industry to reach gigaton scale.

To meet the gigaton goal, the projected ramp-up curve adds a maximum 110 GW of global CSP capacity per year, which is not unprecedented growth if we look at natural

gas for comparison. In 2002, approximately 60 GW of natural gas-combustion turbines were added in the U.S. alone, which represents a year-over-year installed capacity expansion of approximately 25%.^{34,35} Richter et al. (2009) simulated an aggressive CSP deployment schedule that assumes adequate political

will and commitment to CSP and associated transmission build-out. The authors estimate annual deployment will peak at 70 to 80 GW per year around 2030. This deployment schedule would yield 2.1 gigatons of CO₂e savings by 2050. Even with a set of moderate assumptions, the authors estimate the world could have a solar power capacity of more than 830 GW by 2050 based on annual deployments of 41 GW.³⁶ Figure 1 shows the gigaton growth projection for CSP compared to the current projection.

In the absence of a gigaton goal, global solar thermal power capacity is still expected to grow very quickly over the next decade. Emerging Energy Research estimates that CSP capacity will grow at approximately 18% per year to 25 GW by 2020. DLR conservatively estimates that the solar thermal industry could expand to 5 GW installed capacity by 2015, compared to approximately 60 GW projected under the gigaton build-out.

Although CSP does not emit carbon during operation, the construction phase can be carbon-intensive. The life-cycle carbon footprint of solar thermal plants is estimated to be 10 to 90 grams CO₂e per kilowatt hour (kWh) produced.^{37,38} This compares to approximately 1,000 grams CO₂e per kWh for coal and 490 grams per kWh for natural gas plants.^{39,40,41,42} If we take into account the life-cycle emissions of both CSP and the average grid generation plant (assuming 606 grams CO₂e per kWh), the installed CSP capacity would have to be approximately 470 to 540 GW to abate 1 gigaton of CO₂e emissions annually.

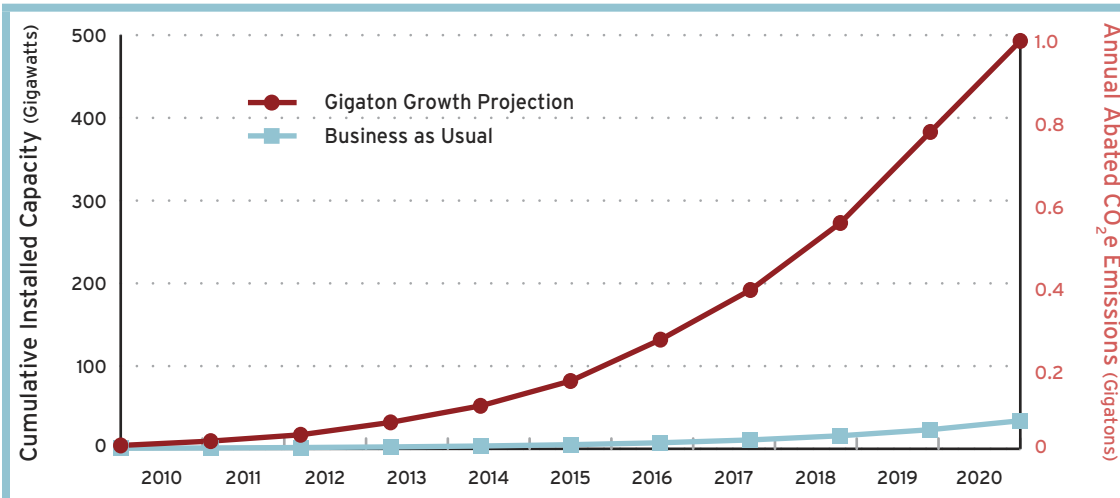


FIGURE 1. Growth in Concentrating Solar Power Generation Capacity. Source: DLR, Emerging Energy Research, L.E.K. Analysis.

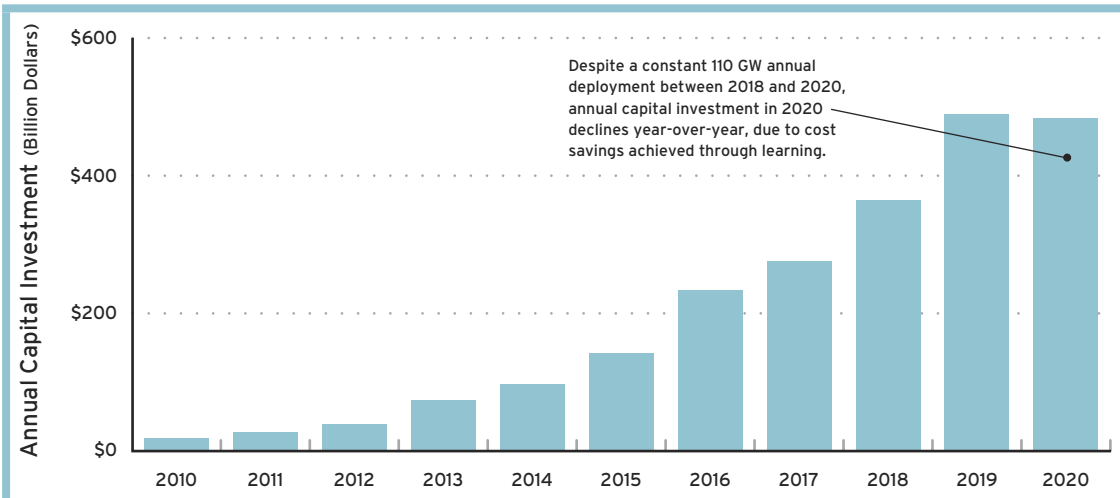


FIGURE 2. Annual Capital Investment in Concentrating Solar Power Generation Capacity. Source: L.E.K. Analysis.

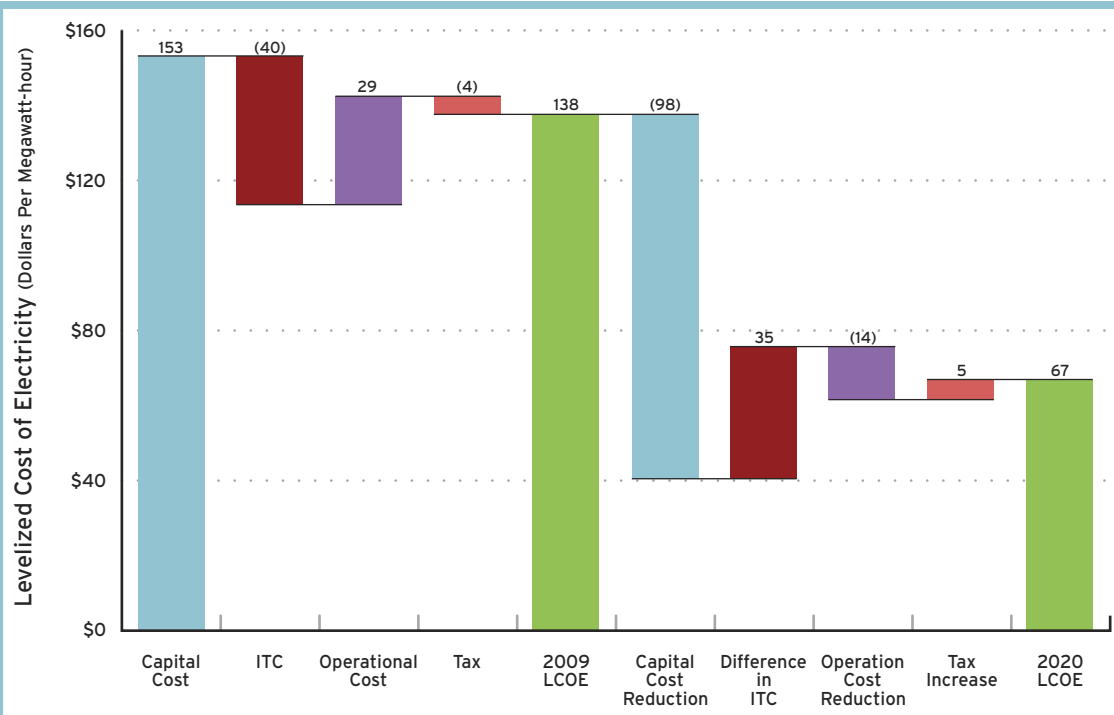


FIGURE 3. Levelized Cost of Electricity (LCOE) for a 100-MW CSP Plant (2009 to 2020).

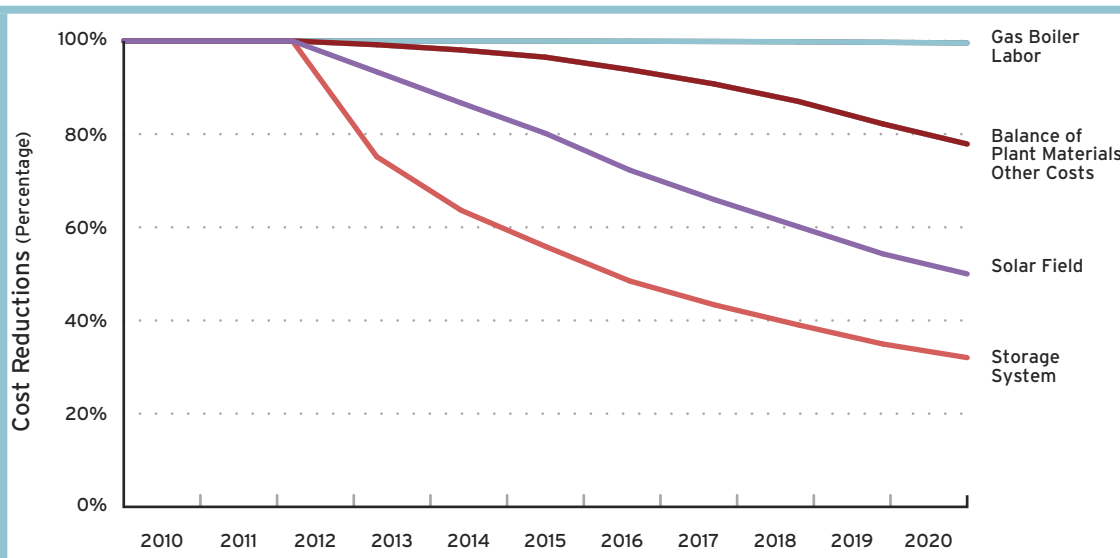


FIGURE 4. Learning Curve-Based Cumulative Cost Reductions.

Capital Investment

To meet the gigaton goal, a cumulative capital investment of approximately \$2.2 trillion (nominal), or an average \$4,546 per kW, is required. This figure excludes incentives or expenses related to financing. Figure 2 shows annual capital investment in CSP from 2010 to 2020 for the gigaton pathway.

To estimate the level of investment required, we have made assumptions about future cost reductions for specific CSP plant components. For example, additional cost reductions are likely in solar field installations, but relatively few cost savings are expected in turbine and boiler construction and design. In total, the capital costs of a CSP plant are expected to decrease by more than 60% in real terms over the next 10 years. As a result, the LCOE of \$67 per megawatt hour (MWh) (real 2009 dollars) in 2020 is 51% lower than the LCOE in 2009 (\$138 per kWh).⁴³ Our LCOE estimates are generally in line with, although slightly higher than, industry estimates, because we include several cost components that are not explicitly accounted for in other studies.^{44,45,46,47} Figure 3 shows the LCOE for a 100-MW CSP plant, and Figure 4 shows cumulative projected cost reductions based on increased knowledge about CSP installations over time.

Jobs in the CSP Industry

Construction and operation of solar thermal plants will have significant economic benefits. A large number of component inputs require specialized production, much of which is likely to be local if there is aggressive regional deployment of CSP.⁴⁸ Additionally, construction labor is likely to be sourced locally. A 100-MW CSP plant is estimated to create 455 construction jobs per year. Another estimated



3,500 jobs are created indirectly within the supply chain to support construction.

Black & Veatch estimate that 94 operations and maintenance (O&M) jobs are created directly at the plant and indirectly within the supply chain for every 100-MW plant, compared to 56 and 13 for a combined-cycle or simple-cycle natural gas plant, respectively.⁴⁹ This is the result of more labor-intensive operations within the CSP plant.

For CSP to reach gigaton scale, close to half a million (approximately 460,000) permanent jobs in operations would be created by 2020. In construction, a maximum of 8.7 million construction workers per year would be required, which is likely a high estimate, as it is a linear extrapolation of current labor requirements. Investment would be needed to provide education and training to expand the solar thermal workforce on that scale.

Figure 5 shows jobs that would be created in the CSP sector during the gigaton scale-up.

Challenges to Accelerated Deployment

Introducing 492 GW of new generation capacity in a 10-year period will require scaling of component industries for solar thermal plants, transmission build-out, and resolution of issues regarding land use and water supply.

SUPPLY CHAIN

Although a significant portion of a CSP plant consists of commodity inputs, components such as mirrors, receivers, and turbines or other generation technology must be sourced from specialized manufacturers. For example, parabolic trough technology requires thin linear parabolic reflectors with a steel frame, specially coated steel absorbers containing a heat-transfer fluid, and steam-driven turbines. Power towers employ components similar to those used in parabolic trough plants,

namely small glass reflectors attached to a metal backing with a special coating, a steel tower structure, and a ground-based generator. All of these industries will have to scale many-fold to provide inputs as the technology is deployed.

The cost of CSP is sensitive to the commodity prices of steel, aluminum, glass, and concrete. Price increases in these commodity markets driven by rising global demand and economic expansion in the developing world (China in particular) could result in higher CSP construction costs. One anticipated supply chain constriction is for molten salt.⁵⁰ The single source of molten salt is in Chile, and competing agricultural uses (for fertilizer) have already led to restrictions in its availability. Alternative storage solutions are under development in response to this pressure.

Tight turbine supply may hamper an accelerated roll-out of CSP. Leading producers of steam turbines include market leaders Siemens and GE, accounting for just under half of total production, as well as Alstom, LMZ, Mitsubishi, Toshiba, Hitachi, and Skoda, among others.⁵¹ Manufacturing capacity for turbines has not kept pace with demand, resulting in stalled availability and leading GE to announce a \$50-million investment to increase production capacity at its steam-turbine facility.⁵² Prior to the economic downturn of 2009, wait periods for steam turbine delivery exceeded 3 years because of bottlenecks at large forging plants. In 2009, they are expected to approach 30 months but are unlikely to fall below 2 years.⁵³

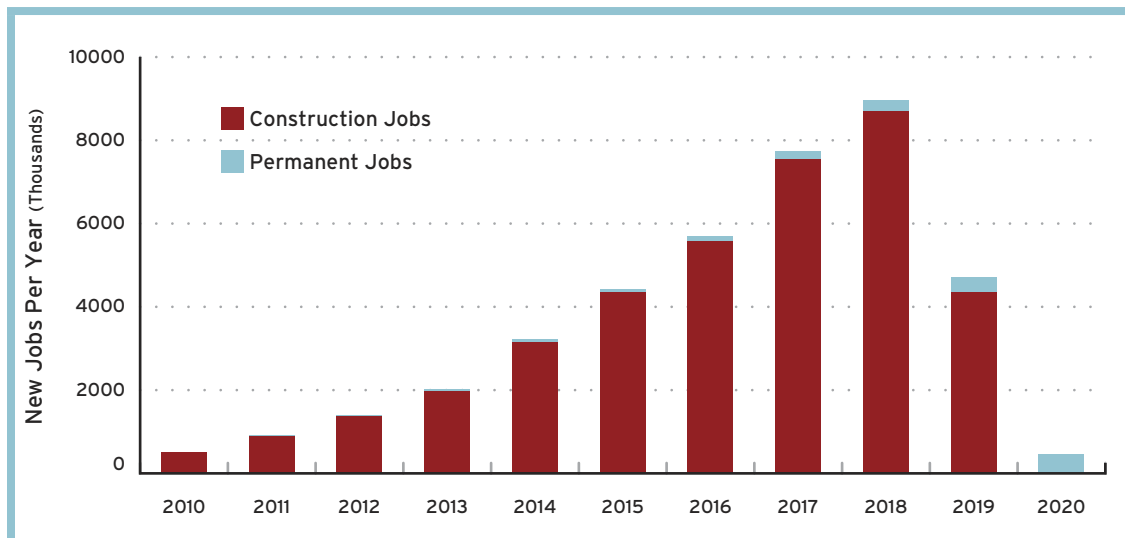


FIGURE 5: Jobs Created in the Concentrating Solar Power Industry. Source: Stoddard, L., et al., L.E.K. Analysis.



LAND QUALIFICATION, ACCESS, AND ECOSYSTEMS

Land-use considerations are an important issue because CSP plants require large areas of contiguous land. For example, Ausra's relatively efficient design requires 1 square mile of space for a 177-MW CSP.⁵⁴ Expanding to 492 GW could require in excess of 3,000 square miles, which is slightly more than 2% of the land mass of Nevada.

Ecosystem concerns arise when proposed sites are in sensitive desert areas. The deployment of large-scale solar affects local ecosystems through shading or complete coverage of land tracts. The need to complete environmental reviews and take habitat concerns into account will slow down deployment in some areas. The lack of unified permitting policies can place substantial multi-year delays on CSP deployment. This is an area where policy support can accelerate permitting and deployment time significantly.

WATER

Depending on the technology used and the local geography, access to water could be a constraint on deployment of CSP. The degree of water constraint depends on a plant's use of water as a working fluid, heat-transfer fluid, and/or cleaning fluid for the solar collectors. Technical advances would allow dry cooling of the steam cycle, reducing water needs by 90% compared to water usage in wet-cooled plants.^{55,56} Innovations in soil-resistant mirror coatings would also dramatically reduce water requirements.

TRANSMISSION

The areas of the world with strong solar thermal resources, including the southwestern U.S., Gobi desert, Northern Africa, and

Tibetan plateau, are not necessarily close to cities and other major load centers.⁵⁷ High insolation requirements make the technology unsuitable for high-demand regions with insufficient sunlight for CSP, such as the UK, Germany, and Japan.⁵⁸ Thus, for CSP reach the gigaton goal, a global transmission build-out would be required to link solar generating regions to load centers. The required new high-voltage transmission lines could use direct current, as this method can transport electricity with lower line losses over long distances (>500km) than alternating current.⁵⁹

Estimates for the costs of transmission infrastructure construction are notoriously unreliable as they are highly dependent on topography, line length, and other project-specific features. Various cost estimates suggest that transmission requirements could add 10% to 20% to the capital investment required for CSP plant deployment.

Technology Innovation

Further technological innovation is required to bring down CSP technology costs and improve operating efficiencies. Key areas for research and development (R&D) include:

- *Increased thermal storage capacity* — Thermal storage allows a plant to increase both the availability and value of its energy.
- *New collector space frame designs* — Components in the solar field account for 25% of the cost of a CSP plant. More efficient designs would minimize materials use and decrease plant installation costs.

- *New reflective surfaces* — New surface treatments could increase optical efficiency of collectors and further reduce solar field costs by reducing the collection area required.
- *Modular collector designs* — Small, modular collectors can be easily installed and rapidly deployed, which would further decrease solar field construction costs.^{60,61}

Game Changers

Several advances could dramatically change CSP expansion prospects, by lowering costs. (See Figure 6.)

SIGNIFICANTLY LOWER COSTS FOR LARGE-SCALE THERMAL ENERGY STORAGE

Molten-salt storage systems cost between \$30 and \$50/kWh-thermal. If storage costs decreased to \$15 to \$20/kWh-thermal or less, CSP with large-scale thermal storage could become a baseload technology. One proposed low-cost storage medium is concrete. First-generation prototypes have successfully been operating for 2 years and generating more than 300 kWh annually.⁶² Effective low-cost thermal storage would increase the capacity factor of CSP plants, enabling them to generate and sell more power and recover costs more quickly.

Currently, thermal storage research is focused on both solid thermal energy storage media and phase-change materials. Direct storage of steam is used at PS10, but this method is limited to providing buffer storage for peak power generation. Solid-state storage media include high-temperature concrete, alumina, and rock. Phase-change materials, such as so-



dium, potassium nitrates, and chlorides, offer cost savings because of the high amount of energy that can be stored in very low volume.⁶³

A cautionary note on storage: although a variety of storage mechanisms are available, they have yet to be proven economically viable. Spain's Andasol 1 is the first grid-tied plant to use molten salt for thermal storage, with the ability to run its 50-MW turbine for 7.5 hours on storage alone. However, the plant

is heavily supported by Spain's feed-in tariffs that pay 2.5 to 3 times the average electricity price and limit qualifying facilities to 50-MW turbines.^{64,65} It remains to be seen whether molten salt or other storage media can be economically deployed without subsidies.

HIGH-OPERATING-TEMPERATURE SYSTEMS

Current CSP plants are designed to operate near 500°C. Raising the operating tem-

perature range would have several material benefits. Most importantly, higher operating temperatures would allow use of dry heat exchangers for thermal exhaust, thereby dramatically decreasing the need for water for cooling. Furthermore, CSP plants would be able to operate with greater turbine efficiency, which would decrease land use per unit of output and support higher density around transmission interconnects.

However, higher-temperature environments can put considerable stress on components, and certain storage salts can become corrosive at high temperatures. Research is directed at overcoming these drawbacks.

Public Policy

The lesson from the 1980s is that stable energy policy can make or break the industry, as evidenced by the Luz bankruptcy, which was precipitated by cancellation of tax credits. Lead times for CSP development and construction are long — in excess of 2 years⁶⁶ — such that, for example, only a distant-horizon investment tax credit (ITC) expiration would allow sufficient time for projects to take full advantage of tax credits. Stable public policy that supports the technology-neutral development of renewable energy — including a direct carbon tax, loan guarantees for large projects, and feed-in tariffs — is needed to support the 1-gigaton growth trajectory. In addition, policy areas that are critical to achieving gigaton scale specifically with solar thermal energy include solar enterprise zones, ITCs and loan guarantees, and transmission regulation.

SOLAR ENTERPRISE ZONES

A preemptive inventory by governments of

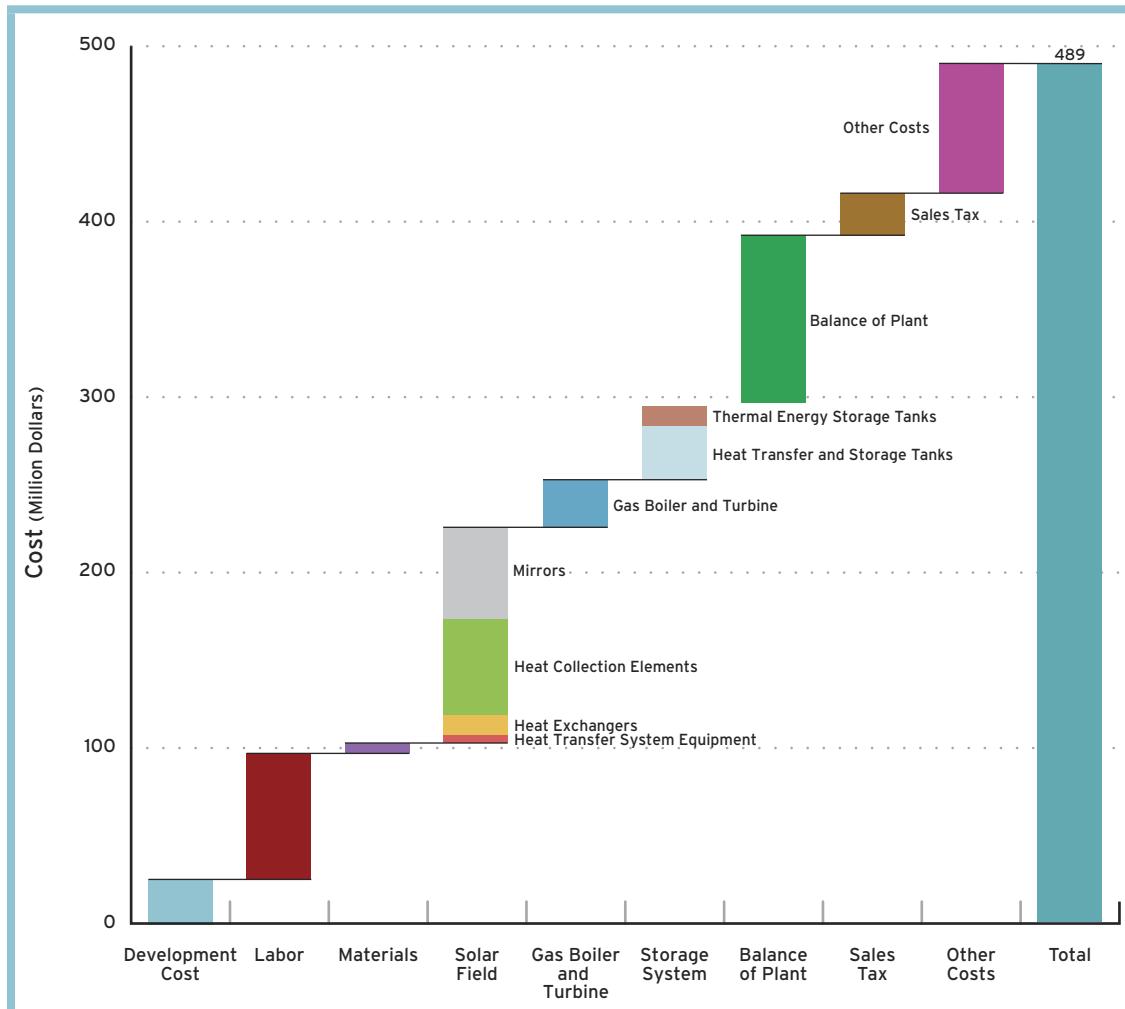


FIGURE 6. CSP Plant Cost by Category for 100-MW Capacity Plant.



available and suitable lands for CSP siting would be a major step in preparing the way for substantial solar thermal expansion. The Renewable Energy Transmission Initiative (RETI) is undertaking such an effort in California, with plans to assess available land based on cost effectiveness and environmental benignity. RETI will then identify renewable energy zones and begin transmission development. RETI is an excellent model for national and international expansion. Government funding could be used to accelerate the effort.

Shading from mirrors where land is sloped can make siting thermal power plants difficult. Public support for CSP would ideally lead to government pre-approval of large areas of desert where the shading and grading impacts of CSP and utility-scale plants would be minimal. Environmental impact assessment may be required for other aspects of the installation, including water usage. Pre-approval could significantly shorten the pre-construction stage and expedite deployment of solar thermal generation.

INVESTMENT TAX CREDITS AND LOAN GUARANTEES

Similar to wind power, solar thermal's long project lead times increase the need for and efficacy of a long-term stable policy environment. Developers will not initiate projects if financing is uncertain. A long-term extension of tax credits in the U.S. and other countries beyond 2016 that matches the long-term horizon for developing CSP could stimulate investment significantly. For example, a National Renewable Energy Laboratory (NREL) analysis simulated the effects of an ITC expiration extension to 11 years. The study found that this extension would lead to a 22-fold increase in CSP deploy-

ment over the business as usual projection.⁶⁷ Conversely, Spain's recent reversal of its feed-in tariffs has left several developers stranded.⁶⁸

Large capital costs are associated with building a solar thermal project. Financing availability and risk premiums are major obstacles for projects. Loan guarantees are, therefore, a powerful tool that government could use to expand the CSP sector while demanding accountability from developers. Currently \$10 billion in loan guarantees is available in the U.S. for early commercial use of new or significantly improved technologies in energy-related projects, and the American Recovery and Reinvestment Act of 2009 appropriated a further \$6 billion in loan guarantees for renewable energy technologies including solar thermal.⁶⁹

TRANSMISSION REGULATION

Current rate-of-return regulations on transmission plants in the U.S. create a barrier to private investment and, consequently, the adoption of solar thermal power. Policy action to revise these regulations would be an important step in supporting large-scale CSP deployment. Congress authorized financial incentives to increase private investment in transmission infrastructure in 2006. However, these incentives have, thus far, not been able to generate sufficient private investment.⁷⁰ The magnitude of the investment required to implement gigaton scale suggests that further aligning the private sector with investments in transmission capacity may be an important catalyst for growth.

Transmission build-out suffers not only from uncertainty about costs but also a history of cost overruns resulting from delays and re-

routing.⁷¹ Regulatory obstacles such as siting, permitting, and environmental concerns can significantly delay transmission construction. Federal oversight and an efficient approval process could significantly aid the rollout of all types of centralized renewable electricity generation, not just solar thermal.

Interactions with Other Gigaton Pathways

The electricity generation profile of a solar thermal plant overlaps with the load profile of a municipal utility, i.e., CSP is suited to meet daytime peak demand particularly on summer days.⁷² Thermal storage or gas-fueled backup enhances the match with utility demand profiles. Thus, CSP can complement clean baseload technologies, such as nuclear and geothermal.

Paired with long-term effective storage, solar thermal could eventually supply baseload power generation. This suggests a possible synergy with the plug-in hybrid vehicle (PHEV) pathway. The proliferation of PHEVs could ultimately provide grid storage for excess power production during the day when solar power plants are at maximum generation. This load could then be transferred to the grid at later points in the day and through the evening.

CSP faces competition from concentrating solar PV and particularly thin-film solar, both of which have similar intra-day and yearly generation profiles. The centralized nature of CSP makes it attractive in terms of wide-scale deployment because on a cost basis it competes more directly with fossil-fuel alterna-

tives. However, the non-distributed nature of most solar thermal necessitates transmission build-out, increasing total deployment cost.

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