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Report to Congressional Requesters

February 2017

ELECTRICITY

Status of Residential Deployment of Solar and Other Technologies and Potential Benefits and Challenges

Accessible Version

GAO-17-142

GAO Highlights

Highlights of GAO-17-142, a report to congressional requesters

February 2017

ELECTRICITY

Status of Residential Deployment of Solar and Other Technologies and Potential Benefits and Challenges

Why GAO Did This Study

Traditionally, electricity has moved in one direction—from electricity suppliers to customers. Today, solar systems allow electricity to be generated at a customer's home and sent to the grid for electricity suppliers to use to meet other customers' electricity needs. Storage systems allow residential customers to store electricity from the grid or their own solar system for use at a later time. Furthermore, customers can use smart devices, such as thermostats, to manage their electricity consumption.

GAO was asked to provide information on the deployment and use of technologies that give customers the ability to generate, store, and manage electricity. This report describes (1) key federal and state policies used to encourage the deployment of these technologies, (2) the extent to which these technologies are being deployed, and (3) the benefits and challenges of deploying these technologies. GAO analyzed available data on technology deployment from EIA and reviewed relevant reports and regulatory documents. GAO interviewed a non-generalizable sample of 46 government agencies and stakeholder organizations. This sample included state regulators and at least one electricity supplier from each of five states: Arizona, California, Hawaii, Minnesota, and New York, which were selected based on state policies and having high levels of technology deployment.

GAO is not making recommendations in this report.

View GAO-17-142. For more information, contact Frank Rusco at (202) 512-3841 or ruscof@gao.gov.

What GAO Found

Federal and state policymakers have used a range of policies to encourage the deployment of solar systems and other technologies that allow residential customers to generate, store, and manage their electricity consumption. For example, federal tax incentives—such as the investment tax credit—have reduced customers' up-front costs of installing solar systems. In addition, a Department of Energy funded database of renewable energy incentives identifies 41 states with net metering policies that require electricity suppliers to credit customers for electricity sent from their solar systems to the grid, providing an additional incentive. Moreover, in 14 states, customers can also receive state tax credits for installing solar systems, according to the database, which further reduces the up-front costs.

According to GAO's analysis of Energy Information Administration (EIA) data, deployment of solar systems has increased significantly in some states, with the total number of residential customers with solar systems increasing sevenfold from 2010 to 2015. However, customers with solar systems represent a very small portion of overall electricity customers—about 0.7 percent of U.S. residential customers in 2015, according to EIA data. Every state experienced growth in the number of customers with residential solar systems, although certain states, such as California and Hawaii, accounted for most of the growth and have had more widespread deployment. For example, about 14 percent of residences in Hawaii have installed a solar system, according to EIA data. Although comprehensive data on the deployment of electricity storage systems and smart devices are not available, the data and information provided by stakeholders GAO interviewed suggest their deployment is limited.

The increasing residential deployment of solar systems and other technologies poses potential benefits and challenges, and some policymakers have implemented or are considering measures to address these, as GAO found in its analysis of reports and stakeholder interviews. Specifically, these technologies can provide potential benefits through more efficient grid operation, for example, if customers use these technologies to reduce their consumption of electricity from the grid during periods of high demand. Nonetheless, grid operators GAO interviewed said they have begun to confront grid management and other challenges in some areas as solar deployment increases. For example, in some areas of Hawaii, solar systems have generated more electricity than the grid was built to handle, which resulted in the need for infrastructure upgrades in these areas. However, grid operators reported that challenges generally have been manageable because overall residential solar deployment has been low. Policymakers in some states have implemented or are considering measures to maximize potential benefits and mitigate potential challenges associated with the increasing deployment of these technologies. For example, two states' regulators have required electricity suppliers to identify areas of the grid where solar and other technologies would be most beneficial to grid operation. In addition, several state regulators recently have allowed electricity suppliers to adopt voluntary time-based electricity prices that increase when demand for electricity is high, providing customers with an incentive to reduce consumption at these times, potentially by using solar, storage, and other technologies.

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Abbreviations

DOE	Department of Energy
EIA	Energy Information Administration
FERC	Federal Energy Regulatory Commission
kWh	kilowatt hour

U.S. GOVERNMENT ACCOUNTABILITY OFFICE

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February 13, 2017

The Honorable Frank Pallone, Jr.
Ranking Member
Committee on Energy and Commerce
House of Representatives

The Honorable Bobby L. Rush
Ranking Member
Subcommittee on Energy
Committee on Energy and Commerce
House of Representatives

The Honorable Jerry McNerney
House of Representatives

The Honorable Paul D. Tonko
House of Representatives

The efficient and reliable operation of the United States' electricity grid is vital to the health of the nation's economy and the well-being of Americans. For more than 100 years, electricity suppliers—including electric utilities—have provided residential customers with reliable access to electricity by planning, building, and operating power plants and transmission and distribution lines. Under this traditional model, the electricity grid operates by moving electricity in one direction, with electricity suppliers delivering electricity generated at large, centralized power plants to customers' homes and businesses. In exchange, customers pay electric bills that include various costs associated with maintaining the grid and providing electricity suppliers with a return on their investments in grid infrastructure. As we previously reported, retail electricity customers, including residential customers, typically have had limited incentive or ability to adjust their consumption of electricity in response to the changing costs of producing the electricity.[1]

The traditional model for generating and selling electricity is changing. In recent years, new technologies have become increasingly available to

[1]GAO, *Electricity Markets: Consumers Could Benefit from Demand Programs, but Challenges Remain*, GAO-04-844 (Washington, D.C.: Aug. 13, 2004).

residential customers that allow them to generate, store, and better manage their consumption of electricity. For example, solar systems allow residential customers to generate their own electricity, and battery systems allow them to store electricity for later use. Additionally, advanced meters—meters for measuring electricity consumption that have communications and measurement capabilities that are more advanced than those of older models—collect data on customer electricity use that can help make customers more aware of their electricity consumption habits.

We were asked to provide information on the deployment and use of technologies that give residential customers the ability to generate, store, and manage their consumption of electricity. This report describes (1) key federal and state policies used to encourage the deployment of these technologies, (2) the extent to which these technologies are being deployed, and (3) the benefits and challenges of deploying these technologies.

To address these three objectives, we identified and selected for review reports published from 2013 to 2016 by academic stakeholders, the Department of Energy's (DOE) national laboratories, and industry groups based on these reports' relevance to residential deployment of new technologies that enable customers to generate, store, and manage their consumption of electricity, among other criteria. In addition, the team reviewed other documentation, including state regulatory filings made by electricity suppliers, key policy decisions by federal and state regulators, and reports on specific topics relevant to our work. In addition, based on data on technology deployment that we obtained from the Energy Information Administration (EIA) and our review of related state policymaking activity, we selected a non-generalizable sample of five states that have been actively addressing issues related to these technologies: Arizona, California, Hawaii, Minnesota, and New York. We interviewed state regulators and at least one electricity supplier in each of these five states. We also identified and selected federal agencies and stakeholders to obtain national and regional perspectives. We selected stakeholder organizations to interview based on their experience with the deployment and use of relevant technologies and with policies related to these technologies; we ensured the stakeholders we spoke to represented a diversity of perspectives. In total, we interviewed representatives from 46 federal agencies and stakeholder organizations, including industry associations, third-party providers of electricity technologies or services, consumer advocacy organizations, and academic institutions, among others. Because this was a non-generalizable sample, the views of those we interviewed are not generalizable to all potential government agencies and stakeholders. In addition, we obtained and analyzed data from EIA's survey of electricity suppliers collected from 2007 to 2015,[2] among other sources, to describe the extent to which these technologies are being deployed. We took steps to assess the reliability of all data used for this report, including reviewing agency documentation on the data, interviewing knowledgeable agency officials, and reviewing the data for errors and inconsistencies. We found the data to be sufficiently reliable for the purposes of this report. See appendix I for additional details about our scope and methodology and appendix II for a list of agencies and stakeholders we interviewed.

We conducted this performance audit from September 2015 to February 2017 in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

Background

This section describes (1) the operation and regulation of the electricity system and (2) advances in technologies available to customers that allow them to generate, store, and manage their consumption of electricity.

Operation and Regulation of the Electricity System

The electricity system involves four distinct functions: electricity generation, electricity transmission, electricity distribution, and grid operations. As shown in figure 1, electricity is generated at power plants, from which it flows over high-voltage, long-distance transmission lines to transformers that convert it to a lower voltage to be sent through a local distribution system for use by residential and other customers. Because electricity is not typically stored in large quantities, grid operators constantly balance the generation and consumption of electricity to

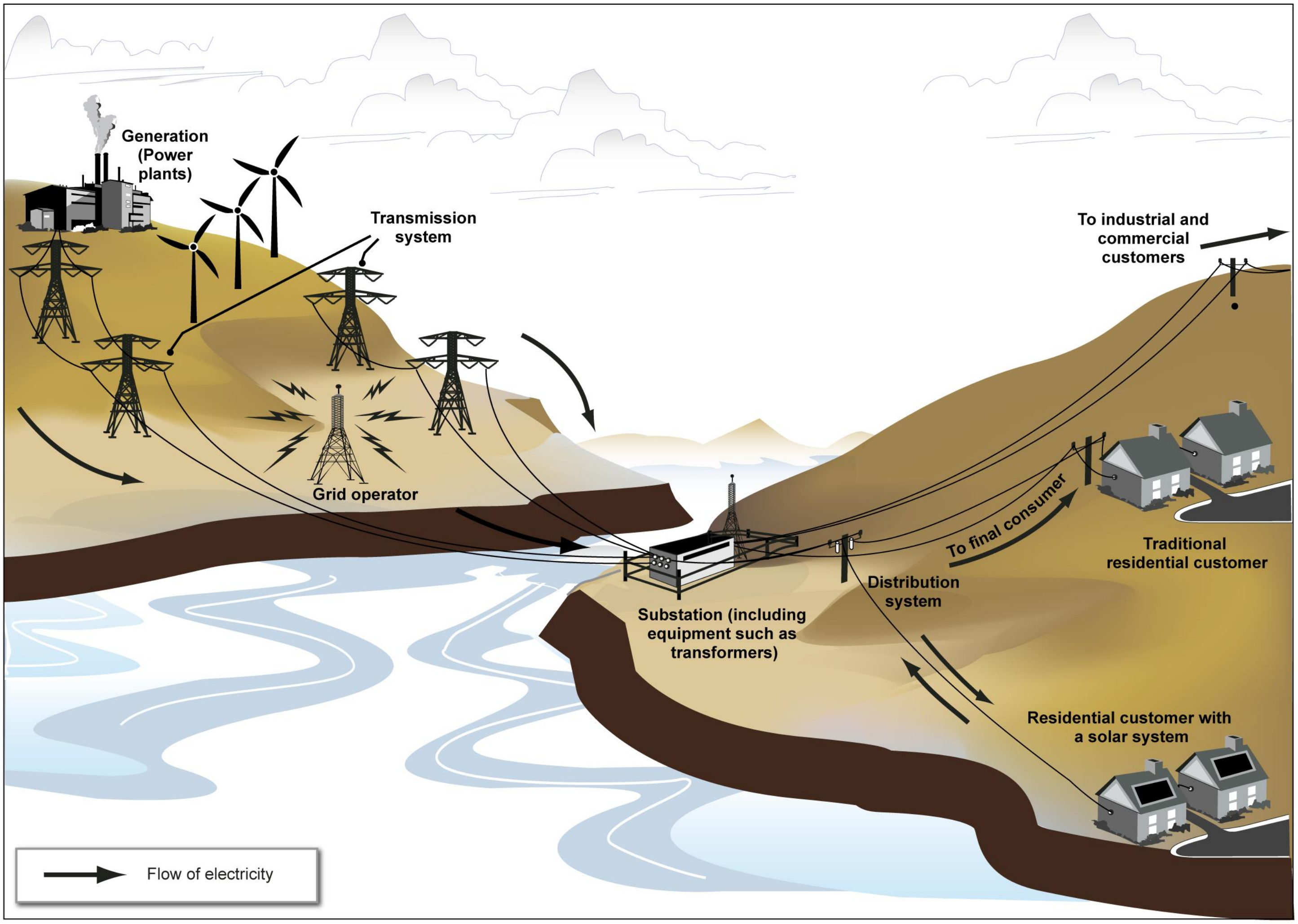
[2]EIA uses Form 861 to survey electricity suppliers about several aspects of supplier operations, including sales, revenues, and number of customers. This survey also collects information on net metering programs, distributed generation, and advanced meter deployment. EIA is a statistical agency within the Department of Energy that collects, analyzes, and disseminates independent information on energy issues.

maintain reliability.[3] In addition, electricity suppliers sell electricity to residential and other customers.[4]

[3]Grid operations are overseen by different entities in different parts of the country. In some regions, a single entity carries out grid operations for both the distribution and transmission systems; in other regions, multiple entities carry out grid operations separately for these systems.

[4]In some regions of the country, the grid operator and electricity supplier are the same entity, which is often referred to as an “electric utility.” In other parts of the country, different entities fill these roles. In this report, we use the term “grid operator” to refer to entities with responsibility for planning and operating the grid. We use the term “electricity supplier” to refer to entities with responsibility for selling electricity to customers.

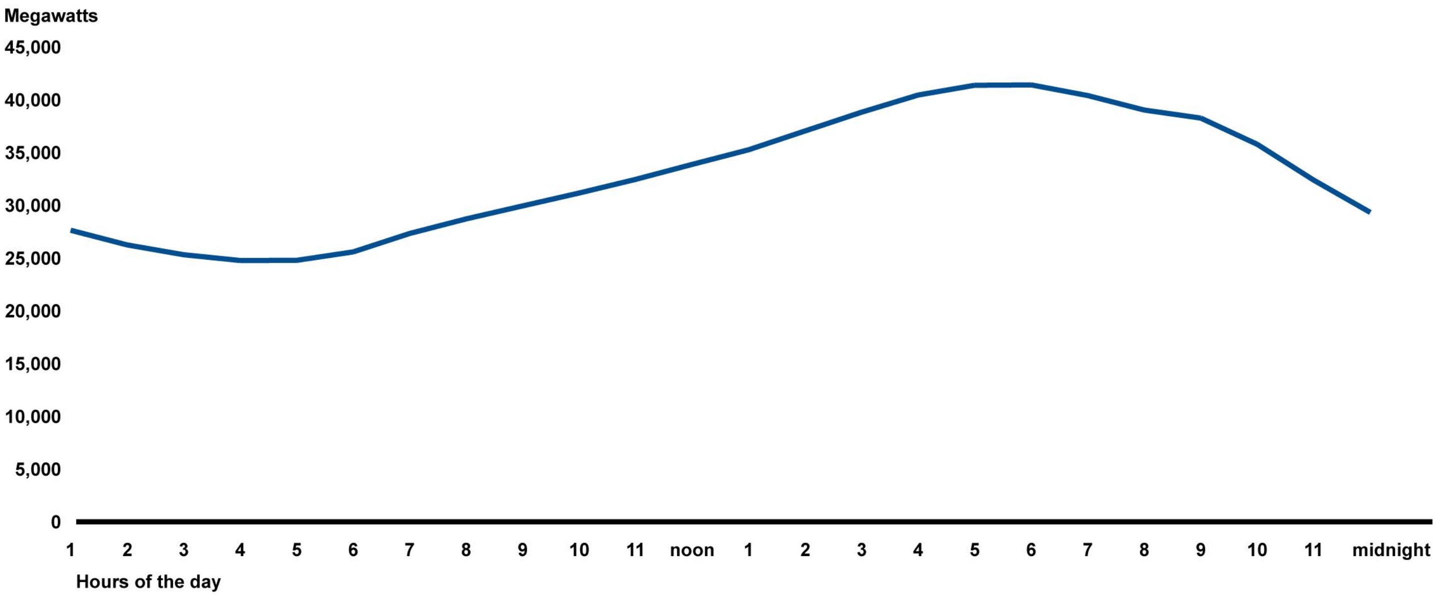
Figure 1: The Electricity System



Source: GAO. | GAO-17-142

Continuously balancing the generation and consumption of electricity can be challenging for grid operators because customers may use sharply different amounts of electricity over the course of a day and throughout the year. For example, in many areas, customer demand for electricity rises throughout the day and reaches its highest point, or peak demand, in late afternoon or early evening (see figure 2 for an example of how demand changes throughout the day). As we noted in a prior report, throughout the day, grid operators direct power plants to adjust their output to match changes in demand for electricity.[5] Grid operators typically first use electricity produced by the power plants that are least expensive to operate; operators then increase the use of electricity generated by more expensive power plants, as needed to match increases in electricity demand. As a result, providing electricity to meet peak demand is generally more expensive than during other parts of the day, because to do so, grid operators use power plants that are more expensive to operate.

Figure 2: Grid Electricity Demand in California on August 18, 2016



Source: GAO analysis of California Independent System Operator data. | GAO-17-142

In general, grid operators perform planning to ensure that grid infrastructure[6] has sufficient capacity—the maximum capability in megawatts to generate and transmit electricity—to meet future peak demand, as we found in our review of reports from DOE and industry

[5]GAO, *Electricity Markets: Demand-Response Activities Have Increased, but FERC Could Improve Data Collection and Reporting Efforts*, GAO-14-73 (Washington, D.C.: Mar. 27, 2014).

[6]Grid infrastructure includes the physical parts of the grid necessary to generate and transmit electricity. These parts include power plants, transmission lines, substations, and distribution lines, among other equipment.

sources. To accomplish this, grid operators typically develop forecasts of future electricity demand based on historical information about customer electricity use combined with assumptions about how customer demand will change in the future based on population growth, economic conditions, and other factors. In general, grid operators assess the adequacy of existing grid infrastructure, identify any capacity needs, and evaluate the cost and effectiveness of potential solutions to address these needs. Potential solutions could include building a power plant to generate additional electricity, building a new transmission line to transport electricity to an area with estimated high future electricity demand, or implementing a program to encourage customers in a high-demand area to use less electricity.

Determining customer prices

State regulators periodically hold proceedings to determine how much customers will pay for electricity, according to our review of several reports from DOE and stakeholders. To determine these prices, state regulators calculate the revenues an electricity supplier will need to cover the supplier's costs. This calculation is based on the total cost of serving electricity customers, such as costs for personnel and fuel. It also includes the cost of investments in infrastructure, such as power plants and transmission lines, plus a level of return on these investments that state regulators determine to be fair. Regulators divide this revenue requirement by an estimate of expected sales in kWh to determine an average price to charge customers (usually in cents per kWh). This calculation is done separately for different customer types—residential, commercial, or industrial. Because these proceedings are complex and time consuming, they are only held periodically, according to our review of several reports. Once prices are established, they often remain fixed until the next proceeding.

Source: GAO review of DOE and stakeholder reports. | GAO-17-142.

Responsibility for regulating the electricity industry is divided between the states and the federal government. Most customers purchase electricity through retail markets. State regulators, often called public utility commissions, generally oversee these markets and the prices retail customers pay for electricity (see sidebar).[7] Before electricity is sold to retail customers, it may be bought, sold, and traded in wholesale electricity markets. The Federal Energy Regulatory Commission (FERC), which oversees wholesale electricity markets, among other things, has statutory responsibility for ensuring that wholesale electricity prices are just and reasonable,[8] and not unduly discriminatory or preferential.

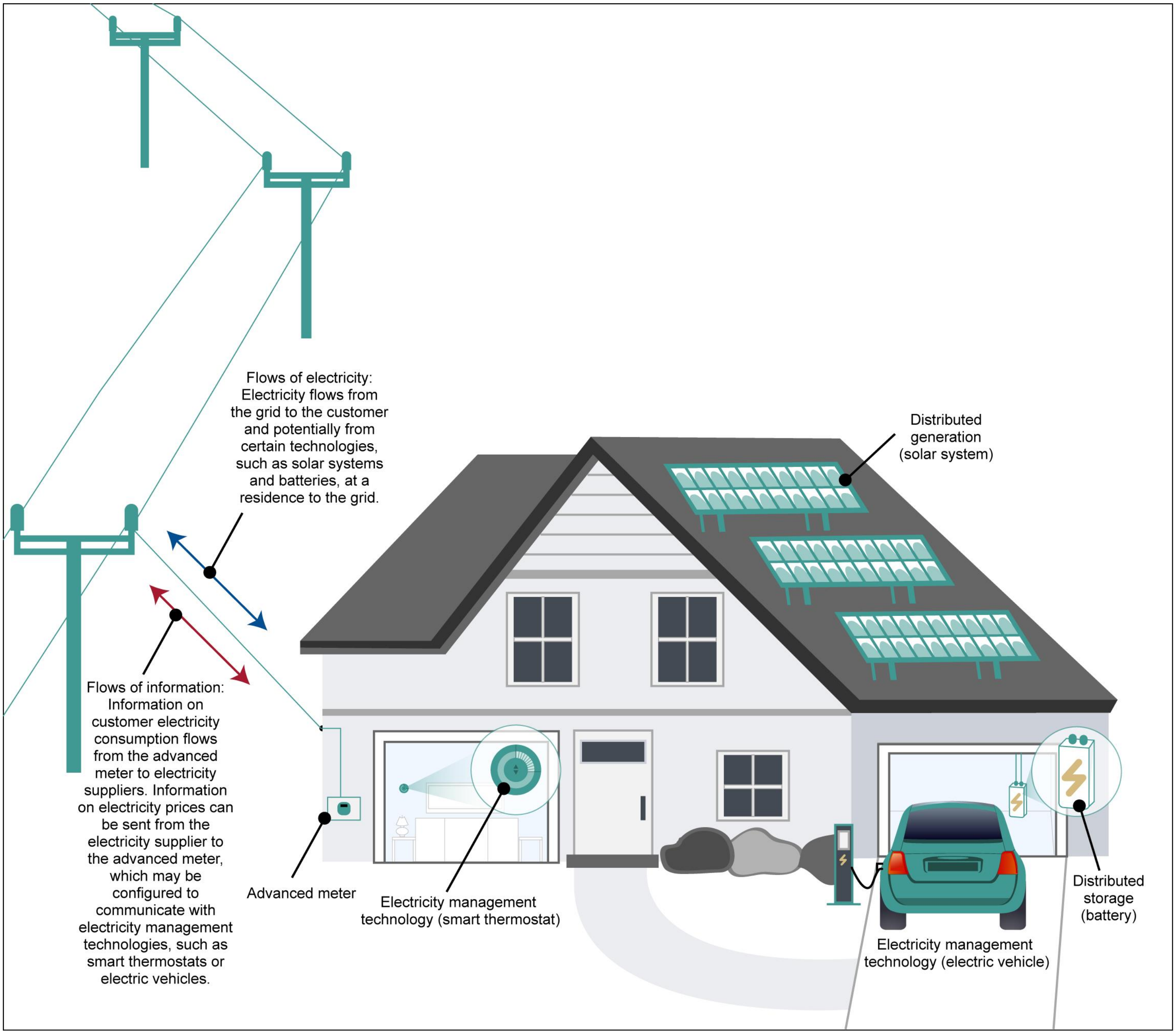
[7]Prices are typically denominated in cents per kilowatt hour (kWh) for residential customers. A kilowatt hour is a common measurement of the amount of energy consumed.

[8]The Federal Power Act does not define "just and reasonable," but FERC and the Supreme Court have interpreted it to mean that rates must fall within "a zone of reasonableness" that balances the interests of electricity suppliers and customers. See 16 U.S.C. §§ 824d - 824e (2016); see also Fed. Power Comm'n v. Hope Natural Gas Co., 320 U.S. 591 (1944); Fed. Power Comm'n v. Conway Corp., 426 U.S. 271 (1976).

Advances in Technologies Available to Customers

Technological innovation in recent years has led to the development and increased availability of new and more advanced technologies that can be deployed where customers live and that give customers greater control over how they use electricity. These technologies can be deployed by customers, electricity suppliers, or third-party providers—independent entities that sell specific products and services to customers. Figure 3 illustrates the deployment of these technologies at a residence.

Figure 3: Example of a Residence with Technologies that Generate, Store, and Manage Consumption of Electricity



Source: GAO. | GAO-17-142

Specifically:

- **Distributed generation systems.** Distributed generation systems are relatively small-capacity electricity generation systems, such as those installed at residences or other customer locations throughout the grid, generally at or near the site where the electricity will be used. A common type of distributed generation system is a solar system, such as solar photovoltaic panels installed on a roof.[9] Solar systems installed at a customer's location allow the customer to generate electricity for their own use and send excess electricity to the grid that electricity suppliers can use to meet other customers' electricity needs. Solar systems utilize inverters—devices installed with the system to convert the electricity it generates into a form usable by the customer and the grid.
- **Advanced meters and associated infrastructure.** Advanced or "smart" meters are deployed at residences and other customers' locations by grid operators to allow them to collect data on customers' electricity use at more frequent intervals than is possible with traditional meters. Advanced meters are integrated with communications networks to transmit meter data to grid operators. This integration can reduce or eliminate the need for grid operator personnel to read meters at a customer's location. Data management systems store, process, and receive data from advanced meters. Certain advanced meters can be enabled to communicate directly with customers' smart devices by sending information, such as electricity prices, that these devices use to take actions such as reducing consumption.[10]
- **Distributed storage systems.** Distributed storage systems—such as batteries located at homes—allow customers to store electricity from the grid or from a distributed generation system for use at a later time. For example, customers with distributed storage systems may store electricity produced from an on-site solar system during the day when

[9]In 2015, solar systems made up 99 percent of distributed generation systems installed by residential customers under a net metering agreement, according to data from EIA. However, other generation technologies can be deployed by residential customers, such as internal combustion engines or distributed wind systems.

[10]For the purposes of this report, advanced meters include basic hourly interval meters and extend to real-time meters with built-in two-way communication capable of recording and transmitting instantaneous data. This excludes less advanced meters that have more limited digital data collection capabilities, referred to as automated meter reading. These less advanced meters collect data for monthly billing purposes only, and they support one-way transmission of data.

their electricity consumption is lower than the amount of electricity the solar system produces. Customers may then use this stored electricity generated by the solar system later in the day, for example, during peak demand periods.

- **Electricity management technologies.** Smart devices—such as smart thermostats, smart appliances, and electric vehicles with automated charging controls[11]—contain electronics capable of automatically adjusting electricity consumption.[12] Smart devices may be controlled by energy management systems that allow customers to automate control of their devices and respond to changing grid conditions. For example, customers could choose to program their electric vehicle to charge at night to avoid charging during peak demand periods.

[11]For the purposes of this report, "electric vehicles" include all-electric vehicles that obtain electricity from the grid as well as plug-in hybrid electric vehicles that are powered by an internal combustion engine that can run on conventional or alternative fuel, with an electric motor that uses energy stored in a battery. Both of these vehicle types can draw electricity from the grid. We do not include in this category hybrid vehicles that cannot draw electricity from the grid.

[12]Historically, less advanced devices have been used by some utilities to facilitate reductions in electricity consumption by residential customers who have pre-arranged agreements to reduce their electricity consumption when needed based on grid conditions. For example, basic communication equipment and switches can be installed to allow grid operators to remotely control some residential customer appliances, such as water heaters, to reduce electricity usage when high system demand poses challenges to the reliable operation of the grid.

Federal and State Policymakers Have Used a Variety of Policies to Encourage Deployment of Solar Systems, Advanced Meters, and Other Residential Technologies

Federal and state policymakers have used a variety of policies to encourage deployment of solar systems, advanced meters, and other residential electricity storage and management technologies.[13] Specifically, policymakers have used (1) federal financial incentives and state electricity policies to encourage residential deployment of solar systems; (2) federal grants and state requirements to encourage residential deployment of advanced meters; and (3) federal and state financial incentives and state deployment targets to encourage residential deployment of electricity storage and management technologies.

Federal Financial Incentives and State Electricity Policies Have Been Used to Encourage Residential Deployment of Solar Systems

Federal and state policymakers have used financial incentives and other policies to encourage residential deployment of solar systems. Many of these policies shorten the expected payback period of solar systems—the period of time it takes customers to realize savings equal to the cost of installation. These policies typically do so by reducing the up-front costs of installation or by increasing the level of expected savings from the system. At the federal level, the government has established tax incentives encouraging residential deployment of solar systems. For example, the Investment Tax Credit provides a tax credit, equal to 30 percent of the cost of installing a solar system, to the owner—either a customer that owns the system or third-party provider that installs and owns the system on behalf of a customer.[14] This tax credit can generally be claimed in full in the tax year during which the system is completed, allowing the customer to immediately offset a large portion of the installation costs.[15] Data are not available on the amount of revenue losses attributable to the use of the federal tax credits for residential solar systems. However, the federal government is expected to forgo billions of dollars in tax revenue as a result of individuals and corporations claiming

[13]Our review focused on methods of direct policy support for the deployment of these technologies, as opposed to research and development activities.

[14]A business that leases a solar system installed on a residential customer's property can also be eligible for this credit on the date the solar system is placed into service.

[15]In order to realize the full benefit of tax incentives, a taxpayer must have sufficient taxable income to use the credits or depreciation deductions over the period of years these incentives are provided.

federal tax credits for installing solar systems and other renewable energy technologies.[16]

At the state level, policymakers have used several types of policies to encourage residential deployment of solar systems.

- **Net metering policies.** Net metering policies implemented by state regulators generally require electricity suppliers to offer net metering programs that credit customers for the electricity they send to the grid from their solar or other distributed generation system. As of July 2016, 41 states had established policies that require electricity suppliers to offer net metering programs to electricity customers, according to the Database of State Incentives for Renewables and Efficiency.[17] Under net metering programs, electricity suppliers generally subtract the amount of electricity customers send to the grid from the amount of electricity they purchase from the grid to determine the net amount of electricity for which customers are billed. This reduces or in some cases eliminates customers' payments for electricity they obtain from the grid. Net metering programs can

[16]In December 2015, the Joint Committee on Taxation estimated that the federal government was expected to forgo $7.7 billion in income tax revenue because of individuals and corporations using the section 48 (26 U.S.C. § 48) Investment Tax Credit for solar systems owned by businesses, including solar systems at residences as well as utility-scale power plants, from fiscal years 2015 through 2019. In addition, the Joint Committee on Taxation estimated that the federal government was expected to forgo $3.0 billion in tax revenue over this period because of homeowners using the section 25D (26 U.S.C. § 25D) residential energy-efficient property credit for qualifying projects, including residential solar systems. According to Internal Revenue Service (IRS) officials, the agency does not collect data isolating the portion of the section 48 Investment Tax Credit used for residential solar systems. For the section 25D residential energy-efficient property credit, IRS officials told us that the agency collects data on credits claimed for qualifying solar property. However, the Joint Committee on Taxation does not separately estimate the revenue loss by fuel type. For more information on the types of federal tax incentives available to encourage solar systems, see GAO, *Electricity Generation Projects: Additional Data Could Improve Understanding of the Effectiveness of Tax Expenditures*, GAO-15-302 (Washington, D.C.: Apr. 28, 2015).

[17]The Database of State Incentives for Renewables and Efficiency is a comprehensive source of information on state incentives and policies that promote renewable energy and energy efficiency. The database is funded by DOE and operated by the North Carolina Clean Energy Technology Center at North Carolina State University. We reviewed their data collection methodologies and found them to be sufficiently reliable for our purposes. For more detail, see appendix I. In addition to the 41 states that require electricity suppliers to offer net metering programs, the database identifies two states that have some electricity suppliers that voluntarily offer net metering programs. The database also identifies four states that have other policies to compensate customers for electricity sent to the grid.

provide more value for customers who pay high electricity prices because these programs often credit customers for electricity they send to the grid at the same retail price they pay to purchase electricity from the grid. For example, a customer facing an electricity price of 23 cents per kWh would receive a $23 bill credit for each 100 kWh increment of electricity sent to the grid, whereas a customer facing a price of 10 cents per kWh would be credited $10 for sending the same amount of electricity to the grid.

- **Policies allowing third-party-owned solar systems.** Some states have adopted policies that make it possible for third-party providers to install solar systems, which the providers own and operate, on residential customers' private homes—thereby allowing solar systems to be deployed on the homes of customers who could not otherwise pay the up-front costs of installing the systems. Under these arrangements, the third-party provider pays to install the solar system, and the customer agrees to buy electricity generated by the solar system or to make lease payments on the system to the third-party provider. As of July 2016, at least 26 states authorized third-party providers to enter into agreements to sell electricity in this way to homeowners, according to the Database of State Incentives for Renewables and Efficiency. Third-party providers may be able to obtain federal tax incentives that are not available to individual homeowners, in addition to claiming the federal Investment Tax Credit.[18] These tax benefits may be passed through, in part, to residential customers in the form of lower prices for electricity purchased from the solar system or more favorable system lease terms.
- **Incentives.** State financial incentives encourage the residential deployment of solar systems by offsetting some of the up-front cost of deploying the systems. For example, as of October 2016, 14 states provided personal tax credits for installing solar systems, according to the Database of State Incentives for Renewables and Efficiency. In addition to tax incentives, states can provide grants, loans, or other financial support to individuals who install solar systems. For example,

[18]For example, the federal tax code allows businesses that own solar, wind, and other energy projects to deduct their depreciation over a 5-year period, rather than over a longer period more reflective of the projects' actual useful life. This accelerated depreciation allows businesses to deduct larger amounts from their taxable income sooner than they would be able to if the systems were depreciated over their useful life. This is beneficial because of the time value of money—having a lower tax payment today is worth more than having the lower payment in the future. For more information about other tax credits, see GAO-15-302.

the California Public Utilities Commission reported that from 2007 to 2016, the California Solar Initiative made available more than $2 billion for a program that funded rebates to residential and other customers who installed solar systems.[19]

- **Other policies.** States have established several other types of policies to encourage the deployment of residential solar systems, as we found in our review of stakeholder reports and the Database of State Incentives for Renewables and Efficiency. These policies are described in table 1.

Table 1: Other State Policies That Can Encourage Deployment of Solar Systems by Residential Customers[a]

Policy	Description	How the policy can facilitate deployment of solar systems
Green banks	States can establish and fund institutions, called green banks that work to develop less expensive financing options for installation of solar systems.	Green banks can provide access to standardized financing products, which can lower third-party providers' installation costs and prices for customers.
Regional Greenhouse Gas Initiative	The Regional Greenhouse Gas Initiative is a mandatory market-based program in the Northeastern United States to reduce greenhouse gas emissions from the power sector. The program caps carbon dioxide emissions from power plants by auctioning a limited number of tradeable emissions allowances for purchase by power plant owners.	Funds generated by auctioning emissions allowances may be used to fund state programs, such as those providing grants or low-interest financing to businesses and homeowners seeking to install rooftop solar systems, among other projects.
Renewable portfolio standards with requirements for distributed generation resources	States can establish a renewable portfolio standard or goal that sets targets for how much electricity is to be generated from renewable sources. In some cases, these standards have specific provisions requiring electricity suppliers to procure electricity from distributed generation systems, including solar systems at residences.	By requiring or encouraging that a portion of the electricity a state consumes comes from specific sources, such as distributed generation, renewable portfolio standards can create market demand for electricity from these sources. Additionally, residential customers installing solar systems in some states with renewable portfolio standards may have access to an additional financial incentive from the sale of renewable energy credits—credits that represent the environmental benefits provided by the system. In some cases these credits can be sold or used to offset the cost of the solar system.

[19]The California Solar Initiative included, among other programs, a general market rebate program for residential and non-residential customers that was available for installation of photovoltaic and other solar technologies. California state officials we interviewed told us that funding for this initiative has ended.

Shared solar system policies	State laws can establish programs that facilitate the deployment of shared solar systems—systems that are jointly owned or whose benefits are shared among separate individual owners. Approximately half of all households are unable to host a solar system because their roofs are too shaded, too small, or owned by a landlord, among other factors, according to a study by the National Renewable Energy Laboratory.[b] Shared solar systems may help increase access to renewable energy for these customers.	Some state regulators have provided incentives for shared solar deployment, such as virtual net metering, which provides a credit on a customer's bill for electricity generated by a shared solar system, based on that customer's assigned portion of the system.
Streamlined interconnection requirements	Interconnection requirements include the technical rules and procedures for allowing customers to connect residential solar and other systems to the grid. Interconnection requirements can add to the cost and complexity of installing solar systems by requiring studies to ensure that systems do not negatively impact how the grid operates.	Some states have worked to streamline interconnection requirements to facilitate deployment of solar systems by, for example, limiting required inspections and ensuring their timeliness.[c]

Source: GAO analysis of stakeholder reports and the Database of State Incentives for Renewables and Efficiency. | GAO-17-142

[a]This table, as well as GAO's work on this report, excludes policies that support research and development into new technologies or to improve existing technologies, which can also affect the economics of deploying technologies.

[b]Department of Energy, National Renewable Energy Laboratory. *Shared Solar: Current Landscape, Market Potential, and the Impact of Federal Securities Regulation*. NREL/TP-6A20-63892 (Golden, CO: April 2015).

[c]According to FERC officials, in November 2013, FERC issued Order No. 792 revising its Small Generator Interconnection Procedures and Agreement to reduce the time and cost to process small generator interconnection requests, maintain reliability, increase energy supply, and remove barriers to the development of new energy resources.

Federal Policymakers Have Used Grants to Encourage Residential Deployment of Advanced Meters, and Some States Have Required Deployment

Federal policymakers have used grants, and state policymakers have used requirements and regulatory decisions, to encourage residential deployment of advanced meters. At the federal level, DOE reported that it provided more than $3.4 billion in grants through its Smart Grid Investment Grant program from 2009 through 2015 for upgrades to the electricity grid, including the deployment of advanced meters. In addition, DOE provided about $600 million through its Smart Grid Demonstration Program for demonstration projects that involved innovative applications of existing and emerging grid technologies and concepts, which supported some additional advanced meter deployments.[20] At the state

[20]Section 1304 of the Energy Independence and Security Act of 2007 directed the Secretary of Energy to establish a Smart Grid Regional Demonstration initiative, and section 1306 directed the Secretary to establish a Smart Grid Investment Matching Grant program, Pub. L. No. 110-140, 121 Stat. 1492, 1786-1791 (2007) (codified at 42 U.S.C. §§ 17384, 17386). Subsequently, funds were provided to DOE under the American Recovery and Reinvestment Act of 2009 to implement these programs, along with others authorized under title XIII of the Energy Independence and Security Act of 2007, as amended. Pub. L. No. 111-5, 123 Stat. 115, 138 (2009).

level, policymakers in some states have enacted policies that require regulated grid operators to deploy advanced meters at residences and other customer locations or to file deployment plans with regulators, according to an EIA analysis.[21] For example, the California Public Utilities Commission established a requirement that the three grid operators it regulates install advanced meters at customers' residences; the commission also authorized the operators to recover associated deployment costs through increased retail electricity prices. In addition, DOE officials told us that regulators in some states have approved proposals from the grid operators they regulate to install advanced meters and recover the costs of installation from customers. However, some state regulators do not have jurisdiction over all grid operators in their state, such as those that are municipally owned; as a result, state regulatory policies may not affect the deployment of advanced meters by all grid operators in a state.

Federal and State Financial Incentives and State Deployment Targets Have Been Used to Encourage Residential Deployment of Electricity Storage and Management Technologies

Federal and state policymakers have used financial incentives, and state policymakers have used deployment targets, to encourage residential deployment of electricity storage and management technologies. The federal government has provided incentives to promote these technologies, though federal support for these technologies has been more limited than federal support for advanced meters and solar systems. For example, DOE funding through both the Smart Grid Investment Grant program and Smart Grid Demonstration Program provided some support for the installation of smart devices, including thermostats that can receive price and other data from electricity suppliers.[22] Furthermore, customers who install residential storage systems potentially are eligible for the Investment Tax Credit when they use the storage system to store energy from their solar system; however, there is no federal tax incentive for stand-alone storage systems. Additionally, customers who purchase a qualifying electric vehicle potentially can receive a federal tax credit of $2,500 plus an additional credit depending on the size of the vehicle's

[21] Department of Energy, Energy Information Administration. *Smart Grid Legislative and Regulatory Policies and Case Studies* (Washington, D.C.: December 2011).

[22] Expenditures in these programs to deploy customer devices were substantially lower than expenditures to deploy advanced meters.

battery.[23] Electric vehicles are primarily used for transportation, but potentially can also be used as an electricity storage and management technology.

At the state level, we identified examples of state policies that have encouraged the deployment of electricity storage and management technologies, based on interviews with stakeholders and our review of state documentation. For example, in 2013, the California Public Utilities Commission set targets for the electricity suppliers that it regulates to procure about 1.3 gigawatts of storage capacity by 2020; this includes procuring capacity from distributed storage systems installed by residential and other customers. In 2012, California's governor issued an executive order focused on reducing greenhouse gas emissions that established a target of having more than 1.5 million zero-emission vehicles—including electric vehicles—on the road in the state by 2025. In addition, the New York State Energy Research and Development Authority partnered with an electricity supplier in the state to provide residential and other customers with a financial incentive of $2.10 per watt for distributed storage systems installed and operational before June 1, 2016 in order to reduce the electricity supplier's peak demand.

The Deployment of Solar Systems and Advanced Meters Has Increased in Some States, but Other Technologies Have Not Been Widely Deployed

The deployment of solar systems and advanced meters has increased, especially in some states, but other technologies have not been as widely deployed. Specifically, our analysis of EIA data indicated that the deployment of residential solar systems has increased significantly in some states, but residential solar systems account for a small portion of nationwide electricity generation. Additionally, our analysis of EIA data indicated that advanced meters have been widely deployed among residential customers in some states, and the use of advanced meters has increased nationwide. However, available information suggests that residential electricity storage and management technologies have not been widely deployed.

[23]This credit begins to phase out for a given company's electric vehicles after the first 200,000 new, qualified plug-in vehicles manufactured by that company are sold. In December 2015, the Joint Committee on Taxation estimated the federal government will collect $1.2 billion less in tax revenue than it otherwise would have from fiscal years 2015 through 2019, due to this tax credit. The IRS collects data on the number of tax returns on which this credit is claimed, but it does not collect or compile data on the number of customers with electric vehicles or their locations, according to IRS officials.

The Deployment of Residential Solar Systems Has Increased Significantly in Some States, but Their Estimated Generation Remains a Small Portion of Nationwide Electricity Generation

Residential customers increasingly deployed solar systems from 2010 through 2015. Specifically, the total number of residential electricity customers with solar systems increased sevenfold over this period, according to EIA data.[24] Despite this significant increase, our analysis of EIA data found that only about 0.7 percent of all residential customers nationwide had installed solar systems in 2015. In addition, residential solar generation was low overall, accounting for approximately 0.1 percent of nationwide electricity generation, according to our analysis of EIA estimates.[25]

At the state level, every state experienced increases in the number of residential customers with solar systems from 2010 through 2015, but certain states accounted for most of the growth, according to EIA data. For example, during this period, more residential customers in California installed solar systems than customers in any other state. Furthermore, California, together with nine other states, accounted for nearly all of the increase in the number of customers with solar systems.[26] The three states with the highest proportion of residential customers with solar systems in 2015 were Hawaii, with more than 14 percent; California, with 4 percent; and Arizona, with 3 percent. These three states had state or local policies that encouraged the installation of solar systems. These policies included net metering policies and policies that allow residential customers to purchase power from third parties that install solar systems on customers' roofs, among others. Figure 4 shows data from EIA on the

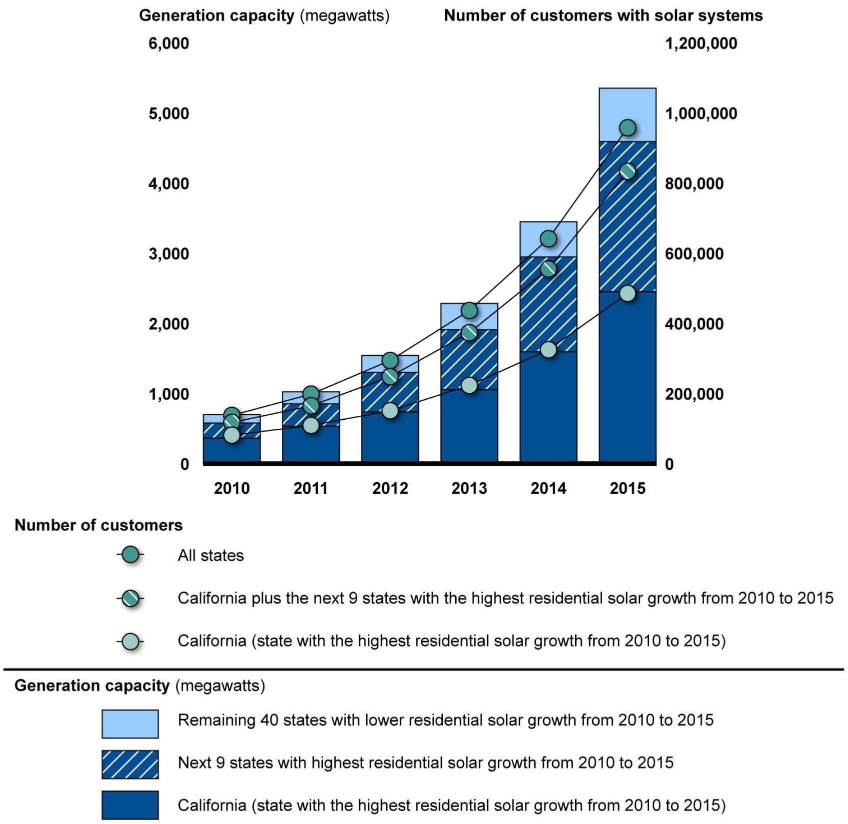
[24]EIA data used for this analysis are reported by electricity suppliers through EIA Form 861. These data include all residential solar systems operated under a net metering arrangement with an electricity supplier. Some residential customers may generate electricity with a system that is not net metered, such as when using a back-up generator; these activities would not be included in the data. For more information on how we conducted our analysis of EIA data, see Appendix I.

[25]Estimates of electricity generation from residential solar systems are from EIA's Electric Power Monthly publication in September 2016. The estimates are based on EIA's modeling of data from its monthly and annual survey of electricity suppliers and other sources, as well as some monthly reported generation estimates.

[26]Specifically, 404,092 additional residential customers in California installed net metered solar systems from 2010 through 2015. The next nine states with the most growth had 311,921 additional residential customers install net metered solar systems during this period. California and the next nine states accounted for 87 percent of new residential, net metered solar system customers over this period. The remaining 40 states had 103,970 additional customers install net metered solar systems from 2010 through 2015 (13 percent).

number of customers who installed solar systems and the systems' total electricity generation capacity from 2010 through 2015.[27]

Figure 4: Number of Customers Installing Residential Solar Systems and the Systems' Total Electricity Generation Capacity, 2010 through 2015



Source: GAO analysis of Energy Information Administration data. | GAO-17-142

Note: After California, the next nine states with the greatest increase in number of customers who installed residential solar systems and growth in total electricity generation capacity, from 2010 through 2015, were (in alphabetical order) Arizona, Colorado, Hawaii, Louisiana, Maryland, Massachusetts, Nevada, New Jersey, and New York, according to EIA data.

In addition to identifying the aforementioned federal and state policies to encourage the deployment of residential solar systems, we identified through our review of reports and discussions with stakeholders that other

[27]Some electricity suppliers and third-party providers also have begun to deploy shared solar systems—systems that are jointly owned or whose benefits are shared among individual participants. Comprehensive data were not available on the extent of residential customer participation in these systems.

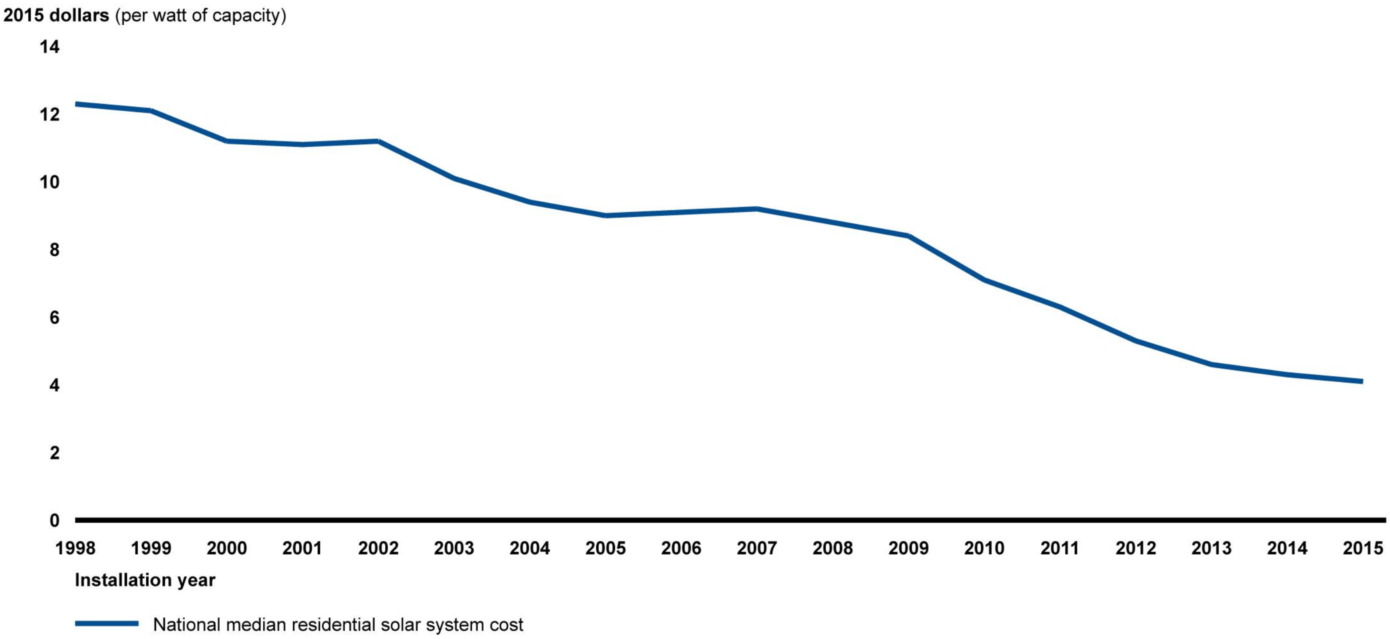
factors—such as increased efficiency, declining system costs, and high electricity prices—also contributed to the deployment of residential solar systems in some states. The efficiency of solar photovoltaic panels has substantially increased across a broad range of manufacturers and panel types over the past several decades, according to a National Renewable Energy Laboratory analysis.[28] As a result, similarly sized panels can produce more electricity, improving the cost effectiveness of systems because customers may need to purchase and install fewer panels to achieve a desired amount of electricity generation. Additionally, recent decreases in the costs of solar systems have made them more economical for residential customers nationwide. DOE's Lawrence Berkeley National Laboratory reported that the national median price to install a residential solar system has decreased since 1998, with the most rapid declines occurring after 2009.[29] (See fig. 5 below.) Based on these data, a 6-kilowatt residential solar system that would have cost about $51,000 in 2009 cost approximately $25,000 in 2015.[30]

[28]National Renewable Energy Laboratory. *Best Research Cell Efficiencies* (Golden, CO: Apr. 20, 2016) accessed Aug. 5, 2016, http://www.nrel.gov/pv/

[29]Barbose, Galen and Darghouth, Naim. *Tracking the Sun IX: The Installed Price of Residential and Non-Residential Photovoltaic Systems in the United States.* Lawrence Berkeley National Laboratory. (Berkeley, CA: August 2016).

[30]The median generating capacity of a residential solar system in 2015 was 6.1 kilowatts, according to Lawrence Berkeley National Laboratory. This generating capacity is based on the direct current rated generating capacity of the solar panels, as is common for residential and commercial solar systems.

Figure 5: Declining Cost of Residential Solar Systems



Source: GAO analysis of data from Lawrence Berkeley National Laboratory. | GAO-17-142

Note: System costs were adjusted for inflation by Lawrence Berkeley National Laboratory and are presented in 2015 dollars. Costs reflect total installed costs per watt of direct current rated electricity-generating capacity of the solar panels. These costs reflect total installed costs excluding the impact of any state or federal incentives, such as the Investment Tax Credit.

High electricity prices in some states also contributed to increasing solar system deployment, according to several stakeholders we interviewed, including electricity suppliers. Solar systems produce savings for customers when the cost of the electricity that the systems generate is lower than the cost of electricity that customers would otherwise have purchased from the grid. Generally, the higher the retail price for grid electricity, the more likely it is that a solar system will be cost effective for customers, according to stakeholders we interviewed. For example, in 2015, Hawaii had the highest retail electricity price for residential customers—29.6 cents per kWh, compared to the national average of 12.7 cents per kWh. Hawaii also had the highest proportion of customers that deployed residential solar systems, with more than 14 percent of residential customers having systems by the end of 2015.

Advanced Meters Have Been Widely Deployed in Some States

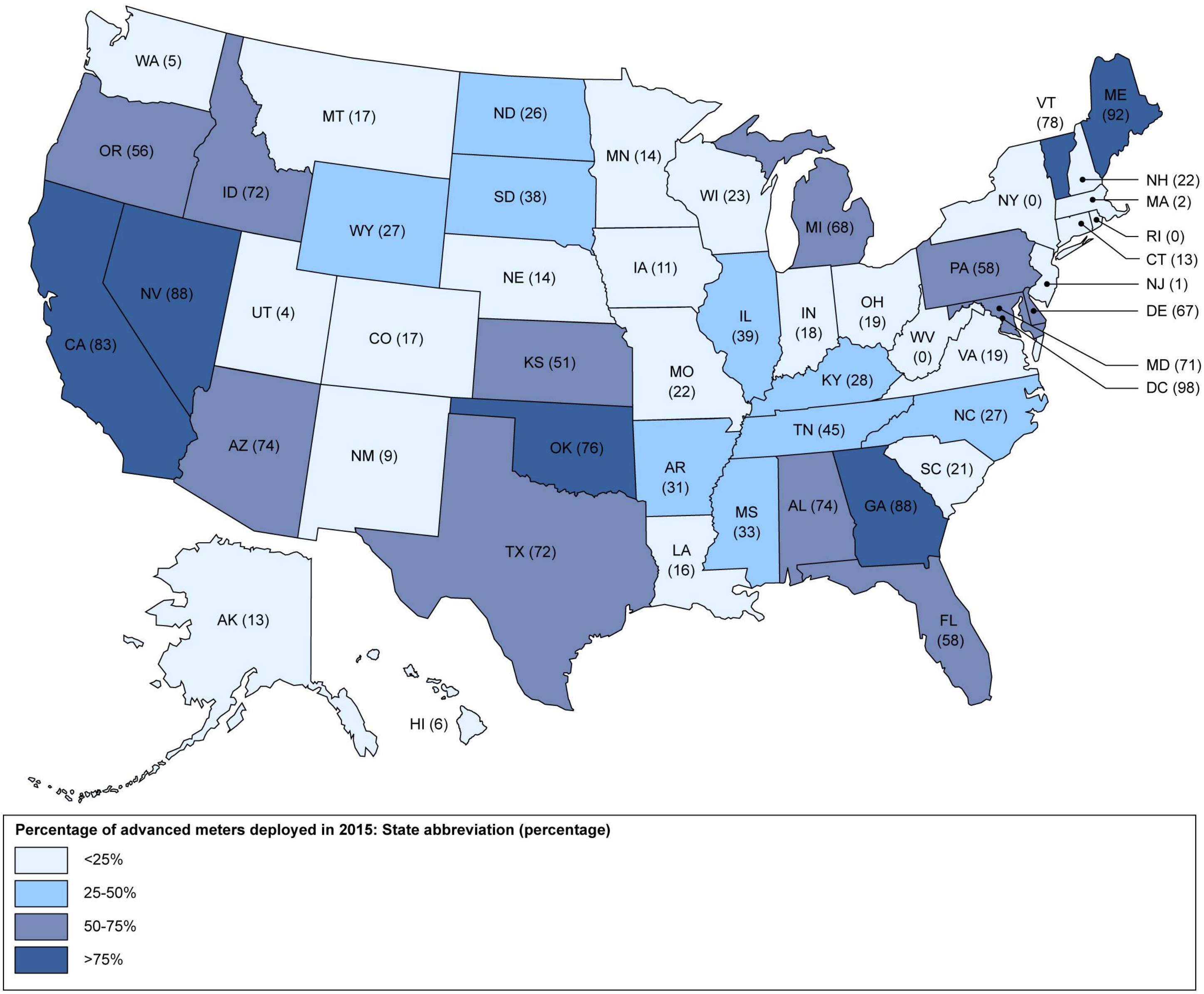
Grid operators widely deployed advanced meters among residential customers in some states from 2007 through 2015, according to EIA data.[31] Nationwide, according to EIA data, the number of advanced meters installed at residences grew 26-fold in recent years, from 2 million meters in 2007 to 57 million meters (43 percent of all residential meters) in 2015. However, as of 2015, levels of advanced meter deployment at residences varied substantially by state, as shown in figure 6. Some states that have experienced widespread deployment of advanced meters—such as California, Maine, and Vermont—had established policies requiring or encouraging grid operators to deploy meters.[32] For example, in California, about 99 percent of the residential meters installed by the state's three regulated grid operators were advanced meters, as of 2015, according to EIA data.[33] Other states, such as New York and Rhode Island, had virtually no advanced meter deployment.

[31]EIA data on advanced meters are from its annual electric power industry report and are based on the results of its Form 861 survey of electricity suppliers.

[32]Customers in California, Maine, and Vermont may opt out of advanced meter installation.

[33]A small number of customers in California chose to keep their traditional meters in exchange for paying an additional fee to cover the cost of reading their meter, according to the California Public Utilities Commission's annual smart grid report. California Public Utilities Commission. *Annual Report to the Governor and the Legislature California Smart Grid per Senate Bill 17 (Padilla, 2009)*. (San Francisco, CA: January 2015).

Figure 6: Advanced Meters as a Percentage of Total Meters Installed at Residences, by State and District of Columbia, in 2015



Sources: GAO analysis of Energy Information Administration data, Map resources (map). | GAO-17-142

In addition to the aforementioned federal and state policies to encourage the deployment of advanced meters, stakeholders we interviewed told us that the economic benefits of installing meters also contributed to their deployment. For example, advanced meters allow electricity suppliers to use fewer personnel and other resources for on-site meter reading. In one case, representatives from a rural cooperative electricity supplier in Arizona said that they began installing some form of advanced meters about 15 years ago, largely because on-site meter readings for their dispersed customer base were time consuming and costly.[34] These representatives said that all of their approximately 40,000 customers now have advanced meters.

Available Information Suggests that Residential Electricity Storage and Management Technologies Have Not Been Widely Deployed

Residential electricity storage and management technologies have not been widely deployed, according to electricity suppliers we interviewed and available data from EIA; however, comprehensive data on their deployment were not available. Residential deployment of distributed storage systems, such as battery storage systems, has been limited, according to representatives from several electricity suppliers we interviewed, although comprehensive data on the deployment of these systems were not available.[35] For example, representatives from one electricity supplier we interviewed said that as of May 2016, there were 72 customers with residential storage systems in their service territory of more than 1 million customers. Similarly, residential deployment of other technologies that can manage electricity consumption—such as smart thermostats, smart appliances, and electric vehicles—is limited, according to several electricity suppliers we interviewed. Comprehensive data are not available on the extent to which residential customers have deployed these electricity management technologies. However, available data from EIA indicate that certain electricity management technologies are becoming increasingly available. Specifically, the number of electric vehicles available for sale has increased from almost none in 2010 to more than 90,000 in 2014, according to EIA data.[36] Several stakeholders told us that several factors have kept the deployment of these technologies low. These factors include high up-front costs for technologies such as distributed storage systems, which can cost a few thousand dollars per system. In addition, as discussed later in this report,

[34]An electric cooperative is an electricity supplier owned by and operated for the benefit of those using its services.

[35]EIA has proposed collecting information on systems that combine distributed generation with storage in its 2017 survey of electricity suppliers, according to a *Federal Register* notice. Agency Information Collection Extension With Changes, 81 Fed. Reg. 31,623 (May 19, 2016).

[36]EIA data are from its annual survey of alternative-fuel vehicles. These data reflect the number of vehicles made available for sale by suppliers and do not directly reflect the number of vehicles sold to or in use by residential customers.

customers may have limited opportunities to receive electricity bill savings that offset these up-front costs.

Increasing Residential Technology Deployment Poses Potential Benefits and Challenges, and Some Policymakers Are Considering Measures to Maximize Benefits and Mitigate Challenges

Solar systems, advanced meters, and electricity storage and management technologies could increase the efficiency of grid operations, but the increasing deployment of residential solar systems has begun to pose challenges for grid management in some areas. Policymakers have implemented or are considering measures to maximize the potential benefits and mitigate the potential challenges associated with the increasing deployment of these technologies.

Solar Systems, Advanced Meters, and Other Technologies Could Increase the Efficiency of Grid Operations and Provide Other Benefits

Solar systems, advanced meters, and electricity storage and management technologies have the potential to lead to more efficient grid operations by enabling individual customers to generate, store, and manage their consumption of electricity in response to conditions on the grid, as we found in our analysis of reports and stakeholder interviews. For example, the supply of electricity must constantly be balanced with demand for electricity, and customers can use these technologies to decrease individual consumption of electricity from the grid when demand is high and increase consumption when demand is low. More efficient grid operations can reduce the cost of producing electricity and reduce the need for investments in additional generation, transmission, and distribution infrastructure, according to several reports we reviewed. Some of these cost savings can result in lower consumer prices.[37] These technologies can provide additional benefits, such as potentially reducing greenhouse gas and other harmful emissions. Several grid operators we

[37]Individual customers who install these technologies may see distinct benefits, such as reduced electricity bills.

interviewed identified various factors that could affect the extent to which these benefits are realized, including where technologies are located, how they are operated, and variations in conditions on the grid, among others. Below we highlight several potential benefits associated with solar systems, advanced meters, and other electricity storage and management technologies identified in our review of reports and interviews with stakeholders:

- **Solar systems.** Several reports we reviewed and stakeholders we interviewed identified examples of how residential solar systems can help make grid operations more efficient. For example, in some locations, electricity generated by solar systems can reduce peak demand for electricity from the grid, which can lower electricity costs. Additionally, because these systems generate electricity near the point where it is consumed, they can potentially reduce how much electricity grid operators have to transmit to customers, which can help defer the need to upgrade distribution or transmission lines, thus avoiding potential cost increases for customers.[38] In addition, grid operators and third-party providers told us that improvements in solar system technologies, such as advanced inverters, may create additional ways for solar systems to increase the efficiency of grid operations. Advanced inverters have a variety of potentially useful functions, including the ability to adjust a solar system's electricity output. Grid operators can use these functions to help balance moment-to-moment changes in electricity demand. In addition, according to several reports we reviewed, solar systems generate electricity without producing greenhouse gas emissions or other harmful pollutants, and electricity generated by these systems can offset the need for electricity generated by power plants that emit these pollutants.[39]
- **Advanced meters.** Advanced meters can improve the efficiency of grid operations by providing grid operators with better information on grid conditions and by enabling customers to manage their generation, storage, and consumption of electricity in ways that align

[38] The ability of solar systems to allow electricity suppliers to defer upgrades to distribution and transmission infrastructure varies by location based on the capacity of existing infrastructure and the extent to which solar systems generate electricity during periods of peak demand.

[39] Greenhouse gases, such as carbon dioxide, trap heat in the atmosphere and are linked to climate change. Other pollutants can include sulfur dioxide and nitrogen oxides, which have been linked to respiratory illnesses and acid rain.

with grid conditions, as we found in examples provided during interviews with several stakeholders and in reports we reviewed. According to DOE officials, advanced meters can provide more detailed information about grid conditions by, for example, notifying grid operators when individual customers have lost electricity service. This information helps grid operators identify and remedy outages in a more timely manner. In addition, advanced meter data collection and communications capabilities, when enabled, can help customers better manage their electricity consumption in ways that align with grid conditions, such as by reducing electricity consumption during peak demand periods.[40] Specifically, advanced meters measure customer electricity consumption data at shorter intervals than traditional meters, and this more detailed information can help customers better understand and adjust their electricity consumption patterns. Additionally, certain advanced meters can communicate information on grid conditions (e.g. periods of high demand) directly to smart devices that can automatically modify their electricity consumption (e.g. by reducing consumption during these periods of high demand).

- **Electricity storage and management technologies.** Technologies that enable customers to store electricity and manage their electricity consumption could help improve the efficiency of grid operations, among other benefits, according to reports we reviewed and stakeholders we interviewed. In particular, customers could use technologies, such as smart thermostats and possibly electric vehicles, to modify their electricity consumption in response to the overall demand for electricity from the grid. For example, a customer could program a smart thermostat to reduce electricity consumption when demand for electricity is high. Likewise, storage systems can store electricity generated at times of low demand for use when demand is high. These systems also can provide other benefits to individual customers, such as giving customers a temporary source of backup electricity in the event of an outage.

Using multiple residential technologies in combination increases the potential to improve the efficiency of grid operations, according to

[40]EIA data indicate that the percentage of customers who have daily access to their electricity consumption data through a web portal or other electronic means is low but increasing—the percentage of residential customers nationwide with this access increased from 22 percent in 2013 to 26 percent in 2015. In addition, EIA data indicate that the percentage of advanced meters that communicate data on electricity prices to smart thermostats and other smart devices is low but growing—the percentage of advanced meters that communicate such data grew from 3 percent in 2013 to 10 percent in 2015.

stakeholders we interviewed and reports we reviewed. For example, while a solar system could reduce demand during peak periods, several grid operators we interviewed told us that peak demand in their service areas occurs in the evening, when solar systems generate little or no electricity. However, a solar system combined with a storage system could store electricity generated during the day for use in the evening, when the demand for electricity is high. In addition, smart devices provide customers with the flexibility to shift their consumption to periods when a solar system is producing electricity so they can make full use of the electricity the system generates.

Increasing Deployment of Residential Solar Systems Has Begun To Pose Grid Management and Other Challenges In Some Areas

Several grid operators we interviewed told us they have begun to experience grid management and other challenges in some areas as deployment of residential solar systems increases, but they said these challenges generally have been manageable because overall deployment of these systems has been low. Several stakeholders we interviewed identified various factors that could affect the extent to which these challenges occur, including where solar systems are located, how they are operated, and variations in conditions on the grid, among others. Several stakeholders also identified similar challenges potentially posed by other residential technologies, although these technologies have not been widely deployed. The challenges we identified in our analysis of reports we reviewed and in the views of stakeholders and federal officials we interviewed include the following:

- **Limited information.** Several grid operators we interviewed told us that they typically only have information on customers' net consumption of electricity from the grid, and they generally do not know (1) how much electricity is being generated by a customer's residential solar system or (2) how much total electricity is being consumed at a customer's location. According to these grid operators, such information is important to effectively manage grid operations and meet customers' total electricity needs at all times. For instance, during periods when a solar system is not producing electricity, such as when clouds or snow prevent sunlight from reaching solar panels, customers may be forced to shift from relying on their solar system to relying on the grid to meet their total electricity needs. For areas with high deployment of residential solar systems, this lack of information can contribute to uncertainty about how best to prepare for and respond to changes in electricity demand, which can, in turn, result in higher costs for customers, as we found in our review of reports. For example, grid operators may need to pay for a greater number of flexible, fast-starting power plants to be on standby to account for changes in demand. If operators had better information, they might not need to have as many plants on standby. Having a greater number of fast-starting plants on standby can raise operating costs, which operators can pass on to all customers in the form of higher electricity bills. Representatives from the transmission system operator in California told us that they also lack information about the electricity usage patterns of electricity storage and management technologies, such as storage systems and customer smart devices. This lack of information could further complicate grid operation and planning if the technologies are added to the grid in increasing numbers.

- **Limited control.** Grid operators generally do not control where residential solar systems are installed or how much electricity these systems produce and when. The installation of solar systems is generally based on customers' preferences, while the amount of electricity that solar systems generate is generally based on the amount of usable sunlight available to the systems. In contrast, grid operators generally control the level of electricity generated by power plants and, in many regions, plan for the types of power plants that are built and where they are located. According to several reports we reviewed, the lack of grid operators' control over solar systems' output can present challenges to these operators and result in additional costs if solar systems' locations and electricity output do not align with grid conditions. For example, according to representatives from a grid operator in Hawaii, high concentrations of residential solar systems in some neighborhoods sent more electricity to the grid than the distribution infrastructure in those neighborhoods was designed to accommodate. These representatives said that this resulted in the need to upgrade the distribution infrastructure to increase the amount of electricity it could accommodate from solar systems; these upgrades in turn resulted in additional costs for customers. In addition, according to representatives from two grid operators we interviewed, a lack of control over rooftop solar systems has, in some circumstances, resulted in the operators reducing the amount of electricity generated by large, renewable power plants under their control, even though electricity from these larger renewable power plants is less expensive to procure than the electricity that grid operators purchase from residential solar systems.[41] Furthermore, the location and operation of other residential technologies—such as storage systems and smart devices—are not controlled by grid operators. Based on our review of several reports, these technologies could mitigate or exacerbate operational challenges depending on how well their use aligns with grid conditions.

- **Lower revenues for electricity suppliers.** Under the traditional business model, electricity suppliers earn revenue when they sell electricity to customers. Customers who install solar systems use less electricity from the grid, and this decline in usage can reduce electricity supplier revenues, according to several reports we reviewed. In addition, net metering policies under which electricity suppliers credit customers for the electricity these customers send to the grid can reduce electricity supplier revenues. Lower consumption of electricity from the grid may produce some cost savings for suppliers (e.g. reduced fuel consumption). However, several electricity suppliers we interviewed told us that many of their costs—such as costs associated with investments they previously made to build and maintain power plants and transmission and distribution lines—are fixed in the short term and will not decline even if solar customers use less electricity from the grid.[42] To the extent that reduced electricity supplier revenues exceed any cost savings from customers' use of solar systems, suppliers may collect insufficient revenues to cover the costs of operating and maintaining the grid, and they may earn a lower financial return, as we found in our review of reports from DOE national laboratories and other stakeholders.[43] Our review of these sources also found electricity storage and management technologies could exacerbate challenges related to lower revenues, for example, if storage systems facilitate further reductions in customers' use of electricity from the grid. According to several reports we reviewed

[41]Under net metering arrangements, electricity suppliers provide customers with credits on their electricity bills for the electricity their solar systems send to the grid. These credits generally offset customers' consumption of electricity from the grid on a one-for-one basis. This means that electricity suppliers are, in effect, paying the retail price for electricity purchased from residential customers' solar systems.

[42]According to several reports we reviewed, solar and other electricity storage and management technologies can, over the long run, allow electricity suppliers to defer or avoid the need for investments in distribution and transmission infrastructure.

[43]State regulators determine an appropriate level of return that electricity suppliers are allowed to earn on their investments in grid infrastructure. However electricity suppliers generally are not guaranteed this level of return, and their return may be lower if electricity sales are lower.

from multiple sources, the greater use of residential storage and electricity management technologies—particularly storage systems—in combination with significantly expanded deployment of solar systems, could lead to a cycle of reduced electricity consumption, declining supplier revenues, and increasing electricity prices, potentially creating long-term financial challenges for electricity suppliers.

- **Cost shifts among customers.** If electricity suppliers collect revenues that are insufficient to cover the costs of operating and maintaining the grid, as a result of lower electricity consumption from customers who have solar systems, some of these costs could be shifted to non-solar customers, according to several reports we reviewed and stakeholders we interviewed.[44] Several electricity suppliers we interviewed expressed concern about cost shifts. Two suppliers told us that while cost shifts had been negligible with low levels of deployment, increasing deployment has made cost shifts more significant. According to an electricity supplier in Arizona, as reported in a 2013 filing to the state regulator, an average of $1,000 in costs per net-metered solar system per year were shifted from residential customers with net-metered solar systems to customers without such systems. This resulted in a shift of an estimated $18 million in total annual costs.[45] Another Arizona electricity supplier told us that in its service territory, costs were often shifted from wealthier customers, who could afford to install residential solar systems, to lower-income customers, such as customers on tribal reservations.

[44]Cost shifts may occur for reasons other than the reduced consumption of electricity that results from the installation of residential solar systems. For example, as customers use energy-efficient lighting and appliances to reduce their consumption of electricity from the grid, costs may shift to other customers who do not use these technologies.

[45]As a result of this filing, the Arizona Corporation Commission ordered Arizona Public Service Company to implement an interim monthly charge on customers who install distributed generation systems on or after January 1, 2014. In the Matter of Arizona Public Service Company's Application for Approval of Net Metering Cost Shift Solution, Decision No. 74202, Docket No. E-01345A-13-0248 (Ariz. Corp. Comm'n, Dec. 3, 2013). Officials from Arizona Public Service Company told us that they have updated the cost shift information in their current rate case docket, and the cost shift estimate is now approximately $860 per net-metered system per year and almost $52 million in total annual cost shift, due to the growth of rooftop solar adoption that has occurred since 2013. In January 2017, in a general rate case on net metering, the Arizona Corporation Commission voted to phase out compensation for electricity sent to the grid at the retail rate, instead establishing a methodology under which future rates will likely be set at lower levels. In the Matter of the Commission's Investigation of Value and Cost of Distributed Generation. Decision No. 75859, Docket No. E-00000J-14-0023. (Ariz. Corp. Comm'n, Jan. 3, 2017).

Nevertheless, according to several reports we reviewed, solar systems can provide benefits to the grid and society, as well as result in financial savings for other customers. Recent estimates of the specific costs and benefits of solar systems have varied widely, according to a DOE national laboratory report we reviewed; these variations have led to differing estimates of the potential cost shifts some customers may face.[46]

- **Increasing complexity of electricity industry oversight.** The increasing deployment of solar systems may increase the complexity of overseeing the electricity industry, according to our analysis of reports and the views of stakeholders we interviewed. For example, increases in residential customers' deployment of solar systems may affect electricity transmission system operations. Residential solar systems, when installed in large enough numbers within a geographic area, can generate electricity that moves onto the transmission system, according to two reports we reviewed. In areas with high solar system deployment, grid reliability problems could cause a large number of these systems to disconnect from the grid at the same time.[47] Such an occurrence could, in turn, cause a rapid drop in the amount of electricity being sent to the grid from these systems and make it challenging for transmission grid operators to maintain the reliable operation of the grid. The installation of residential solar systems is subject to state oversight, while the reliability of the transmission system is subject to FERC oversight.[48] This may complicate oversight and operation of the transmission system as additional solar and other residential technologies are added to the grid. In addition, once solar systems are installed, FERC-regulated transmission system operators generally do not have information and

[46]Lawrence Berkeley National Laboratory and National Renewable Energy Laboratory, *On the Path to SunShot: Utility Regulatory and Business Model Reforms for Addressing the Financial Impacts of Distributed Solar on Utilities,* NREL/TP-6A20-65670 (Golden, CO: May 2016)

[47]Residential solar systems installed with standard inverters are designed to disconnect from the grid when voltage or frequency levels fall outside a specified range for a specified period of time. This design feature is, among other things, intended to ensure electrical worker safety while working on the grid.

[48]Specifically, FERC approves and oversees enforcement of mandatory standards for the reliable operation of the Bulk Electric System, which, according to the North American Electric Reliability Corporation, includes power plants, transmission facilities, and related equipment. These reliability standards do not apply to facilities used in the local distribution of electric energy.

control over the solar systems' operation.[49] Representatives from DOE told us that electricity storage and management technologies also increase the complexity of electricity industry oversight.

Policymakers Have Implemented or Are Considering Measures to Maximize the Benefits of Deploying Residential Technologies, While Mitigating the Challenges

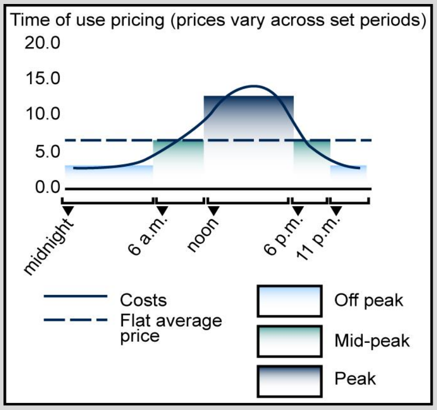
Policymakers in some states and the federal government are considering measures designed to maximize the potential benefits of advanced meters, solar systems, and residential electricity storage and management technologies, while mitigating the potential challenges, based on our analysis of reports and the views of stakeholders we interviewed. For example, based on our review, policymakers are considering measures in several key areas:

- **Prices for electricity purchased from the grid.** Policymakers in several states have implemented or are considering measures to change how customers pay for electricity in order to increase the efficiency of grid operations and provide electricity suppliers with sufficient revenues to maintain the grid. For example, time-based prices—prices that vary throughout the day with demand—can be used to encourage customers to manage their electricity consumption in a way that aligns with conditions on the grid. Specifically, time-based prices are higher when demand for electricity is high and lower when demand for electricity is low, which can encourage customers to shift their electricity consumption from high to low demand times (see sidebar on the following page). However, in 2004, we found that most customers faced unchanging electricity prices, which limited their incentive to respond to changing grid conditions.[50] According to EIA data, as of 2015, only five percent of residential electricity customers nationwide paid time-based electricity prices. Several state regulators recently have allowed electricity suppliers to adopt voluntary time-based prices, and regulators in other states are considering this approach. In addition to time-based prices, policymakers in several states have adopted policies that periodically and automatically adjust customers' electricity prices to ensure that electricity suppliers earn sufficient revenue to cover the costs of operating and maintaining the grid and

[49]In some regions, technologies installed by customers and interconnected through the distribution system can be combined to participate in wholesale electricity markets overseen by FERC. In November 2016, FERC issued a notice of proposed rulemaking to remove barriers to the participation of electric and distributed storage resources in wholesale electricity markets.

[50]GAO-04-844.

Time-based prices



Source: GAO | GAO-17-142

Retail electricity prices historically have been designed to reflect the average cost of serving customers (see dotted line above) for an extended period, up to a year or more, as we found in past GAO work and stakeholder reports. However, as we previously reported, prices also can be designed to vary with the cost of serving retail customers. These time-based prices can be designed in different ways to align with grid conditions, such as in the time-of-use pricing plan illustrated above.

With time-based prices, customers can achieve bill savings by shifting their electricity use from high-cost times to low-cost times. For example, a storage system could be used to store electricity from the grid during times when prices are lower and discharge the stored electricity when prices are higher. Similarly, smart appliances could be programmed to operate during periods when electricity costs are relatively low.

Source: GAO analysis of past work and stakeholder reports| GAO-17-142.

that they earn a rate of return allowed by state regulators.[51] These policies can make electricity suppliers less dependent on selling a specific amount of electricity, because the suppliers earn the same amount of revenue regardless of how much electricity they sell. However, according to two electricity suppliers and a state regulator we interviewed, while such policies help ensure electricity suppliers receive sufficient revenue even as solar systems reduce the amount of electricity that customers purchase, they do not necessarily address concerns about cost shifts among customers.

- **Compensation for electricity sent to the grid.** In order to mitigate challenges related to reduced electricity supplier revenues and cost shifts among customers, among other challenges, policymakers in several states have begun to implement or are considering measures to change how customers are compensated for the electricity they generate and send to the grid.[52] In making this determination, policymakers have considered the benefits that solar systems and other technologies provide as well as any costs that result from the installation of solar systems, among other factors. In October 2015, in Hawaii—a state with high deployment of solar systems and high retail electricity prices—the Hawaii Public Utility Commission closed the state's existing net metering program to new participants and established options for new solar systems, including reducing the price customers would be paid for the electricity they send to the grid.[53] The Commission stated that this would allow the state's electricity suppliers to procure electricity in a more cost-effective manner and reduce electricity costs for all customers. Policymakers in other states have made different decisions about whether and how to modify compensation for electricity sent to the grid based on their assessment of the benefits and costs of distributed solar systems in their states. For example, in California, state regulators made changes to the state's net metering policy that will compensate new

[51]These adjustments can include increasing electricity prices when electricity supplier sales are lower than expected over a given period of time.

[52]State policymakers also have begun to consider various other policy options related to electricity pricing, including minimum bills and higher fixed charges on bills, among others.

[53]The commission established the price change as a 2-year transitional change while the commission continues its work to develop a more comprehensive redesign of policies related to residential technologies. In the Matter of Public Utilities Commission Instituting a Proceeding to Investigate Distributed Energy Resource Policies, Decision and Order No.33258, Docket No. 2014-0192 (Hawaii Pub. Util. Comm'n, Oct. 12, 2015).

solar customers for the electricity they send to the grid at a price that varies throughout the day based on overall customer electricity demand.

- **Grid planning.** Policymakers in several states are beginning to implement or are considering measures to incorporate solar and electricity storage and management technologies into grid planning. In particular, state regulators in California and New York have developed policies requiring regulated electricity suppliers in their states to analyze the grid and identify areas where customer deployment of solar systems and electricity storage and management technologies could provide the greatest benefit, given local grid conditions. Locating combined solar and storage systems in areas where peak demand is projected to exceed the grid's capacity to transmit electricity to customers generally would be more beneficial than locating such a system in an area with ample grid capacity, as we found in our review of reports. For the long term, regulators in New York are considering how prices for electricity could be modified to encourage customers to locate and operate technologies in a way that is most beneficial for grid operation, given conditions throughout the grid, according to state documents we reviewed. Furthermore, according to one stakeholder report we reviewed, electricity prices could be modified to vary by both time and location to provide customers with an economic signal about variations in grid conditions.[54] In addition, some regional transmission operators are beginning to incorporate into their grid planning processes estimates of the future deployment of solar systems, in an effort to identify the extent to which these systems will reduce future demand for electricity from the grid.
- **Technology and data solutions.** Policymakers at the state and federal levels are considering measures to mitigate challenges associated with grid operators' limited information about and lack of control over solar systems as well as to facilitate the greater use of data from advanced meters. For example, efforts are ongoing to develop industry standards to facilitate the development and use of advanced inverters that could provide grid operators with more information about solar systems' electricity generation as well as provide them with some control over these systems' electricity output. Some states—such as California and Hawaii—have begun to develop policies to use advanced inverters for future solar systems that are

[54]Rocky Mountain Institute, *Rate Design for the Distribution Edge: Electricity Pricing for a Distributed Resource Future.* (Boulder, CO: August 2014.)

connected to the grid. Additionally, in 2012, DOE helped launch the Green Button initiative to encourage grid operators to provide customers with electricity usage data from advanced meters in a standardized format.[55] Such standardized data formats allow third-party providers to more easily develop products—such as electricity management software that can control smart devices—and help customers manage their electricity consumption in ways that align with conditions on the grid, according to our review of reports.

- **The role of the electricity supplier.** Policymakers in some states are considering whether the increasing use of solar systems and electricity storage and management technologies necessitate policy changes to ensure electricity suppliers remain financially viable and able to support the reliable operation of the grid. Specifically, some policymakers are considering changes to how electricity suppliers operate and generate revenue, including developing new sources of revenue. For example, according to a publication from the New York State Energy Planning Board, the current business model for electricity suppliers needs reform to ensure electricity suppliers can accommodate and adapt to greater deployment of solar systems and electricity storage and management technologies.[56] As one component of a broad strategy of energy reforms, the New York State Department of Public Service has approved several demonstration projects to identify, among other things, new revenue sources for electricity suppliers. For example, one project involves an electricity supplier in the state administering a website that provides customers with electricity management information and access to third-party providers that sell electricity management products and services. Among other things, this project will evaluate various new sources of revenue for electricity suppliers, such as earning a percentage of revenues from sales of products and services made through this website.
- **Regulatory coordination.** Developing some measures to maximize the benefits and mitigate the challenges associated with the increasing deployment of advanced meters, solar systems, and electricity storage and management technologies may require

[55]More than 50 electricity suppliers have committed to using Green Button, which will provide access to standardized data for more than 60 million homes and businesses, according to DOE. In April 2016, DOE began a similar initiative called Orange Button to standardize data related to solar systems.

[56]New York State Energy Planning Board. *The Energy to Lead: 2015 New York State Energy Plan, Vol. 1* (June 25, 2015.)

coordination between federal and state regulators, as well as others, based on our review of information in reports and the views of stakeholders we interviewed. For example, as we noted in a 2004 report, the actions customers take in response to retail electricity prices can affect the electricity markets under FERC jurisdiction. In recommendations we made in 2004, we emphasized that FERC should continue to coordinate with states and other industry stakeholders to develop complementary policies related to electricity prices.[57] Furthermore, according to DOE officials, among other things, it may be increasingly necessary to integrate electricity distribution and transmission system planning processes and for grid operators and regulators to collaborate to ensure that such technologies do not adversely affect the reliable operation of the transmission system. FERC officials we interviewed agreed that some opportunities exist for FERC and the states to collaborate as technology deployment increases, and they told us that FERC has some mechanisms to achieve such collaboration. Specifically, FERC officials told us that FERC collaborates with the states on issues of emerging interest in a variety of formal and informal settings.[58]

Agency Comments

We provided a draft copy of this report to DOE and FERC for review and comment. DOE and FERC did not provide written comments or indicate their agreement or disagreement with our findings but provided technical comments, which we incorporated as appropriate.

As agreed upon with your offices, unless you publicly announce the contents of this report earlier, we plan no further distribution until 30 days from the report date. At that time, we will send copies to the appropriate congressional committees, the Secretary of Energy, the Chairman of FERC, and other interested parties. In addition, the report will be available at no charge on the GAO website at http://www.gao.gov.

[57] GAO-04-844.

[58] In addition, FERC officials stated that the North American Electric Reliability Corporation—the organization designated by FERC to develop and enforce reliability standards—has examined what changes may be needed to ensure grid reliability with the increasing deployment of small-scale technologies, such as those discussed in this report. FERC said it follows the North American Electric Reliability Corporation's activities, as well as the activities of the states, DOE, and the industry with respect to these technologies.

If you or your staff members have any questions about this report, please contact me at (202) 512-3841 or ruscof@gao.gov. Contact points for our Offices of Congressional Relations and Public Affairs may be found on the last page of this report. GAO staff who made key contributions to this report are listed in appendix III.

Frank Rusco
Director, Natural Resources and Environment

Appendix I: Objectives, Scope, and Methodology

This report examines technologies available to residential customers to generate, store, and manage their consumption of electricity. These technologies include distributed generation systems (e.g. solar systems), advanced meters, distributed storage systems, and electricity management technologies (e.g. electric vehicles and smart devices). Our objectives were to describe (1) key federal and state policies used to encourage the deployment of these technologies, (2) the extent to which these technologies are being deployed, and (3) the benefits and challenges of deploying these technologies.

To address all three of these objectives, we reviewed reports and other documentation, as well as interviewed stakeholders. We identified relevant reports by conducting database and web searches and through suggestions from the stakeholders we interviewed. Specifically, we searched sources including Proquest, Inspec, SciSearch, among others, and the websites of national laboratories and organizations focused on electricity industry research. We selected 20 reports for in-depth review based on their relevance to the residential sector, a focus on commercially available technologies included in our scope, and the source of the report, including the perspective represented by that source. We selected studies from academics and research institutions, such as the Department of Energy's (DOE) national laboratories, as well as studies from industry and other stakeholder groups representing different views. These reports were published from 2013 through 2016. The team also reviewed other documentation, including state regulatory filings made by electricity suppliers, key policy decisions by state and federal regulators, and reports on specific topics relevant to our work.

In addition, we interviewed officials and representatives from 46 government agencies and stakeholder groups.[1] In particular, we interviewed federal officials from DOE, the National Renewable Energy Laboratory, the Lawrence Berkeley National Laboratory, the Federal Energy Regulatory Commission, the Department of the Treasury, and the Internal Revenue Service. Furthermore, we selected stakeholders that provided single-state, regional, and national perspectives based on their experience with the deployment and use of relevant technologies and with policies related to these technologies, and the extent to which the group represented a diversity of perspectives. To select stakeholders

[1]We discussed technologies and policies we identified through our work with these federal officials and stakeholder representatives to confirm that we had identified the key technologies being deployed and the key federal and state policies affecting deployment.

representing single-state perspectives, we used EIA data to identify states that had high deployments of relevant technologies and reviewed state policymaking activity related to these technologies. We selected a non-generalizable sample of five states that have been actively addressing issues related to these technologies: Arizona, California, Hawaii, Minnesota, and New York. We interviewed state regulators and at least one electricity supplier in each state, and, in some cases, additional stakeholders such as state energy departments and consumer advocates. We identified additional stakeholders representing multi-state perspectives through our research, using our past work, and by considering suggestions from other stakeholders. We selected these additional stakeholders to represent different perspectives and experiences and to maintain balance with respect to stakeholders' roles in the market. The stakeholders included industry associations, third-party providers (e.g. solar installers and software vendors), consumer advocacy organizations, academics, electricity suppliers, non-governmental organizations, and regional transmission organizations. Because this was a nonprobability sample of 46 government agencies and stakeholders, views are not generalizable to all potential government agencies and stakeholders. (For a list of stakeholders interviewed, see Appendix II). Throughout the report, we use the indefinite quantifier "several" when three or more stakeholder and literature sources combined supported a particular idea or statement. Our review of policies to encourage deployment focused on methods of direct policy support for the deployment of these technologies, as opposed to research and development activities. In addition, our review did not consider cybersecurity issues or standards for technology interoperability.

To describe the deployment of technologies by residential customers to generate, store, and manage their consumption of electricity, we obtained and analyzed data from the Energy Information Administration's (EIA) survey of electricity suppliers collected on EIA's Form 861.[2] Specifically, we merged data sets on advanced meters, net metering, demand response, distributed generation, dynamic pricing, and retail sales from 2007 through 2015.[3] We calculated yearly totals for key variables,

[2]This survey of electricity suppliers collects information on several aspects of supplier operations, including sales, revenues, and number of customers, as well as information on net metering programs, distributed generation, and advanced meter deployment.

[3]2015 was the latest year of published data from the survey available. For certain data sets, EIA only in later years began collecting data in the categories we analyzed. For example, EIA began collecting net metering data by technology type, such as solar and wind, in 2010.

including: number of advanced meters, number of customers receiving daily access to electricity consumption data, number of residential customers with distributed generation under net metering agreements, and generating capacity of residential customers with distributed generation under net metering agreements, among others. In addition, we calculated percentages to determine the level of deployment, such as the percentage of advanced meters out of all meters and the percentage of residential customers with distributed generation, such as residential solar systems, among others. We analyzed these figures at the national, state, and electricity supplier levels for each year in which data were available. We also obtained and analyzed other data, including: 1) EIA 886 survey data on electric vehicles to determine trends of electric vehicles becoming available in the marketplace each year, 2) EIA estimates of average residential retail electricity prices by state, and 3) EIA estimates on national solar generation by sector. Some technologies, such as battery storage and smart devices, did not have readily available, comprehensive data on deployment. We took several steps to assess the reliability of EIA data. We reviewed relevant documentation, interviewed EIA representatives, reviewed the data for outliers, and addressed outliers through discussions with EIA representatives. In addition, we reviewed available documentation on the Database of State Incentives for Renewables and Efficiency and gathered additional information about the data-gathering practices from knowledgeable representatives at the North Carolina Clean Energy Technology Center, which maintains the database. We determined the data were sufficiently reliable for the purposes of this report.

We conducted this performance audit from September 2015 to February 2017 in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

Appendix II: Government Agencies and Stakeholders Interviewed

1. American Public Power Association
2. Arizona Corporation Commission
3. Arizona Public Service Company
4. C3 Internet of Things
5. California Energy Commission
6. California Independent System Operator
7. California Office of Ratepayer Advocates
8. California Public Utilities Commission
9. Central Hudson Gas & Electric Corporation
10. Clean Energy Collective
11. Con Edison
12. Department of Energy
13. Department of the Treasury
14. Edison Electric Institute
15. Energy Storage Association
16. Federal Energy Regulatory Commission
17. Gridwise Alliance
18. Hawaii Public Utilities Commission
19. Hawaiian Electric Company
20. Internal Revenue Service
21. Interstate Renewable Energy Council
22. James Bushnell, University of California, Davis
23. Lawrence Berkeley National Laboratory
24. Minnesota Public Utilities Commission
25. National Association of Regulatory Utility Commissioners
26. National Renewable Energy Laboratory
27. National Rural Electric Cooperative Association
28. New York Consumer Protection Division - Utility Intervention Unit
29. New York Green Bank
30. New York Independent System Operator

31. New York Public Service Commission
32. New York State Energy Research and Development Authority
33. New York State Smart Grid Consortium
34. NRG Energy
35. Opower
36. Pacific Gas & Electric Company
37. PJM Interconnection
38. Richard Schmalensee, Massachusetts Institute of Technology
39. Rocky Mountain Institute
40. Sacramento Municipal Utility District
41. Solar Energy Industries Association
42. SolarCity
43. Southern California Edison
44. The Utility Reform Network
45. Trico Electric Cooperative
46. Xcel Energy

Appendix III: GAO Contact and Staff Acknowledgments

GAO Contact

Frank Rusco, (202) 512-3841 or ruscof@gao.gov

Staff Acknowledgments

In addition to the contact named above, Jon Ludwigson (Assistant Director), Eric Charles, Paige Gilbreath, and Miles Ingram made key contributions to this report. Important contributions were also made by Antoinette Capaccio, John Delicath, Cindy Gilbert, Michael Kendix, Gregory Marchand, MaryLynn Sergent, Maria Stattel, Sara Sullivan, and Barbara Timmerman.\

Appendix IV: Accessible Data

Data Table for Figure 2: Grid Electricity Demand in California on August 18, 2016

Hour	Sum of All Generation
1	27635
2	26247
3	25317
4	24771
5	24786
6	25585
7	27331
8	28713
9	29944
10	31165
11	32459
12	33878
13	35266
14	37050
15	38828
16	40453
17	41376
18	41411
19	40402
20	39029
21	38267
22	35781
23	32384
24	29327

Data Table for Figure 4: Number of Customers Installing Residential Solar Systems and the Systems' Total Electricity Generation Capacity, 2010 through 2015, Line chart component

Installation Year	Residential
1998	12.3
1999	12.1
2000	11.2
2001	11.1
2002	11.2
2003	10.1

2004	9.4
2005	9.0
2006	9.1
2007	9.2
2008	8.8
2009	8.4
2010	7.1
2011	6.3
2012	5.3
2013	4.6
2014	4.3
2015	4.1

Data Table for Figure 4: Number of Customers Installing Residential Solar Systems and the Systems' Total Electricity Generation Capacity, 2010 through 2015, Line Bar Chart

Location	2,010	2,011	2,012	2,013	2,014	2,015
California, residential solar generating capacity	362.404	529.795	734.319	1053.345	1592.605	2448.731
Next 9 states with highest growth, residential solar generating capacity	215.035	323.114	563.928	854.122	1352.318	2139.181
Remaining 40 states' residential generating solar capacity	119.511	169.401	241.138	374.239	502.11	763.198

Data Table for Figure 5: Declining Cost of Residential Solar Systems

Installation Year	Residential
1998	12.3
1999	12.1
2000	11.2
2001	11.1
2002	11.2
2003	10.1
2004	9.4
2005	9.0
2006	9.1
2007	9.2
2008	8.8

2009	8.4
2010	7.1
2011	6.3
2012	5.3
2013	4.6
2014	4.3
2015	4.1

Data Table for Figure 6: Advanced Meters as a Percentage of Total Meters Installed at Residences, by State and District of Columbia, in 2015

States	Residential - AMI meters as a percent of all meters 2015	Category
AK	13	<25%
CO	17	<25%
CT	13	<25%
HI	6	<25%
IA	11	<25%
IN	18	<25%
LA	16	<25%
MA	2	<25%
MN	14	<25%
MO	22	<25%
MT	17	<25%
NE	14	<25%
NH	22	<25%
NJ	1	<25%
NM	9	<25%
NY	0	<25%
OH	19	<25%
RI	0	<25%
SC	21	<25%
UT	4	<25%
VA	19	<25%
WA	5	<25%
WI	23	<25%
WV	0	<25%
CA	83	>75%

DC	98	>75%
GA	88	>75%
ME	92	>75%
NV	88	>75%
OK	76	>75%
VT	78	>75%
AR	31	25-50%
IL	39	25-50%
KY	28	25-50%
MS	33	25-50%
NC	27	25-50%
ND	26	25-50%
SD	38	25-50%
TN	45	25-50%
WY	27	25-50%
AL	74	50-75%
AZ	74	50-75%
DE	67	50-75%
FL	58	50-75%
ID	72	50-75%
KS	51	50-75%
MD	71	50-75%
MI	68	50-75%
OR	56	50-75%
PA	58	50-75%
TX	72	50-75%

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