RENEWABLES: ENERGY YOU CAN COUNT ON

Solar Power on the Rise

The Technologies and Policies behind a Booming Energy Sector

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Solar power—clean, reliable, and increasingly affordable—is experiencing remarkable growth across the United States and is transforming how and where we produce the electricity vital to modern society. Today's electricity system suffers from a number of critical problems related to the environmental and health effects of extracting and burning fossil fuels such as coal and natural gas, and the volatility of fossil fuel prices.

The United States' economic and environmental well-being depends on a strong shift toward electricity generated with fuels that are abundant and reliable, and have a relatively clean environmental footprint. Solar power offers the potential to generate electricity with no global warming pollution, no other emissions, no fuel costs, and no risks of fuel price spikes. Solar is, to a great extent, an equal-opportunity renewable energy, with sufficient sunshine across the nation to make solar an attractive option in every state.

Options for electricity generation from solar include a range of technologies with different properties and different advantages for home owners, businesses, and utilities.[1] Small-scale solar photovoltaic (PV) systems account for the majority of solar installations as far as number of systems, while large-scale PV systems

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1 This report focuses on solar power for electricity generation; other important solar technologies provide hot water and space heating.

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> ***Solar power has the potential to supply a rapidly growing amount of electricity that is environmentally and economically attractive, nationwide.***

and concentrating solar power (CSP) systems constitute the majority of solar's electricity-generating capacity overall. All three help to stabilize and make the U.S. electricity system more resilient—economically and environmentally.

Solar is undergoing widespread and rapid growth in the United States:

- The amount of solar PV installed in the United States grew by 485 percent from 2010 to 2013 (GTM Research and SEIA 2014a).
- Solar accounted for an average of 16 percent of electricity capacity installed annually in the United States from 2011 to 2013, and almost 30 percent in 2013 (GTM Research and SEIA 2014a, EIA 2011).
- By early 2014, the United States had more than 480,000 solar systems installed, adding up to 13,400 megawatts (MW)—enough to power some 2.4 million typical U.S. households (GTM Research and SEIA 2014b).[2]
- While solar is still a small piece of overall electricity generation, in the leading states—Arizona, California, and Nevada—solar currently provides 2 percent of electricity (EIA 2014a), and in June 2014 California set a one-day record for solar power production equal to 8 percent of its overall electricity demand (California ISO 2014).

Given the abundance of sunshine across the country, solar has the potential to supply a rapidly growing amount of electricity that is environmentally and economically attractive, nationwide. Moreover, when asked what energy sources the United States should emphasize most, more than three-quarters of Americans across the political spectrum chose solar (Jones and Saad 2013). Technical innovations and investments will continue to drive additional solar investments, improving component costs, generation efficiency, and installation costs. Increasingly appealing economics will attract more people to solar investments and expand solar job market opportunities. Avoiding, minimizing, and mitigating environmental impacts will help to maximize solar's benefits. And policies that recognize the value of reducing American reliance on fossil fuels and diversifying the electricity supply will help solar's share of the U.S. energy mixture continue to grow.

This report discusses the major drivers of the rapid adoption of solar power and explores the main types of solar available to individuals, businesses, and utilities. It outlines the technical, economic, environmental, and policy aspects of each solar application, and then summarizes key steps to sustain the strong growth of solar power in the United States and its contribution to a more resilient electricity system in the decades ahead.

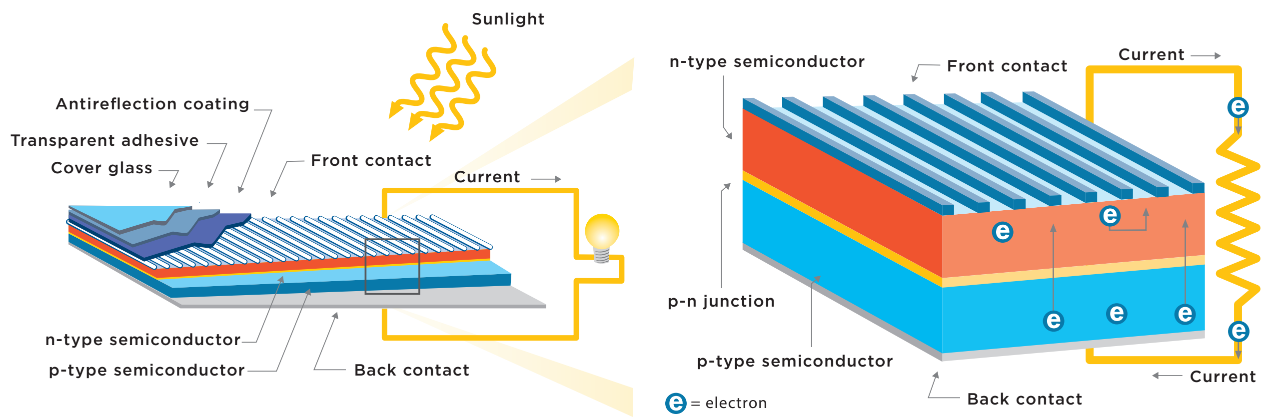
Rooftop Solar

The shift toward clean, reliable, affordable electricity in the United States is most visible in the rapid proliferation of solar panels mounted on the roofs of homes and businesses. Between 2008 and 2013, residential, commercial, and institutional rooftop solar grew an average of more than 50 percent per year (GTM Research and SEIA 2014a). From 2010 to 2013, the price of a typical household system dropped by almost 30 percent, while the capacity of such systems across the United States more than tripled (EIA 2014b; GTM Research and SEIA 2014a; GTM Research and SEIA 2010).

Workers install PV panels on a national forest facility in southeastern Ohio. Solar systems grace a rapidly growing number of houses, office buildings, parking structures, schools, and churches.

2 Power capacity numbers (watts, kilowatts, or megawatts) represent direct-current (DC) values except where noted as alternating current (e.g., MW_{AC}); some values were unspecified in the original sources.

FIGURE 1. Close-up of a PV Cell



Solar cells are composed of two layers of semiconductor material with opposite charges. Sunlight hitting the surface of a cell knocks electrons loose, which then travel through a circuit from one layer to the other, providing a flow of electricity.

In 2014, a solar system is projected to be installed every 2.4 minutes (GTM Research and SEIA 2014b). Individuals and businesses have been attracted not just to the environmental benefits of solar power, but also to the ability to generate their own power and to the fixed and competitive price of electricity that these systems provide.

HOW SOLAR PV WORKS

The PV revolution is based on a high-tech but remarkably simple technology that converts sunlight directly to electricity (Figure 1). Photons of light striking certain materials used in PV panels cause electrons to be released, and when the panels are connected to a circuit, those electrons provide power for the full range of our electricity needs. Solar panels involve no moving parts, no fuel other than the sun, and no other inputs or by-products.

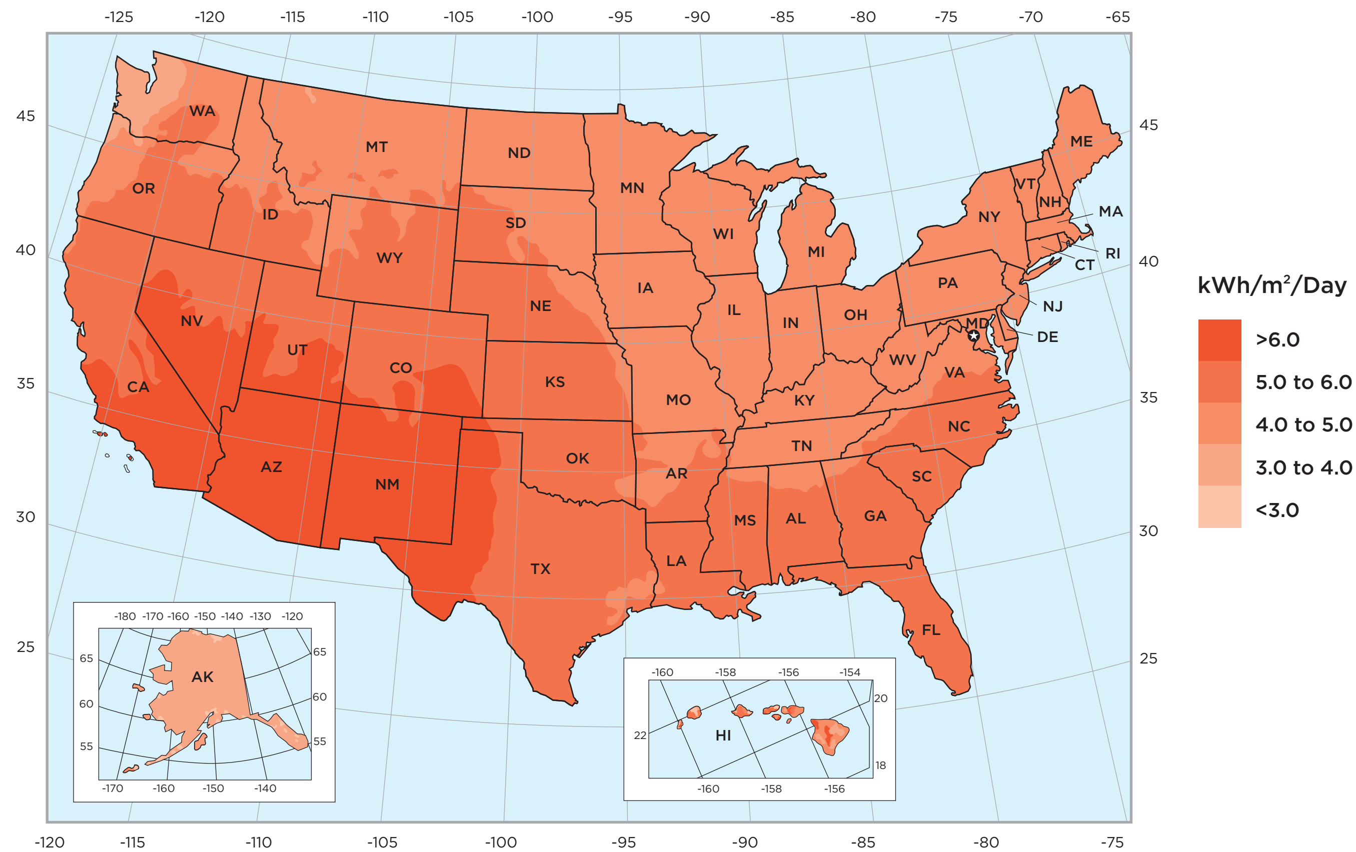
Solar is viable in virtually every part of the country (Figure 2, p. 4). In a sunny location such as Los Angeles or Phoenix, a five-kilowatt residential system produces an average of 7,000 to 8,000 kilowatt-hours per year, roughly equivalent to the electricity usage of a typical U.S. household. And solar achieves similar results in many other parts of the country as well. In northern climates such as that in Portland, ME, that same system on average generates 85 percent of what it would in Los Angeles, and 95 percent of what it would in Miami. The system in Maine would generate 6 percent *more* electricity than in Houston (NREL 2014a).

Small-scale PV is often referred to as "rooftop" because it is most often installed on residential or commercial roofs, but these systems can be installed on other structures such as parking lots or on the ground. In most cases, these systems are considered a form of "distributed" generation because they are connected to the distribution grid of poles and wires that transport electricity from substations. On-site electricity needs are first supplied by the electricity generated by the PV system, with the grid supplying electricity when the sun is not shining. When the home or business generates more electricity than it consumes, the electricity is fed back into the grid.

Integrating rooftop solar into the grid. The transition to an electricity system with a much larger amount of distributed solar provides many benefits to the grid as well as the environment, but it also presents some challenges for utilities and grid operators.

One of the biggest benefits that distributed solar provides to the grid is that it often produces electricity when—and where—that power is most valuable. In many regions, demands on the electricity system peak in the afternoon on hot, sunny days, when air conditioning demands are high and when rooftop solar is performing strongly. Such systems therefore help utilities meet peak demand without firing up seldom-used but expensive and more-polluting power plants fueled by oil or natural gas (Burger 2011). Rooftop systems also reduce strain on electricity distribution and transmission equipment by allowing homes and businesses to first draw power on-site instead of relying completely on the electricity grid. The benefits are twofold: the use of on-site power avoids the inefficiencies of transporting electricity over long distances, and on-site systems potentially allow the utility to postpone expensive upgrades to its infrastructure (Bird et al. 2013).

FIGURE 2. Solar Resources across the Country



In the United States, the sun's energy is strongest in the Southwest, but the amount of sunlight available for PV generation varies by less than 30 percent across much of the country.

NOTE: Annual average solar resource is for PV panels tilted at an angle equal to the latitude of each location. Solar resources for CSP are much stronger in the Southwest than in other parts of the country.

SOURCE: ADAPTED FROM NREL n.d.

However, having power flowing *from* customers, instead of to them, is a relatively new situation for utilities. Neighborhoods where many homes have adopted solar can approach a point at which the rooftop systems can produce more than the neighborhood can use during the day. Yet "feeder" lines that serve such neighborhoods may not be ready to handle flows of electricity in the opposite direction. Several locales around the United States, including Atlantic City, San Diego, and the Hawaiian island of Oahu, have areas approaching that point, potentially causing problems for additional home owners looking to adopt solar. More broadly, the variability of solar generation presents new challenges because grid operators cannot control the output of these systems with the flip of a switch like they can with many non-renewable power plants.

But the issues associated with adding more rooftop PV to the grid are eminently solvable. Fixes to the feeder issue are largely economic, not technical; modifications can be made to existing systems to allow reverse electricity flows, and the primary hurdle is who pays. The variability challenges are well understood in part because grid operators already manage fluctuations caused by constantly changing electricity demand and drops in electricity supplies when large power plants or transmission lines unexpectedly fail. Much of the variability inherent in solar generation is also predictable and manageable. Hours of daylight and seasonal changes are highly predictable, and weather forecasts can help grid operators plan for when cloud cover may hinder electricity generation from rooftop solar systems. Variations caused by local cloud cover can be managed by incorporating many systems across a wide geographic area.

Low levels of renewable energy generation can typically be integrated into the grid at negligible costs, but higher levels will likely require other generators on the system to operate more flexibly, and investments in grid flexibility devices like energy storage, which can help make use of solar power even when the sun is not shining (Bird el al. 2013). Many locales are already successfully accommodating high rates of solar adoption. On the island of Oahu, for example, 1 in 10 utility customers has solar (Wesoff 2014). And studies suggest that it is possible to integrate significantly higher levels of variable renewable energy (solar and wind) into the grid using existing technologies (Mai et al. 2012).

[Unlike fossil fuels, solar panels generate electricity with no air or carbon pollution, solid waste, or inputs other than sunlight.]

THE INCREASINGLY ATTRACTIVE ECONOMICS OF ROOFTOP SOLAR

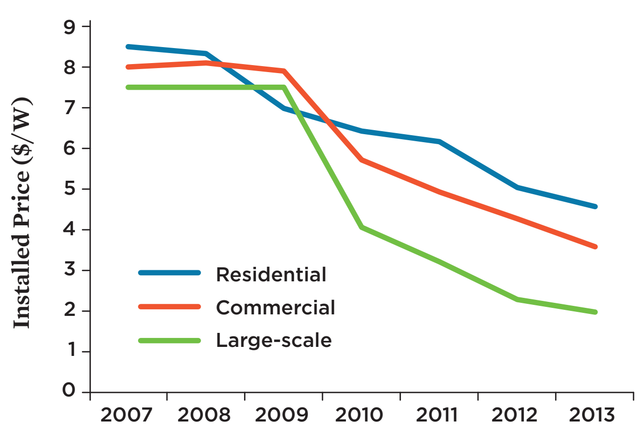
Rooftop solar is increasingly cost-effective for home owners, business owners, and their communities, thanks to reductions in technology prices, innovative financing, and growing networks of solar installers and financial partners (Figure 3). Prices for household systems in the United States fell by 29 percent from 2010 to 2013, from an average of $32,000 for a five-kilowatt system to under $23,000, before tax credits or other incentives (GTM Research and SEIA 2014a). The federal solar investment tax credit returns 30 percent of that purchase price, and state and local tax credits, rebates, and other support in leading states can then cut the total cost to under $10,000 (Internal Revenue Code 2011; see also, for example, Massachusetts 2014).

Dropping prices are due to economies of scale and technological advances. The falling price of rooftop PV systems results from improvements in the technology and economies of scale among manufacturers. Global solar panel production (for rooftop and other markets) increased from 24,000 MW in 2010 to 40,000 MW in 2013 (Mehta 2014). PV costs in the United States are also affected by global market conditions, including the emergence of lower-priced solar products from China.

PV prices in the United States have also benefitted from reductions in “soft” costs, such as those related to sales, permitting, inspection, connection to the electricity grid, and retailers’/installers’ profit margins, due to larger volumes and concentrations of system installations (Ardani et al. 2013). However, soft costs in the United States still constitute more than half of a typical rooftop solar system’s cost, compared with one-fifth in Germany, the world PV leader (Seel, Barbose, and Wiser 2013). Some local agencies have streamlined permitting processes by developing standards that cut down on individual project evaluations, and supportive local governments use a variety of tools to support local solar development (DOE 2011). Some community-led efforts have achieved notable cost reductions and high levels of adoption by pooling demand for solar from local home owners. The “Solarize” movement, for example, begun in 2009 in Portland, OR, initiated a neighborhood-level collective purchasing program that simplified the process by pre-selecting qualified solar contractors and offering home owners information about technology options and financial support. Successful “Solarize” efforts have helped many home owners “go solar” with each campaign, making rooftop solar much more accessible for the communities they serve (Irvine, Sawyer, and Grove 2012).

Ownership options abound. Solar’s increasing success is due in part to innovative ownership structures. Many home owners and businesses are taking advantage of third-party ownership options. Under solar leases or power purchase agreements, electricity customers typically pay little or nothing up front for rooftop systems, then get electricity from the systems over a long period at attractive fixed rates. The systems (and maintenance responsibilities) remain the

FIGURE 3. The Falling Price of Solar PV by U.S. Sector, 2007–2013



Prices for PV systems in the United States have dropped by 50 percent or more in recent years, with the sharpest declines for large-scale projects.

NOTE: In Figures 3 and 5, “Commercial” includes all small-scale non-residential installations. “Large-scale” cost data for 2007–2009 include systems larger than 100 kilowatts.

SOURCES: GTM RESEARCH AND SEIA 2014A; GTM RESEARCH AND SEIA 2013; GTM RESEARCH AND SEIA 2012; BARBOSE ET AL. 2011; BARBOSE, DARGHOUTH AND WISER 2010; GTM RESEARCH AND SEIA 2010; WISER, BARBOSE, AND PETERMAN 2009; WISER ET AL. 2009.

Many large companies in the United States have "gone solar." IKEA has rooftop solar on 89 percent of its stores, including this store in Atlanta, GA, and meets more than one-third of its electricity needs with renewable generation (IKEA 2013; SEIA and Vote Solar 2013). Walmart has more than 200 PV systems, amounting to 89 MW of solar generation capacity (SEIA and Vote Solar 2013).

property of the project developers, which may be private companies or electric utilities themselves (Kollins, Speer, and Cory 2010). Two-thirds of new residential systems are third-party-owned (Munsell 2014).

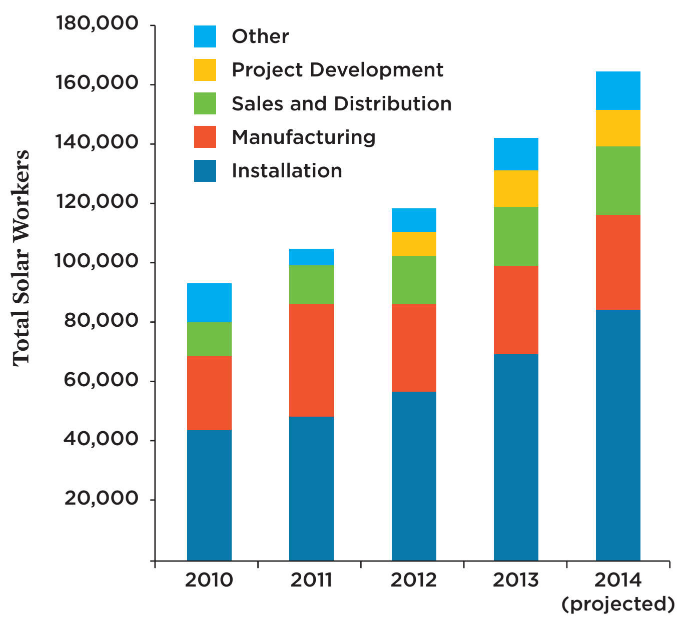
Solar is going mainstream. The falling prices and innovative financing structures mean that rooftop solar is much more broadly available, and that the pool of customers is increasingly economically diverse. During 2011 and 2012, the largest number of rooftop systems was installed in neighborhoods with median incomes of $40,000 to $50,000 in Arizona, and $30,000 to $40,000 in New Jersey (Hernandez 2013). Some states, including Minnesota and California, have policies to specifically target low-income or disadvantaged populations (see, for example, PG&E 2014 and RREAL 2014).

Companies, too, have embraced rooftop solar not only to improve their environmental profiles but also to lower their operating costs. By 2013, the 25 largest users of solar in the United States (by capacity) had installed some 450 MW—enough to power more than 80,000 typical homes. The companies include department stores, consumer goods manufacturers, car companies, and others (SEIA and Vote Solar 2013).

Solar is good for jobs. Solar, including rooftop solar, has proven to be a strong driver of economic development (Figure 4). The U.S. solar industry employed more than 140,000 people in 2013, a 53 percent increase over 2010 (The Solar Foundation 2014). The United States is now home to more than 6,000 solar companies, spread across all 50 states (SEIA 2014a). The solar industry is investing almost $15 billion in the U.S. economy annually (GTM Research and SEIA 2014c).

Because rooftop solar can be installed in cities and towns, as opposed to remote locations, its installations offer job possibilities for local workers. Labor unions, community colleges, and nonprofits across the country have established job training programs and other community partnerships to train local workforces to install solar. For example, GRID Alternatives, a nonprofit solar installation organization working in California, Colorado, the mid-Atlantic, and the New York tri-state area, works with volunteers and workers

FIGURE 4. U.S. Solar Job Growth, 2010–2014



Solar-related jobs, from manufacturing to sales to installation, have increased by an average of 15 percent annually in recent years. More than three-quarters of the workers added in 2013 were for new positions.

NOTE: The Solar Foundation defines solar workers as those who spend at least half of their time supporting solar-related activities.

SOURCE: THE SOLAR FOUNDATION 2014.

in job training programs to install rooftop solar in low-income communities (see *www.gridalternatives.org*).

THE POSITIVE ENVIRONMENTAL PROFILE OF ROOFTOP SOLAR

Unlike the fossil fuels that still provide the bulk of the U.S. power supply, solar panels generate electricity with no air or carbon pollution, solid waste, or inputs other than sunlight. While the manufacturing of solar panels, like all other energy devices, involves emissions, PV electricity generation itself involves none of the emissions of carbon dioxide or other heat-trapping gases that come from burning fossil fuels and are major contributors to climate change (Dell et al. 2014). PV electricity generation has none of the other harmful emissions or wastes associated with coal power, such as mercury, sulfur dioxide, nitrogen oxides, lead, and arsenic (Freese, Clemmer, and Nogee 2008), none of the long-lasting waste or environmental risks associated with nuclear power (Gronlund, Lochbaum, and Lyman 2007), nor any of the environmental risks associated with natural gas, including potential water pollution during extraction (UCS 2014a).

Rooftop PV electricity generation is light on water use and, in most cases, has no impact on wildlife. Almost all power plants that make electricity using steam—including coal and nuclear plants, many natural gas plants, and some other renewable energy facilities—depend on water for cooling, and that dependence can cause problems when cooling water becomes too scarce or too hot. PV systems, in contrast, require no water to make electricity (Averyt et al. 2011). While ground mounting requires land, roof-mounted systems, because they are installed in already built environments, have no impact on wildlife (EPA 2013).

> ***PV systems require no water to make electricity, unlike coal, nuclear, and other power plants.***

Solar panels do involve materials that need careful handling while the panels are manufactured and at the end of their useful lives. As with computer chips, manufacturing solar panels involves a range of hazardous materials—for example, hydrochloric acid, sulfuric acid, nitric acid, and hydrogen fluoride. Non-silicon solar cells contain more toxic materials than those used in traditional silicon cells, including gallium arsenide, copper-indium-gallium-diselenide, and cadmium telluride (Hand et al. 2012). End-of-life recycling is one approach to keeping solar materials out of landfills; European PV manufacturers have a region-wide program (*www.pvcycle.org.uk*) and some manufacturers in the United States have their own programs (SEIA 2014b; see also First Solar 2014).

SMART POLICIES: WHAT MAKES ROOFTOP SOLAR GROW

Federal, state, and local policies will continue to be key to the success of rooftop solar and the clean electricity that these systems provide. Examples of effective policies being used today include:

BOX 1.

Rooftop Solar beyond the Rooftop

Innovative policies in many jurisdictions mean that rooftop solar is not limited to those with sun-drenched roofs. Renters, condominium owners, and people with shaded roofs may not be able to take advantage of solar on their own roofs, yet "shared solar" solutions broaden opportunities for all electricity users.

"Virtual" net metering allows households to take advantage of solar generation that is not directly connected to their electricity meters. Such policies allow customers in multifamily buildings to take advantage of solar generated from one meter on the building or allow electricity customers to subscribe to electricity generated from a larger off-site solar system—or even own it outright—and apply the solar generation as a credit on their electricity bills.

At least 11 states have virtual net metering, or related "neighborhood" net metering or community solar gardens (Farrell 2012). Colorado, for example, allows groups of 10 or more customers to subscribe to a nearby system of up to two megawatts (Colorado General Assembly 2010).

Even utility customers who cannot or do not take advantage of rooftop systems can benefit from their neighbors' adoption of the technology—benefits that may outweigh any added costs on customers' electricity bills from solar support programs (Bird et al. 2013; RMI 2013). Solar investments may save a utility money, as discussed above, which can help all customers. Likewise, environmental benefits from avoiding fossil fuel generation also accrue to all customers.

BOX 2.

Rooftop Solar and Utility Business Models

Although rooftop solar can save utilities money, lower electricity sales due to solar can create challenges under traditional business models based on volume of sales (Bird et al. 2013). If a utility anticipates that it will receive less revenue to cover its fixed costs, it might oppose increased solar investments, despite their economic and environmental benefits.

Some of these concerns can be addressed by restructuring the way utilities make money and cover costs. Where allowed, utilities may directly invest in rooftop solar, which allows them to earn a direct profit on the capital expenditures (Bird et al. 2013). Regulators that oversee utilities—setting rates or regulating profits—can help determine the full cost and benefits of rooftop solar to the grid. They can then have all parties pay their fair shares for the benefits they receive, a process that would help assure utilities that they will receive the revenue necessary to maintain needed grid investments.

- **Net metering.** Net metering policies give system owners credit on their utility bills for excess electricity generation. Forty-three states and the District of Columbia have net metering in place (DSIRE 2013). In at least 34 of those states, customers are credited for net generation at the full retail rates of electricity, not the lower wholesale rates (DSIRE 2014a).
- **Feed-in tariffs.** Some places around the United States have implemented feed-in tariffs, similar to those that have helped drive substantial renewable energy development in Europe (EIA 2013a). Under feed-in tariffs in place in at least seven states, home owners and businesses are paid under standardized contracts offering fixed prices for solar generation, over an established, often long-term period (EIA 2013b).
- **Value-of-solar tariffs.** System owners can also be paid based on the calculated value of the broad suite of benefits that solar systems provide. Such value-of-solar tariffs quantify not only the benefits of providing electricity but also the value of providing instantaneous power to the grid, a solar installation's contribution toward delaying or avoiding system upgrades, and specific environmental benefits from avoiding the use of fossil fuels (Rábago 2013). The city of Austin, TX, pioneered this approach in 2012 (DSIRE 2014b), and other jurisdictions have since initiated similar efforts (see, for example, Minnesota Department of Commerce 2014).
- **Solar carve-outs.** Some states target small-scale solar within their broader efforts to increase investments in renewable energy. Sixteen states require utilities to invest in solar energy and/or distributed generation as part of their broader renewable electricity standards (see below). Colorado and New Jersey, for example, each require that at least 3 percent of the state's electricity come from distributed generation (chiefly solar) by 2020 (DSIRE 2014c; DSIRE 2014d). Such "carve-outs" offer solar system owners potential additional revenue.
- **Tax incentives and subsidies.** In addition to the 30 percent federal tax credit, 45 states and the District of Columbia have tax incentives for home owners and businesses for renewable energy purchases, and some local governments offer incentives such as property tax exemptions (DSIRE 2014e). Under property-assessed clean energy (PACE) programs, participating municipalities provide financing for purchases of solar systems (or other renewable energy or energy efficiency projects) on homes or commercial properties, then recover the costs through property taxes over time (PACENow 2014).

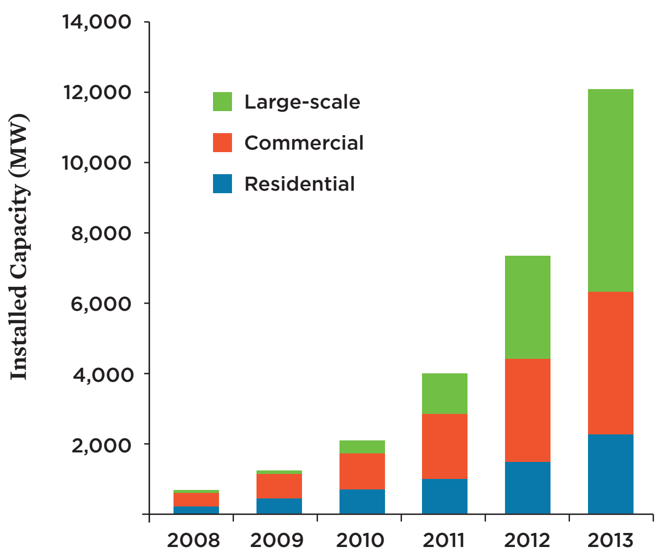
Large-scale PV

In many ways, rooftop solar is benefitting from the growth in the large-scale PV market across the country. Large-scale PV systems accounted for more than half of all solar capacity installed from 2010 to 2013, with overall capacity doubling or tripling each year (Figure 5) (GTM Research and SEIA 2014a). Such systems are similar to rooftop solar in some aspects and different in others.

HOW SOLAR SCALES UP

Large-scale PV projects use the same types of solar panels as rooftop solar. But while a rooftop system may consist of dozens of panels, a single large-scale project may have hundreds of thousands or even millions. The 290 MW_{AC} Agua Caliente project in Yuma County, AZ, for example, involves 4.9 million solar panels (DOE n.d.). Large PV systems are also more likely to have mechanisms by which they track the sun in order to increase electricity generation, by 40 percent or more (GTM 2012).

FIGURE 5. The Growing Scale of Solar PV by U.S. Sector, 2008–2013



Solar PV is experiencing impressive growth in the residential, commercial, and large-scale sectors, with the total 2014 year-end capacity projected to be 2.5 times that of 2012. For CSP, 2014 is projected to be the largest year in history (GTM Research and SEIA 2014b).

SOURCE: GTM RESEARCH AND SEIA 2014A.

Large-scale solar systems feed their electricity into the high-voltage electricity grid and thus have some similarities with the centralized power plants around which the U.S. electric system evolved. Large solar projects often require transmission lines to carry the electricity to urban centers, which requires investment in building the lines themselves and results in "line losses" as some of the energy is converted into heat and lost.[3] This reliance on transmission lines makes large solar systems vulnerable to heat waves that reduce the efficiency of transmission lines and transformers, and storms and wildfires that can damage lines (Davis and Clemmer 2014; DOE 2013).

The inherently modular nature of PV technology, however, helps to make PV systems more resilient to extreme weather. Even if a section of a solar project is damaged, most of the system is likely to continue working. Large coal, natural gas, and nuclear plants are much more prone to cascading failures when part of a system is damaged. And while large-scale solar systems depend on transmission lines that may be affected by extreme weather, the projects themselves are frequently back in service soon after the events (Davis and Clemmer 2014).

As with rooftop solar, the amount of generation from large-scale PV depends on the amount of sunshine at any given time. Some solar variation, such as sunrises and sunsets, can be predicted and planned for. But when clouds block the sun, generation from a solar array can drop suddenly.

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Large-scale solar is an important part of moving the electricity sector away from fossil fuels and their many negative consequences. The 50 MW_{AC} Macho Springs solar project, owned by Southern Power and Turner Renewable Energy, is the largest solar facility in New Mexico, a state with an increasing amount of solar and other renewable energy generation helping the power sector address global warming and other issues.

3 *Such losses can account for 5 to 8 percent of the electricity the lines are transporting (Bird et al. 2013).*

Conversely, on particularly sunny days with high amounts of solar on the grid, if the output from non-renewable energy power plants is not reduced to allow for the solar generation, electricity supplies could exceed demand and cause instability on the grid.

Such variability is handled in several ways. Better forecasting tools allow for more accurate predictions of when solar generation might decline. Installing solar across a large geographic area minimizes the impacts of generation variability due to local cloud cover. Grid operators can shift electricity supply, storing excess energy for later use, for example. Or they can shift electricity demand, by encouraging customers to use electricity when it is more readily available. Grid operators can also collaborate with neighboring regions to expand electricity import/export capabilities and share resources. Studies show that regional electricity grids can handle 30 percent or more of their electricity coming from solar and wind with minimal added costs (see, for example, GE 2014).

THE ECONOMIC BENEFITS OF SCALE

The cost of large-scale PV, like that of rooftop solar, has dropped dramatically in recent years. While power from large-scale PV may be more expensive than the wholesale prices set by natural gas or other power plant options, electricity from new large PV projects in 2013 was half as expensive on average as in 2010, with reductions driven by falling solar panel prices, inverter prices, and soft costs (Pierce 2014). Cost for large projects were on average 60 percent lower than those for residential solar on a per-watt basis, even with added costs such as mounting structures and engineering (GTM Research and SEIA 2014b).

> ***One way to minimize impacts is to locate solar projects on degraded lands.***

THE ENVIRONMENTAL PROFILE OF LARGE-SCALE SOLAR

Like rooftop systems, large PV projects are energy sources that require no combustion and make electricity without contributing to global warming. They also use essentially no water and generate no waste other than during manufacturing and potentially at the end of their useful lives.

Large-scale solar can present challenges with regard to the land area that the projects occupy—challenges common to all large construction projects. A project may need several acres of land for each megawatt of installed solar capacity (Ong et al. 2013). Apple's 40 MW Data Center Solar Farm in Maiden, NC, for example, covers 200 acres, while 125 MW_{AC} of the Arlington Valley solar project in Maricopa County, AZ, cover some 1,160 acres (Reuters 2013; Lane 2012). In all environments—plains, deserts, and mountains alike—large PV projects can have impacts on important plant and animal habitats and can pose threats to cultural and archeological sites. And large solar projects require transmission lines, which can present their own environmental challenges—for example, bird collisions with the wires (APLIC 2014).

Disturbed lands such as closed landfills can be excellent locations for PV projects. In Michigan, solar panels on a 100-year-old former landfill are supplying electricity to the nearby city of Eaton Rapids.

Disruptions can be avoided, minimized, or mitigated by careful site selection and project design, robust analysis of environmental and cultural impacts, and other efforts before, during, and after project construction. In San Luis Obispo County, CA, for example, cooperation between state and federal resource agencies and the developers of large-scale solar in grassland areas helped protect habitat for the endangered San Joaquin kit fox and giant kangaroo rat (Moler 2013).

Another approach to minimizing impacts is to locate projects on already degraded lands or marginal farmland (EPA 2014; Huntley 2012). Closed landfills host an increasing number of mid-sized projects, given the appropriateness of such sites for solar, the challenge in using the sites for other purposes, and the sites' proximity to towns and cities. A six-megawatt project at the Dennis landfill on Massachusetts' Cape Cod, for example, will meet local municipal electricity needs and a portion of the schools' (Dennis 2014). Forty-seven acres of the former New York City Freshkills landfill on Staten Island, NY—once the largest landfill in the world—is being turned into a 10 MW solar farm (NYC 2013).

THE POLICY ENVIRONMENT OF LARGE-SCALE PV

As with rooftop solar, the development of large-scale PV has been accelerated through several types of well-crafted state and federal policies:

- **Renewable electricity standards.** A key driver of large-scale renewable energy development across the country has been the requirement for utilities to get specified amounts or percentages of their electricity sales from renewable energy by certain dates. Twenty-nine states and the District of Columbia have enacted such renewable electricity standards, and eight other states have set renewable energy goals (UCS 2013).[4] In some states large-scale solar is boosted by the carve-outs requiring a certain portion of utilities' compliance with the standard to come from solar or by multipliers that give extra compliance credit for solar investments.
- **Tax policies.** The solar investment tax credit available to home owners also covers large systems. The federal tax code also improves the economics of large-scale solar by allowing for accelerated depreciation of solar equipment; the 2010 federal stimulus bill provided for even faster depreciation (SEIA 2014c). As with rooftop systems, some state and local governments provide sales and property tax exemptions to help lower the cost to system owners (DSIRE 2014f; DSIRE 2014g).
- **Permitting reforms.** Efforts by local, state, and federal agencies to improve the permitting process can help to reduce the significant time and cost for all parties involved. Large solar systems often require permits at both the state and local levels. Projects to be located on federal property also involve federal land and wildlife agencies.

Turning Up the Heat with Concentrating Solar Power

In contrast to PV's use of the sun's light, CSP (or solar thermal power) generates electricity using the sun's heat. The United States was a pioneer in the development of CSP, and California's Mojave Desert hosts some of the earliest operating CSP plants in the world, installed in the 1980s. Although most large-scale solar capacity is now PV, CSP was once at the forefront, and recent projects have significantly increased the installed U.S. capacity of CSP. By early 2014, the United States had more than 1,400 MW_{AC} of CSP, almost 60 percent more than in 2013 (GTM Research and SEIA 2014a; GTM Research and SEIA 2014b).

CONCENTRATING SOLAR: THE TECHNOLOGY

CSP comes in two main designs: parabolic troughs and central receivers, or "power towers."[5] Both types use mirrors to concentrate sunlight onto a fluid, often oil or molten salts, and heat it to boil water. The resulting steam drives turbines that spin generators, in much the same way as in coal, nuclear, or natural gas plants.

CSP comes in different forms, and involves different options. Left: The 250 MW_{AC} Solana parabolic trough project outside Phoenix, AZ, is one of several CSP projects in the United States that incorporate energy storage. Right: The 390 MW_{AC} Ivanpah power tower project, located next to a golf course and highway near California's border with Nevada, cools its electricity-producing steam with air instead of water, cutting water consumption by 90 percent or more.

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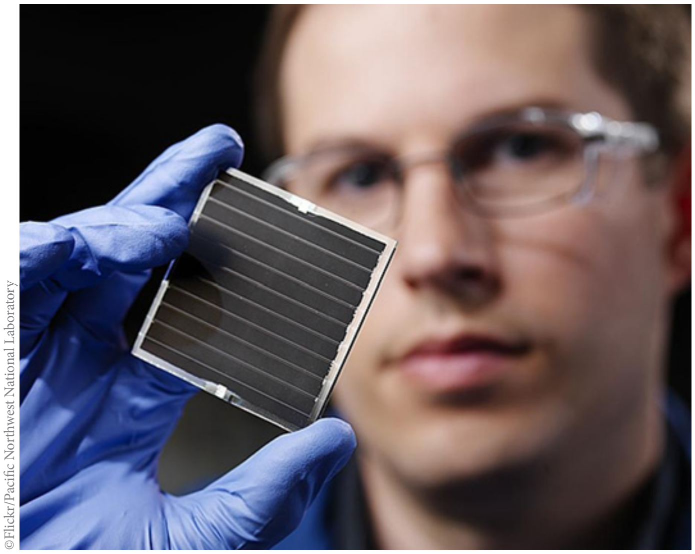
4 The strongest, in California, requires that a third of its electricity come from renewable sources by 2020 (UCS 2014b).
5 A third type, parabolic dishes, has also been developed, but is not yet widely used.



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Research laboratories have achieved solar-cell efficiencies of more than 40 percent—more than double the efficiencies of solar panels currently on the market (NREL 2014c). Investment in research for new solar technologies will continue to improve the affordability of solar for an increasingly broad range of customers.

Because CSP plants require very strong solar resources where clouds and haze do not interfere, their development in the United States has been largely in the desert Southwest, although facilities have also appeared in Florida and Hawaii (NREL 2014b). CSP plants require significant infrastructure for collecting steam and generating electricity, and large areas of land, which limits project design options and locations for CSP plants and generally makes them an option for large-scale generation only (IEA 2010).

One advantage of CSP over PV and many other renewable energy technologies is its ability to store the sun's energy as heat in molten salts, and to use it to make electricity when the sun is no longer shining and at times when it may be most valuable to the grid. The molten salt heated by concentrating the sun's energy can be stored and kept hot for several hours. When electricity is needed, the heat stored in the salts can make the necessary steam. This storage lets CSP systems extend the "shoulder hours" of their generation patterns and generate electricity a few hours before the sun rises and a few hours after it sets, making it easier to integrate electricity from such plants into the grid (Denholm and Mehos 2011). Even without storing the salts, since CSP systems generate electricity using very high temperatures, momentary cloud cover does not lead to the same minute-by-minute variation in electricity production that PV systems experience (Jorgensen, Denholm, and Mehos 2014).

THE ECONOMICS OF CSP

CSP's ability to store energy and, to an extent, provide electricity on demand is an important characteristic that can make the electricity more valuable to the grid and can help utilities avoid the costs of building new power plants to meet projected future demand.

However, CSP projects have not seen the rapid growth that the PV market has experienced in recent years, largely because of their overall less-favorable economics. The main components of CSP projects—steel and mirrors—have not experienced the dramatic cost declines that solar panels have. Several large solar projects slated to use CSP—including the proposed 1,000 MW_{AC} Blythe solar project near the California-Arizona border (Solar Trust of America 2011)—switched to PV technology due to the relatively rapid decline in the cost of PV panels.

CSP AND THE ENVIRONMENT

CSP shares many of the positive environmental aspects of other solar electricity options, including its ability to produce electricity without global warming pollution, other air or water pollutants, or fuel depletion. Some challenges posed by CSP projects related to land use and wildlife habitat are similar to those faced by large PV projects, while others are unique to CSP technology.

CSP facilities require large swaths of intensely sunny, relatively level land, which usually implies locating them in desert ecosystems, and these can be fragile. Project developers may scrape and grade sites in order to install the structures that support the mirrors, potentially disrupting the habitats of ground-dwelling animals. Several actual or proposed CSP projects in the Mojave Desert have run into troubles because of the desert tortoise, a species native to the U.S. Southwest and Mexico that is already threatened by development, climate change, and other issues (Defenders of Wildlife 2014; USFWS 2014). While modular PV projects can more easily be built around physical constraints (such as tortoise habitat) or be scaled back to minimize impacts, this flexibility is much less available to CSP. Project developers can, however, reduce impacts to plants and animals by building on already disturbed lands or by placing mirrors more efficiently to make optimal use of land (Chu 2012).

[***One advantage of CSP is its ability to store the sun's energy and use it to make electricity when the sun is no longer shining.***]

Unique to CSP power towers is the issue of solar flux created by the mirrors. The extreme heat created by the concentrated energy can singe and kill passing birds and bats. Incidents of bird deaths were first reported at the Ivanpah solar facility in the Mojave soon after its launch in 2014 (Kagan et al. 2014). Understanding and minimizing such wildlife impacts is an important issue for the future of power towers.

CSP's water use depends largely on choices around cooling systems. CSP plants often use water to cool the steam once it has been used to generate electricity. CSP plants with conventional "wet cooling" may evaporate even more water per unit of electricity than coal or nuclear power plants (Macknick et al. 2012). Some CSP projects in the United States, including Ivanpah and the Genesis solar project (also in California), cool steam with air instead of water, cutting water consumption by 90 percent or more (NREL 2014b).

POLICY: RESEARCH AND DEVELOPMENT ON CSP STORAGE

As with large-scale PV projects, CSP investments have been driven mainly by the requirements of states' renewable electricity standards. CSP projects also benefit from federal incentives like the federal investment tax credit. Further, since CSP projects are more likely to be built in the western United States on federal lands, they are benefitting from efforts by state and federal agencies to coordinate permitting studies and agree on investments to reduce environmental impacts.

CSP project designs continue to evolve; therefore, policies that also support research and development into engineering innovations, including how to take advantage of CSP's storage capability to make it easier to integrate larger amounts of solar electricity into the electric grid, will make CSP costs more competitive and allow the projects to demonstrate the value that renewable resources bring to the grid.

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State policies can help utilities prioritize investments in storage. In 2013, California's public utilities commission took an important step in that direction by directing the state's investor-owned utilities to acquire storage by 2020 (Wisland 2013).

The Future of Solar Power in America

Solar has great potential to provide economical, clean, and reliable power; it works at a broad range of scales and has already begun to play an important role across our nation's electricity system. Solar power's position as an equal-opportunity renewable energy resource in every state has helped to fuel its impressive growth in recent years.

Solar appears headed for much greater levels of service. The U.S. National Renewable Energy Laboratory found that, under scenarios with widespread adoption of renewable energy, solar has an important role to play, potentially accounting for 4 percent of national electricity generation in 2030, and 13 percent in 2050 (Hand et al. 2012). And research suggests that in many parts of the country residential solar will be cheaper than grid electricity in the very near future (Ong, Denholm, and Clark 2012).

The ability of individuals, businesses, and utilities to continue to capitalize on solar's potential and to reap increasing benefits will not happen by itself. It will depend on concrete actions to support solar's continued acceleration. Important focus areas include:

- **Renewable electricity standards.** States should maintain and strengthen their key policies for driving renewable energy investments, including solar.
- **The solar tax credit.** The federal investment tax credit that has been so important for solar's rise is set to decline at the end of 2016 from 30 percent to 10 percent; Congress will need to take action to sustain that support.
- **Federal power plant carbon standards.** States should ensure that solar plays a strong role in their plans to reduce emissions to comply with the Environmental Protection Agency's new carbon standards.
- **The full value of solar.** Assessing the full range of benefits and costs of solar, particularly rooftop solar, will help policy makers decide the most appropriate way to assist more people in adopting solar.
- **Storage.** Lower costs and the greater availability of energy storage technologies will help provide electricity more consistently and at times of peak demand.
- **New utility business models.** Utilities should modify their business models to accommodate high levels of rooftop solar and encourage continued solar development, from rooftops to large-scale projects.

- **Research and development.** Solar's prospects will be enhanced by continued progress in reducing costs—through greater economies of scale, increasing cell and module efficiencies, improved inverters and mounting systems, better heat transfer, and streamlined transactions.

Solar is a broadly accessible, low-emissions energy choice for America. Forward-looking policies and investment decisions by government, industry, and individuals will continue to be crucial for driving solar's impressive development. From rooftops to landfills to large open spaces, harnessing the full power of solar energy will be a key part of our nation's transition to clean, reliable, and affordable electricity that can safeguard our environment, protect our health, and power our economy.

***John Rogers** and **Laura Wisland** are senior analysts in the Union of Concerned Scientists (UCS) Climate and Energy Program.*

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