Rooftop solar on the rise

Small solar projects are delivering 10 times as much power as a decade ago

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Executive summary

SOLAR ENERGY IS ABUNDANT, affordable and a big part of America's transition to renewable energy.[1] Solar power is particularly valuable when it produces energy right where we need it: on the rooftops of our homes and businesses.

Rooftop solar is good for the environment and consumers – reducing our dependence on fossil fuels, easing strain on the grid during periods of high demand, increasing resilience to threats like extreme weather, and limiting the amount of land needed for clean energy, all at steadily falling cost.[2]

State and local policies that make it easier for homeowners and business owners to install and connect solar energy systems, and that compensate them fairly for the electricity they generate, can ensure that rooftop solar plays an important part in America's energy future.

Small-scale solar energy – of which rooftop solar is the largest component – is growing rapidly in the U.S., producing 10 times as much power in 2022 as a decade earlier. Small-scale solar generated enough electricity in 2022 to power 5.7 million typical American homes – more than all the homes in the state of Pennsylvania.[3]

- The rapid growth of rooftop solar in the U.S. has been driven by the rapid uptake of installations on homes. Residential solar energy systems generated 64% of all electricity from small-scale solar installations in the U.S. in 2022.

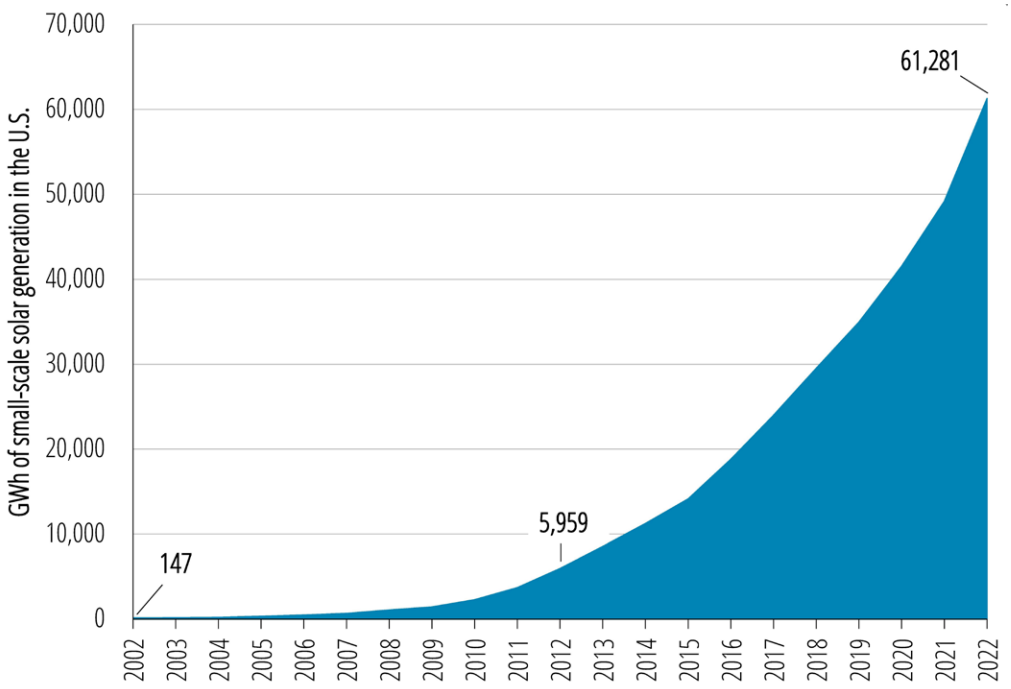

Figure ES-1. Small-scale solar energy growth in the U.S., 2002-2022[4]

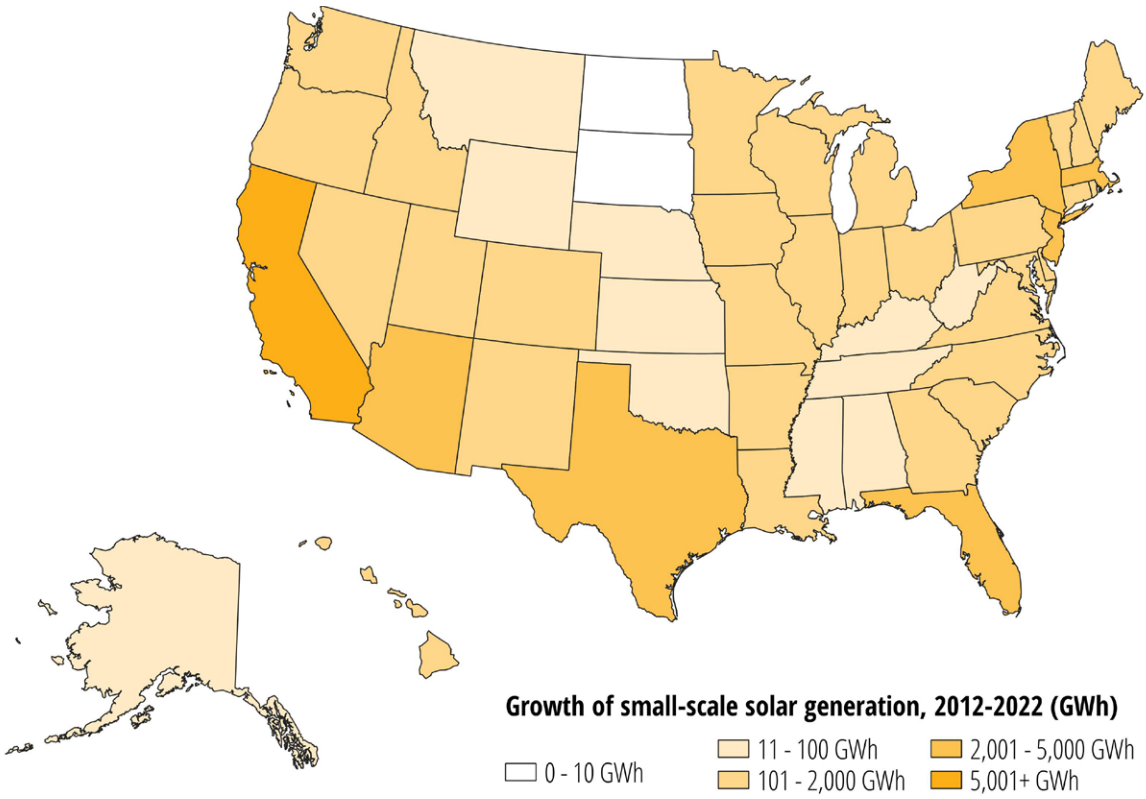

Figure ES-2. Growth of small-scale solar generation, 2012-2022 (in GWh)[12]

The U.S. has only scratched the surface of rooftop solar's potential. Rooftop solar has the technical potential to generate electricity equivalent to about 45% of all electricity sales in the U.S. at 2022 demand levels.[5] **In 2022, the U.S. only generated about 1.5% of all the electricity it used from rooftop solar.**[6]

- Big, flat commercial rooftops are some of the most promising places to expand solar energy. The rooftops of American warehouses alone have the potential to produce 185.6 TWh of solar electricity each year – enough to power almost 19.4 million average American homes.[7] Although rooftop solar on warehouses can be difficult to incentivize due to landlord-tenant relationships, realizing the solar potential of warehouse roofs could have a significant and positive impact on clean energy goals and grid resilience in the future.
- The U.S. also has over 100,000 large retail buildings, with enough solar potential to power almost 8 million homes.[8]
- Solar panels on small buildings, including homes, have the potential to produce 926 TWh of electricity every year, enough to power nearly 86 million typical American homes.[9]

TABLE ES-1. TOP 10 STATES FOR TOTAL SMALL-SCALE SOLAR GROWTH, 2012-2022[11]

State	Increase in small-scale solar generation (in GWh), 2012-2022
California	21,668
Arizona	3,397
New York	3,323
Massachusetts	3,227
Texas	2,919
Florida	2,483
New Jersey	2,202
Nevada	1,291
Illinois	1,236
Maryland	1,174

States with pro-solar policies have seen a surge of rooftop solar installations on both homes and businesses in the last decade. States such as Massachusetts, New Jersey and Illinois with strong pro-solar policies have experienced consistent, strong growth in rooftop solar. Meanwhile, states that have been inconsistent in their support of rooftop solar have seen solar installations lag or surge. California, the nation's leader in rooftop solar, recently eliminated key policies that supported the growth of solar energy, a move that is expected to lead to a sharp decline in new solar installations in the state at a time of rising demand for clean energy.[10]

Consistent statewide permitting and interconnection policies, supportive rate designs and solar incentives can help make rooftop solar accessible and attractive to homeowners and business owners. To maximize rooftop solar's tremendous potential, state governments should focus on eliminating red tape and utility obstacles to rooftop solar, offering incentives and financing support for homeowners and business owners interested in going solar, and ensuring that homeowners and business owners are fairly compensated for the power they generate.

Governments should also encourage individuals, organizations and businesses to take advantage of the incentives for rooftop solar in the 2022 Inflation Reduction Act (IRA), including:

- Homeowners can claim a federal income tax credit for 30% of the cost of a rooftop solar investment.[13]
- Businesses can claim either an investment tax credit similar to that described above or a production tax credit that, for the first 10 years of a system's use, reduces the businesses' income tax liability for each kilowatt-hour of electricity produced by solar panels.[14]
- Governments, nonprofits, churches and other organizations that do not pay taxes can receive the full value of either of these tax credits in a direct payment through the IRA's "elective pay" provision.[15]

Introduction

BEFORE RESEARCHERS at the University of Delaware built the first fully solar-powered home in America in 1973, producing a substantial portion of a building's electricity from a solar array on-site was just an idea.[16]

Today, solar panels on the roofs of homes and businesses generate power equivalent to the annual usage of 5.7 million typical American homes.[17]

The rapid rise of rooftop solar over the last 50 years is thanks in part to the researchers and engineers who drove rapid advances in solar technology, the entrepreneurs who figured out how to make and install solar panels efficiently and affordably, and the advocates and political leaders who created the public policies that laid the foundation for it all.

But if you are one of the 3.9 million Americans who have installed solar panels on your home, the rise of solar power in America is also because of you.[18]

Every American who has installed solar panels has voted with their wallet and their rooftop for a clean energy future – and helped to make it a reality, both through their own action and through their influence on others.[19]

The annual amount of electricity generated by rooftop solar in the U.S. is 10 times what it was a decade ago. And that electricity is being produced right where we use it, in our communities, reducing the need for electricity from big power plants carried by long-distance transmission lines.

But while millions of Americans have "gone solar," there is still plenty of room for solar energy to grow. Solar energy is the most abundant energy resource on earth and it has a big role to play in the energy transition.[20] Solar on homes and businesses has the technical potential to generate an amount of electricity equivalent to about 45% of all national electricity sales at 2022 demand levels, providing a large share of the clean power we would need to end our reliance on polluting fossil fuels.[21]

This report celebrates the dramatic growth of rooftop solar power in America over the last decade and illustrates how far we have yet to go to take full advantage of our immense solar energy potential.

With strong public policies, millions more Americans will have the opportunity to power their lives with energy from the sun, and move the nation to a cleaner, healthier energy system.

Rooftop solar is good for the environment and consumers

IN THE SOLAR INDUSTRY, "distributed generation" refers to any behind-the-meter generation, while "utility-scale generation" is front-of-meter and plugs directly into the grid. For the purposes of this report, distributed, or "small-scale," solar power is generated on-site in parking lots and yards and on the roofs of homes and other buildings, including through community solar programs. Rooftop solar panels make up the majority of small-scale solar in the United States.[22] (As such, in this report, we use "rooftop solar" as shorthand for distributed, "small-scale" solar.)

Rooftop solar has myriad benefits for the environment and consumers. It reduces the need for dirty power plants and expensive transmission lines, is economical, can help to increase the grid's resilience to extreme weather and other shocks, and can be installed on a variety of surfaces not suitable for other uses – reducing the need to disturb natural land for energy production.

Rooftop solar can reduce strain on the grid as electricity demand grows

Increasing rooftop solar capacity can reduce the need for central power plants.[23] The more electricity a region can generate from rooftop solar, the less dependent it can be on fossil fuels. It can also help regions avoid transmission and distribution investments.

New England states like Massachusetts, Rhode Island, Connecticut and Vermont rank among the top states for rooftop solar GWh generated per capita in 2022 (see appendices). As a result, New England is demonstrating the benefits of rooftop solar for the grid. Rising rooftop solar capacity in the region has made one of the region's dirtiest power plants – the Mystic Generating Station – obsolete.[24] The power plant will close in summer 2024. ISO New England, the regional grid operator, had previously said Mystic was needed to prevent blackouts during the winter, but now says that, thanks to increasing solar capacity, its services are no longer needed to keep the grid reliable through New England's legendary winters.[25] Increasing solar capacity played a big role in that story; ISO New England, the regional grid operator, reported about 5,400 MW of solar capacity – mostly on rooftops – in 2022.[26]

Rooftop solar can also reduce strain on the grid by helping to meet new demands for electricity arising from the electrification of transportation. As electric cars, trucks and buses replace gasoline-powered vehicles, demand for electricity will increase.[27] Homeowners could use rooftop solar to provide power for vehicle charging, reducing strain on the grid and potentially saving money.[28] There are also ample opportunities for businesses. A solar array on a warehouse could be paired with batteries and charging stations to power heavy-duty electric vehicles or supply electricity to EVs with bidirectional chargers. In Montgomery County, Maryland, for example, plans are moving ahead to build the largest renewably-powered bus depot in the U.S. The depot will feature a variety of vehicle chargers powered by rooftop and canopy solar and battery storage.[29]

Rooftop solar also helps to limit how much transmission and distribution investment is needed. Because rooftop solar generates power that can be used on-site, it reduces

the need for transmission from central generating stations, potentially saving states and municipalities time and money on their energy transitions.[30] To reach renewable energy targets, some expansion of transmission infrastructure will be necessary, but maximizing the potential of rooftop solar can help to minimize the amount we need to build.

Rooftop solar is cost-effective

Solar in general is the cheapest new-build electricity in many markets, costing about 29% less than the cheapest fossil fuel alternative.[31] Rooftop solar arrays typically requires less framing and foundation work than ground-mounted ones, potentially reducing installation costs.[32]

Compared to buying electricity from a utility company, rooftop solar can save homeowners money. The initial investment can be substantial, but most buyers can expect to break even in about eight to nine years and ultimately to save between $20,000 and $96,000 over the life of their solar arrays.[33] The cost-effectiveness of rooftop solar depends in large part on state and local policies, especially how well homeowners and business owners can expect to be compensated for the electricity they generate. (See page 19.)

Current incentives make rooftop solar an even better deal. Under the Inflation Reduction Act of 2022, homeowners can claim a federal income tax credit for 30% of the cost of rooftop solar installation.[34] Businesses and some non-profits can claim a similar 30% credit if their project meets certain criteria, and additional credits are available if the project meets the criteria for one of three "adders" defined in the bill: it is sited near environmentally harmful industries like coal mining or oil extraction (defined as "energy communities" in the IRA), benefits a low-income community, or meets certain domestic content requirements.[35]

Businesses can claim that credit or a production tax credit that, for the first 10 years of a system's use, reduces the businesses' income tax liability for every kilowatt-hour of electricity the panels produce.[36]

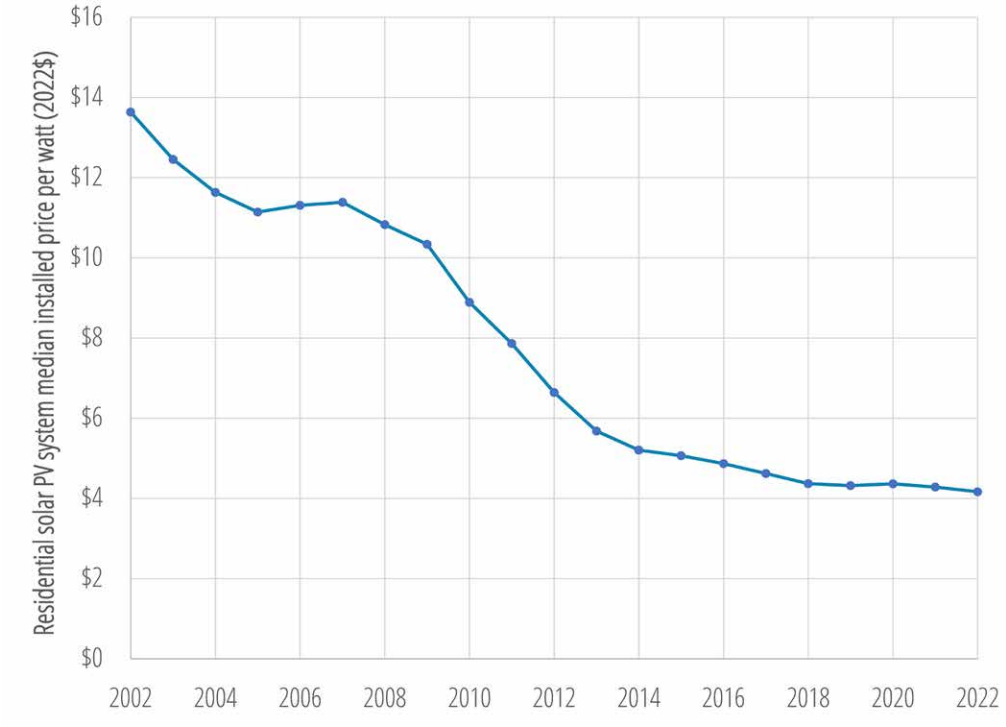

Figure 1. Median installed price of residential solar panels per watt, 2002-2022 (in 2022 dollars)[40]

Nonprofits and local governments can also benefit, even though they do not have tax liability. The Inflation Reduction Act made nonprofits eligible for an elective pay option under the Solar Investment Tax Credit (ITC) for which businesses are eligible, enabling schools, hospitals, charities, faith-based organizations, rural electric co-ops and other tax-exempt entities to receive payments equivalent to 30% of the cost of installing a solar PV system.

Additionally, the per-watt cost of residential solar panels has fallen by about 70% in the last 20 years (adjusted for inflation) and continues to fall, making it cheaper for property owners to go solar.[37] Similarly, the cost of battery storage fell considerably in the last decade – by about 85%.[38] Home energy storage remains expensive – running between $8,500 and $10,000 per battery – but prices are expected to continue to fall in coming years.[39]

Distributed power generation and storage can benefit both the owners of the generation systems and other ratepayers in the area. For example, Green Mountain Power in Vermont has incentivized consumers to install batteries and the program paid off for all ratepayers, saving GMP customers up to $3 million a year.[41]

Rooftop solar can increase grid resilience

Rooftop solar can help to reduce demand on the grid, especially at peak times when the grid is under the most strain. When paired with energy storage, solar panels can even serve electricity demand in the evening hours once the sun has set – a strategy known as "load shifting." Using this strategy, rooftop solar that powers batteries and/or vehicles also allows for local control over time of use, allowing owners to charge when it's least expensive (or when electricity is not in peak demand).

Demand spikes are a problem for grids across America that can lead to dangerous blackouts. In the summer of 2023, about two-thirds of the country faced elevated risk of blackouts.[42] In Texas, a heat wave led to a spike in electricity demand that pushed the grid to the brink.[43] Blackout and rolling blackout threats from extreme weather are likely to become more common and serious as climate change makes heat waves more frequent, long-lasting and intense.[44]

Rooftop solar can also improve grid reliability and resilience at times that seem less intuitive. In New England, for example, increasing rooftop solar capacity is expected to make the grid more reliable during the region's notoriously gloomy winters.[45] That capacity has allowed the region to close a polluting power plant that was formerly needed to protect against winter blackouts.[46] Rooftop solar could help to ease similar problems in other regions. During Texas' power crisis in winter 2021, there were 13 days during which power production fell short of anticipated demand. On 11 of those days, rooftop solar could have supplied more than enough power to meet daily shortfall, on aggregate, if Texas had taken full advantage of its potential for rooftop solar power.[47]

Paired with battery storage units, rooftop solar can protect buildings where it is installed from losing power even during blackouts.[48] Similarly, microgrids can protect entire communities from losing power when there are disruptions to the broader electric grid. Microgrids are small, independent grids that can operate separately from the main grid. In Panton, Vermont, for example, utility company Green Mountain Power developed a microgrid with a solar array and battery capacity. The microgrid will protect local homes, farms and businesses from blackouts and eliminate reliance on fossil fuel backups.[49] Microgrids and battery storage are key parts of Green Mountain Power's "Zero Outages Initiative," which includes the distribution of residential batteries to customers in remote areas of the state to enable them to retain power during grid disruptions.[50]

Similarly, virtual power plants (VPPs) can help stabilize the grid with distributed power sources and storage. A VPP is a collection of devices, such as electric vehicles, batteries and solar arrays, that can be flexibly charged, discharged and managed. When aggregated and coordinated, they can function similarly to a traditional power plant but with more flexibility.[51]

Rooftop solar has a small land-use footprint

Compared to most energy sources, rooftop solar has a small land-use footprint. To end America's dependence on fossil fuels, both ground-mounted utility-scale solar arrays and rooftop solar will be needed, but maximizing rooftop solar's potential can help to limit land-use conflicts, reducing the extent to which clean energy comes into conflict with conservation.

Utility-scale solar has a significant land-use footprint, though not necessarily a larger impact than production of fossil fuels.[52] While there is considerable room for creativity when it comes to siting ground-mounted utility-scale solar arrays to reduce conflicts with sensitive ecosystems or other land uses, distributed solar is far more flexible. It can be installed in spaces that are not suitable for other uses, such as on top of homes, parking lots, retail stores, warehouses, schools, libraries, houses of worship and government buildings. Solar photovoltaics can even be integrated directly into products such as roofing shingles and windows.[53]

Each gigawatt of rooftop solar capacity installed instead of utility-scale projects could potentially prevent the need to convert almost 5,200 acres of land, according to an analysis based on California data.[54] Maximizing the U.S.'s rooftop solar potential could significantly reduce the land-use changes that result from the energy transition.

As solar panels become more efficient, both utility-scale and small-scale arrays will require less space to generate the same amount of electricity.[55] Adopting higher-efficiency rooftop solar would further reduce the demand for natural land for utility-scale projects, even as it helps to meet America's growing demand for clean energy.

Rooftop solar is growing rapidly in the U.S.

Rooftop solar generation in the U.S. increased more than 10x in the last decade

Rooftop solar power has experienced explosive growth over the last decade. America generated 10 times as much power from small-scale solar installations in 2022 as it did in 2012 – an increase of 55,322 GWh. Two thirds of that growth occurred between 2017 and 2022.[57]

In total, solar panels on rooftops and in other small-scale applications in the U.S. generated 61,281 GWh of electricity in 2022. That's equivalent to the power used by 5.7 million typical American homes.[58]

The top five states for total rooftop solar generation in 2022 were California, Arizona, New York, Massachusetts and New Jersey.

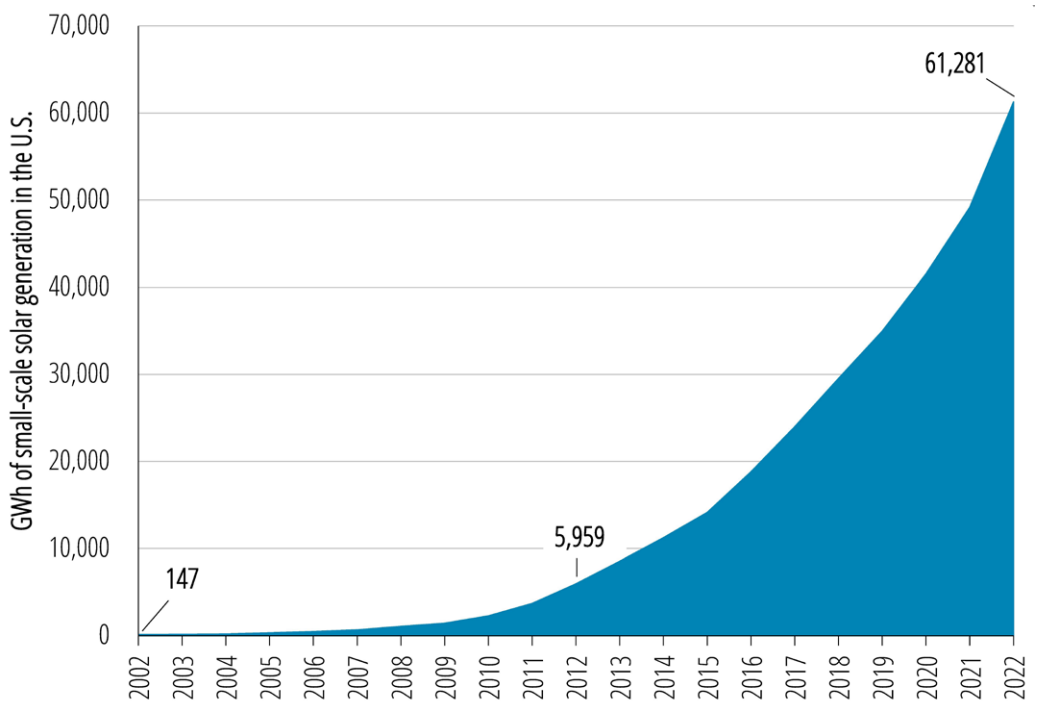

Figure 2. Small-scale solar growth in the U.S., 2002-2022[56]

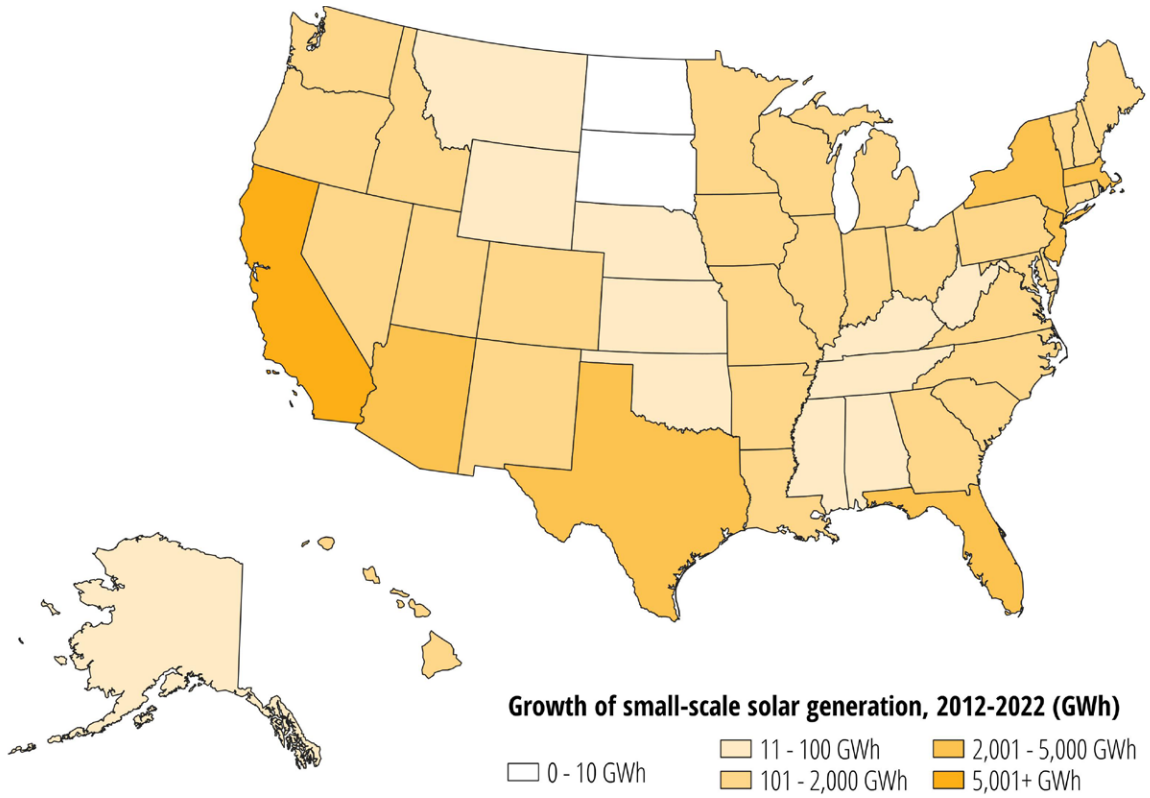

Figure 3. Growth of small-scale solar generation, 2012-2022 (in GWh)[59]

Solar on homes is driving the growth in small-scale solar

A boom of solar panels on homes has driven the growth of rooftop solar in the U.S. In 2014, when the U.S. Energy Information Administration started tracking small-scale solar generation by sector, the residential sector contributed just 44% of all power production from small-scale installations – less than 5,000 GWh. Commercial solar – that is, solar on the sites of businesses, warehouses and distribution centers – led the way at that time, with 46% of all small-scale solar production, producing about 5,150 GWh.[60]

Today, residential solar produces 64% of all electricity from small-scale installations. Residential solar produced 39,510 GWh of electricity in 2022 while commercial produced 17,724 GWh.[61] This is an indication of the increased popularity of solar power among homeowners and landlords, but also a concerning sign for America's ability to tap the abundant solar energy potential on structures such as warehouses and superstores.

The industrial sector has historically been a minor player in distributed solar. Nevertheless, that sector, which includes agriculture, construction, mining and manufacturing, generated about 3.5 times more electricity from rooftop solar in 2022 than it did in 2014.[62]

Between 2014 and 2022, electricity generation from solar on homes increased by 34,563 GWh.[63] That's equivalent to the electricity needed to power about 3.2 million homes.[64]

The growth of commercial generation has been significant, but somewhat more modest, growing by 12,578 GWh over that same period.[65]

Most states are generating more electricity from solar on homes than from solar on businesses and industrial sites, but there are exceptions, including some of the top states for rooftop solar, such as New York, which has encouraged the growth of commercial solar with incentives and community solar programs.

Leading states are experiencing rapid growth in solar, while others are lagging

The growth of rooftop solar has not been uniform across the country. California has historically dominated the market for small-scale solar, but many other states have seen significant growth. States such as Texas, New York, Florida and Arizona are starting to catch up, with rooftop solar generation at least doubling in each of those states between 2017 and 2022.

There is considerable regional variation in the amount of electricity generated from rooftop solar. About one-half of rooftop solar generation is in the West. The Northeast produces just under one-quarter and the Southwest, Southeast and Midwest produce the rest.[67]

TABLE 1. TOP SMALL-SCALE SOLAR PRODUCERS, 2022

Top states for small-scale solar generation 2022 (in GWh)					
Commercial		**Industrial**		**Residential**	
California	5,320	California	2,889	California	15,912
Massachusetts	1,945	Georgia	212	Arizona	3,132
New York	1,920	New Jersey	208	Texas	2,575
New Jersey	1,413	Massachusetts	137	Florida	2,291
Arizona	848	Pennsylvania	76	New Jersey	1,551
Illinois	749	Nevada	50	New York	1,534
Hawaii	488	Connecticut	49	Massachusetts	1,337
Texas	420	South Carolina	41	Nevada	1,208
Rhode Island	393	Ohio	37	Colorado	1,006
Connecticut	376	Arkansas	33	Maryland	938

TABLE 2. TOP TEN STATES FOR TOTAL SMALL-SCALE SOLAR GROWTH, 2012-2022[66]

State	Increase in small-scale solar generation (in GWh), 2012-2022
California	21,668
Arizona	3,397
New York	3,323
Massachusetts	3,227
Texas	2,919
Florida	2,483
New Jersey	2,202
Nevada	1,291
Illinois	1,236
Maryland	1,174

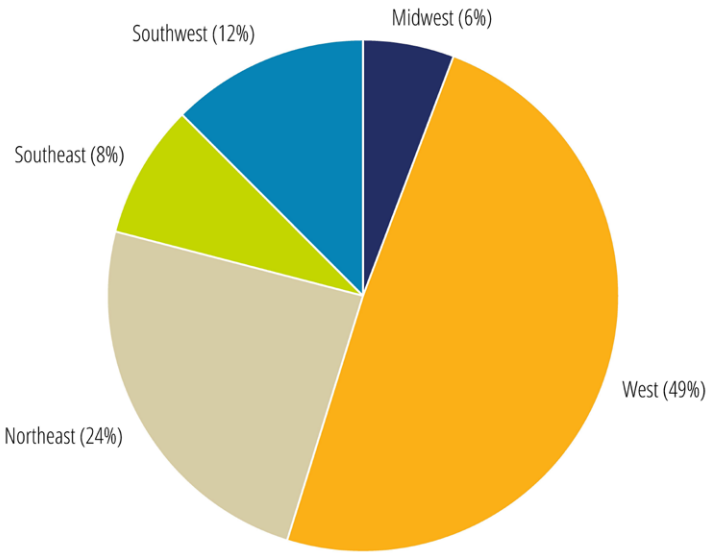

Figure 4. Regional contributions to total small-scale solar generation in the U.S., 2022 (figures do not add to 100% due to rounding)

Rooftop solar still has room to grow

America has barely begun to tap its rooftop solar potential

Despite rapid growth in rooftop solar over the past decade, most of the nation's rooftop solar potential remains untapped. The U.S. has so far only tapped about 1/28th of our rooftop solar potential.[69]

Rooftop solar likely has the technical potential to generate electricity equivalent to about 45% of all national electricity sales at the 2022 level of demand.[70]

In 2022, the U.S. only generated about 1.5% of all electricity used from rooftop solar.[71]

A look at the top 10 states for rooftop solar potential shows the vast amount of untapped clean energy potential in many states – including the nation's leading solar states. California, while far and away the nation's leader for small-scale solar, has only tapped slightly more than 10% of its technical potential for rooftop solar. Texas ranks second for rooftop solar potential, but has tapped less than 2% of it, while Midwestern states Ohio and Michigan have tapped 0.5% or less of their potential. (See Table 3.)

Taking full advantage of the potential for rooftop solar would enable some states to obtain a large share of their electricity from the sun. In 2016, the National Renewable Energy Laboratory found that California has the technical potential to generate electricity from rooftop solar equivalent to 74% of its electricity sales. Maine and Vermont could generate electricity equivalent to 60% of electricity sales and 20 other states could generate electricity equivalent to one-third or more of electricity sales.[72] While solar panels produce more electricity at some times than

TABLE 3. TOP 10 STATES FOR ROOFTOP SOLAR POTENTIAL AND THE PERCENTAGE OF POTENTIAL TAPPED THROUGH 2022[181]

State	Annual rooftop solar generation potential (TWh/year)	Percentage of rooftop potential generated in 2022
California	236	10.20%
Texas	160	1.87%
Florida	126	2.02%
New York	67	5.15%
Ohio	65	0.50%
Illinois	64	1.95%
Pennsylvania	61	1.32%
Michigan	58	0.43%
North Carolina	55	1.08%
Georgia	54	0.72%

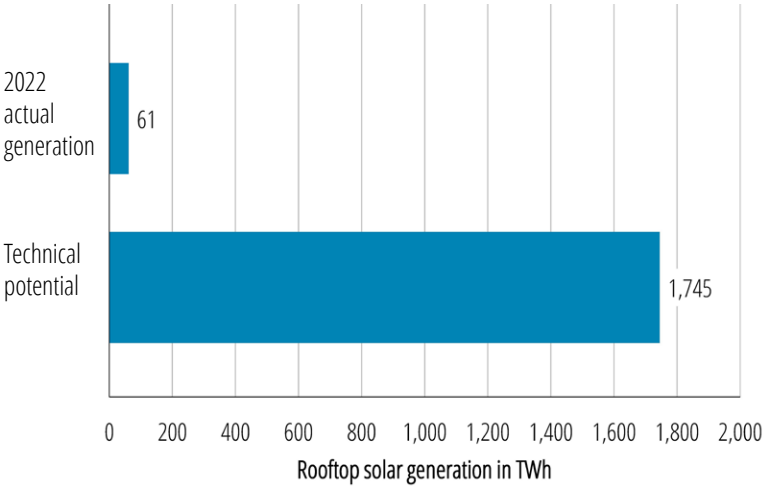

Figure 5. Actual small-scale solar generation and technical potential[68]

others, and are therefore limited in their ability to meet all of a region's electricity needs, small-scale solar – particularly when paired with energy storage – can meet a large share of America's demand for energy.

Big opportunities ahead for solar on businesses

Commercial and industrial sites across America are prime candidates for distributed solar installations. Solar panels on superstores, warehouses, farms and other sites could help businesses save money and provide a large supply of clean energy.

Rooftop solar can reduce commercial and industrial buildings' reliance on electricity from the grid by as much as 80% and save companies up to 95% on their electric bills.[73] Over 20 years, average small-to-medium businesses could save about $101,259 in electricity costs by going solar, depending on their region and utility.[74]

The rooftops of American warehouses have the potential to generate 185.6 TWh of solar electricity each year – enough to power almost 19.4 million average homes.[75] That means warehouses could generate electricity from rooftop solar equivalent to the electricity use of about 16% of all U.S. households.[76]

On-site commercial solar is growing – about 3% over five years, according to a 2022 report, and with major corporations beginning to see the value of going solar, that growth is expected to continue.[77] Lowe's, the home improvement retailer, is one example of a major company that has invested in solar. Lowe's announced earlier this year it plans to install rooftop solar panels at 174 locations in California, New Jersey and Illinois.[78] Rooftop solar will help Lowe's reach its renewable energy and greenhouse gas emissions targets and, when complete, the solar projects will supply about 90% of the anticipated energy usage at each site.[79] For many other companies, though, huge opportunities for rooftop solar are still untapped. Companies like FedEx, for example, have millions of square feet of roof space that could be capturing the sun's rays and producing electricity.[80]

State policy plays an important role in making it easy – or difficult – to take advantage of the solar energy potential of commercial rooftops. In New Jersey, for example, a new law that went into effect in July 2022 requires that all large new warehouses set aside at least 40% of roof area for the future installation of a solar system – one of a number of policies that could ease the way for future commercial solar projects.[81] On the other hand, state legislation that makes it more difficult for commercial buildings to afford, permit or connect solar power can create obstacles to the growth of commercial solar.[82]

Distributed solar can coexist with industrial sites

The relatively small land-use footprint of distributed solar makes it compatible with a variety of industrial land uses. Solar panels can be installed on many types of industrial infrastructure not suitable for other uses, like the roofs of factories, or share space with water treatment facilities or landfills.[83]

For example, landfills in the U.S. currently have total solar capacity of about 2.4 GW but, with 10,000 closed landfills across the country, there's the potential to increase that capacity 25-fold.[84]

Governments and nonprofits can save money with solar power

In addition to homes and businesses, distributed solar installations are also a cost-saving, emissions-reducing energy option for nonprofits, local governments, houses of worship and schools.

Under the Inflation Reduction Act, nonprofits and local governments are eligible to benefit from tax credits for rooftop solar installation.[85] The act made nonprofits eligible for an elective pay option under the Solar Investment Tax Credit (ITC), enabling schools, hospitals, charities, faith-based organizations, rural electric co-ops and other tax-exempt entities to receive payments equivalent to 30% of the cost of installing a solar PV system.[86]

Solar power is increasingly popular with local governments for its emissions-cutting and cost-saving potential.[87] In Montgomery County, Maryland, for example, local governments have installed at least 7.6 MW of solar on county facilities, producing enough electricity annually to power 800 homes.[88] As a result, the county expects to save about $10 million over 20 years.[89]

Houses of worship make up a small but outsized portion of the overall U.S. non-residential solar PV market, making up just 0.6% of all non-residential buildings but 2% of all non-residential PV systems.[90] In some states, 10% or more of houses of worship have solar arrays.[91]

Solar installations at schools have increased significantly; K-12 public schools saw a 139% increase in installed solar between 2014 and 2020 and about 5.3 million schoolchildren now attend school at one of the 7,300 schools across the country that have solar arrays.[92]

Solar installations can save school districts money. The Batesville School District in Arkansas expects to save $4 million over 20 years after installing a solar array on-site.[93] Savings like this can mean schools have significantly more flexibility in their budgets. With the extra funds, the Batesville School District gave teachers an unprecedented raise.[94]

Rooftop solar is thriving in places with strong pro-solar policies

IN GENERAL, STATES with pro-solar policies generate more power from rooftop solar than those that lack pro-solar policies. Current federal incentives under the Inflation Reduction Act are helpful, but state-level policies remain the primary driver in shaping the complex policy landscape that influences solar growth.[95]

One way to get a sense of how good a job states are doing encouraging the growth of rooftop solar is to look at rooftop solar generation per capita. Larger states tend to have more potential for rooftop solar, so a larger number isn't always an indication that one state is doing better than another.

For example, the small New England states of Rhode Island and Vermont don't look like they generate very much electricity from rooftop solar (527 GWh and 211 GWh in 2022, respectively), but both rank among the top states for rooftop solar generation per capita. This suggests that these states are doing a relatively good job at getting on track to reach their rooftop solar potential. On the other end of the spectrum, Texas generates a relatively large total amount of electricity from rooftop solar (2,995 GWh in 2022) but is middle-of-the-pack on generation per capita.

Four of the most important types of solar policies are solar incentives, supportive rate designs, interconnection

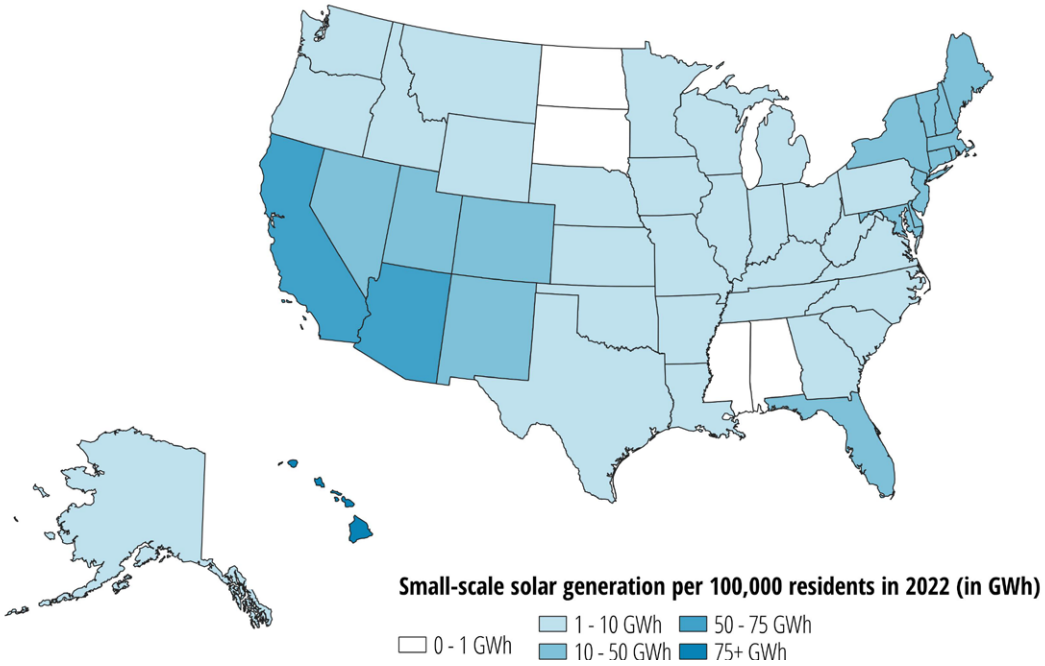

Figure 6. Small-scale solar generation per 100,000 residents in 2022 (in GWh)

policies and permitting processes. Each can vary considerably by state and can have a big impact on how much solar is built.

Solar incentives

State-level solar incentives for homeowners and business owners include state property tax credits and property tax exemptions, typically meaning that property owners do not have to pay property tax on the added value of the solar array or on some portion of it; low-cost financing, which helps property owners who want to go solar afford a loan in order to do so; and sales tax exemptions for solar energy systems, which exclude some purchases of solar arrays from state sales tax.[96] These incentives can help homeowners and businessowners to afford the cost of rooftop solar installation.

Some states also offer direct cash payments or certificates of sellable value for every kWh produced, such as renewable energy credits or solar renewable energy credits.[97] These policies have helped make going solar more attractive and economical in these states.

States with strong solar incentives, like New York and Massachusetts, have seen small-scale solar grow rapidly.[98]

Supportive rate design

Net metering gives homeowners and business owners credit for any electricity their distributed power systems generate and feed back into the grid.[99] For every extra kilowatt-hour that their solar array supplies to the grid, they receive some form of compensation.

Historically, "net metering" has referred to policies that provide compensation for excess power at the retail rate – the equivalent of making a consumer's electricity meter "spin backwards." Over time, states and utilities have devised an array of ways to compensate consumers for solar power, including "net billing" (in which consumers are credited for power supplied to the utility at less than the retail rate) and value-of-solar tariffs. These compensation mechanisms, in turn, differ greatly in their implementation from state to state. For the sake of simplicity, many use the term "net metering" as a generic catch-all to describe all these varying ways of compensating solar producers.

Net metering is critical to the economic viability of rooftop solar. Some states have standards for net metering that utilities regulated by the state's utility commission are required to follow. Other states allow utilities to mostly set their own net metering practice. The actual amount that the owners of distributed generation systems are compensated for varies widely and can change frequently, but guaranteed compensation for excess power can help make solar installations more accessible to low- and moderate-income households.

Net metering policies influence not only whether people choose to go solar, but also how they do so. While supportive net metering policies encourage people to build enough solar to meet their maximum demand, under weaker policies it often only makes sense to build enough for the median demand of the site.

States with supportive rate design policies make it easier for solar panels to "pencil out" economically for would-be solar homeowners and businesses, reducing the amount of time it takes consumers to pay back the initial cost of solar energy in energy savings and, in turn, encouraging more rapid solar adoption. Changes to net metering programs can have big impacts on solar installation rates.[100] To encourage growth in small-scale solar across sectors, homeowners and business owners must be confident that they will be fairly compensated for any excess electricity they generate, both now and in the future.

Although they vary in strength, all 10 of the top 10 states for small-scale solar generation in 2022 had some form of policy to compensate solar producers for the excess energy they supply to the grid (net metering, value-of-solar tariffs, or net billing, which varies in how fairly it compensates homeowners).[101]

In addition to how compensation for exporting excess power works, the overall design of retail rates in states impacts the growth of rooftop solar. Fixed fees for owners of distributed generation systems, for example, disincentivize going solar in North Carolina.[102]

Changes to net metering that decrease the rate at which owners are compensated for generating that power can result in the pace of rooftop solar growth slowing in that state.[103]

Interconnection policies

How hard is it to get a rooftop solar system connected to the grid? The answer to that question determines, in large part, how quickly rooftop solar in each state can grow. Interconnection policies are those that dictate the processes, technical requirements, timelines and costs associated with connecting distributed generation systems to the grid.[105] In many states, applicants for rooftop solar face long interconnection delays and unpredictable costs.[106]

Freeing the Grid, an ongoing initiative that tracks interconnection policies in the U.S., grades states' interconnection policies from A to F. The better the grade, the easier it is for property owners to get a rooftop solar system up and running. Generally, states with grades of A, B or C tend to have more rooftop solar than states with grades of D or F. Twenty-one states are graded A, B or C. Of those, only five – Arizona, California, Illinois, Michigan and New York – earned Bs and just one – New Mexico – earned an A. A and B-graded states made up about 28% of the U.S. population in 2022 but generated 55% of the nation's small-scale solar power.[107]

New Mexico has become an exemplar by developing interconnection rules that recognize the value of energy storage in addition to generation, creating a simplified review track for small-scale projects and increasing transparency about grid conditions for developers and consumers considering a new solar project.[108]

On the other hand, at least 13 states do not have any interconnection policies at all, instead allowing utilities to make their own rules and timelines.[109]

Seven of the top 10 states for small-scale solar generation in 2022 are graded C or above on Freeing the Grid's interconnection grading.[110] The bottom 10 states for rooftop solar per capita in 2022 all earned Freeing the Grid interconnection grades of D or F.[111]

Permitting

In many places, before installation can begin, solar projects must apply for interconnection and approval from the local electric utility, approval from their local jurisdiction, such as a city or county building department, and a local building permit.[112] These steps all serve important purposes, but can be unnecessarily slow and costly, especially when multiple local authorities have overlapping jurisdiction over solar project approval, meaning that each project must be inspected and approved by multiple authorities.

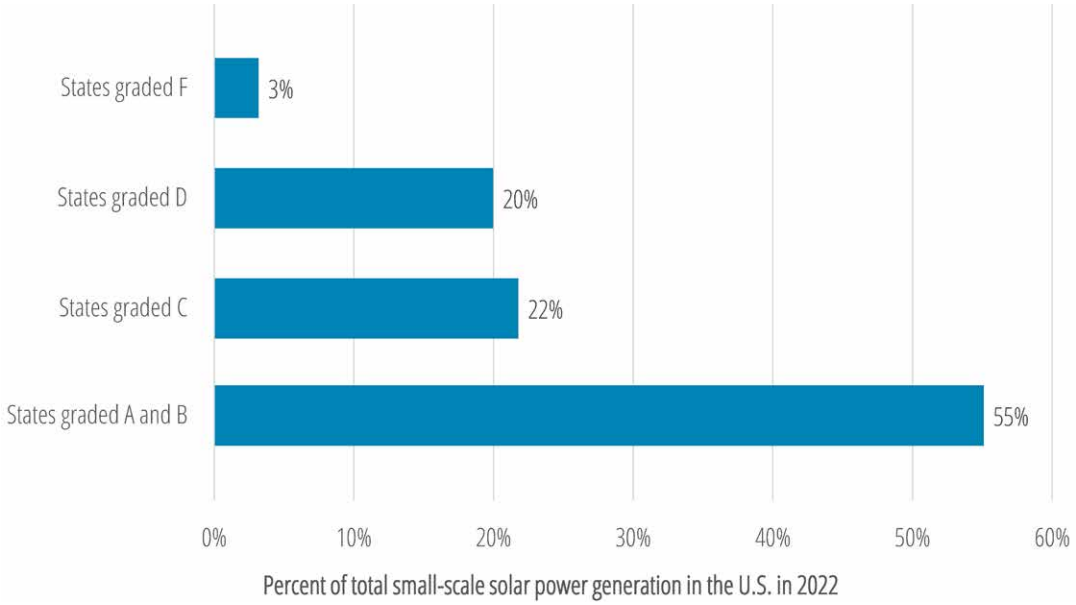

Figure 7. Average five-year growth of small-scale solar in states with different Freeing the Grid interconnection policy grades[104]

Slow, costly permitting processes are a barrier to the growth of rooftop solar in many places.[113] The median duration of the permitting process for a PV system in the U.S. is 50 days, but there is considerable variation within that; about 30% of applications take less than one month, but 19% take more than four months.[114] For commercial projects, interconnection applications can take anywhere from six to 14 months to process for approval.[115]

While the cost of solar panels has fallen dramatically in recent years, "soft costs" – including the costs of permitting, inspection and interconnection – have remained stubbornly high.

With 20,000 distinct jurisdictions and 3,000 utilities, permitting processes lack consistency and simplicity.[116] In some jurisdictions, solar installers must research the local zoning code, customize installation plans and apply for zoning approval before installation – a time-consuming and costly process. In addition, some jurisdictions require property owners to submit permit applications in person to local permitting offices, charge varying permit fees that can make solar installers' cost estimates to potential customers inaccurate, or have local building requirements that add on to state and national requirement for solar panel systems.[117] As a result, solar installations can be unnecessarily slow and complex, increasing the risk of cancellations – creating additional costs that solar installers must recover from their customers.[118]

Automated permitting can help standardize permitting processes, reducing costs and shrinking project timelines while relieving some of the administrative burden that traditional permitting places on local jurisdictions. The National Renewable Energy Laboratory and the U.S. Department of Energy have developed the Solar Automated Permit Processing Plus (SolarAPP+) software to make it easier for jurisdictions to issue permits for code-compliant residential PV systems.[119]

On average, SolarAPP+ projects are permitted, installed and inspected 13 business days sooner than projects permitted in the traditional way.[120] Speeding up permitting can help reduce compliance costs and shrink overall installation timelines.[121]

Fast-growing solar states show the power of strong policies

Pro-solar policies pay off in Massachusetts

Massachusetts has some of the best net metering and incentive policies in the country for encouraging the growth of rooftop solar, and it shows in the state's

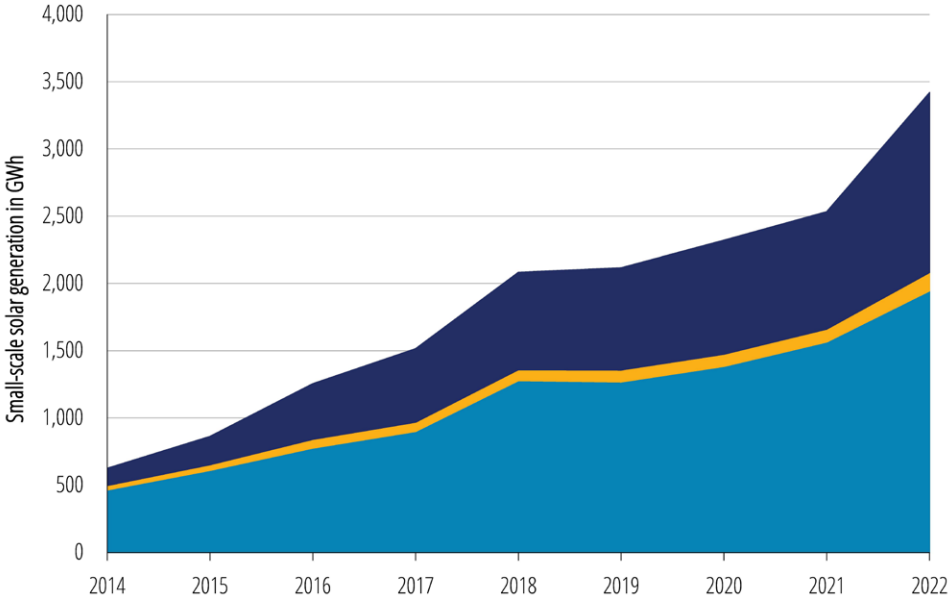

Figure 8. Small-scale solar growth by sector in Massachusetts, 2014-2022[122]

production of solar energy. Massachusetts ranked fourth in the nation for total rooftop solar generation in 2022 and fourth for rooftop solar generation per capita. Massachusetts is also a top producer of solar power by businesses – only California generated more solar power from commercial rooftops in 2022 – and, compared to most states, generates a relatively large amount of electricity from solar on industrial sites. Although the policy environment is mostly positive for rooftop solar growth in Massachusetts, the long interconnection queue has been an obstacle to growth.[123]

Between 2017 and 2022, rooftop solar generation in Massachusetts has increased by about 2.25 times.

It isn't a coincidence that rooftop solar in Massachusetts is thriving. The state has strong solar incentives and supportive rate design, and has historically had a relatively hospitable interconnection environment, earning a C grade from Freeing the Grid.

Massachusetts is one of the top states for solar incentives.[124] State-level incentives include the SMART program – a program through which the state gives incentive payments to homeowners, calculated as the current base incentive rate multiplied by the output of their solar system – a 15% state tax credit on purchases of residential renewable energy systems, 20 years of property tax exemption for solar installations, and a sales tax exemption for homeowners who purchase solar panels for installation on their homes.[125]

In August 2022, Massachusetts raised its limits on who can enroll in net metering, which should help rooftop solar grow even more in the coming years.[126]

In short, because of pro-solar policies, rooftop solar is accessible and attractive to homeowners and business owners in Massachusetts. Nonetheless, there are recent signs of slowing in Massachusetts' rooftop solar market, the result of lengthening delays in interconnecting new solar energy systems and challenges in updating the state's electric grid.[127] Overcoming those barriers will be essential to meeting the state's aggressive clean energy and climate goals.

Innovation in New Jersey

The Mid-Atlantic may not be the warmest or sunniest place in America but that hasn't stopped New Jersey from becoming a rooftop solar powerhouse. Generating 3,172 GWh of electricity in 2022, New Jersey ranked fifth for total rooftop solar generation.

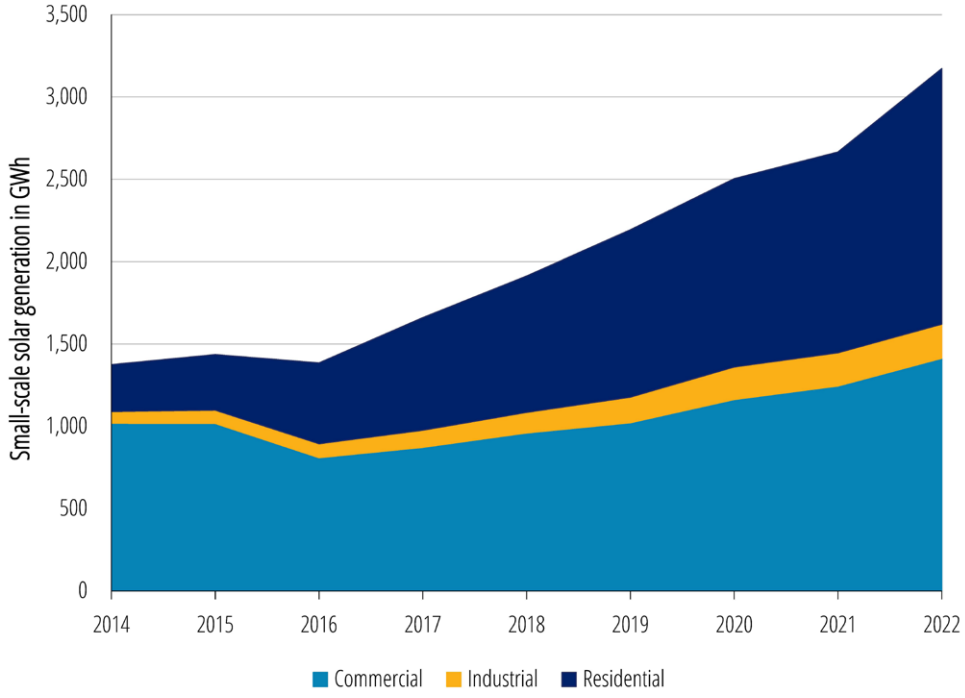

Figure 9. Small-scale solar growth by sector in New Jersey, 2014-2022[128]

Unlike many states, in New Jersey residential and commercial small-scale solar are neck-and-neck. Of the 3,172 GWh generated by small-scale solar in New Jersey in 2022, 1,413 GWh was generated by the commercial sector.

New Jersey supports both residential and commercial solar with state-level incentives.[129] It also offers net metering at the full retail price.[130]

Additionally, New Jersey supports a community solar program that proves solar can fit almost anywhere. Community solar programs make the benefits of solar accessible to people who can't install panels on their own roof because they are renters, they can't afford it, or their electrical systems aren't well suited for it, by allowing them to become subscribers who help to build and then benefit from solar projects in their communities.

Since the program launched in 2018, the state has approved 150 community solar projects with a total of 243 MW of capacity. The 29 that are already operational have 50 MW of capacity and provide more than 6,000 New Jersey households with clean electricity.[131]

New Jersey's community solar program demonstrates the land-use benefits of rooftop solar as it aims to make use of otherwise wasted space, like warehouse roofs, water treatment reservoirs and contaminated sites like landfills.[132]

New Jersey still has commercial solar potential left to tap and there is more the state can do to take advantage of it. New Jersey has more than 13,000 warehouses with approximately 431 million square feet of roof space suitable for solar installations – enough to potentially generate about 7,280 GWh of electricity.[133] Since 2022, New Jersey has required all large new warehouses to be built with "solar-ready" roofs.[134]

Building solar from the ground up in South Carolina

South Carolina is no solar giant, but it has seen rapid growth in rooftop solar since 2014. Like many other states, South Carolina had essentially no rooftop solar installed a decade ago. But from less than one GWh generated in 2014 to nearly 100 GWh in 2022, solar on businesses has helped to propel South Carolina to a place in the middle of the pack nationally today.

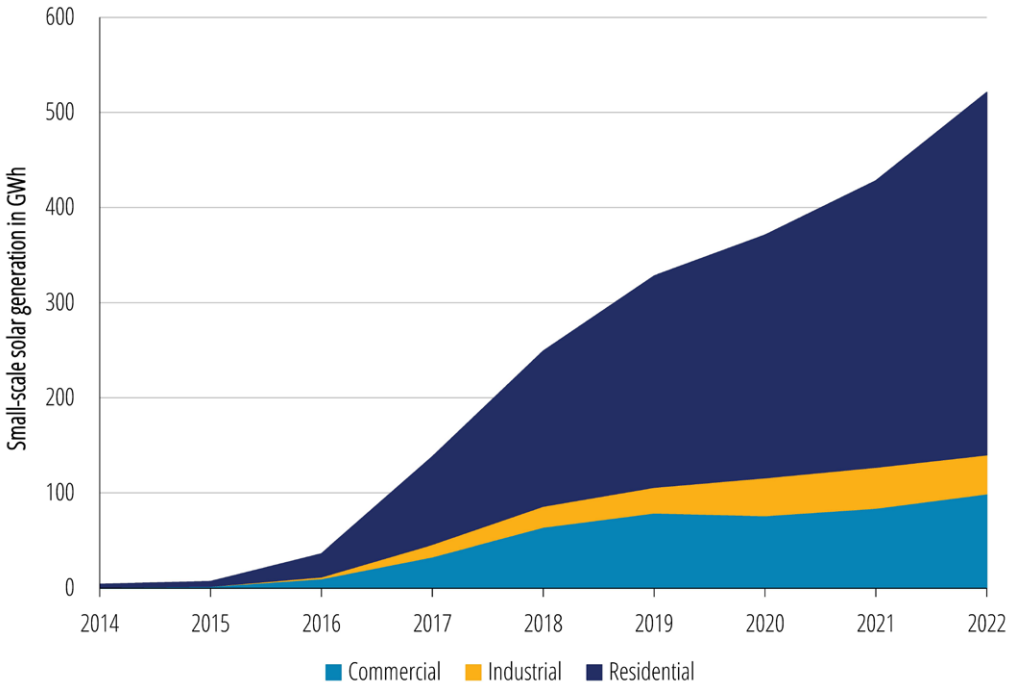

Figure 10. Small-scale solar growth by sector in South Carolina, 2014-2022[135]

Solar on homes has also grown rapidly in South Carolina, from 3 GWh in 2014 to 381 GWh in 2022.

Almost all of South Carolina's solar growth occurred between 2017 and 2022. South Carolina ranked sixth in the nation for solar installations in 2020 and the Solar Energy Industries Association estimates South Carolina will add another 2,024 MW of solar capacity in the next five years.[136]

South Carolina's solar policy environment is mixed. The state requires that utilities offer some form of net metering, but the rates vary by utility.[137]

Duke Energy, one of South Carolina's largest utilities, increased its cap on net metering enrollment in 2021 and offers net metering at a rate of up to 11 cents/kWh – approximately the retail rate – but it still restricts net metering enrollment, which likely discourages South Carolinians from going solar.[138]

South Carolina's 2019 Energy Freedom Act encouraged utilities to clarify and standardize net metering. Unfortunately, most of the act's recommendations are ultimately voluntary for utilities.[139]

Less-supportive policies put solar progress at risk

Leading states have shown that rooftop solar blooms where strong pro-solar policies make it advantageous to homeowners and businesses. Yet, across the country, there is no shortage of cautionary tales of states that reversed course on solar policy, or simply never adopted strong solar policies to begin with. Rooftop solar growth in those states has typically lagged, stalling the nation's transition to clean energy. Recent policy moves in the nation's leading state for rooftop solar – California – could lead to a similar drop in solar adoption there, making that state's road to a clean energy future more difficult.

New policies slam the brakes on rooftop solar in California

California has been America's solar energy leader, in large part due to consistent, strong policy support for rooftop solar power. Recent policy changes, however, put the future of rooftop solar in the state at risk.

California's strong support of rooftop solar began in 1996 with the passage of the Electric Utility Industry

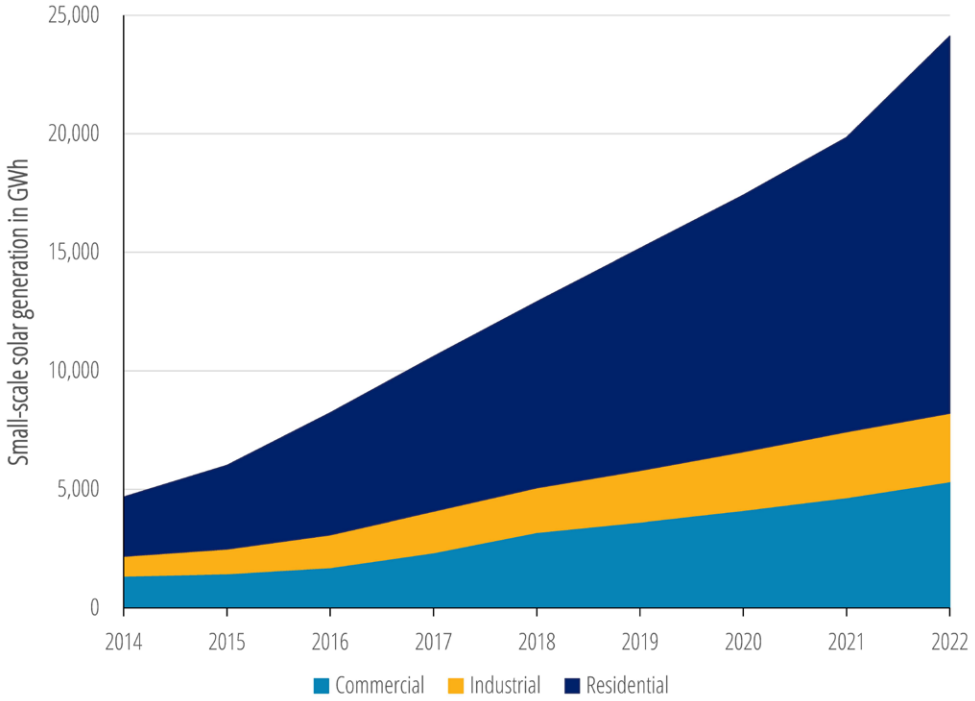

Figure 11. Small-scale solar growth by sector in California, 2014-2022[140]

Restructuring Act, which incentivized utilities to adopt net metering and created state rebates to help reduce to cost of solar arrays.[141]

Further support for solar installations came from the 2006 Million Solar Roofs initiative, which aimed to install solar arrays on one million roofs by 2019 and achieved that goal.[142]

As a result of these and other pro-solar policies, California now produces more electricity from small-scale solar projects annually than any other state. In 2022, small-scale solar projects in California generated about 24,121 GWh of electricity – more than 20,000 GWh more than second-place Arizona.[143] Rooftop solar arrays generate about 11% of California's electricity.[144] The amount of electricity produced by small-scale solar in California increased by about 21,700 GWh between 2012 and 2022 – with about 13,500 GWh of that since 2017. While California has seen significant growth across sectors, residential leads the way, making up about 70% of the growth since 2017.[145]

In 2022, however, the California Public Utilities Commission (CPUC) replaced the state's existing net metering rules, which had helped to fuel the growth of small-scale solar power, with a new "net billing tariff," effective April 2023.[146] The new rules effectively trim compensation for single family homeowners installing solar panels by about 75%.[147] Instead of taking five to six years for a solar array to pay for itself, it could now take 14-15 years in California.[148] These new rules apply only to new solar customers and arrays, with older units to be phased out of older compensation structures over 20 years.[149]

Customers' compensation for the power they generate will vary depending on the season and time of day, a feature intended to encourage more installations of battery storage – a necessary step for solar power to cover more of the state's electricity needs.[150] However, in December 2023 the CPUC changed the compensation system yet again, this time undercutting the value of solar power fed back to the grid during peak hours – the main incentive for installing battery storage.[151]

Market forecasts predicted a slowdown in the California solar market and solar installers have predicted that the new rules would "significantly harm" their business.[152] Those predictions seem to be coming true; rooftop solar project sales in California have dropped 77 to 85% since April 2023.[153] That decrease could result in job cuts affecting about 22% of the state's solar industry workforce.[154]

In the fall of 2023, similar net metering rules were applied to sites with multiple electric meters, including apartment buildings, schools, farms and commercial strips.[155] The new rules begin to take effect in early 2024.[156]

The CPUC did decide to allow multifamily housing residents to continue to directly consume the solar power they generate rather than force them to sell it in bulk to utilities, a departure from their original proposal.[157] Electricity use at multifamily sites that is not covered by residents' electric bills, however, does not qualify for this. That includes common areas like lobbies and garages, as well as decarbonization upgrades like heat pumps and charging stations for electric vehicles.[158] This aspect of the rules could discourage landlords from offering electric vehicle charging stations because they would not be allowed to use the solar panels they have onsite to offset the electricity used by the charging stations.[159]

The CPUC is now considering an even more drastic change: transitioning all customers to flat income-adjusted electric fees paired with more traditional volumetric charges.[160] Volumetric charges reward customers who use less electricity; they also reward customers who are cancelling out some of their electricity use with on-site solar generation. Shifting to flat fees could make distributed solar considerably less attractive for California property owners.

In addition to being a national leader in the adoption of small-scale solar power, California has among the nation's most ambitious clean energy and climate change commitments. Meeting those commitments will require the state to dramatically increase its production

of clean energy, including from solar panels on residential and commercial rooftops. The state's recent about-face on solar policy threatens to slow its clean energy progress and make its ambitious clean energy goals that much harder to meet.

Rooftop solar rollercoaster in Nevada

Alterations to Nevada's net metering policies demonstrate the impact these policies can have on the rooftop solar market.[161]

In 2015, Nevada's Public Utility Commission raised fixed costs on customers enrolled in net metering as part of a plan that was expected to reduce the compensation that owners of distributed energy systems received for excess power they generated by about 75%.[162] Solar growth in Nevada stalled. Residential solar installations over the next year fell by 47% compared to the previous year.[163] In 2017, the state legislature reinstated net metering with no additional costs to distributed generation customers.[164] Since then, residential solar growth has recovered and Nevada is now a top-ranked state for small-scale solar generation.

Since the reinstatement of net metering in 2017, residential solar has grown by 321% in Nevada.[165] In 2022, small-scale solar projects in Nevada generated about 1,385 GWh, the eighth-most of any U.S. state.

Room for growth in the Midwest

The Midwest's rooftop solar growth has lagged that of other regions, due in part to weak net metering policies and a lack of clear renewable energy goals. However, there are signs of improvement.

The Midwest currently generates less energy from rooftop solar than any other region, but that is not for lack of potential.[167] In most of the Midwest metro areas tracked by Project Sunroof, more than half of all buildings are solar-viable. Cities like St. Louis, Mo. and Topeka, Kan., have tremendous rooftop solar potential, but the upper Midwest also has prime real estate for solar installations.[168] Chicago roofs, for example, could generate 6.8 million MWh of electricity every year – enough to avoid about 6 million metric tons of carbon dioxide emissions. That's approximately equivalent to taking 1.3 million cars off the road for one year.[169]

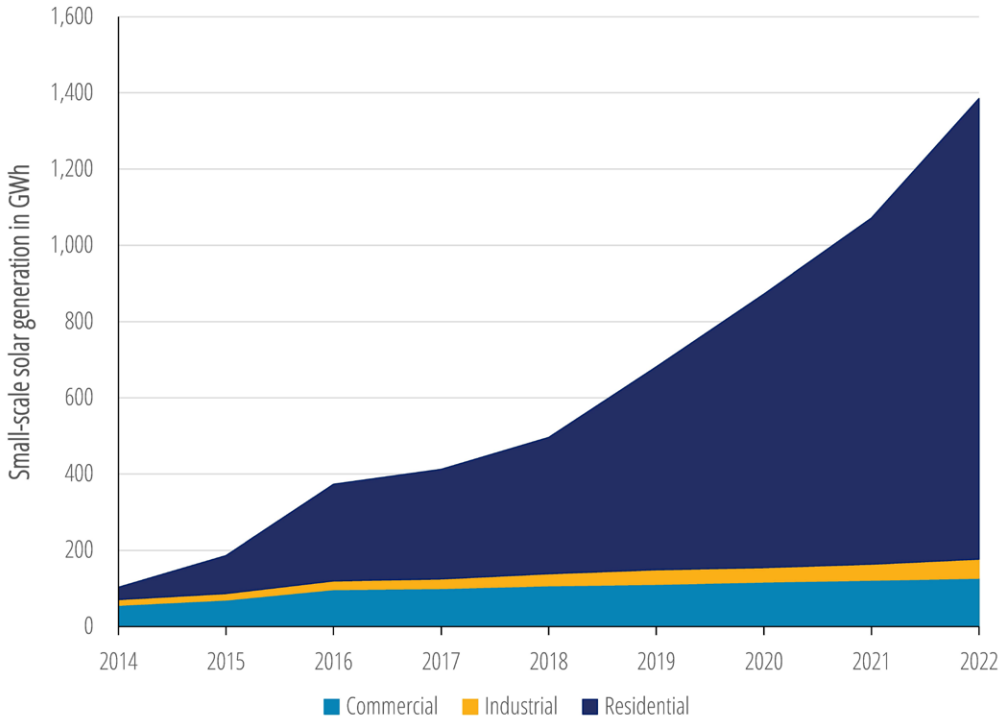

Figure 12. Small-scale solar growth by sector in Nevada, 2014-2022

In some Midwestern states, weak net metering policies have failed to incentivize distributed solar. A recent change to Indiana's net metering policies that limits how much homeowners can earn for the excess solar they generate, for example, may keep rooftop solar growth slow in the state.[170] Similarly, Michigan's two largest utilities have caps that limit distributed energy generation and the state phased out retail-rate net metering starting in 2016.[171] South Dakota has no statewide standard for net metering, meaning homeowners and business owners can't count on compensation, receiving only what their utility chooses to offer at that particular time.[172] Because many Midwestern states lack statewide policies for rooftop solar compensation, utilities and municipalities can mostly set their own standards, which can have consequences for the growth of solar in that region.

Illinois is an outlier in the Midwest. Generating 1,247 GWh of electricity from rooftop solar in 2022, Illinois is by far the largest producer of electricity from rooftop solar in the Midwest and a good example for the rest of the region. Illinois residents are well-compensated for excess solar by the state's net metering policy, and state-level solar incentives and strong interconnection policies further encourage the growth of small-scale solar in the state.[173] Small-scale solar generation in Illinois increased by about 1,189 GWh between 2017 and 2022.

Illinois' Climate and Equitable Jobs Act of 2021 had some positive consequences for solar. It increased funding for Illinois' Solar for All program and provided funding to help the state get from 9% to 40% renewable energy by 2030 and to 50% by 2040.[174] The act is expected to lead to the construction of about 5,800 MW of new rooftop and community solar capacity.[175]

There are positive signs for the future of small-scale solar in the Midwest. Although the region's total generation from small-scale solar remains small compared to that of other regions, it has grown considerably since 2014. And across the region, legislation has been introduced that could make the Midwest more fertile ground for small-scale solar. These bills aim to improve net metering, introduce or expand community solar programs and more.[176]

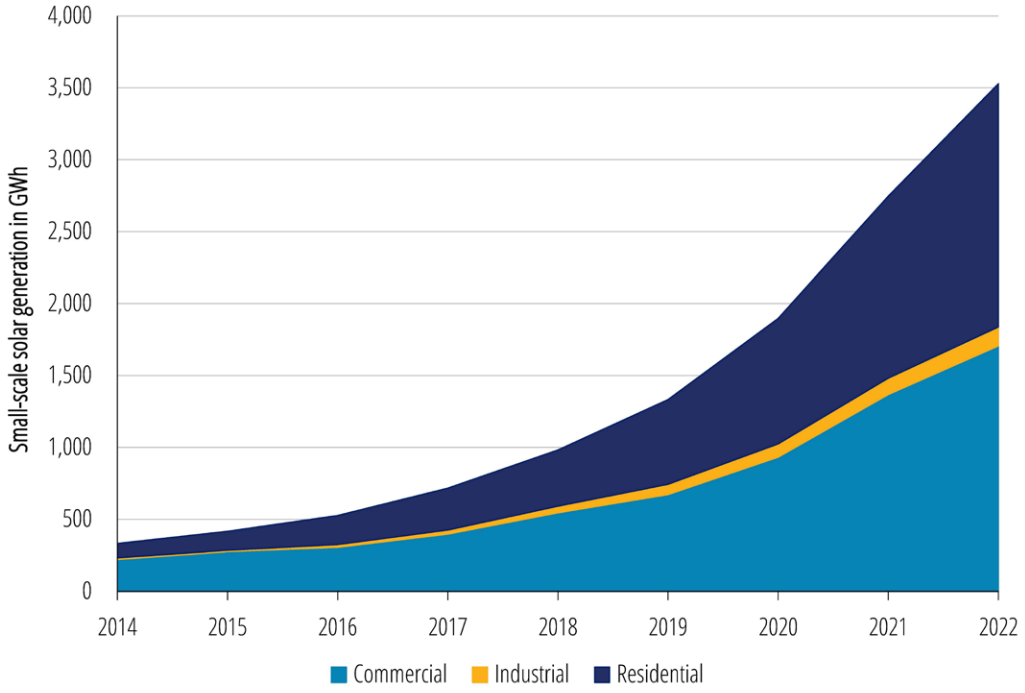

Figure 13. Small-scale solar growth by sector in the Midwest, 2014-2022[166]

Policy recommendations

ROOFTOP SOLAR IS GROWING RAPIDLY in the U.S., but still falls far short of its vast potential.

To combat climate change, increase resilience, and reduce dependence on fossil fuels, local and state governments, along with utilities, should set ambitious goals to increase the amount of clean solar energy produced on the rooftops of homes and businesses and implement the policies required to achieve those goals.

States and local governments should adopt policies that make it easy for households and businesses to connect solar power to the grid.

- States should update their interconnection policies in alignment with best practices, such as those outlined in the Interstate Renewable Energy Council's Model Interconnection Procedures, 2023 edition.[177]
- Cities and counties should establish online automated permitting systems for small onsite solar projects. (The National Renewable Energy Lab has developed SolarAPP+, free online permitting software that helps local governments process permits more easily. States could support adoption of automated permitting by providing funds for technical backup for local governments that implement the software.)
- States should provide support for the installation of solar energy on community buildings, such as schools, libraries and community centers.
- States should adopt policies that enable the creation of virtual power plants that would make it possible for utility customers to sell the energy stored in consumer-sited batteries to the broader grid. This would increase the availability of consumer-sited power to provide energy during times of high demand.
- States should adopt policies that enable property owners to use Power Purchase Agreements and other third-party financing tools to make solar investments financially accessible.

States should provide clear, long-term rules for net energy metering.

- States should adopt net energy metering rules sufficient to provide fair compensation to owners of rooftop solar panels for the electricity they provide to the power grid and to encourage growth of residential and commercial rooftop solar installations.
- States should take into account the full benefits of rooftop solar, including present and future climate benefits, land conservation and community resilience benefits, and reduction in the need for new transmission and distribution lines, when determining how solar power owners should be compensated for the electricity they supply to the grid.
- States should ensure consistent, predictable compensation for the anticipated lifetime of customers' solar installations. Overly complex systems for calculation of compensation, or systems that produce compensation values that vary dramatically from year to year, will not provide homeowners and business owners with

the confidence needed to make a large, upfront investment in solar energy systems.

- Similarly, utilities must honor commitments they made to customers who installed solar panels in past years regarding how much they would be paid for solar energy they supply to the grid. Retroactively changing those agreements undermines consumer faith and confidence, deterring some customers from making further investments in clean energy.
- States and utilities should avoid assessing discriminatory fees on owners of solar panels, or excessive demand charges, both of which undermine the economic case for going solar.

Officials at all levels of government should implement policies specifically aimed toward encouraging businesses to adopt solar power. These policies include:

- Enabling and enacting financing tools like third-party and Commercial Property Assessed Clean Energy (C-PACE) financing of solar installations to help remove financial barriers to solar adoption; and,
- Supporting community solar power programs to allow businesses to go solar in partnership with their communities, and within those programs prioritizing deployment of community solar on rooftops, for example via higher compensation or credit multipliers.

States should ensure access to rooftop solar energy for renters and in low-income communities, which will help maximize the amount of rooftop solar installed.

- Customers who qualify for adjusted electricity rate programs and who install solar panels should be eligible for retail net metering in all cases.
- States should institute or maintain virtual net energy metering, which allows tenants to benefit financially from solar installed on multifamily buildings and will allow more landlords to install solar power.
- States should institute community solar programs, which make the benefits of solar accessible to people who can't install panels on their own roof because they are renters, can't afford it, or have electrical systems that aren't well suited for it.

Methodology

DATA FOR SMALL-SCALE solar energy from 2014 to 2022 came from the U.S. Energy Information Administration's report on net generation from solar by state by sector, filtered for small-scale solar photovoltaic, last updated fall 2023, downloaded Nov. 7, 2023.

Data for small-scale solar energy from 1984 to 2013 came from the U.S. Energy Information Administration's State Energy Data System comprehensive state-level estimate for 1960-2021. The dataset for all consumption estimates in physical units was used. The SOTGP variable was used for total solar generation in each year. The SOEGP variable was used for large-scale solar generation in each year. The SOEGP data was subtracted from the SOTGP data for each year to calculate an estimate for small-scale solar.

Rankings for growth are based on total increase and, where specified, per-capita total increase. Population data is from the U.S. Census Bureau, National Population Totals and Components of Change: 2020-2022, available at https://www.census.gov/data/tables/time-series/demo/popest/2020s-national-total.html.

Information about the technical potential for solar capacity in the U.S. and states came from the National Renewable Energy Laboratory's 2016 report *Rooftop Solar Photovoltaic Technical Potential in the United States: A Detailed Assessment*.[178] In 2016, NREL found that with average solar panel efficiency of 16%, rooftop solar had the technical potential to generate 1,432 TWh of electricity annually. As of 2020, median solar panel efficiency for non-residential installations was up to 19.5%.[179] Electricity use was also up slightly – at about 3,900 TWh.[180] Adjusting for the increased efficiency, rooftop solar now has the technical potential to generate 1,745.25 TWh annually – enough to cover about 44.75% of U.S. electricity use.

For the purposes of this report, the U.S. regions are as follows. The Midwest: Iowa, Illinois, Indiana, Kansas, Michigan, Minnesota, Missouri, North Dakota, Nebraska, Ohio, South Dakota and Wisconsin. The West: Alaska, California, Colorado, Hawaii, Idaho, Montana, Nevada, Oregon, Utah, Washington and Wyoming. The Northeast: Connecticut, D.C., Delaware, Massachusetts, Maryland, Maine, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island and Vermont. The Southeast: Alabama, Arkansas, Florida, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, South Carolina, Tennessee, Virginia and West Virginia. The Southwest: Arizona, New Mexico, Oklahoma and Texas.

Appendices

Appendix A-1. All small-scale solar in the U.S. by state

State	Small-scale solar generation, 2022 (GWh)	Rank	Small-scale solar generation per 100,000 residents (GWh)	Rank	Increase from 2017-2022 (GWh)	Rank	Increase from 2012-2022 (GWh)	Rank
Alabama	22	47*	0	49	14	46*	21	48
Alaska	16	49	2	43	14	46*	16	49
Arizona	3,994	2	54	3	2,101	5	3,397	2
Arkansas	230	33	8	27	220	26	226	32
California	24,121	1	62	2	13,516	1	21,668	1
Colorado	1,372	9	23	13	841	10	1,152	11
Connecticut	1,057	13	29	9	650	11	1,016	13
Delaware	158	38	16	18	66	41	123	38
District of Columbia	176	37	26	11	124	35	153	37
Florida	2,542	7	11	19	2,249	4	2,483	6
Georgia	385	24	4	38	159	33	343	23*
Hawaii	1,327	10	92	1	356	19	1,082	12
Idaho	179	36	9	25	163	32	176	36
Illinois	1,247	12	10	21	1,189	8	1,236	9
Indiana	281	28	4	35	246	24	276	27
Iowa	308	27	10	23	219	27	307	26
Kansas	87	40	3	39	70	40	86	40
Kentucky	101	39	2	42	76	38	98	39
Louisiana	272	29	6	29	72	39	248	29
Maine	336	25	24	12	295	22	330	25
Maryland	1,283	11	21	15	548	12	1,174	10

*indicates tied rankings

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State	Small-scale solar generation, 2022 (GWh)	Rank	Small-scale solar generation per 100,000 residents (GWh)	Rank	Increase from 2017-2022 (GWh)	Rank	Increase from 2012-2022 (GWh)	Rank
Massachusetts	3,419	4	49	4	1,903	6	3,227	4
Michigan	246	30	2	41	181	30	218	33
Minnesota	243	31	4	34	184	29	233	31
Mississippi	22	47*	1	48	11	48	22	46*
Missouri	528	18	9	26	324	20	508	20
Montana	53	43	5	32	38	42	45	43
Nebraska	36	44	2	46	31	43	35	44
Nevada	1,385	8	44	6	973	9	1,291	8
New Hampshire	240	32	17	17	153	34	234	30
New Jersey	3,172	5	34	7	1,512	7	2,202	7
New Mexico	586	17	28	10	382	17*	536	17
New York	3,471	3	18	16	2,289	3	3,323	3
North Carolina	594	16	6	30	408	16	554	16
North Dakota	2	50*	0	50	2	49	2	50*
Ohio	326	26	3	40	197	28	270	28
Oklahoma	85	41	2	44	79	37	84	41
Oregon	404	21	10	24	225	25	343	23*
Pennsylvania	809	14	6	28	452	15	592	15
Rhode Island	527	19	48	5	472	14	516	19
South Carolina	520	20	10	22	382	17*	518	18
South Dakota	2	50*	0	51	1	50	2	50*
Tennessee	75	42	1	47	-12	51	70	42
Texas	2,995	6	10	20	2,519	2	2,919	5
Utah	776	15	23	14	487	13	763	14
Vermont	211	35	33	8	100	36	196	35
Virginia	389	23	4	33	323	21	376	22
Washington	393	22	5	31	277	23	378	21
West Virginia	33	45	2	45	25	44	30	45
Wisconsin	222	34	4	37	166	31	202	34
Wyoming	23	46	4	36	18	45	22	46*

*indicates tied rankings

Appendix A-2. Residential small-scale solar by state

State	Residential solar generation, 2022 (GWh)	Rank	Residential solar growth, 2014-2022 (GWh)	Rank	Residential solar growth, 2017-2022 (GWh)	Rank	Residential solar growth, 2014-2022 (%)	Rank	Residential solar growth, 2017-2022 (%)	Rank
Alabama	5	49	5	49	3	48	NA	NA	150	38
Alaska	10	48	10	47*	9	46	NA	NA	900	6
Arizona	3,132	2	2,596	2	1,891	4	484	39	152	37
Arkansas	123	31*	121	30	117	26*	6,050	6	1,950	2
California	15,912	1	13,418	1	9,383	1	538	38	144	40
Colorado	1,006	9	829	10	689	9	468	41	217	31
Connecticut	633	13	581	12	403	13	1,117	27	175	36
Delaware	114	33	98	36	55	40	613	36	93	44
District of Columbia	108	36	100	35	85	32	1,250	25	370	19
Florida	2,291	4	2,236	4	2,101	3	4,065	8	1,106	4
Georgia	109	35	105	33*	93	30	2,625	16	581	11
Hawaii	834	11	511	13	225	21	158	45	37	47
Idaho	139	27	137	27	127	23	6,850	4	1,058	5
Illinois	494	15	489	14	473	10	9,780	3	2,252	1
Indiana	110	34	107	32	94	29	3,567	12	588	10
Iowa	123	31*	115	31	92	31	1,438	21	297	25
Kansas	59	41	58	41	48	41	5,800	7	436	16
Kentucky	66	40	65	40	56	38*	6,500	5	560	12
Louisiana	253	23	154	23	61	36	156	46	32	48
Maine	83	38	74	38	56	38*	822	32	207	32
Maryland	938	10	862	9	440	11	1,134	26	88	45
Massachusetts	1,337	7	1,209	7	790	8	945	30	144	39
Michigan	148	25*	140	25	117	26*	1,750	20	377	18
Minnesota	149	24	141	24	119	25	1,763	19	397	17
Mississippi	11	47	10	47*	8	47	1,000	29	267	26
Missouri	333	19	285	21	236	19	594	37	243	29
Montana	39	42	30	42	28	42	333	44	255	27
Nebraska	24	44*	23	44	21	43	2,300	17	700	7
Nevada	1,208	8	1,176	8	921	5	3,675	10	321	21

*indicates tied rankings

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State	Residential solar generation, 2022 (GWh)	Rank	Residential solar growth, 2014-2022 (GWh)	Rank	Residential solar growth, 2017-2022 (GWh)	Rank	Residential solar growth, 2014-2022 (%)	Rank	Residential solar growth, 2017-2022 (%)	Rank
New Hampshire	134	28	125	29	78	33	1,389	22	139	41
New Jersey	1,551	5	1,267	6	867	6	446	42	127	42
New Mexico	448	16	396	17	320	16	762	33	250	28
New York	1,534	6	1,372	5	801	7	847	31	109	43
North Carolina	414	17	403	16	347	14	3,664	11	518	14
North Dakota	1	51	1	51	1	51	NA	NA	NA	NA
Ohio	148	25*	138	26	121	24	1,380	23	448	15
Oklahoma	72	39	70	39	68	35	3,500	13	1,700	3
Oregon	261	22	225	22	176	22	625	35	207	34
Pennsylvania	501	14	413	15	338	15	469	40	207	33
Rhode Island	130	29*	129	28	102	28	12,900	1	364	20
South Carolina	381	18	378	18	289	17	12,600	2	314	23
South Dakota	2	50	2	50	2	49*	NA	NA	NA	NA
Tennessee	25	43	25	43	2	49*	NA	NA	9	49
Texas	2,575	3	2,482	3	2,230	2	2,669	14	646	8
Utah	640	12	624	11	422	12	3,900	9	194	35
Vermont	130	29*	105	33*	60	37	420	43	86	46
Virginia	300	21	289	20	259	18	2,627	15	632	9
Washington	331	20	303	19	234	20	1,082	28	241	30
West Virginia	24	44*	21	45	18	44	700	34	300	24
Wisconsin	100	37	93	37	76	34	1,329	24	317	22
Wyoming	19	46	18	46	16	45	1,800	18	533	13

*indicates tied rankings

Appendix A-3. Commercial small-scale solar by state

State	Commercial solar generation, 2022 (GWh)	Rank	Commercial solar growth, 2014-2022 (GWh)	Rank	Commercial solar growth, 2017-2022 (GWh)	Rank	Commercial solar growth, 2014-2022 (%)	Rank	Commercial solar growth, 2017-2022 (%)	Rank
Alabama	16	41	13	38	11	38*	433	24	220	18
Alaska	5	48	5	45	4	46*	NA	NA	400	8
Arizona	848	5	366	7	213	10	76	43	34	46
Arkansas	74	31	72	27	70	20	3,600	5	1,750	2
California	5,320	1	3,976	1	2,985	1	296	27	128	28
Colorado	343	11	169	13	131	13	97	41	62	39
Connecticut	376	10	308	9	220	9	453	23	141	25
Delaware	32	38	-20	50	4	46*	-38	47	14	48
District of Columbia	68	33	46	34	39	32*	209	30*	134	27
Florida	235	14	171	12	142	12	267	28	153	24
Georgia	63	34	-30	51	33	34	-32	46	110	31
Hawaii	488	7	260	10	128	14	114	37	36	45
Idaho	12	43*	10	41*	8	42	500	20	200	20*
Illinois	749	6	733	4	711	4	4,581	3	1,871	1
Indiana	164	18*	158	14	147	11	2,633	6	865	6
Iowa	173	17	157	15	117	15	981	11	209	19
Kansas	27	39	25	35	22	36	1,250	8	440	7
Kentucky	34	37	23	36	19	37	209	30*	127	29
Louisiana	19	40	15	37	11	38*	375	25	138	26
Maine	253	13	249	11	239	8	6,225	2	1,707	3
Maryland	316	12	145	16	112	16	85	42	55	41
Massachusetts	1,945	2	1,481	3	1,046	3	319	26	116	30
Michigan	93	28	67	31	59	26	258	29	174	23
Minnesota	71	32	61	32	47	28	610	17	196	22
Mississippi	11	45	10	41*	5	45	1,000	10	83	34

*indicates tied rankings

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State	Commercial solar generation, 2022 (GWh)	Rank	Commercial solar growth, 2014-2022 (GWh)	Rank	Commercial solar growth, 2017-2022 (GWh)	Rank	Commercial solar growth, 2014-2022 (%)	Rank	Commercial solar growth, 2017-2022 (%)	Rank
Missouri	183	16	119	18	77	18	186	34	73	36
Montana	14	42	12	39	10	41	600	18	250	15
Nebraska	9	46*	9	43	7	43*	NA	NA	350	10*
Nevada	127	22	71	28*	27	35	127	36	27	47
New Hampshire	95	26*	90	22	69	21	1,800	7	265	13
New Jersey	1,413	4	395	5	541	5	39	44	62	38
New Mexico	136	21	69	30	60	25	103	40	79	35
New York	1,920	3	1,737	2	1,485	2	949	12	341	12
North Carolina	164	18*	101	20	52	27	160	35	46	44
North Dakota	1	50*	1	47*	1	48*	NA	NA	NA	NA
Ohio	141	20	75	25	45	29*	114	38	47	43
Oklahoma	12	43*	11	40	11	38*	1,100	9	1,100	5
Oregon	124	23*	83	23	45	29*	202	32	57	40
Pennsylvania	232	15	123	17	94	17	113	39	68	37
Rhode Island	393	9	383	6	366	6	3,830	4	1,356	4
South Carolina	99	25	98	21	66	22	9,800	1	200	20*
South Dakota	1	50*	1	47*	1	48*	NA	NA	NA	NA
Tennessee	50	36	-10	49	-13	51	-17	45	-21	49
Texas	420	8	349	8	289	7	492	22	221	17
Utah	124	23*	106	19	61	23*	589	19	97	33
Vermont	79	30	71	28*	39	32*	888	13	98	32
Virginia	85	29	74	26	61	23*	673	15	254	14
Washington	61	35	53	33	42	31	663	16	221	16
West Virginia	9	46*	8	44	7	43*	800	14	350	10*
Wisconsin	95	26*	79	24	75	19	494	21	375	9
Wyoming	3	49	2	46	1	48*	200	33	50	42

*indicates tied rankings

Appendix A-4. Industrial small-scale solar by state

State	Industrial solar generation, 2022 (GWh)	Rank	Industrial solar growth, 2014-2022 (GWh)	Rank	Industrial solar growth, 2017-2022 (GWh)	Rank	Industrial solar growth, 2014-2022 (%)	Rank	Industrial solar growth, 2017-2022 (%)	Rank
Alabama	1	35*	1	34*	1	31*	NA	NA	NA	NA
Alaska	0	43*	0	41*	0	38*	NA	NA	NA	NA
Arizona	14	20	-69	51	-3	50	-83	22	-18	30
Arkansas	33	10	33	8	33	4	NA	NA	NA	NA
California	2,889	1	2,052	1	1,147	1	245	16	66	19
Colorado	23	14*	21	14*	21	11	1,050	6	1,050	2
Connecticut	49	7	42	5	28	7*	600	9	133	12
Delaware	12	21*	8	24	7	18*	200	18	140	11
District of Columbia	0	43*	0	41*	0	38*	NA	NA	NA	NA
Florida	16	18*	15	18	7	18*	1,500	3	78	18
Georgia	212	2	211	2	32	5	21,100	1	18	25
Hawaii	4	29*	4	27*	1	31*	NA	NA	33	22
Idaho	28	12	28	10	28	7*	NA	NA	NA	NA
Illinois	4	29*	4	27*	4	22*	NA	NA	NA	NA
Indiana	7	26	7	25	6	20*	NA	NA	600	3
Iowa	12	21*	11	20*	9	16*	1,100	4*	300	8
Kansas	1	35*	1	34*	1	31*	NA	NA	NA	NA
Kentucky	2	33*	2	32*	2	30	NA	NA	NA	NA
Louisiana	0	43*	0	41*	0	38*	NA	NA	NA	NA
Maine	0	43*	0	41*	0	38*	NA	NA	NA	NA
Maryland	29	11	23	12	-4	51	383	12	-12	29
Massachusetts	137	4	104	4	68	3	315	13	99	17
Michigan	5	27*	4	27*	4	22*	400	11	400	5*
Minnesota	23	14*	22	13	18	13	2,200	2	360	7
Mississippi	1	35*	1	34*	0	38	NA	NA	0	26*

*indicates tied rankings

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State	Industrial solar generation, 2022 (GWh)	Rank	Industrial solar growth, 2014-2022 (GWh)	Rank	Industrial solar growth, 2017-2022 (GWh)	Rank	Industrial solar growth, 2014-2022 (%)	Rank	Industrial solar growth, 2017-2022 (%)	Rank
Missouri	12	21*	11	20*	11	15	1,100	4*	1,100	1
Montana	0	43*	0	41*	0	38*	NA	NA	NA	NA
Nebraska	3	31*	3	30*	3	28*	NA	NA	NA	NA
Nevada	50	6	35	7	25	10	233	17	100	15*
New Hampshire	11	25	10	22	6	20*	1,000	7	120	14
New Jersey	208	3	136	3	104	2*	189	19	100	15*
New Mexico	1	35*	0	41*	0	38*	0	21	0	26*
New York	18	17	13	19	4	22*	260	15	29	23
North Carolina	16	18*	16	17	9	16*	NA	NA	129	13
North Dakota	0	43*	0	41*	0	38*	NA	NA	NA	NA
Ohio	37	9	30	9	31	6	429	10	517	4
Oklahoma	1	35*	1	34*	1	31*	NA	NA	NA	NA
Oregon	19	16	17	16	4	22*	850	8	27	24
Pennsylvania	76	5	21	14*	20	12	38	20	36	21
Rhode Island	3	31*	3	30*	3	28*	NA	NA	NA	NA
South Carolina	41	8	41	6	28	7*	NA	NA	215	9
South Dakota	0	43*	0	41*	0	38*	NA	NA	NA	NA
Tennessee	0	43*	0	41*	-1	49	NA	NA	-100	31
Texas	0	43*	0	41*	0	38*	NA	NA	NA	NA
Utah	12	21*	9	23	4	22*	300	14	50	20
Vermont	2	33*	2	32*	0	38*	NA	NA	0	26*
Virginia	5	27*	5	26	4	22*	NA	NA	400	5*
Washington	1	35*	1	34*	1	31*	NA	NA	NA	NA
West Virginia	1	35*	1	34*	1	31*	NA	NA	NA	NA
Wisconsin	27	13	27	11	16	14	NA	NA	145	10
Wyoming	1	35*	1	34*	1	31*	NA	NA	NA	NA

*indicates tied rankings

Notes

1. Femke Nijsse et al., "The momentum of the solar energy transition," *Nature Communications*, October 17, 2023, archived at https://web.archive.org/web/20231107214328/https://www.nature.com/articles/s41467-023-41971-7.

2. "Falling cost": Galen Barbose et al., Lawrence Berkeley National Laboratory, *Tracking the Sun: Pricing and Design Trends for Distributed Photovoltaic Systems in the United States: 2023 Edition*, September 2023, archived at https://web.archive.org/web/20231225235241/https://emp.lbl.gov/sites/default/files/5_tracking_the_sun_2023_report.pdf, p. 26.

3. 5.7 million homes based on average household electricity use of 10,791 kWh annually from U.S. Energy Information Administration, *How Much Electricity Does an American Home Use?*, updated October 20, 2023, archived at https://web.archive.org/web/20231107205630/https://www.eia.gov/tools/faqs/faq.php?id=97&t=3. Number of households in Pennsylvania from United States Census Bureau, *Quick Facts: Pennsylvania*, archived at https://web.archive.org/web/20231207142057/https://www.census.gov/quickfacts/fact/table/PA/PST045222, accessed December 7, 2023.

4. Data from U.S. Energy Information Administration. See methodology.

5. In 2016, the National Renewable Energy Laboratory found that with average solar panel efficiency of 16%, rooftop solar had the technical potential to generate 1,432 TWh of electricity annually. As of 2020, average solar panel efficiency was up to 19.5%. Electricity use was also up slightly – at about 3,900 TWh. Adjusting for the increased efficiency, rooftop solar now has the technical potential to generate 1,745.25 TWh annually – enough to cover about 45% of U.S. electricity use. Original sources: Pieter Gagnon et al., National Renewable Energy Laboratory, *Rooftop Solar Photovoltaic Technical Potential in the United States: A Detailed Assessment*, 2016, archived at https://web.archive.org/web/20231017210143/https://www.nrel.gov/docs/fy16osti/65298.pdf, viii; 19.5% efficiency: Galen Barbose et al., Lawrence Berkeley National Laboratory, *Tracking the Sun: Pricing and Design Trends for Distributed Photovoltaic Systems in the United States: 2023 Edition*, September 2023, summary data tables, downloaded from https://emp.lbl.gov/sites/default/files/7_summary_tables_and_figures.xlsx, January 2, 2024.

6. U.S. retail electricity sales to end use customers were about 3.9 million GWh in 2022. Source: Energy Information Administration, *Electricity Explained: Electricity Generation, Capacity, and Sales in the United States*, archived at https://web.archive.org/web/20231018135349/https://www.eia.gov/energyexplained/electricity/electricity-in-the-us-generation-capacity-and-sales.php, accessed October 2023.

7. Bryn Huxley-Reicher, Frontier Group, and Johanna Neumann, Environment America Research & Policy Center, *Solar on Warehouses*, 2023, accessed at https://environmentamerica.org/center/resources/solar-on-warehouses/. Includes only warehouses built before 2019.

8. Bryn Huxley-Reicher, Frontier Group, Wade Wilson and Ben Sonnega, Environment America Research and Policy Center, *Solar on Superstores: Big Roofs, Big Potential for Renewable Energy*, Winter 2022, accessed at https://environmentamerica.org/wp-content/uploads/2022/01/AME-Solar-on-Superstores-1_20_22.pdf.

9. Solar potential: Pieter Gagnon et al., National Renewable Energy Laboratory, *Rooftop Solar Photovoltaic Technical Potential in the United States: A Detailed Assessment*, 2016, archived at https://web.archive.org/web/20231017210143/https://www.nrel.gov/docs/fy16osti/65298.pdf, p. 38; number of typical homes based on average electricity consumption of 10,791 kWh per household per year from U.S. Energy Information Administration, "How much electricity does an American home use?", *Frequently Asked Questions*, updated October 20, 2023, archived at https://web.archive.org/web/20231229165432/https://www.eia.gov/tools/faqs/faq.php?id=97&t=3.

10. Jeff St. John, *Canary Media*, "California is a rooftop solar giant. New rules could change that," April 13, 2023, archived at https://web.archive.org/web/20231127195754/https://www.canarymedia.com/articles/solar/california-is-a-rooftop-solar-giant-new-rules-could-change-that.

11. Data from the Energy Information Administration. See methodology.

12. Data from the Energy Information Administration. See methodology.

13. U.S. Office of Energy Efficiency and Renewable Energy, *Homeowners' Guide to the Federal Tax Credit for Solar Photovoltaics*, updated March 2023, archived at https://web.archive.org/web/20231110163122/https://www.energy.gov/eere/solar/homeowners-guide-federal-tax-credit-solar-photovoltaics.

14. U.S. Office of Energy Efficiency and Renewable Energy, *Federal Solar Tax Credits for Businesses,* updated August 2023, archived at https://web.archive.org/web/20231110163507/https://www.energy.gov/eere/solar/federal-solar-tax-credits-businesses.

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