


SunShot Vision Study

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SunShot
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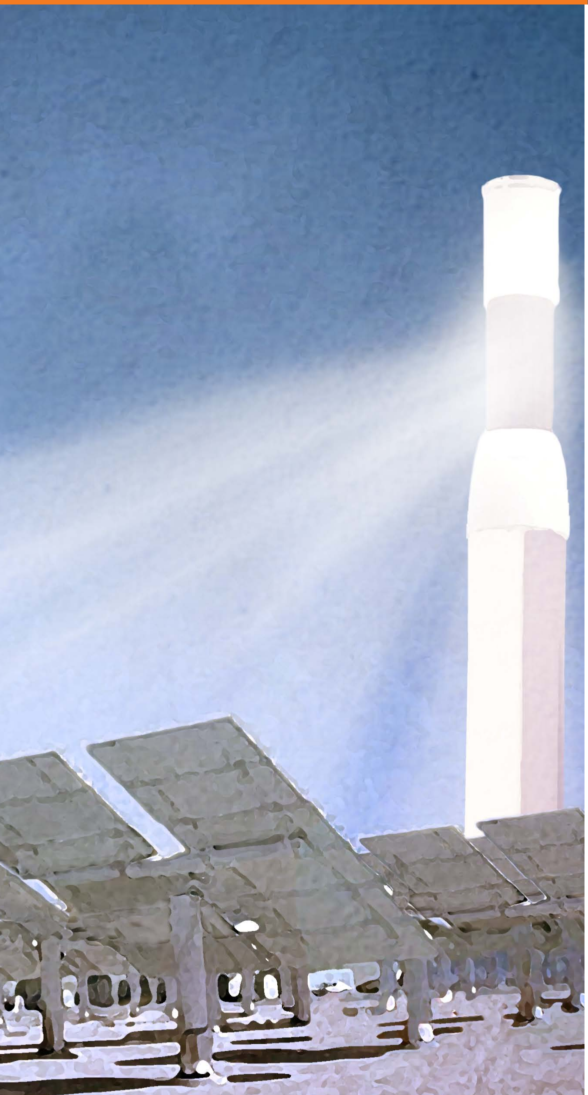

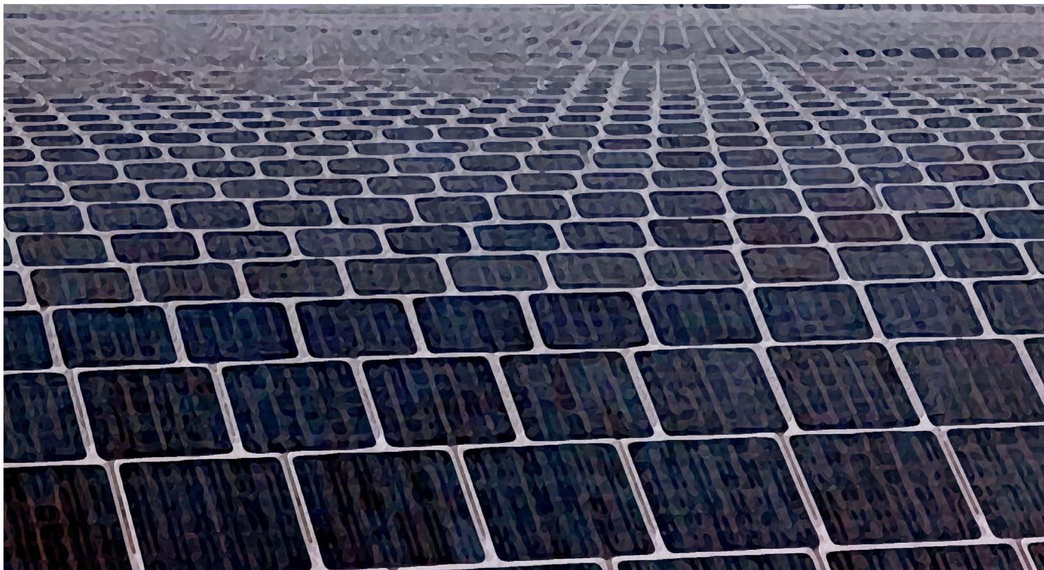

Executive Summary

The objective of the *SunShot Vision Study* is to provide an in-depth assessment of the potential for solar technologies to meet a significant share of electricity demand in the United States during the next several decades. Specifically, it explores a future in which the price of solar technologies declines by about 75% between 2010 and 2020—in line with the U.S. Department of Energy (DOE) SunShot Initiative's targets. As a result of this price reduction, solar technologies are projected to play an increasingly important role in meeting electricity demand over the next 20–40 years, satisfying roughly 14% of U.S. electricity demand by 2030 and 27% by 2050.[1] In terms of technology, the SunShot Initiative and this report both focus on photovoltaics (PV) and concentrating solar power (CSP). Details about how the SunShot Initiative is organized to achieve its targets and increase American competitiveness in solar energy can be found on the initiative's website (www.eere.energy.gov/solar/sunshot/).

The *SunShot Vision Study* uses the National Renewable Energy Laboratory's (NREL) Regional Energy Deployment System (ReEDS) and Solar Deployment System (SolarDS) models to develop and evaluate a SunShot scenario and a reference scenario. In both scenarios, the models are used to develop a least-cost geographical deployment of solar technologies and other generating technologies (conventional and other renewable). The scenarios assume the federal investment tax credit (ITC) and production tax credit (PTC) run through their currently established expiration dates—end of 2016 and 2012, respectively—but that existing supports for conventional technologies that are embedded in the tax code or through other provisions continue indefinitely. Further, the scenarios do not incorporate any additional costs for mercury and air toxins, carbon emissions, or other environmental externalities associated most strongly with conventional generation technologies. Key variables evaluated by the models include solar resource quality, cost of electricity, transmission requirements, reserve requirements, variability impacts, and projected fuel prices. For the SunShot scenario, solar technology installed system prices are assumed to reach the SunShot Initiative's targets by 2020: $1/watt (W) for utility-scale PV systems, $1.25/W for commercial rooftop PV, $1.50/W for residential rooftop PV, and $3.60/W for CSP systems with up to 14 hours of thermal energy storage capacity.[2] The reference scenario is modeled with moderate solar energy price reductions to enable comparison of the costs, benefits, and challenges relative to the reference case of achieving the SunShot price targets.

The *SunShot Vision Study* examines the potential pathways, barriers, and implications of achieving the SunShot Initiative's price-reduction targets and resulting market-penetration levels. Key factors examined include current and

[1] All results in this report refer to the *contiguous* United States (excluding Alaska and Hawaii), unless otherwise noted, e.g., solar technologies are projected to satisfy roughly 14% of contiguous U.S. electricity demand by 2030 and 27% by 2050.
[2] Note that throughout this report all "$/W" units refer to 2010 U.S. dollars per peak watt-direct current (DC) for PV and 2010 U.S. dollars per watt-alternating current (AC) for CSP, unless otherwise specified.

projected costs, raw material and labor availability, manufacturing scale-up, grid integration, financing, and siting and environmental issues.

The *SunShot Vision Study* does not prescribe a set of policy recommendations for solar energy in the United States, nor does it present a vision of what the total mix of energy sources should look like in the future. The *SunShot Vision Study* does, however, provide analysis and insights that could help policymakers design and implement measures aimed at optimizing solar energy's potential within an integrated national energy policy framework. The study's focus on both a 20- and 40-year time horizon allows sufficient time to implement and realize the benefits of policy changes. It also provides a framework for analyzing both the short- and long-term evolution of the U.S. electricity-generation system, and is long enough to envision substantial change to the system as a whole. Thus, this study provides insights about both the near- and long-term technology investments and policy changes that may be required to achieve the envisioned levels of market penetration.

The *SunShot Vision Study* is meant to be the most comprehensive review of the potential for U.S. solar electricity generation to date. The study was initiated by the DOE Solar Energy Technologies Program (SETP) and managed by NREL.[3] Key findings of the *SunShot Vision Study* include the following:

- *Achieving the level of price reductions envisioned in the SunShot Initiative could result in solar meeting 14% of U.S. electricity needs by 2030 and 27% by 2050. However, realizing these price and installation targets will require a combination of evolutionary and revolutionary technological changes.* The SunShot Initiative aims to reduce the price of solar energy systems by about 75% between 2010 and 2020. Achieving this target is expected to make the cost of solar energy competitive with the cost of other energy sources, paving the way for rapid, large-scale adoption of solar electricity across the United States. Existing challenges can be addressed through technological advances—e.g., efficiency improvements, materials substitutions, and expanded material supplies—and planning. Significant manufacturing scale-up is required under the SunShot scenario, but solar manufacturers have demonstrated the ability to scale up rapidly over the past decade. The continued expansion and price reductions anticipated over the next decade should enable the required high-volume, low-cost production.
- *Achieving the SunShot price targets is projected to result in the cumulative installation of approximately 302 gigawatts (GW) of PV and 28 GW of CSP by 2030, and 632 GW of PV and 83 GW of CSP by 2050*. To achieve these cumulative installed capacities, annual installations must reach 25–30 GW of PV and 3–4 GW of CSP in the SunShot scenario between 2030 and 2050. By 2030, this translates into PV generating 505 terawatt-hours (TWh) per year of electricity or 11% of total U.S. electricity demand, and CSP generating 137 TWh per year or 3% of total demand. By 2050, this

[3] This study draws heavily on research, analysis, and material developed for DOE's draft *Solar Vision Study*. The *Solar Vision Study* was launched in June 2009 and drew on a steering committee and working groups with more than 140 representatives from solar companies, utilities, financial firms, universities, national laboratories, non-profit organizations, industry associations, and other organizations. A draft of the *Solar Vision Study* was circulated for external review during June 2010. The post-review version of the *Solar Vision Study* was used as the starting point for the *SunShot Vision Study*.

translates into PV generating 1,036 TWh per year or 19% of total demand, and CSP generating 412 TWh per year or 8% of total demand.

- *Annual U.S. electricity-sector carbon dioxide (CO_2) emissions are projected to be significantly lower in the SunShot scenario than in the reference scenario: 8%, or 181 million metric tons (MMT), lower in 2030, and 28%, or 760 MMT, lower in 2050.* This would provide carbon emissions reductions that are equivalent to taking 30 and 130 million cars off the road by 2030 and 2050, respectively. The emissions reductions are primarily a result of the displacement of natural gas and coal generation. Before 2030, solar primarily offsets natural gas generation, while post-2030, solar begins to significantly offset coal generation.
- *Both the SunShot and reference scenarios require significant transmission expansion. In the reference scenario, transmission is expanded primarily to meet growing electricity demand by developing new conventional and wind resources. In the SunShot scenario, transmission is expanded at a similar level, but in different locations in order to develop solar resources.* In the reference scenario, transmission capacity is projected to increase from about 88,000 gigawatt-miles (GW-mi) in 2010 to 102,000 GW-mi in 2030, and 110,000 GW-mi in 2050—a 15% and 25% increase, respectively. In the SunShot scenario, transmission capacity is expected to increase to 100,000 GW-mi in 2030 and 117,000 GW-mi in 2050, a 13% and 32% increase, respectively. Expanding transmission at these rates would require a level of investment well within the historical range of transmission investments during the past few decades.
- *The level of solar deployment envisioned in the SunShot scenario poses significant but not insurmountable technical challenges with respect to grid integration and could require substantial changes to system planning and operation practices.* The main grid integration challenges at the bulk system levels are expanding access to transmission capacity and dealing with the additional variability and uncertainty of solar generation. The impact and cost of variability and uncertainty can be reduced by improving access to flexible resources in the system (both generation and load) and optimizing their deployment. Improved solar production forecasts and better access to well-functioning electricity markets are two key enabling factors. At the distribution system level, the main technical challenges are related to control of voltage and system protection with high-penetration PV. In addition to technological advances, existing codes and standards must be revised, and better models and analysis techniques are needed.
- *The land area that is potentially suitable for solar deployment is enormous and thus land, per se, is not a constraint on meeting the SunShot scenario level of deployment. However, it is important to make careful selection of sites in order to provide access to available or planned transmission, and to minimize conflicts with environmental, cultural, and aesthetic interests.* The land area required to supply all end-use electricity in the United States using PV is only about 0.6% of the country's total land area.[4] Similarly, the technical potential for CSP is enormous: about 17,500 TWh of annual CSP

[4] This calculation is based on deployment/land in the entire United States (including Alaska and Hawaii).

electricity generation, which is more than four times the 2010 U.S. annual demand, could be sited in seven southwestern states on land that has been pre-screened to avoid prominent land-use issues and to meet technical requirements such as insolation and slope. About 370,000–1,100,000 hectares (ha) (900,000–2,700,000 acres) are required for utility-scale solar installations in 2030 under the SunShot scenario, and about 860,000–2,500,000 ha (2,100,000–6,300,000 acres) are required in 2050. The required land area is equivalent to about 0.05%–0.14% of the contiguous U.S. land area in 2030 and about 0.11%–0.33% in 2050. Solar development in the SunShot scenario is greatest in the South and Southwest. Often the highest-quality solar resource areas are dry environments that are typically not well suited for cropland or offer little value for forestry and rangeland.

- *Siting poses significant, but not insurmountable, regulatory challenges to achieving the level of solar market penetration envisioned in the SunShot scenario.* The regulatory framework for siting utility-scale solar projects and associated transmission infrastructure is complex, costly, and time consuming. Similarly, distributed PV installers, both in the residential and commercial sectors, face the challenges and expense associated with complex and variable codes and permits, zoning ordinances, and restrictive covenants. Streamlining of siting and regulatory requirements for utility-scale and distributed solar projects, as well as electricity-transmission projects, would help to enable the rapid solar development envisioned under the SunShot scenario.
- *Water-use constraints will require CSP technologies to transition away from wet cooling toward dry and hybrid cooling.* Although PV requires very little water (for occasional panel washing), CSP with traditional wet cooling uses similar amounts of water as used by some conventional electricity-generation technologies. However, dry or hybrid CSP cooling technologies can reduce water use by 40%–97% compared with wet cooling. Because most land suitable for CSP is in the Southwest, where water availability is constrained, it is very likely that in order to achieve the level of deployment projected in the SunShot scenario, most CSP plants will need to use dry or hybrid cooling.
- *Financing the scale of expansion in the SunShot scenario will require significant new investments in the solar manufacturing supply chain and in solar energy projects.* Building out U.S. PV and CSP manufacturing capacity to meet the level of installations envisioned in the SunShot scenario would require cumulative investments of roughly $25 billion through 2030 and $44 billion through 2050. On an annual basis, the required level of investments would be on the order of $1–$3 billion, well below private sector investments in solar in the United States during the past couple of years. Investments in the solar supply chain have historically been financed by a mix of venture capital, private equity, public equity, and corporate debt. Financing solar project deployment under the SunShot scenario, however, will cost much more than financing the supply chain—on the order of $40–$50 billion per year between 2030 and 2050. On a cumulative basis, this translates into roughly $250 billion through 2030 and $375 billion through 2050. The primary financing challenge will be managing the transition from the pre-2020 period, when solar electricity is less cost competitive with

other electricity sources, to the post-2020 period, when the availability of cost-competitive solar energy should stimulate private solar investment and facilitate use of mainstream financial instruments.

- *Achieving the SunShot scenario level of solar deployment would result in significant downward pressure on retail electricity prices.* By 2030, the average retail price for electricity in the SunShot scenario is projected to be 0.6 cents/kilowatt-hour (kWh) less than in the reference scenario, which translates into a cost savings of about $6 per month, per household. By 2050, the average retail price of electricity is projected to be 0.9 cents/kWh less, which translates into a cost savings of about $9 per month, per household. Across all market sectors, the lower electricity prices in the SunShot scenario translate into about $30 billion in annual cost savings by 2030 and $50 billion in annual savings by 2050, compared to the reference scenario.
- *Achieving the SunShot scenario level of solar deployment could support 290,000 new solar jobs by 2030, and 390,000 new solar jobs by 2050*. These figures include direct and indirect jobs for the PV and CSP supply chains. The U.S. PV workforce is expected to grow from about 46,000 in 2010 to 280,000 in 2030 and to 363,000 in 2050. The U.S. CSP workforce is expected to grow from about 4,500 in 2010 to 63,000 in 2030 and to 81,000 in 2050. Labor requirements for manufacturing of PV and CSP components are readily transferable from other industries. Similarly, CSP power plant development can tap into the same skilled engineering and construction labor pool used for conventional fossil-fuel power plant development. The workforce to support distributed PV installations will require additional training and certification within the existing residential and commercial construction industries.
- *Sensitivity analyses indicate that a number of factors could influence the level of solar deployment envisioned in the SunShot scenario, including more aggressive cost reductions in other renewable and conventional electricity-generation technologies, fossil fuel prices, electricity demand growth, and other assumptions.* For example, sensitivity analyses indicate that there is a solar price threshold at which solar deployment increases non-linearly as price decreases. Similarly, sensitivity analyses show that assuming larger price reductions for non-solar renewable technologies in the SunShot scenario would result in higher penetration of those technologies, particularly wind. Some sensitivity analyses are presented in Appendix C. Additional sensitivity analyses will be published in supplementary technical reports. The *SunShot Vision Study* looks primarily at the implications of and challenges associated with a very low-cost solar future, and generally assumes much less aggressive improvements in other renewable technologies. There are, however, significant opportunities to reduce the cost of other renewable technologies and thus see additional benefits from their market penetration as well.