# Executive Summary

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The objective of this report 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 by 2030. Specifically, it explores two scenarios: one in which U.S. electricity demand keeps growing and solar provides 10% of total demand by 2030, and one in which strong efficiency measures limit growth in electricity demand and solar growth provides 20% of total demand by 2030. In terms of technological focus the emphasis of this report is on photovoltaics (PV) and concentrating solar power (CSP) technologies, which produce electricity, with a limited discussion of solar heating and cooling (SHC) technologies, which displace electricity and fossil fuel use.

It is important to understand that the 10% and 20% scenarios are not projections. The Solar Vision Study does not *predict* that solar energy will meet 10% or 20% of U.S. electricity needs by 2030. Rather, it examines the potential pathways that could be taken and the barriers that must be overcome if these goals are to be achieved as well as the implications of achieving them. Key factors examined include current and projected costs, raw material and labor availability, manufacturing scale-up, grid integration, siting and environmental issues, financing, and policy.

The Solar Vision Study provides a basis for policy makers to design and implement specific measures that will maximize solar energy's potential within an optimized national energy policy framework. The study's 20-year time horizon allows sufficient time to implement and realize the benefits of significant policy changes: 20 years is short enough to analyze the evolution of the U.S. electricity-generation system yet long enough to envision substantial change. The study can also provide insights about the technology investments and policy changes that may be required in a post-2030 timeframe.

The Solar Vision Study is meant to be the most comprehensive and impartial review of the potential for U.S. solar energy to date. To obtain the most recent and accurate information and analysis, the study drew on a steering committee and working groups with over 140 representatives from solar companies, utilities, financial firms, universities, national laboratories, non-profits, industry associations, and other organizations. A separate peer review of the report included additional participants from a wide range of organizations. Finally, the report was posted online for public comment.

Key findings of the Solar Vision Study include the following:

- **Meeting 10%–20% of U.S. electricity needs with solar energy by 2030 does not require technological breakthroughs or unprecedented growth rates; however, in order to be achievable in a cost effective manner continued solar cost reductions and performance improvements will be required.** The Vision market-penetration targets can be achieved using a combination of commercially proven and emerging solar technologies. By

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2030, continued R&D and learning-associated improvements could reduce the capital cost of PV by 60% and CSP by 35%. This would make residential PV broadly competitive with retail electricity rates by 2015–2020 and commercial PV, utility-scale PV, and CSP broadly competitive with commercial retail and utility wholesale electricity rates by 2020–2030. Challenges exist, such as constraints on tellurium and indium supplies for PV, but such challenges can be addressed through technological advances (e.g., efficiency improvements, materials substitutions, and expanded material supplies) and strategic planning. Rapid manufacturing scale-up is required under the Vision scenarios, but solar manufacturers have demonstrated the ability to scale-up rapidly over the past few decades. The continued expansion and cost declines anticipated over the next 20 years should enable the required high-volume production.

- **Achieving the Vision targets requires installing approximately 136 GW of PV and 43 GW of CSP (in the 10% scenario) and 240 GW of PV and 63 GW of CSP (in the 20% scenario) by 2030.** To achieve these cumulative installed capacities, annual installations must reach 13 GW of PV and 4 GW of CSP (in the 10% scenario) and 23 GW of PV and 5 GW of CSP (in the 20% scenario) by 2030. Although the installed capacities of CSP are less than the installed capacities of PV, because CSP is located in areas with the best solar resources and employs thermal storage, CSP and PV each generate about half the solar energy (i.e., half the TWh per year) by 2030 in both scenarios.

- **In 2030, U.S. electricity-sector $CO_2$ emissions are 7% (170 million metric tons) lower in the 10% scenario and 28% (600 million metric tons) lower in the 20% scenario relative to reference case projections.** This is equivalent to taking 30–100 million cars off the road. The emissions reduction is lower in the 10% scenario because in this scenario solar energy primarily displaces natural gas, which has a lower carbon intensity than the electricity-sector average. In the 20% scenario, solar energy displaces a larger share of coal, which has a higher carbon intensity than the electricity-sector average.

- **The 10% scenario is achievable with the current electricity infrastructure, but the 20% scenario requires significant transmission expansion and grid-operation advancements.** The 20% scenario requires nearly three times the marginal transmission expansion compared with the 10% scenario: 7,900 GW-miles in the 10% scenario vs. 21,100 GW-miles in the 20% scenario. The 20% scenario also introduces grid integration challenges due to the increased rate and range over which the generation fleet must ramp, uncertainty in net load, and potential curtailment of variable generation during low-load periods (particularly during the spring). A number of technical and industry strategies, that are either currently available or under development, can increase the ability to integrate electricity generated by variable sources such as solar technologies.

- **The land area suitable for solar deployment is enormous and is not a major constraint on meeting the Vision targets, although solar sites must be selected and developed in a way that minimizes environmental impacts.** About 460,000 hectares are required for utility-scale solar installations in 2030 under the 10% scenario and 790,000 hectares under the

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20% scenario. Solar development is greatest in the South and Southwest. In the 20% scenario, the required land area is equivalent to about 0.1% of the U.S. land area, or about 0.5% of the area dedicated to cropland in the United States.

- **Siting poses significant, but not insurmountable, challenges to achieving the Vision targets.** The regulatory framework for siting utility-scale solar projects and associated transmission infrastructure is complex, costly, and time consuming. Similarly, distributed PV installers face the challenges and expense associated with complex and variable codes and permits, zoning ordinances, and restrictive covenants. To enable the rapid solar development required under the Vision scenarios, the siting regulatory landscape must be streamlined for utility-scale and distributed solar projects as well as electricity-transmission projects.
- **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 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 most CSP plants would need to use dry or hybrid cooling to achieve the Vision targets.
- **Financing the growth required under the Vision scenarios for the solar supply chain and transmission expansion is less challenging than financing the growth required for solar installation projects.** The cumulative supply-chain investment requirements (i.e., investments in scaling up manufacturing capacity) are $30 billion for the 10% scenario and $55 billion for the 20% scenario (all values in 2009 dollars); attracting this level of investment is unlikely to be a problem because the required financing mechanisms are generally well developed and liquid. The cumulative additional transmission investments are $7 billion for the 10% scenario and $18 billion for the 20% scenario relative to the reference cases; significant challenges for transmission expansion include cost allocation and cost recovery. The cumulative investment required for solar installation projects is an order of magnitude larger: $490 billion for the 10% scenario and $850 billion for the 20% scenario. There does not appear to be adequate third-party tax equity to finance this level of investment, thus alternative and more effective financing mechanisms will be required to meet the Vision targets.
- **Achieving the Vision scenarios produces a relatively small effect on retail electricity prices.** The average retail electricity price increases by less than 0.1 cents/kWh in the 10% scenario and by about 0.9 cents/kWh in the 20% scenario (relative to reference case projections). This translates into an average cost increase of about $0.70 per month per household (a 1% increase) in the 10% scenario and $6.80 per month per household (a 10% increase) in the 20% scenario in 2030.
- **The U.S. solar workforce increases from about 14,000 in 2009 to 260,000 in 2030 in the 10% scenario and to 410,000 in the 20% scenario.** These figures include direct and indirect jobs for the PV and CSP supply

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chains. The U.S. PV workforce grows from about 13,000 in 2009 to 180,000 in 2030 in the 10% scenario and to 310,000 in the 20% scenario. The U.S. CSP workforce grows from about 1,000 in 2009 to 80,000 in 2030 in the 10% scenario and to 100,000 in the 20% scenario. Labor requirements for manufacturing of PV and CSP components are readily transferable from other industries. Similarly, PV and CSP power plant development can tap into the same skilled engineering and construction labor pool used for conventional fossil power plant development. The workforce to support distributed PV installations will require additional training and certification within the existing residential and commercial construction industries.

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