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# Electricity end uses, energy efficiency, and distributed energy resources baseline

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Any remaining errors, omissions, or mischaracterizations are the responsibility of the authors.


## Disclaimer

## Scope and Organization

This report was developed by a team of analysts at Lawrence Berkeley National Laboratory, with Argonne National Laboratory contributing the transportation section, and is a DOE EPSA product and part of a series of "baseline" reports intended to inform the second installment of the Quadrennial Energy Review (QER 1.2). QER 1.2 provides a comprehensive review of the nation's electricity system and cover the current state and key trends related to the electricity system, including generation, transmission, distribution, grid operations and planning, and end use. The baseline reports provide an overview of elements of the electricity system. This report focuses on end uses, electricity consumption, electric energy efficiency, distributed energy resources (DERs) (such as demand response, distributed generation, and distributed storage), and evaluation, measurement, and verification (EM&V) methods for energy efficiency and DERs.

Chapter 1 provides context for the report and an overview of electricity consumption across all market sectors, summarizes trends for energy efficiency and DERs and their impact on electricity sales, and highlights the benefits of these resources as well as barriers to their adoption. Lastly it summarizes policies, regulations, and programs that address these barriers, highlighting crosscutting approaches, from resource standards to programs for utility customers to performance contracting.

Chapters 2 through 5 characterize end uses, electricity consumption, and energy efficiency for the residential, commercial, and industrial sectors as well as electrification of the transportation sector. Chapter 6 addresses DERs—demand response, distributed generation, and distributed storage.

Several chapters in this report include appendices with additional supporting tables, figures, and technical detail. In addition, the appendix also includes a separate section that discusses current and evolving EM&V practices for energy efficiency and DERs, approaches for conducting reliable and cost-effective evaluation, and trends likely to affect future EM&V practices.

## Description of Energy Models[a]

Unless otherwise noted, this report provides projections between the present-day and 2040 using the "EPSA Side Case," a scenario developed using a version of the Energy Information Administration's (EIA's) National Energy Modeling System (NEMS). Since the EPSA Side Case was needed for this and other EPSA baseline reports in advance of the completion of EIA's Annual Energy Outlook (AEO) 2016, it uses data from EIA's AEO 2015 Reference Case, the most recent AEO available at the time. However, since AEO 2015 did not include some significant policy and technology developments that occurred during 2015, the EPSA Side Case was designed to reflect these changes.

The EPSA Side Case scenario was constructed using EPSA-NEMs,[b] a version of the same integrated energy system model used by EIA. The EPSA Side Case input assumptions were based mainly on the final release of the 2015 Annual Energy Outlook (AEO 2015), with a few updates that reflect current technology cost and performance estimates, policies, and measures, including the Clean Power Plan and tax credits. The EPSA Side Case achieves the broad emissions reductions required by the Clean Power Plan. While states will ultimately decide how to comply with the Clean Power Plan, the Side Case assumes that states choose the mass-based state goal approach with new source complement and assumes national emission trading among the states, but does not model the Clean Energy Incentive

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[a] Staff from DOE's Office of Energy Policy and Systems Analysis authored this description.
[b] The version of the National Energy Modeling System (NEMS) used for the EPSA Side Case has been run by OnLocation, Inc., with input assumptions by EPSA. It uses a version of NEMS that differs from the one used by the U.S. Energy Information Administration (EIA).

Program because it is not yet finalized. The EPSA Side Case also includes the tax credit extensions for solar and wind passed in December 2015. In addition, cost and performance estimates for utility-scale solar and wind have been updated to reflect recent market trends and projections, and are consistent with what was ultimately used in AEO 2016. Carbon capture and storage (CCS) cost and performance estimates have also been updated to be consistent with the latest published information from the National Energy Technology Laboratory.

As with the AEO, the EPSA Side Case provides one possible scenario of energy sector demand, generation, and emissions from present day to 2040, and it does not include future policies that might be passed or unforeseen technological progress or breakthroughs. EPSA-NEMS also constructed an "EPSA Base Case" scenario, not referenced in this report, which is based primarily on the input assumptions of the AEO 2015 High Oil and Natural Gas Resource Case. Projected electricity demand values forecast by the EPSA Base Case and Side Case are very close to each other (within 3% by 2040). However, the values forecast by the EPSA Base Case are closer to those that were ultimately included in the AEO 2016 Reference Case.

EPSA Side Case data also are used when most-recent (2014) metrics are reported as a single year or are plotted with future projections. Doing so ensures consistency between current and forecasted metrics. Overlapping years between historical data and data modeled for forecasts are not necessarily equal. Historical data are revised periodically as EIA gathers better information over time, while forecasted cases, which report a few historical years, do not change once they are released to the public.

# List of Acronyms and Abbreviations

| Acronym / Abbreviation | Stands For |
|---|---|
| ACEEE | American Council for an Energy-Efficient Economy |
| AEO | Annual Energy Outlook |
| AMI | advanced metering infrastructure |
| AMO | DOE Advanced Manufacturing Office |
| ARRA | 2009 American Recovery and Reinvestment Act |
| ASHRAE | American Society of Heating, Refrigerating, and Air-Conditioning Engineers |
| BEV | Battery Electric Vehicle |
| CAFE | Corporate Average Fuel Economy |
| CAISO | California ISO |
| CBECS | Commercial Buildings Energy Consumption Survey |
| CFLs | compact fluorescent lamps |
| CHP | Combined Heat and Power |
| $CO^2$ | carbon dioxide |
| CPP | Clean Power Plan |
| CPP | Critical Peak Pricing |
| CPUC | California Public Utilities Commission |
| CSE | cost of saved energy |
| CUVs | crossover utility vehicles |
| DCLM | Direct Control Load Management |
| DER | Distributed Energy Resources |
| DOE | U.S. Department of Energy |
| DSM | demand side management |
| DSO | Distribution System Operator |
| EAC | DOE's Electricity Advisory Committee |
| EERS | energy efficiency resource standard |
| EIA | U.S. Energy Information Administration |
| EM&V | Evaluation, Measurement, and Verification |
| EMCS | Energy Management Control Systems |
| EPA | U.S. Environmental Protection Agency |
| EPSA | DOE Office of Energy Policy and Systems Analysis |
| ERCOT | Electric Reliability Council of Texas |
| ESCOs | energy service companies |
| FCTO | DOE's Fuel Cell Technology Office |
| FCV | Fuel Cell Vehicle |
| FEMP | Federal Energy Management Program |
| FERC | Federal Energy Regulatory Commission |
| FFV | Ethanol Flex-Fuel Vehicle |
| FITs | feed-in tariffs |
| FRCC | Florida Reliability Coordinating Council |
| GDP | gross domestic product |

| Acronym / Abbreviation | Stands For |
|---|---|
| GHG | greenhouse gases |
| GWP | global warming potential |
| HEVs | hybrid electric vehicles |
| HOV | high-occupancy vehicle |
| HVAC | heating, ventilation, and air-conditioning |
| Hz | hertz |
| ICEs | internal combustion engines |
| ICLEI | International Council for Local Environmental Initiatives |
| ICT | information and communication technologies |
| IDM | Industrial Demand Module |
| IECC | International Energy Conservation Code |
| IEMS | Industrial Energy Management Systems |
| IL | Interruptible Load |
| INL | Idaho National Laboratory |
| IRP | integrated resource planning |
| ISO | Independent System Operator |
| ISO-NE | ISO-New England, Inc. |
| ITC | investment tax credit |
| kWh | kilowatt-hours |
| LBNL | Lawrence Berkeley National Laboratory |
| LCOE | levelized cost of electricity |
| LCR | Load as a Capacity Resource |
| LDV | light-duty vehicle |
| LED | light emitting diode |
| LEED | Leadership in Energy and Environmental Design |
| Li-ion | Lithium-ion |
| LMP | locational marginal pricing |
| LR | learning rate |
| LSE | load serving entity |
| MATS | Mercury and Air Toxics Standards |
| MECS | Manufacturing Energy Consumption Survey |
| MELs | Miscellaneous Electric Loads |
| MISO | Midcontinent Independent System Operator |
| MMWh | million megawatt-hours |
| MRO | Midwest Reliability Organization |
| MRO-MAPP | Midwest Reliability Organization-Mid-Continent Area Power Pool |
| MUSH | municipalities, universities, schools, and hospitals |
| NEMS | National Energy Modeling System |
| NERC | North American Electricity Reliability Council |
| NPCC | Northeast Power Coordinating Council |
| NPCC-NE | NPCC-New England |

| Acronym / Abbreviation | Stands For |
|---|---|
| NPCC-NY | NPCC-New York |
| NREL | National Renewable Energy Laboratory |
| NYISO | New York ISO |
| ORNL | Oak Ridge National Laboratory |
| PACE | Property Assessed Clean Energy |
| PC | personal computer |
| PCTs | programmable communicating thermostats |
| PEV | plug-in electric vehicle |
| PHEV | Plug-in Hybrid Electric Vehicle |
| PJM | PJM Interconnection, LLC |
| PTC | production tax credit |
| PV | photovoltaic |
| QER | Quadrennial Energy Review |
| QTR | Quadrennial Technology Review |
| R&D | research and development |
| RD&D | Research, development, and deployment |
| RECS | Residential Energy Consumption Survey |
| RETI | Real estate business trust |
| REV | "Reforming the Energy Vision" |
| RFC | Reliability First Corporation |
| RTO | Regional Transmission Organization |
| RTP | real-time pricing |
| SDG&E | San Diego Gas and Electric |
| SEIA | Solar Energy Industries Association |
| SERC | Southeast Electric Reliability Council |
| SERC-E | Southeast Electric Reliability Council -East |
| SERC-N | Southeast Electric Reliability Council -North |
| SERC-SE | Southeast Electric Reliability Council -Southeast |
| SGIG | Smart Grid Investment Grant |
| SPP | Southwest Power Pool, Inc. |
| SSL | solid-state lighting |
| TBtu | trillion British thermal units |
| TOU | time-of-use pricing |
| TRE | Texas Reliability Entity |
| TRE-ERCOT | TRE-Electric Reliability Council of Texas |
| TWh | terawatt-hours |
| USDA | U.S. Department of Agriculture |
| V2B | vehicle-to-building |
| V2H | vehicle-to-home |
| VAR | volt-ampere reactive |
| VOS | value of shipments |
| VTO | DOE's Vehicle Technologies Office |

| Acronym / Abbreviation | Stands For |
|---|---|
| WECC | Western Electricity Coordinating Council |
| WECC-CA-MX | WECC-California-Mexico Power |
| WECC-NWPP | WECC-Northwest Power Pool |
| WECC-RMRG | WECC-Rocky Mountain Reserve Group |
| WECC-SRSG | WECC-Southwest Reserve Sharing Group |
| ZEV | Zero Emission Vehicle |
| ZNEB | Zero-Net Energy Building |

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# Executive Summary[a]

This report is one of series of "baseline" reports intended to inform the second installment of the Quadrennial Energy Review (QER 1.2). QER 1.2 provides a comprehensive review of the nation's electricity system and cover the current state and key trends related to the electricity system, including generation, transmission, distribution, grid operations and planning, and end use. This report focuses on end uses, electricity consumption, electric energy efficiency, distributed energy resources (DERs) (such as demand response, distributed generation, and distributed storage), and evaluation, measurement, and verification (EM&V) methods for energy efficiency and DERs.[b]

The report provides an overview of electricity consumption across all sectors, and summarizes cost, technology, and other trends for energy efficiency and DERs and their impact on electricity supply and demand. This report also describes the benefits of these resources as well as barriers to their adoption by examining a number of cross-sector and sector-specific policies, regulations, and programs.

Unless otherwise noted, the projections included in this report are drawn from an EPSA Side Case created by the U.S. Department of Energy's (DOE's) Office of Energy Policy and Systems Analysis (EPSA). This EPSA Side Case is a projection for the electric generation sector through 2040 that was formulated using a version of the National Energy Modeling System (EPSA-NEMS).

## Electricity Overview

In 2014, electricity accounted for 18% of U.S. delivered energy [c] [1]and 39% of total primary energy consumption (or 38.4 quads of energy).[d] The electric power sector also generated 30.3% of the nation's total GHG emissions.[e] [2] The residential and commercial sectors each consumed about the same share of total electricity —38% and 36%, respectively —with the industrial sector accounting for 26% of electricity demand. Electricity use in the transportation sector is minimal, constituting less than 1% of total U.S. electricity consumption.[3]

Since the 1950's, growth in U.S. electric consumption has gradually slowed each decade (See Figure ES-1). A number of factors have led to this gradual slowing of electricity demand, including "slowing population growth, market saturation of major electricity-using appliances, efficiency improvements in appliances, and a shift in the economy toward a larger share of consumption in less energy-intensive industries." [4] Looking forward to 2040, the EPSA Side Case projects electricity use to grow slowly and its share of total delivered U.S. energy consumption is expected to increase slightly, from 18% to 20%.[f] [g]

Energy efficiency policies—such as building energy codes, appliance and equipment standards and labeling, and targeted incentives—have played a significant role in slowing the growth of electricity

[a] Staff from DOE's Office of Energy Policy and Systems Analysis authored the Executive Summary, with input and guidance from the report authors.

[b] EPSA considers DERs to include Distributed Generation, Distributed Storage, and Demand-Side Management Resources (including energy efficiency). End-use energy efficiency is often reported separately from other DERs, though it technically constitutes a DER since implementation occurs on the premises of an end-user.

[c] The remaining 82% is comprised of petroleum and other liquid fuels (49%), natural gas (27%), and all other fuels (coal, biofuels, and renewable resources) represent 6%.

[d] 38.4 quads were used to generate 3,900 TWh of electricity. Total energy consumption in 2014 was 98.3 quads.

[e] In 2014, the Electric Power Industry generated a total of 2,080.7 MMT $CO_2e$, or 30.3% of total U.S. greenhouse gas emissions.

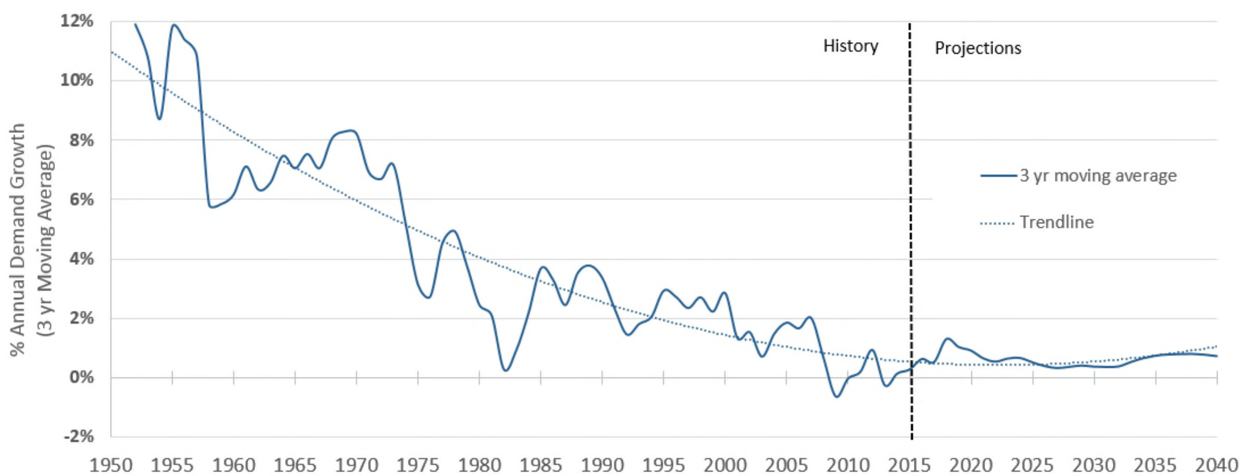
[f] Between 2014 and 2040, electricity use is projected to grow at an annual rate of 0.65%. In terms of delivered energy, electricity will increase from 18% to 20% of total U.S. energy consumption, a roughly 18% increase from 12.76 to 15 quads.

[g] In terms of total primary, or source energy, the electric sector will increase from 13% to 14%.

consumption. Advances in technology and the continued growth of the broader energy efficiency and energy management industry have also played important roles in achieving significant levels of energy savings.

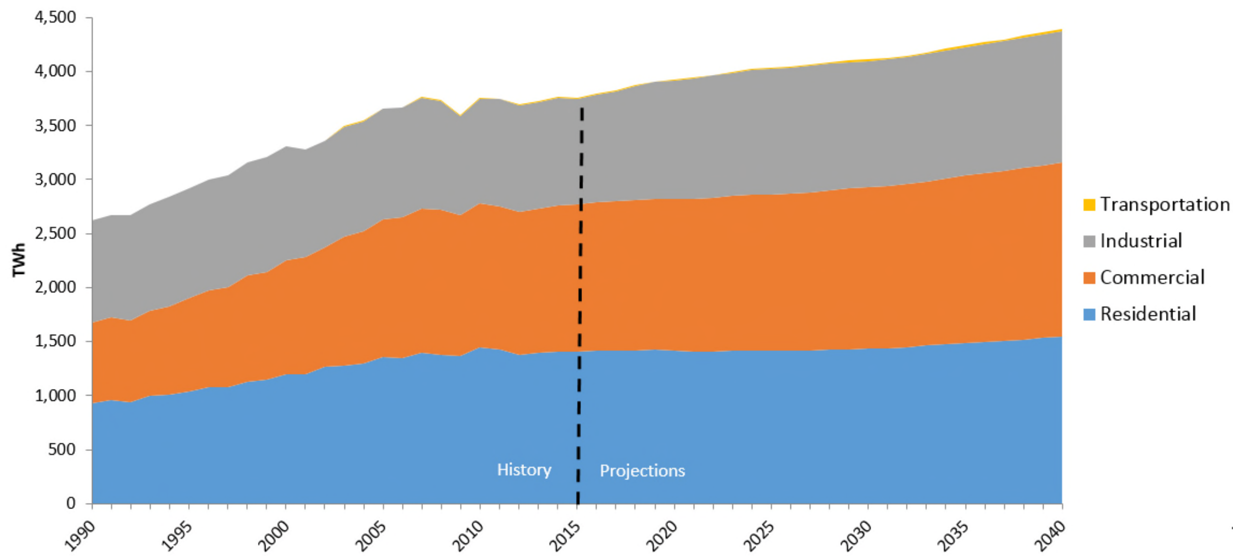
In recent years, there has been significant growth in distributed generation, particularly rooftop solar PV, which has been fostered by lower installation and hardware costs and supportive policies, such as net metering and renewable portfolio standards with set-asides or multipliers for distributed generation. Electric vehicles have the potential to transform both the transportation and utility sectors. Over time, as distributed energy resources grows, consumer demand will be met by a more diverse mix of non-traditional grid-sourced electricity and from sources like distributed generation and distributed storage. Such developments would pose both challenges and opportunities for grid operators.

**Figure ES-1. U.S. retail electric sales – average demand growth, 1950–2040[5]**




*Growth of electricity demand, expressed here as annual percentage change over a three-year moving average, has slowed in each decade since the 1950s. Data includes all sectors, including transportation.*

**Figure ES-2. U.S. electricity consumption by sector, 1990–2040[6] [7]**




*EPSA Side Case Projections begin in year 2015. Electricity is measured in terms of site consumption.*

## Key Findings: Cross-Sector

State Policies and Utility Programs: *States that have actively created and implemented resource standards, ratepayer-funded programs, and other supporting regulatory policies[a] have seen the greatest growth in energy efficiency and DERs.*

Resource standards have established clear goals that are driving state and utility initiatives to spur demand-side resources, including energy efficiency, distributed generation, combined heat and power, and others. Ratepayer-funded incentives for high efficiency products and other investments are now widespread. They have been most prevalent when supported by state regulatory policies. However, many states and utilities have not adopted policies and programs that enable demand-side resources to be fully exploited. While 16 states are achieving at least 1% in energy efficiency savings through rate-payer funded programs (as a percent of total annual retail electricity sales), 15 states are saving less than 0.25%.[8]

Regional and Demographic Considerations: *One key driver of the slow, but steady increase in total U.S. electricity consumption is internal population migration. Opportunities to improve energy efficiency and usage of DERs vary by climate and household demographics, so tailoring programs to local needs is important.*

The West and South Census regions, where average household electricity consumption is higher than other regions,[b] are both experiencing high population growth rates. Housing stock also varies by Census region—for example the South has a higher proportion of manufactured homes and the Northeast has

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[a] An energy efficiency resource standard (EERS) is a quantitative, long-term energy savings target for utilities that can include targets for peak load demand reduction as well as energy efficiency (see Appendix Section 7.2.1). A state Renewable Portfolio Standard (RPS) requires utilities and other electricity suppliers to purchase or generate a targeted amount of qualifying renewable energy or capacity by specified dates.

[b] Electricity use for space heating is particularly high in the South Census Region. The South, and to a lesser extent the West, Census regions also have high cooling loads. See Figure 2.9.

higher proportions of single-family attached homes and apartment units. By occupant demographic, lower-income households use less energy (MWh/household) compared to higher-income households, but pay considerably more of their after-tax income on electricity expenditures.[a] In addition, renters pay 26.7% more on energy expenditures per sq. foot compared to homeowners.[b] [9] Effective solutions for improving energy efficiency for these and other populations exist, such as targeted marketing and outreach, but deployment varies widely by state.

Public Sector Initiatives: *Efforts at the federal, state and local level are resulting in large energy savings in government and institutional buildings.*[c] [10] *This leadership will continue to play an important role in encouraging broader market adoption of energy efficiency and DERs.*

Public procurement has often been focused on high-efficiency products, and improved contracting structures have led to the widespread use of performance contracting and energy service companies. In support of Executive Order 13693, the federal government has also created goals for renewable energy and energy efficiency adoption throughout its facilities.[d] [11]

Increasing Electrification: *Electrification of end-uses and technologies is continuing to occur gradually across all sectors, further increasing the need for continued improvements in energy efficiency.*

Most new end-use services are powered by electricity, and population and economic growth tends to be concentrated in regions and sectors where reliance on electricity is greater. Plug-in hybrid and all-electric light duty vehicles are beginning to increase electricity use in the transport sector. In addition, the long-term objective of largely decarbonizing the economy[12] may ultimately require increased electrification. All of these trends mean that the U.S. population and economy are very likely to become increasingly dependent on electricity services, which heightens the need to ensure electric system security and reliability.

Evaluation, Measurement, and Verification (EM&V) Practices: *Credible and transparent EM&V practices are critical in supporting the successful implementation and expansion of energy efficiency and DERs. These practices are particularly important in evaluating utility demand-side programs and performance contracts, and are continually advancing as technologies and analytical tools improve.*

EM&V practices have continued to improve and evolve over time, driven by increased investment in energy efficiency and DERs and accelerated development of new technologies and analytical tools. Advances in EM&V technologies and methods are also driven by the increased importance of quantifying non-energy impacts such as avoided emissions, grid impacts, system reliability, economic development, and consumer benefits (e.g., increased comfort and productivity). The increased deployment of advanced metering infrastructure (AMI), wireless and non-intrusive load metering, and improved analytical tools, collectively referred to as "M&V 2.0," has the potential to lower costs, increase the speed at which results are available, and provide more accurate savings calculations. Other

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[a] See Figure 2.11. For example, electricity accounts for 4.2% of after-tax income for households earning between $30-40,000 annually. Households with annual after-tax income of $100-120,000 spend only 1.8% on electricity expenditures.
[b] Note that total energy expenditures includes non-electricity sources such as natural gas and heating oil.
[c] For example, between FY 2003–2014, federal buildings subject to National Energy Conservation Policy Act energy reduction goals collectively decreased total electricity use per total gross square footage (Btu/GSF) by approximately 13.8%.
[d] Executive Order 13963, Planning for Federal Sustainability in the Next Decade, was released in March 2015 and established goals for use of 25% renewable energy by 2025 and 2.5% annual reductions in building energy intensity (btu/gross square foot).

advances, such as in the development of big data and non-energy impact analytical tools, are also improving the cost-effectiveness and value of EM&V.

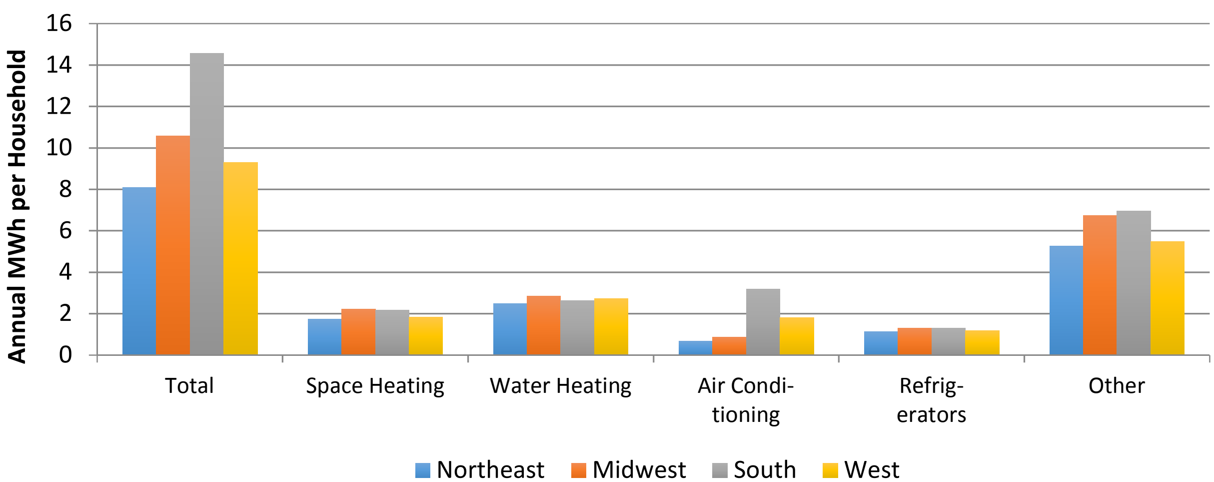
## Residential, Commercial, and Industrial Sector Trends

### Residential Sector Trends

The residential sector accounts for about 38% of total U.S. electricity demand. Single-family detached homes consume the majority—74%—of electricity consumption across the nation's total stock of 113.6 million homes.[13] Residential electricity consumption increased steadily between 1990 and 2007, but in more recent years there has been little or no annual growth. Improvements in the electricity productivity (MWh/household) of the residential sector, largely attributed to the increasing efficiency of most end-uses, have led to this recent period of low growth. Electricity usage per capita and per square foot are declining. As a result, under business-as-usual assumptions, total electricity consumption is projected to increase very slowly to 2040, at a lower annual growth rate compared to the 1990-2007 timeframe.

Continued improvements in energy efficiency are likely to accelerate in new and existing homes and across appliances, lighting, water heating, heating and cooling equipment, and electronics. Building energy codes, appliance and equipment standards, and efficiency programs implemented by utilities and federal, state and local governments have played an important role in enabling these trends, and require ongoing support if the U.S. is to continue increasing energy savings. In terms of household expenditures, an average of 2.5% of annual income is spent on electricity.[14] However, electricity use and its share of total household expenditures vary by region and household demographics. Average household electricity consumption is highest in the South Census regions, largely because of greater use of electricity for space cooling and heating, and water heating. [15] In addition, low-income households spend a greater share of their total income on electricity[a] and renters on average spend 26.7% more on energy expenditures per square foot compared to homeowners.[b] [16]

**Figure ES-3. Residential electricity usage (MWh/household/year) by Census region and end use[17]**




*Households display a wide variation in electricity usage by end use and region.*

[a] For example, electricity accounts for 4.2% of after-tax income for households earning between $30-40,000 annually, where for households earning between $100-120,000 spend only 1.8%. See Figure 2.10 - Electricity consumption by household income.
[b] Note that total energy expenditures include electricity and other fuels, such as natural gas and heating oil.

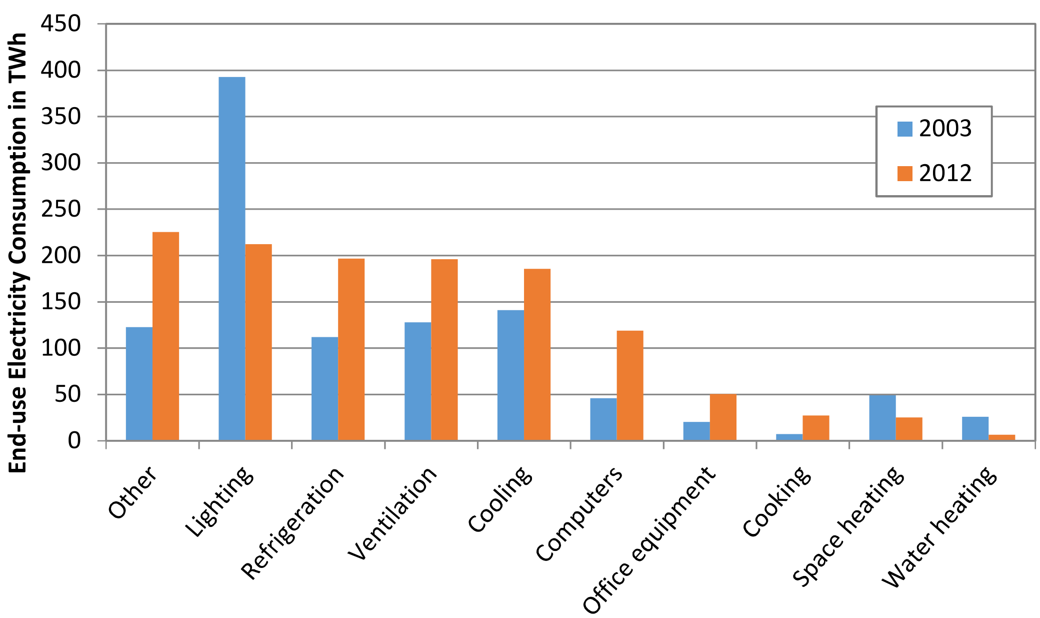
## Commercial Sector Trends

There are about 87 billion square feet of commercial space in the U.S., spread across more than 5 million commercial and institutional buildings.[18] Commercial electricity consumption accounts for about 36% of total U.S. electricity demand. This sector is very diverse and includes office, retail, health care, education, warehouse and several other types of buildings, ranging in size from a few thousand to millions of square feet per building. Four types of commercial buildings account for more than 50% of total delivered electricity consumption—office, mercantile, education, and health care.[a]

Commercial sector square footage and energy use has grown steadily, although electricity intensity (kWh/square foot) is improving, largely driven by increases in energy efficiency across end uses.[b] From 2013 to 2040, commercial end-use intensity, measured in kWh per square foot, is projected to decrease by 8.8%.[19] This decrease is led by a significant decline in the electricity intensity of lighting,[20] but is also offset by a significant increase in miscellaneous electric loads.[c]

The efficiency of most commercial end uses is increasing and this trend is likely to accelerate as newer, more efficient buildings and equipment increase as a share of total building and equipment stock. The efficiency programs now being implemented by Federal, state and local agencies, and utilities, have enabled these trends and will require support if they are to continue.

**Figure ES-4. Comparison of commercial end-use electricity consumption between 2003 and 2012[21]**




*Consumption across most end uses is increasing. Lighting and space heating consumption have each decreased by about 50%.*

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[a] 56.4% total: offices account for 20.4%, mercantile (malls and non-mall retail) accounts for 16.6%, education accounts for 10.8%, and health care accounts for 8.6%.

[b] Between 2003 to 2012 total kWh/sq. ft. in the commercial sector decreased by 8%. See CBECS 2012

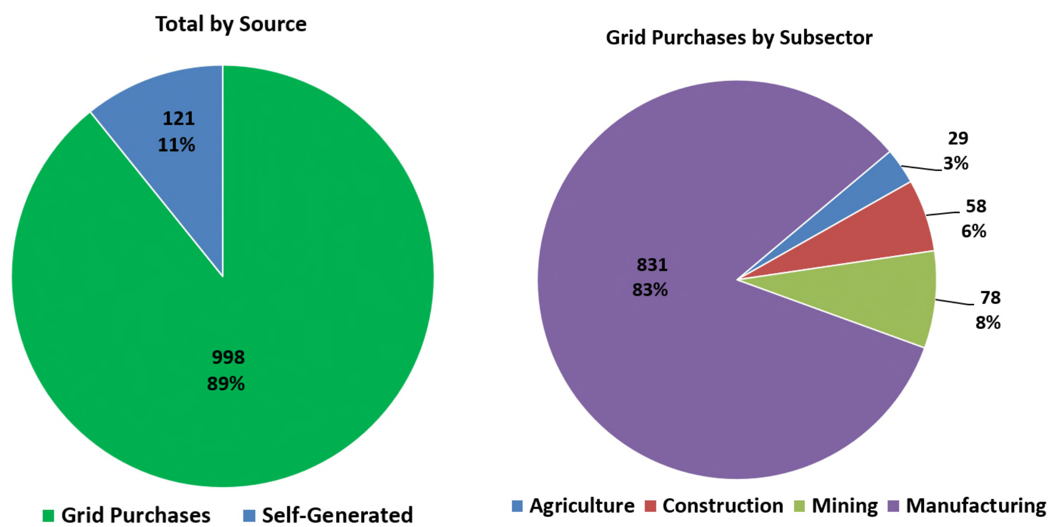
[c] MELs represent a diverse set of products defined by what they are not, rather than by what they are. They are not major appliances, such as refrigerators, and are also not linked to the major end uses—lighting, space heating and cooling, and water heating. MELs include a broad range of products across all sectors, the largest of which include televisions, pool heaters and pumps, set-top boxes, and ceiling fans. See Chapters 2 and 3 for more detail.

## Industrial Sector Trends

The industrial sector is extremely diverse, composed of a wide variety of small, medium, large, and very-large facilities. Primary sub-sectors include manufacturing, mining, construction, and agriculture. Industrial electricity consumption accounts for 26% of total annual U.S. electricity consumption, though electricity's share of total industrial energy consumption is relatively low compared to the residential and commercial sectors.[a] [22] In addition, unlike the commercial and residential sectors, there is a considerable amount—11%—of electricity use in the industrial sector that is self-generated, the majority through Combined Heat and Power (CHP).[b] Total grid-purchased electricity in the industrial sector was relatively flat from 1990 to 2014.[c] Grid-purchased electricity is projected to increase rapidly from 2010 until 2025, after which growth slows to 2040. This projected growth is largely driven by strong economic growth assumptions—an average annual GDP growth rate of 2.4% from 2013 to 2040 results in a doubling of GDP between 2010 and 2040.

Electricity productivity in the industrial sector ($/kWh) has improved rapidly over the last 15 years[d] and continued improvement will depend on persistent attention to efficiency. Energy-intensive sub-sectors (e.g., metals and chemicals manufacturing) represent the greatest opportunities for targeted efficiency improvements. In the manufacturing sub-sector, which accounts for over 80% of total industrial grid-electricity consumption, machine drives[e] make up half of industrial electricity use. The next biggest end use, process heating and cooling, makes up just over a tenth of total industrial electricity use.

**Figure ES-5. U.S. industrial electricity consumption in 2014 (TWh)[23]**




*The manufacturing sub-sector accounts for the majority—83%—of total industrial electricity consumption.*

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[a] Electricity accounts for 15% of total energy consumption in the industrial sector.

[b] CHP generates useful hot water or steam and electricity from a single system at or near the point of use. For more information on combined heat and power, see http://www.eia.gov/todayinenergy/detail.cfm?id=8250. Some CHP-generated electricity is consumed on-site (self-generation); some is sold off site (grid sales).

[c] Grid-purchased electricity in 1990 was 946 TWh and 998 TWh in 2014.

[d] Electricity productivity, measured as dollars of gross domestic product (GDP) produced per kilowatt-hour (kWh), nearly doubled between 1990 and 2014, while industrial electricity sales were flat.

[e] Machine drives convert electric energy into mechanical energy and are found in almost every process in manufacturing; they comprise motors and the process systems they drive.

## Key Findings – Buildings

Note: This report contains separate chapters and findings for the residential, commercial, and industrial sectors. Key findings for buildings are combined below to avoid repetition. Key findings specific to the industrial sector remain separate.

Appliances and Equipment: *Appliance and equipment efficiency improvements have and will continue to be a key driver in lowering electricity demand in the residential, commercial and industrial sectors.*

Since most appliance and equipment lifetimes range from just a just few years to less than 25 years, efficiency gains in these products will have broad impacts between now and 2040. A combination of government programs, such as ENERGY STAR, federal and state standards, private development, and market forces are driving major gains in product efficiency. New technologies, testing and labeling of high efficiency products, targeted incentives and procurement by governments and utilities, and regularly updated minimum standards have achieved significant savings.

Consumer Adoption of New Technologies that Support Energy Management: *Connected devices and Energy Management Control Systems (EMCS) are decreasing in cost and improving in functionality.*

Market penetration for these products and services is still relatively low, particularly in the residential sector and for small to medium-sized commercial buildings. These new technologies and systems, and the broader 'Internet of Things,' provide a wide range of options for consumers to manage their energy use, either passively using automated controls, or through active monitoring and adjustment of key systems.

New Building Efficiency and Very-Low or Zero-Net Energy Buildings (ZNEB*): The efficiency of new buildings is rapidly increasing across all sectors.*

Advances in building design and modeling, construction techniques, and key building components and systems have led to large efficiency gains. These advances, combined with building energy rating programs, have helped create growing interest in very low energy or zero-net energy buildings. More energy-efficient new buildings are likely to have the greatest impact in the commercial sector, where the rate of new additions and building replacements is highest.

Existing Building Efficiency: *While considerable progress has been made in improving the deployment of retrofit investments in existing buildings, there remain significant opportunities for more savings.*

Efficiency gains in the heating and cooling of existing buildings depend largely on significant investments in the performance of the building envelope and key heating and cooling systems. Similar opportunities exist in certain other long-lived capital stocks. Access to financing is one critical barrier preventing some consumers and businesses from undertaking more significant retrofit investments. Other barriers include transaction costs (retrofits can be time-consuming to execute) and the fact that energy costs may be small compared to total business operating costs, making it difficult to convince building owners to make energy efficiency investments.

Miscellaneous Electric Loads (MELs):[a] *MEL devices are expected to represent an increasing share of total electricity demand, particularly for the residential and commercial sectors where there is an increased service demand for entertainment, computing, and convenience appliances.*[24]

The MELs category represents a diverse set of products defined more by what they are not, rather than by what they are. MELs represent electric loads not linked to a building's core functions—lighting, space heating and cooling, refrigeration, and water heating. They include a broad range of products across all sectors, including include televisions, pool heaters and pumps, security systems, and ceiling fans.[25] Between 2014 and 2040, the EPSA Side Case projects the share of electricity demand from computers, office equipment and other MELs to increase from 32% to 43% of residential use and from 37% to 51% for commercial use. In general, the products responsible for these loads are not as effectively addressed by existing government and utility efficiency programs and new strategies for understanding the growth and improving the efficiency of MELs are needed.

## Key Findings – Industrial Sectors

Strategic Energy Management and Innovative Technologies: *Strategic energy management approaches, such as ENERGY STAR for Industry, ISO 50001 (an international energy management standard) and Superior Energy Performance® (a program that helps companies to incorporate ISO 50001 into their production management practices and motivates them to set and reach savings goals) help individual businesses identify operational efficiency opportunities.*

Optimizations of the entire industrial sector offer additional efficiency improvement opportunities, although their magnitudes have yet to be fully understood. Potential improvements include: the use of innovative technologies such as "smart manufacturing" (i.e., manufacturing processes driven by information technology), supply-chain efficiencies, process intensification (an optimization of chemical processes), and circular economy (i.e., reaping maximum use from resources and renewing them at the end of their useful life).

Machine Drives: *These offer the largest opportunities for electricity efficiency, particularly in the industrial sector.*

While minimum standards requiring the use of new, higher-efficiency motors will produce substantial energy savings, the greatest opportunity can be found in improving overall system design and management. Variable speed drives, combined with better system design and state-of-the-art motor controls, can result in substantially greater gains. [b]

Combined Heat and Power (CHP) and Utilization of Waste Heat: *Waste heat and CHP represent significant opportunities to improve energy efficiency in the industrial sector.*

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[a] MELs is often is used to refer to end uses that may also be categorized as 'plug loads' or 'other end uses.' However, the terms are not wholly overlapping and there is not necessarily consensus on the definitions. For example, some plug loads may not be considered MELs.

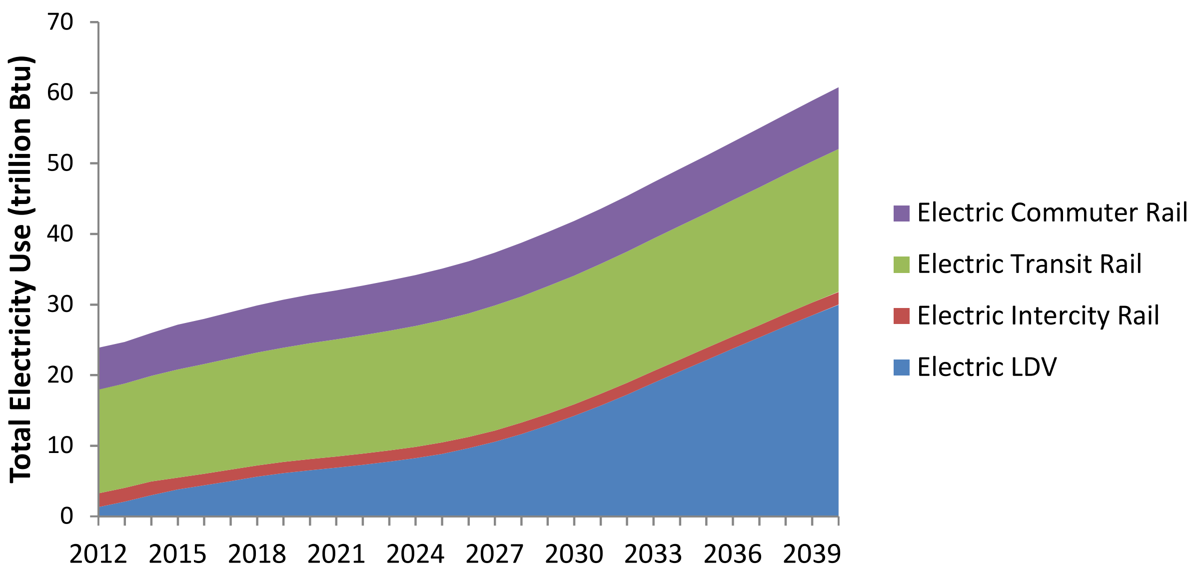
[b] The largest improvement is improving overall system designs (62% of estimated potential savings), followed by adopting variable-speed drives (25%) and upgrading motors to newer, high-efficiency technologies (13%). See Section 4.4.

Recovery of waste heat and use of CHP represent significant opportunities to recover the thermal energy lost during the conversion of energy into work.[a] Electricity generated from CHP can use 25-35% less primary energy than electricity from the grid.[b] However, overall growth in CHP capacity has stalled since the early 2000's. A host of factors have contributed to this decrease, including high equipment costs, technical complexity, and policy changes that decreased the value of electricity generated from CHP sources.

## Transportation Sector Trends

In contrast to the residential, commercial, and industrial sectors, which rely heavily on electricity, transportation uses very little—less than 1% of total U.S. annual electricity consumption. Furthermore, electricity provides only about 0.1% of all transportation energy use[26] and the majority of this—about 88%—is by passenger rail.[c] In 2014, there were over 200 million total light-duty cars and trucks registered in the United States. Of these, only about 270,000 (0.1%) were either battery electric vehicles (BEV) or plug-in hybrid electric vehicles (PHEV).[27] Opportunities for significant growth in transportation electricity use are largely limited to rail and light-duty vehicles. In both these transportation modes, such growth is likely to occur relatively slowly in the near to mid-term, because substantial changes in infrastructure, technology, and consumer preferences are required before significant growth in electricity use would be likely. These factors make long-term projections of electrification in the transportation sector particularly difficult and current projections of future rates vary significantly (see Section 5.8.5).[d]

**Figure ES-6. EPSA Side Case projection of total electricity use for transportation in the United States[28]**




[a] Within the manufacturing sub-sector, The Manufacturing Energy and Carbon Footprints analysis estimates that 7,228 TBtu, or 51% of the 14,064 TBtu of total delivered energy to the U.S. manufacturing sector, was wasted as efficiency losses in 2010.

[b] See section 6.2.1.3

[c] Passenger rail includes transit, intercity, and commuter rail. See section 5.2.4 Public Transit

[d] Some factors that complicate long-term projections are future oil prices, future battery costs and performance, mainstream consumer reactions to the positive values, and the trade-offs associated with plug-in vehicles.

## Key Findings – Transportation

Electric Vehicle Policies and Incentives: *The market for EVs is evolving rapidly, making it difficult to isolate the impacts of specific incentives and policies. Initial analysis suggests that EV adoption is greatest when multiple actions are taken in parallel.*

Since the introduction of mass-market electric vehicles in 2010, several types of EV incentives have been provided by federal, state and local governments and utilities.[a] Evolving factors, such as price reductions for vehicles and charging equipment, range improvements, growing new model availability, and fluctuating gasoline prices, make it difficult to isolate the impact of a specific incentive or policy from these broader market trends. Some analyses suggest that EV adoption is greatest when multiple actions are taken in parallel, such as improving consumer awareness, providing direct subsidies, and making infrastructure investments.[b]

Evolving Consumer Preferences in Transportation: *Consumer behavior is changing—growth in vehicle miles traveled is decreasing and ride-sharing services are becoming more prevalent. These changing consumer preferences and other factors that influence EV growth make predicting future levels of transportation electrification difficult.*

In recent years the U.S. has experienced substantial urban population growth. This growth is driven in part by the influx of young professionals, whom are also beginning to purchase fewer personal vehicles and instead relying more on ride- and car-sharing services. It is unclear if these are lasting trends and, if so, to what extent they will affect prospects for EVs and other new car sales. While EV adoption and interest have increased dramatically in recent years, there remain significant barriers to widespread adoption and there is also little data available on what motivates mainstream consumers to purchase EVs. All of these factors make predicting the future growth of transportation electricity use difficult—some models show that conventional vehicles will still account for 70% of sales in 2040, whereas others predict they will fall to about 20% as EVs and other alternate vehicles increase their market share.[c]

Grid Integration and Public Charging Networks for EVs: *Public charging for EVs is a critical component for encouraging consumer adoption of EVs, but policy and business models have yet to be fully developed that support robust networks. In addition, vehicle-to-grid communication and time-of-use pricing will be a vital component of a future where EVs are widespread.*

Increased electrification of the light-duty vehicle (LDV) fleet will lead to both challenges and opportunities for grid operators. Uncontrolled charging can contribute to increased peak electricity demand. A modern power system that supports vehicle-to-grid communication and time-of-use pricing will be a vital component of a future where EVs make up a large fraction of the total LDV fleet.[d] In addition, federal, state, and local governments are working to develop public charging networks and a number of businesses promote charging stations at workplaces and retail shopping locations. An

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[a] These incentives cover vehicle purchase as well as electric vehicle supply equipment in the form of purchase rebates, tax credits, discounted registration fees, free high-occupancy vehicle (HOV) lane access, parking benefits, and more.

[b] See 5.7 – 'Barriers and the Policies, Regulations, and Programs That Address Them' for additional discussion.

[c] See 5.8.5 – 'Projections of Transportation Electricity Use' for additional discussion.

[d] Increased electrification of transportation will present both challenges and opportunities to the electric grid. Vehicle-to-grid communication will help minimize uncontrolled vehicle charging (which may increase peak load) and enable the use of EV battery capacity as a distributed storage resource.

extensive network of public charging stations may help to allay "range anxiety"[a] for fully electric vehicles. However, effective business models have yet to be fully developed for these stations.

Barriers to Electric Vehicle Market Penetration: The two types of electric vehicles – plug-in hybrids (PHEVs), which combine electric and conventional powertrains, and pure battery electric vehicles (BEVs) – each have significant barriers that limit their current share of the light-duty vehicle market.

PHEVs have high initial costs because of their dual powertrains and expensive batteries; BEVs also have high initial costs primarily due to the cost of their larger batteries. However, if battery prices continue to decrease as they have in recent years, this barrier will be considerably reduced. Another barrier specific to BEVs is their inability to be refueled quickly, which can limit their suitability and appeal to consumers. An extensive network of public charging stations can help to allay "range anxiety," the concern that a pure battery electric vehicle will lose its charge before reaching a desired destination. Growth in multi-vehicle households and burgeoning acceptance of shared vehicles, especially in urban areas, may mitigate this barrier, but there is insufficient experience to predict the long term impact of these factors on electric vehicle growth.

## Distributed Energy Resources (DERs)

Distributed energy resources (DERs) represent a broad range of technologies that can significantly impact how much, and when, electricity is demanded from the grid. Though DERs have no single established definition, EPSA considers them to include Distributed Generation, Distributed Storage, and Demand-Side Management Resources.[b] Chapter 6 focuses on: 1) distributed generation and storage technologies that are more modular and that reside on a utility's primary distribution system or on the premise of an end-use consumer; and 2) demand response and other enabling technologies, such as smart meters, that allow grid operators and consumers to better manage individual and system demand. It is also worth noting that not all DERs are connected to an electric grid, as can be the case for Combined Heat and Power and microgrids.[c]

### Distributed Generation: Solar PV, Distributed Wind, and Combined Heat and Power

Distributed generation resources include a broad range of technologies, such as CHP (largely in industry), solar PV, waste-to-energy, biomass combustion, and fuel cells. This report focuses on solar PV, distributed wind, and CHP, which represent the most prevalent distributed generation technologies used for primary, non-emergency power.[d] [29] Total distributed generation capacity, including CHP,

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[a] Range anxiety is the concern that a pure battery electric vehicle will lose its charge before reaching a desired destination

[b] End-use energy efficiency, discussed in Chapters 1-4, technically constitutes a DER since implementation occurs on the premises of an end-user.

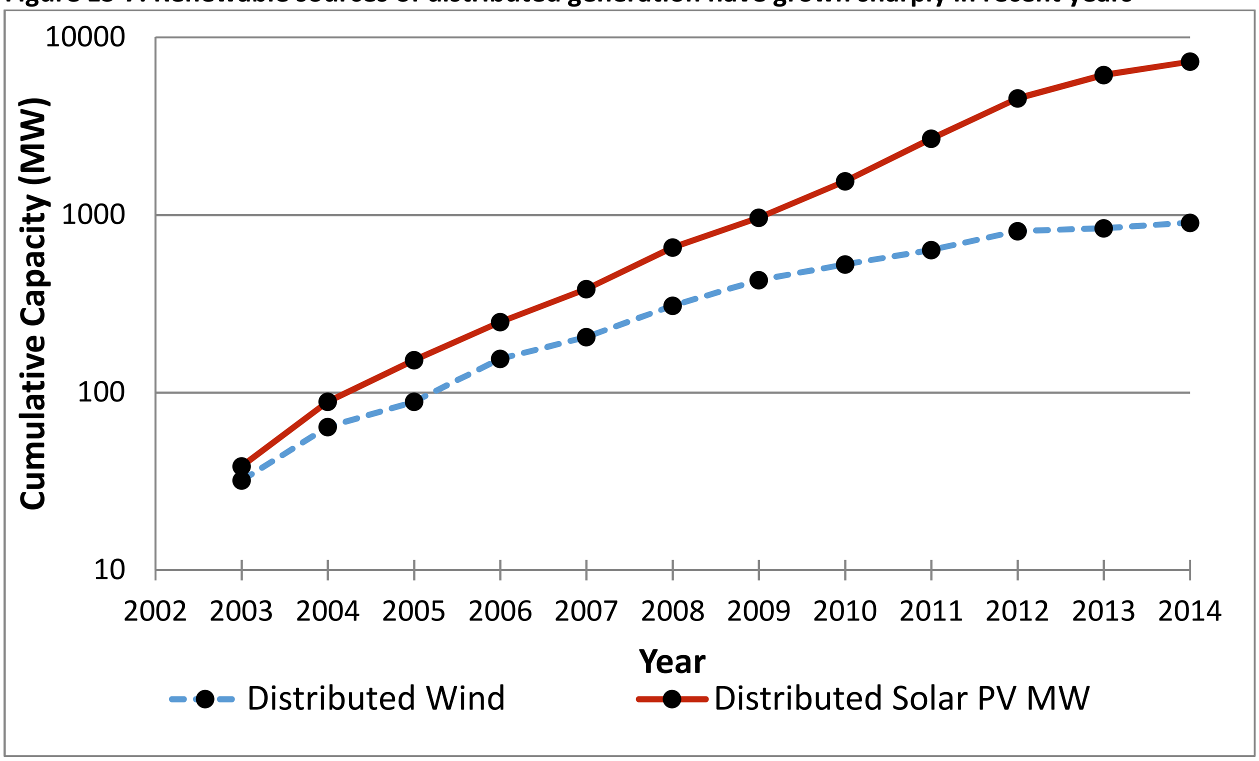
[c] A microgrid itself is not a DER, but relies on DERs within a defined electrical boundary that acts as a single controllable entity with respect to the grid (see Section 6.2.3).

[d] *Standby* (or partial requirements) *service* is the set of retail electric products for utility customers who operate on-site, non-emergency generation. Utility standby rates cover some or all of the following services: backup power during an unplanned generator outage; maintenance power during scheduled generator service for routine maintenance and repairs; supplemental power for customers whose on-site generation under normal operation does not meet all of their energy needs, typically provided under the full requirements tariff for the customer's rate class; economic replacement power when it costs less than on-site generation; and delivery associated with these energy services.

distributed PV, and distributed wind was estimated at 91 GW in 2014, equivalent to about 8.5% of the capacity of the nation's electric power sector.[a]

Distributed solar PV generating capacity, driven by a significant reduction in the cost of PV panels, has grown by a factor of 80 between 2004 and 2014.[30] Despite this record growth, electricity from solar PV remains a small percent of total U.S. generation—less than 1% of total annual electricity load—and is projected by the EPSA Side Case to comprise of about 2.2% of total U.S. electricity generation by 2040.[31] Distributed wind currently provides a very small portion of end-use electricity—less than 0.25% of total annual commercial electricity consumption. Distributed wind increased steadily from 2003 to 2012, but growth has since levelled off and total capacity has been relatively flat for the last three years as its competitiveness has declined relative to solar PV and other low-cost sources of electricity.[b] CHP is predominantly installed at industrial facilities and represents the largest source of distributed electricity generation—current CHP capacity is about 7% of total generating capacity of the nation's electric power sector.[32] CHP systems use 25% to 35% less primary energy than grid-sourced electricity, on average.[33]

**Figure ES-7. Renewable sources of distributed generation have grown sharply in recent years[34 35]**




## Demand-Side Management: Demand Response, Distributed Storage, and Smart Meters

Advances in communications, metering, sensors, controls, and storage technologies are enabling consumers, utilities, and other service providers to more actively or passively manage electricity loads in response to price and other system constraints. Small-scale distributed electricity storage is becoming more widely available and can reduce peak load, improve electrical stability, reduce power quality disturbances, and facilitate increased penetration of variable wind and solar resources. There are a

[a] Distributed generation capacity is included in the electric power sector capacity. CHP accounts for 83 GW- of the 91 GW of the distributed generation capacity. See section 6.2.1.

[b] See Section 6.2.1 for detailed data.

number of technologies available, including stationary battery storage, thermal storage (e.g., use of ceramic bricks, chilled water, or hot water from electric water heaters), and plug-in electric vehicles with onboard batteries. Though the technology options for distributed storage are increasing, there is currently only 364 MW of distributed storage capacity available in the U.S., which represents a tiny fraction—less than 0.1%—of total electricity generating capacity.[a] [36]

Demand response, which allow utilities, grid operators, or other intermediaries to call for specific reductions in demand when needed, offers benefits in reducing peak load and supplying ancillary services, such as frequency regulation. Industrial and large commercial users still dominate most demand response programs, but lower costs are allowing a broader range of small commercial and residential participants. Because of slow annual load growth, total capacity of demand response programs has not grown in recent years (and this trend is expected to continue in the near term). However, the potential long-term impact of such technologies and programs is large (see 6.3.4), particularly as the quantity of variable renewable energy increases.

Smart meter infrastructure, sensors, and communication-enabled devices and controls give electricity consumers and utilities new abilities to monitor electricity consumption and potentially lower usage in response to time-of-use, local distribution, or price constraints. Smart meters also provide a number of other benefits, including enhanced outage management and restoration, improved distribution system monitoring, and utility operational savings.[37] Microgrids[b] are also becoming more prevalent as distributed generation, storage, and demand management technologies have decreased in price and the public begins to place greater emphasis on ensuring system reliability during grid outages and natural disasters. While the total capacity of microgrids is now fairly small (~1.2 GW), it has been growing rapidly in recent years.

### Key Findings - Distributed Energy Resources (DERs)

Distributed Generation and Grid Integration: *DG has experienced significant growth in recent years due to lower technology costs and key supporting policies. Future growth may continue to be highly dependent on state policies.*

Past growth in distributed generation has been highly policy-dependent. Supportive policy incentives, such as net metering,[c] coupled with dramatic reductions in installed costs, have led to rapid growth of distributed solar PV. However, some states and utilities are adjusting or even reversing these policies,[d] making solar PV and other distributed generation less financially attractive. States with longer-term policies (e.g., targets, incentives) have seen more distributed generation adoption. Future growth will continue to be highly dependent on local and state policies and thus vary geographically. Higher penetration of variable renewable energy resources, both on the distribution system and at the bulk power level, will require greater grid flexibility. A modernized smart grid could balance short-term

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[a] The vast majority—about 93%—off total energy storage capacity in the U.S. is pumped hydropower, which is traditionally considered grid-based storage and is not discussed in detail in this report.

[b] Microgrids are a group of interconnected loads and DERs within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid.

[c] Net metering policies provide a billing mechanism that allows consumers to generate electricity at their homes or businesses using eligible technologies (e.g., solar, wind, hydro, fuel cells, geothermal, biomass), reduce purchases from the utility, and receive a credit on their utility bills for net excess energy.

[d] In late 2015 and early 2016, the Public Utilities Commission of Nevada established new net metering rules that increased fixed charges and lowered the value of generation credits for customers with solar PV systems.

electricity supply variations by relying on demand response and distributed storage, but the regulatory environment to support such services is still evolving.

Distributed Storage: *Declining costs for storage technology, driven by greater production of batteries for electric vehicles and state-level storage mandates,*[a] *will drive greater adoption of distributed energy storage.*

Between 2007 and 2014, the cost of lithium-ion battery packs declined by almost 60%,[b] [38] helping to contribute to forecasts showing rapid growth in distributed energy storage over the next decade. For large utility customers, utilizing distributed storage to reduce their utility demand charges[c] is a key motivator. Distributed storage can provide multiple benefits simultaneously, such as improving power quality and reducing peak system demand.

Demand Response: *Lower-cost technologies for communicating with and managing end-use equipment are creating new or expanded opportunities for demand response, particularly for small and medium-size customers.*

Third-party aggregators and emerging business models may facilitate the expanded use of demand response, but the regulatory environment remains unsettled. State-level actions that support demand response include new pilot programs, approving investments in enabling communication technologies, and implementing time-varying pricing.

In addition to those described above, this report includes a number of additional key insights, findings, opportunities, and barriers. It also provides market characterization and descriptions of specific policies, technologies, and market forces that influence electricity use across all sectors. Chapter 1 provides an overview of electricity use, summarizes trends for energy efficiency and DERs and their impact on electricity sales, and highlights the benefits of these resources as well as barriers to their adoption. Chapters 2 through 5 examine electricity use by sector—Residential, Commercial, Industrial, and Transportation. Chapter 6 covers Distributed Energy Resources. Finally, the appendices include a number of additional supporting figures, tables, and technical details for each chapter. The appendix also includes a detailed overview of current practices, barriers, and emerging trends within the field of Evaluation, Measurement, and Verification.

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[a] In 2013, California passed Assembly Bill 2514, which mandates the state to install 1.3 GW of energy storage to their electricity grids by 2020.

[b] Between 2007 and 2014, Li-ion battery packs decreased in cost from $1,000/kWh to $410/kWh.

[c] Demand charges are tied to peak electricity demand (in kilowatts) and can comprise up to 30% of a commercial customer's electricity bill

# 1 Introduction and Summary of Electricity Use, Energy Efficiency, and Distributed Energy Resources

President Obama issued a Presidential Memorandum establishing a Quadrennial Energy Review (QER) in January 2014.[39] The Administration-wide QER will enable the Federal Government to translate policy goals into a set of analytically based, integrated actions—executive actions, legislative proposals, and budget and resource requirements for proposed investments—over a 4-year planning horizon. The White House Domestic Policy Council and Office of Science and Technology Policy jointly chair an interagency QER Task Force. The U.S. Secretary of Energy provides support to the QER Task Force through an Executive Secretariat in the U.S. Department of Energy's (DOE's) Office of Energy Policy and Systems Analysis (EPSA); this support includes coordination of activities related to the preparation of the QER report, policy analysis and modeling, and stakeholder engagement.

Unlike other Federal quadrennial review processes, where an analysis is done every 4 years, the QER is being conducted through installments to allow for granular analysis of key energy subsectors. The fourth installment is intended to be a synthesis of the previous three. This structure will provide policy makers both deep and broad policy analysis of the complex and interdependent elements that comprise the Nation's energy system.

The first installment of the QER examined the Nation's infrastructure for transmission, storage, and distribution, including liquid and natural gas pipelines; the grid; and shared transport such as rail, waterways, and ports. On April 21, 2015, the QER Task Force released its first QER installment (QER 1.1) entitled, *Energy Transmission, Storage, and Distribution Infrastructure*.[40] Given the critical enabling role of electricity articulated in this report, the Obama Administration determined that the second installment of the QER (QER 1.2) will develop a set of findings and policy recommendations to help guide the modernization of the Nation's electric grid and ensure its continued reliability, safety, security, affordability, and environmental performance through 2040.

The QER 1.2 catalogs in individual "baseline" reports the current state and key trends of the individual elements of the electricity system including generation, transmission, distribution, grid operations and planning, and end use. QER 1.2 will include significant analyses of end-use infrastructure and services (see text box on next page), and examine how the evolving nature of supply and demand is changing traditional perceptions of the electric sector. This baseline report examines end use, energy efficiency, and distributed energy resources (DER) in the electricity sector.

Scoping for this report began in late 2014 when EPSA convened an End-Use Working Group, representing six national energy laboratories, to support investigation of top-priority research gaps and questions related to future electricity end uses, energy efficiency, and DERs—demand response, distributed generation, and distributed storage. Over the course of several months, the group defined and cataloged end-use infrastructure and services provided, conducted a literature review to identify and summarize key studies, compiled a list of end-use analysis tools developed by national energy laboratories, summarized projected trends, identified policies that currently affect end-use infrastructure and electricity consumption, and identified questions that require further research and analysis.

This report builds on the group's work. It takes a sector-specific approach to characterize end uses and electricity consumption for the residential, commercial, industrial, and transportation sectors, including the following:

- Electricity uses by subsector
- Electricity consumption today and projected through 2040
- Trends affecting electricity use
- Energy efficiency technologies, strategies, and adoption levels
- Markets and market actors
- Relevant policies, regulations, and programs
- Research gaps

### Electricity End-Use Infrastructure

Electricity end-use infrastructure includes physical components that use, require, or convert energy to provide products or services in the residential, commercial, industrial, transportation, and distributed energy resource sectors. The electric meter has traditionally been viewed as the end of the electricity system, the final node in a utility's network of wires, sensors, generators, and controls. However, recent trends indicate that opportunities for energy efficiency, demand response, distributed generation, and energy storage are increasingly bringing the consumer into the electricity system.

The report also characterizes DERs—resources that affect consumption of grid-supplied electricity in all sectors by shifting the timing of electricity use, producing electricity at or near consumer sites, or storing electricity (from the electricity grid or produced by consumers onsite) for use at another time. Among the topics covered are DER technologies and strategies; current and projected DER adoption levels; policies, regulations, and programs that affect DER deployment; and research gaps.

The report includes a review of evaluation, measurement, and verification (EM&V) methods for energy efficiency and DERs, including current practices, issues associated with conducting reliable and cost-effective evaluation, and trends that may indicate how impact evaluation may be conducted and used over the next 25 years.

Lawrence Berkeley National Laboratory (LBNL) prepared the report with Argonne National Laboratory contributing the transportation section.

Several overarching questions guide this baseline analysis:

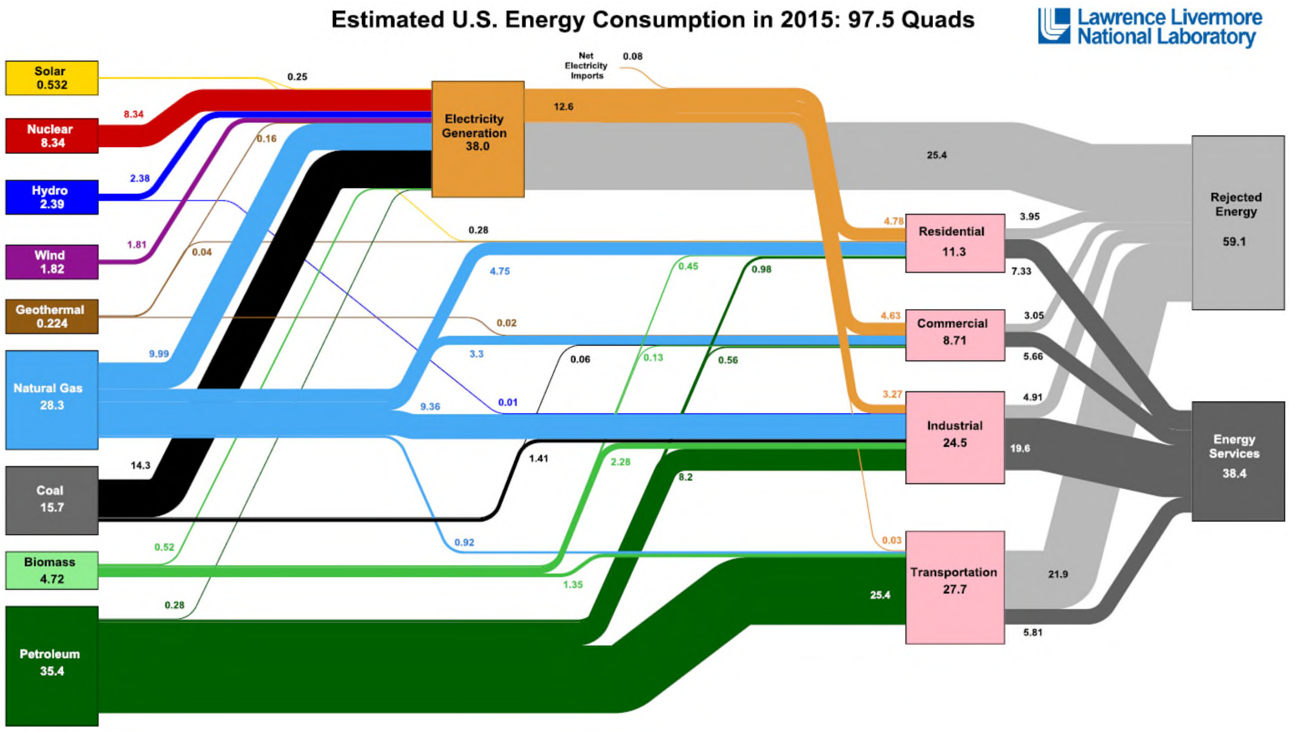
- What levels and patterns of electricity consumption exist today and are projected through 2040 in total and in the industrial, commercial, residential, and transportation sectors?
- What is the status of energy efficiency deployment by sector (industrial, commercial, residential, and transportation) today, and what are the trends and barriers?
- What existing policies, regulations, and programs (Federal, State, and local) influence electricity consumption, consumer choice, and consumer control over electricity use in each market sector?
- What are some of the existing policies, regulations, and programs that have encouraged more efficient use of electricity across end uses?
- What major trends—e.g., social, economic, technology, market, and environment—may affect future electricity consumption by market sector and end use?

In addition to these questions, the report addresses topics specific to each sector, to DERs, and to EM&V.

## 1.1 Electricity Use

Electricity generation accounts for the largest portion of U.S. energy use—nearly all of the nation's coal, nuclear, and non-biomass renewable sources consumed and one-third of natural gas sources. Of the approximated 97.5 quads of energy used in the United States in 2015, about 38.0 quads were used to generate 3,700 terawatt-hours (TWh) of electricity (Figure 1.1).

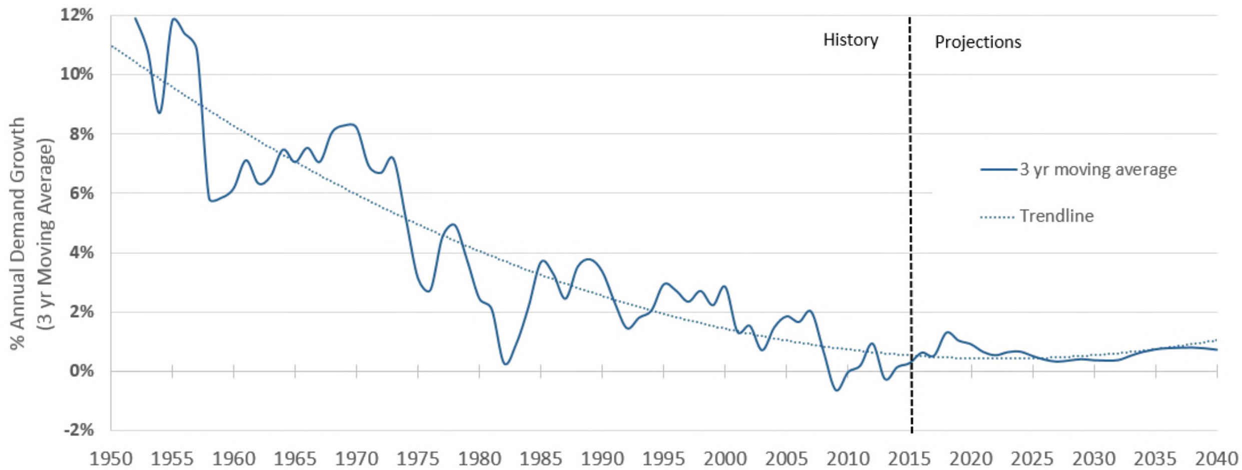
**Figure 1.1. U.S. energy flow chart, 2015** [41]




*The energy flow chart details the sources of energy production, how Americans are using energy across each sector. A large portion of energy is lost in energy transformation and line losses.*

While electricity dominates energy use, the growth in electric loads has slowed. Since the 1950's, growth in U.S. electric consumption has gradually slowed each decade (see Figure 1.2). A number of factors have led to this gradual slowing of electricity demand, including "slowing population growth, market saturation of major electricity-using appliances, efficiency improvements in appliances, and a shift in the economy toward a larger share of consumption in less energy-intensive industries." [42]

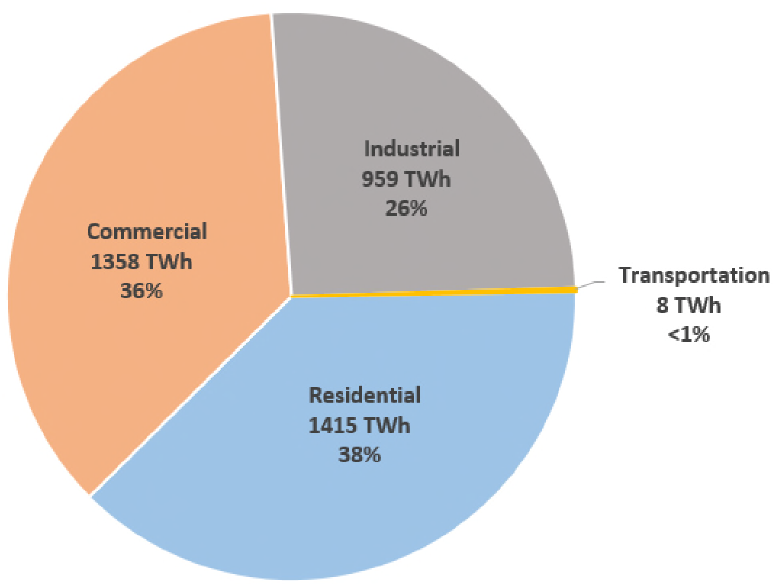
**Figure 1.2. U.S. electricity demand growth, 1950–2040**[43]




*Growth of electricity demand (annual percentage change expressed as a three-year moving average, on vertical axis) has slowed in each decade since the 1950s, from 9.8% per year from 1949 to 1959 to only 0.7% per year since 2000.*

In 2014, electricity made up 18% of total U.S. consumption of delivered, or site, energy.[a] The residential and commercial sectors consumed about the same amount of electricity—38% and 36%, respectively—with the industrial sector accounting for 26% of the electricity consumed. The transportation sector used less than 1% of the electricity consumed (Figure 1.3).[44]

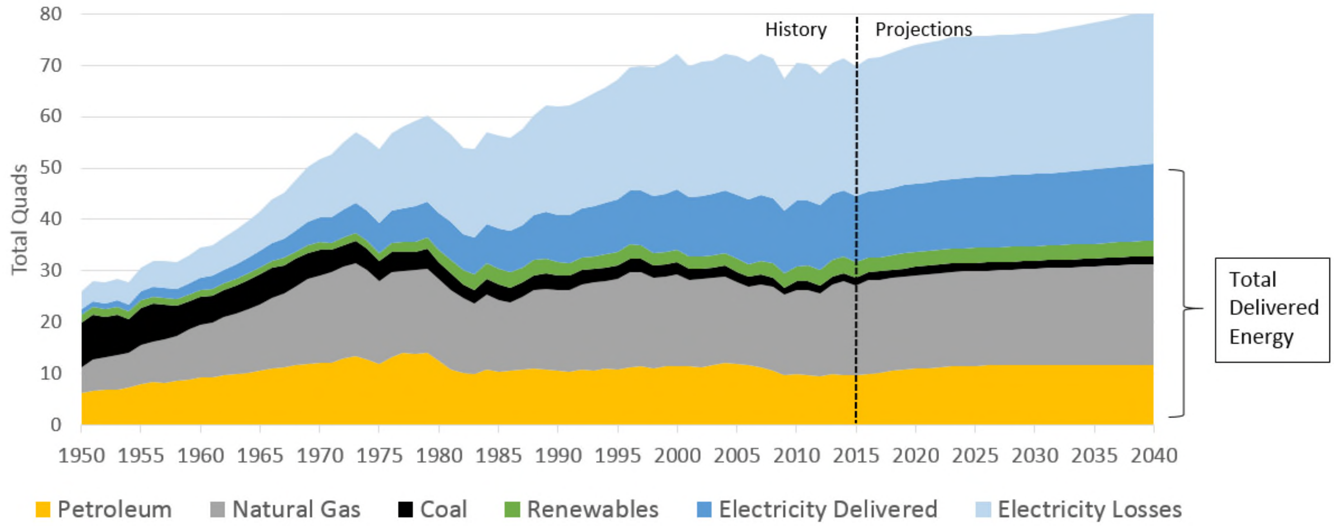
**Figure 1.3. U.S. electricity consumption by market sector, 2014**[45]




[a] Per EIA's glossary: Delivered, or site, energy is "The amount of energy delivered to the site (building); no adjustment is made for the fuels consumed to produce electricity or district sources. This is also referred to as net energy."

Electricity use in the United States is projected to grow at an average rate of 0.65% per year from 2014 to 2040 to about 20% of U.S. energy consumption (roughly an 18% increase), from 12.76 quads to 15 quads.[46] For comparison, the Summary of Electric Use and Trends Appendix (Section 7.1) shows historical trends in U.S. electricity consumption by market sector (Figures 7.1 thru 7.4) and by region (Figure 7.5).

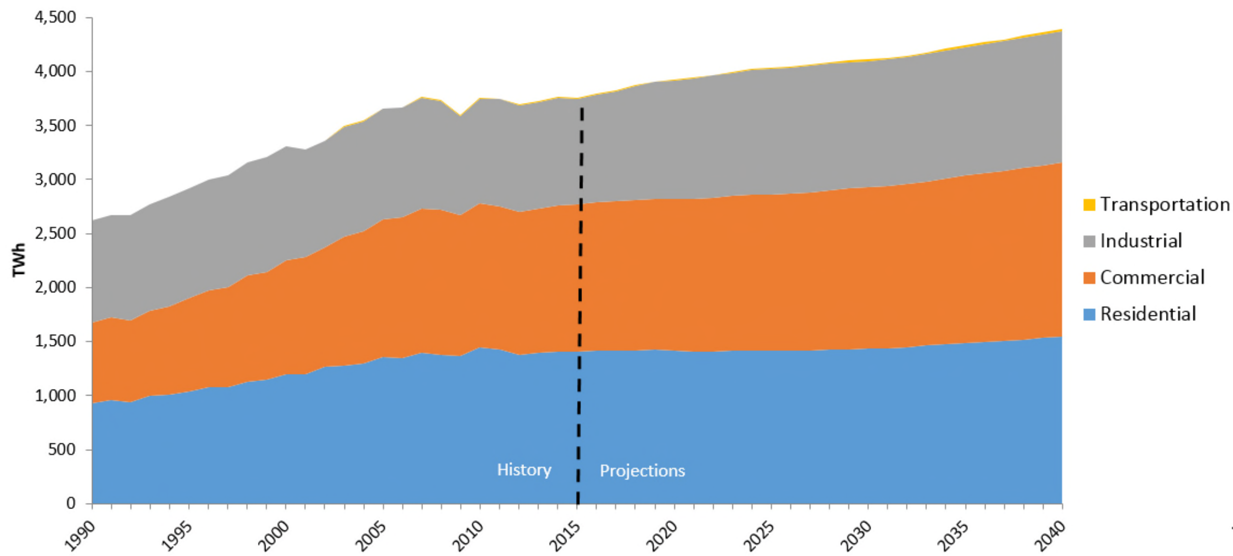
**Figure 1.4. Electricity's share of delivered energy consumed in the U.S., excluding transportation, 1950 to 2040[47]**




*Electricity delivered to the residential, commercial, and industrial sectors is expected to increase by about 18%, from about 12.8 quads in 2014 (about 28% of total delivered energy to these sectors) to about 15 quads (about 30% of delivered energy) in 2040. Where fuels are used to generate electricity, they are incorporated into the electricity share. Data does not include transporation energy use.*

By sector, electricity consumption is projected to rise by 9% in the residential sector (from 1,415 TWh in 2014 to 1,545 TWh in 2040), although the sector's share of total electricity consumption will fall from 38% to 35% over that time. Commercial sector electricity use is projected to increase 19% (from 1,358 TWh in 2014 to 1,615 TWh in 2040), and its share of total electricity use will increase slightly, from 36% to 37%. Industrial sector electricity use is expected to rise 27% between 2014 and 2040 (from 959 TWh to 1,218 TWh), while the sector's share of total electricity use increases from 26% to 28%. In the transportation sector, electricity consumption is projected to rise by 134% (from 7.6 TWh in 2014 to 17.8 TWh in 2040), although its share of total electricity use is projected to remain below 1% in 2040 (Figure 1.5).[48]

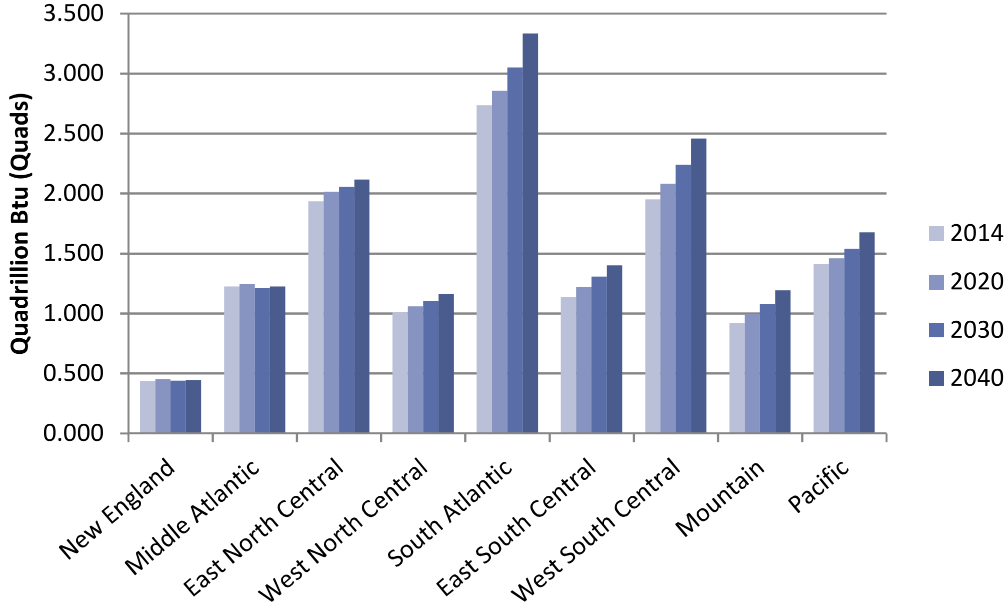
**Figure 1.5. U.S. Electricity consumption, all sectors, 1990 to 2040**[49]




*In 2014, the residential sector consumed the most electricity of any sector (1,415 TWh, 38% of total consumption), followed by the commercial sector (1,358 TWh, 36% of total consumption) and the industrial sector (959 TWh, 26% of total consumption), with transportation using just 7.6 TWh (less than 1% of total consumption). Overall, electricity consumption is expected to grow by about 18% between 2014 and 2040. The highest growth is projected for the transportation sector—an increase of 134%, although it will still make up less than 1% of total consumption (in yellow, at the top of the graph). Electricity consumption in the residential sector is expected to grow the most slowly, by 9%.*

Based on projections within Census divisions, growth in electricity consumption by 2040 is expected to be highest in the Mountain division (30% growth, from 0.92 quads in 2014 to 1.19 quads in 2040) and the West South Central division (26% growth, from 1.95 quads in 2014 to 2.46 quads in 2040). Only moderate growth in electricity consumption is projected for the New England division (just 2% between 2014 and 2040, from 0.436 quads to 0.44 quads), with consumption growth in the Middle Atlantic division expected to fall 0.1% from 1.226 quads in 2014 to 1.24 quads in 2040.[50] See Figure 1.6.

**Figure 1.6. U.S. electricity consumption by Census division, projections to 2040[51]**



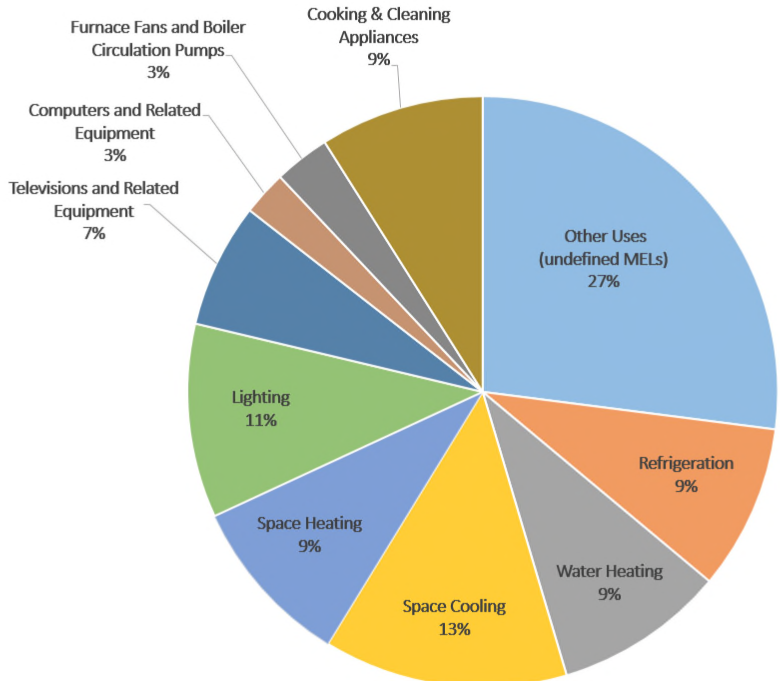

*In 2014, electricity consumption was greatest in the South Atlantic and the West South Central divisions. Consumption is expected to grow fastest in the Mountain and West South Central divisions. New England consumes the least electricity, with 2% growth projected. In the Middle Atlantic division, growth in consumption is expected to fall slightly between 2014 and 2040.*

Two snapshots of residential electricity consumption by end use show how the residential electricity profile is projected to change between 2014 and 2040. In 2014 (Figure 1.7), "Other uses," or undefined MELs,[a] were the biggest single consumer of residential electricity (27%), followed by space cooling (13%), lighting (11%), space heating (9%), water heating (9%), and refrigeration (9%). In 2040 (Figure 1.8. Residential electricity consumption by end use, 2040), the share of "Other uses" will increase to 35%. Space cooling will remain the second-largest electricity consumer, increasing its share to 18%. Water heating and refrigeration are expected to roughly maintain their share of electricity consumption. The share of electricity consumption attributed to space heating and lighting will decrease, with space heating accounting for 6% of electricity consumption and lighting just 4%—a decrease of more than half its share.[52]

Figure 1.9 and 1.10 show how the commercial sector's electricity profile is expected to change between 2014 and 2040. "Other uses" already are the biggest consumer of commercial electricity (38% in 2014), followed by lighting (19%), ventilation (11%), space cooling (10%), and refrigeration (8%). By 2040, "Other uses" are projected to grow to 50% of commercial electricity use. Lighting will remain the commercial sector's second largest electricity end use, but its portion of total electricity consumption will decrease to 13%. Space cooling and ventilation are expected to mostly maintain their share of consumption. Another growing end use in the commercial sector is non-personal computer (PC) office equipment, which is expected to increase its share of commercial electricity consumption, from 5% in 2014 to 7% in 2040.[53]

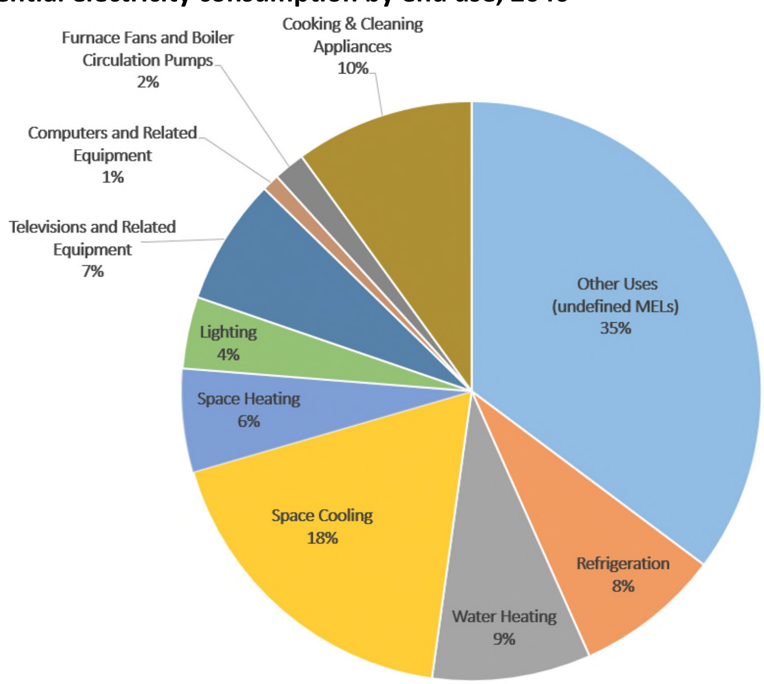
[a] "Other uses" are undefined Miscellaneous Electric Loads (MELs), which are loads not characterized by NEMs in more granular terms. Undefined MELs represent a broad range of devices and end uses —see Sections 2.4.4 and 3.4.3 and Appendix Table 7.5. As characterized by NEMS, "Other Uses" also includes an adjustment to reconcile supply-side and end-use consumption data. See Appendix section 7.4.1 for additional detail.

**Figure 1.7. Residential electricity consumption by end use, 2014**[54]



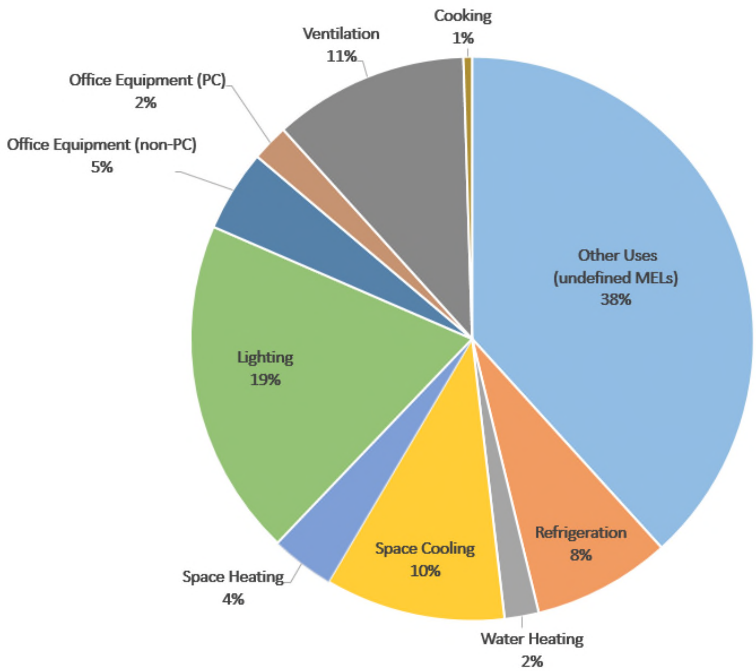

*In 2014, "Other uses" were the single-largest consumer of residential electricity (27%), followed by space cooling, lighting, space heating, water heating, and refrigeration. Cooking and cleaning appliances include dishwashers, clothes dryers, and clothes washers.*

**Figure 1.8. Residential electricity consumption by end use, 2040**[55]



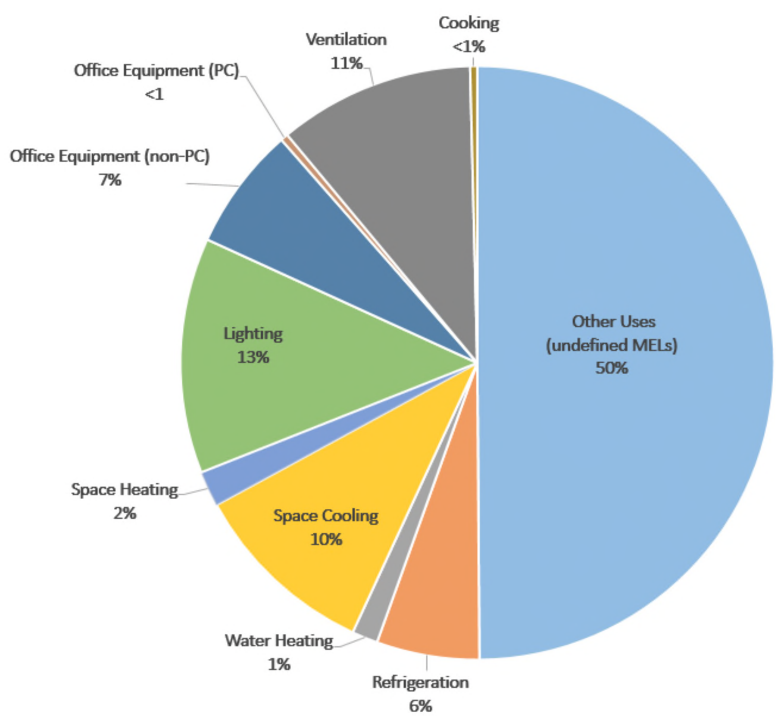

*In 2040, "Other uses" are projected to remain the largest user of electricity in the residential sector, followed by space cooling, water heating, and refrigeration.*

**Figure 1.9. Commercial electricity consumption by end use, 2014**[56]




*In 2014, "Other uses" were the largest consumer of commercial electricity (38%), followed by lighting, ventilation, space cooling, and refrigeration. See Appendix 7.4.1 for an alternative characterization of commercial end uses.*

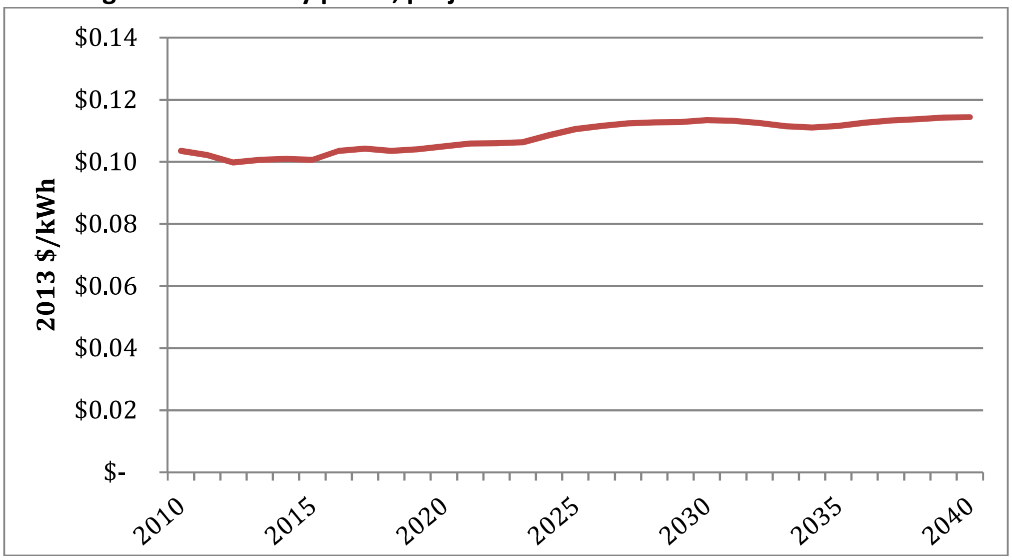
**Figure 1.10. Commercial electricity consumption by end use, 2040**[57]




*In 2040, "Other uses" are projected to dramatically increase their share of commercial electricity consumption, growing to 50% of total use, followed by lighting, space cooling, ventilation, and non-PC office equipment).*

Demand for electricity is dependent in part on electricity prices. National electricity prices are expected to continue to increase (see Appendix Figure 7.6 for historical prices). The average price is expected to rise to 11.4 cents per kilowatt-hour (kWh) by 2040, an increase of more than 13% compared to 2014 (Figure 1.11).[58] Greater detail on electricity price projections is provided in Appendix 7.1.

**Figure 1.11. Average U.S. electricity prices, projections to 2040**[59]

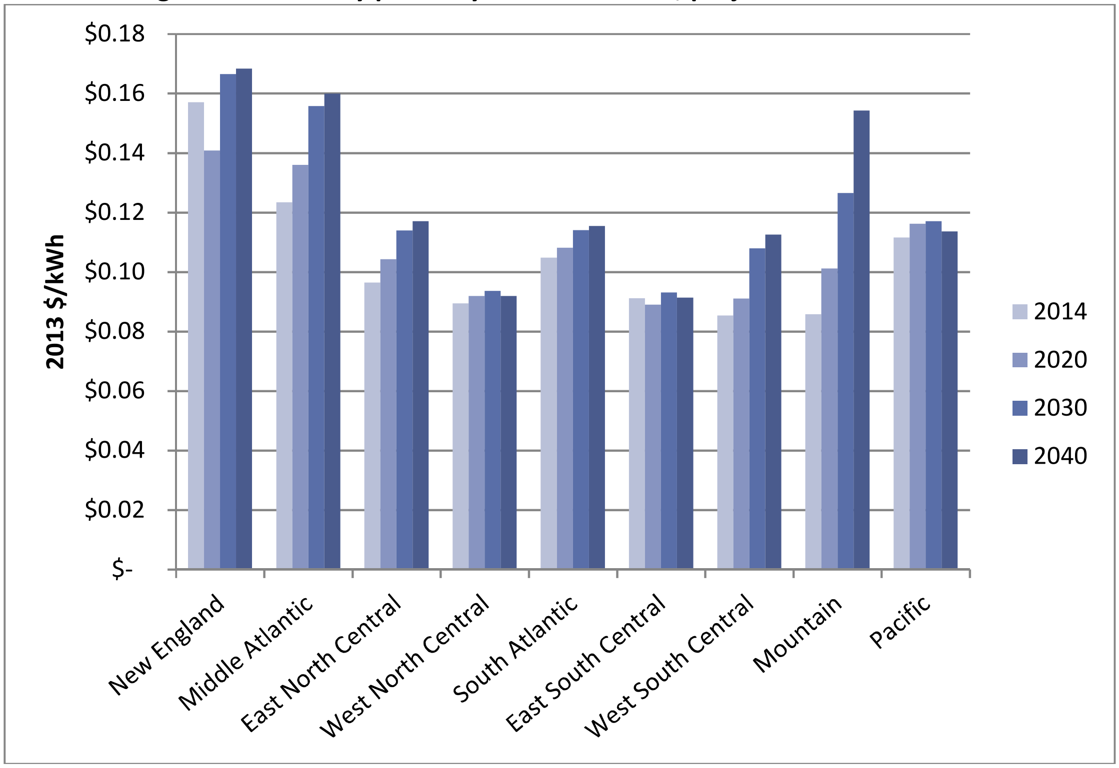



*The national average price of electricity is projected to increase in real terms (constant 2013 dollars). From 2014 to 2040, prices are projected to rise from 10.1 cents per kWh to 11.4 cents per kWh, a 13% increase.*

Regional prices vary. In 2014, average electricity prices by division were (from lowest to highest) 8.5 cents per kWh in the West South Central division, 8.6 cents per kWh in the Mountain division, 8.9 cents per kWh in the West North Central division, 9.1 cents per kWh in the East South Central division, 9.6 cents per kWh in the East North Central division, 10.5 cents per kWh in the South Atlantic division, 11.2 cents per kWh in the Pacific division, 12.3 cents per kWh in the Middle Atlantic division, and 15.7 cents per kWh in the New England division.[60]

Between 2014 and 2040, average electricity prices are projected to rise in all Census divisions except for the East South Central division, where prices are expected to stay flat at just over 9 cents per kWh. Prices are expected to increase most in the Mountain division, by about 80%, to more than 15 cents per kWh in 2040. Prices are expected to remain highest in New England, at nearly 17 cents per kWh in 2040 (a 7% increase), and the Middle Atlantic, where prices are expected to rise 30% to 16 cents per kWh in 2040. Prices are expected to remain lowest in the West North Central division, with a modest 3% increase to just over 9 cents per kWh by 2040, and the East South Central division, also at just more than 9 cents per kWh in 2040.[61] See Figure 1.12.

**Figure 1.12. Average U.S. electricity prices by Census division, projections to 2040**[62]



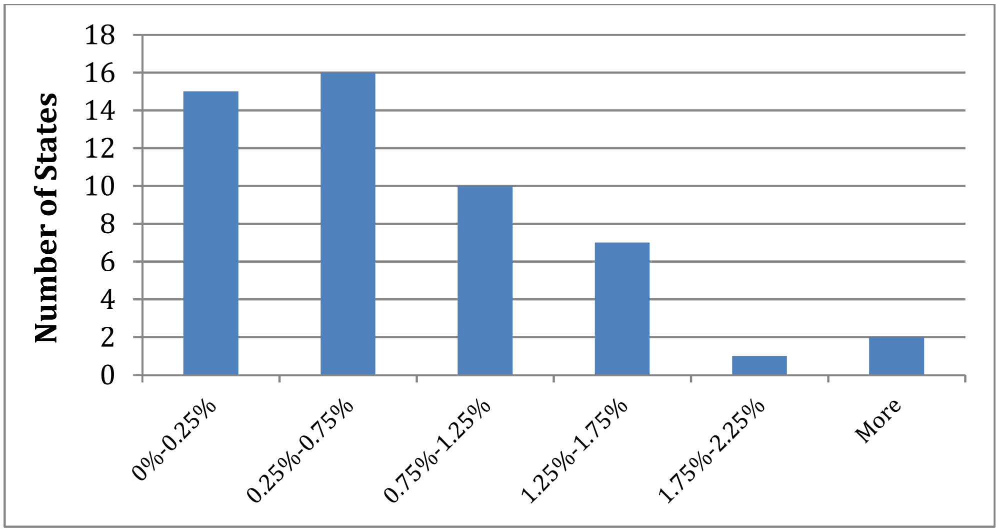

*Average U.S. electricity prices (in 2013 dollars) are projected to be higher in 2040 than in 2014, except in the East South Central division. Prices remain highest in the New England and Middle Atlantic divisions. The Mountain division is projected to have the greatest increase in prices.*

## 1.2 Impacts of Energy Efficiency and DERs on Electricity Consumption

In 2013, LBNL projected incremental annual energy savings from utility customer-funded electric efficiency programs to reach about 0.8% per year in the United States by 2025, driven primarily by compliance with statewide savings or spending targets typically focused on these programs.[63] These projections included savings not captured in EIA's Reference Case, offsetting the majority of projected growth in its projections of retail electric sales. These figures also do not include savings from energy efficiency programs outside the utility sector. Efficiency programs funded by electric utility customers, as well as energy efficiency standards for appliances and equipment and more efficient building energy codes, are likely to continue to offset the majority of electric load growth.

Nearly a third of states already are saving at least 1% of electricity consumption each year through programs funded by utility customers. About another third of states—most relatively new to energy efficiency—are saving between 0.25% and 0.75% (Figure 1.13).[64] Many states are increasing their efficiency targets as they meet initial goals and are on track to achieve higher savings. Electric energy efficiency programs funded by utility customers spent $6 billion in 2013 (Figure 2.19).[65]

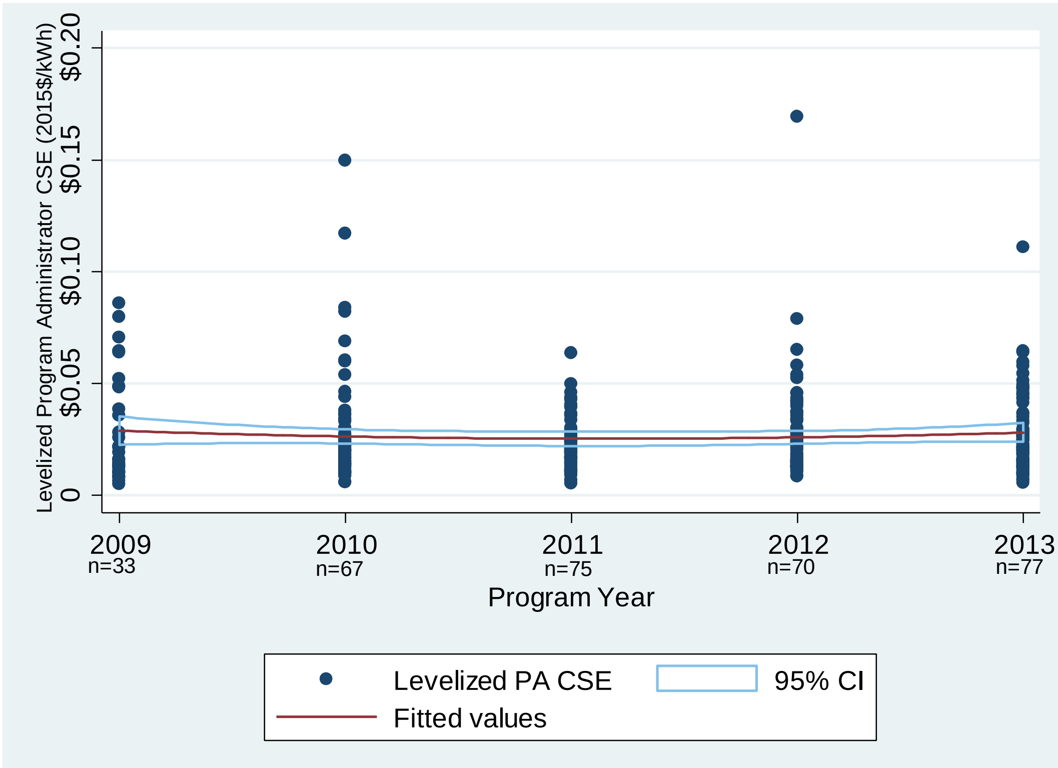
**Figure 1.13. Percent electricity savings in 2014 from energy efficiency programs funded by utility customers**[66]




*Nearly a third of states are saving at least 1% of electricity consumption each year through programs funded by utility customers.*

These programs are highly cost-effective. For example, LBNL estimates the average total cost of saving electricity among U.S. utility efficiency programs across all market sectors for the period 2009 to 2013 at 4.6 cents per kWh, split roughly in half between the utility (or other program administrator) and program participants.[67] For comparison, the average price of electricity in the U.S. in 2014 was 10.44 cents per kWh.[68] Another way to view cost-effectiveness is to compare the cost of energy efficiency and new power plants. The levelized cost of efficiency is estimated at $0 to $50/megawatt-hour (MWh), versus natural gas combined-cycle generation, with its sensitivity to fuel prices, at $52 to $78/MWh.[69] The average cost of saving electricity remained relatively flat from 2009 to 2013 (Figure 1.14). Variability in costs over time and by region depends on factors such as efficiency requirements in energy policy and building codes, retail electricity rates, cost-effectiveness screening practices, labor and material costs, and many other factors.

**Figure 1.14. Recent trends in the program administrator cost of saved energy (CSE), 2009-2013** [70]




*The average cost to utilities (or other program administrators) of saving electricity in the United States (red line) through efficiency programs remained fairly flat from 2009 to 2013, averaging $0.028 cents/kWh. The levelized program administrator cost of saved energy is "the cost of the electricity saved in an efficiency program when the upfront program costs are spread (i.e. amortized) over the projected lifetime of the measures installed in the program divided by the annual energy saved." Program participant costs are not included in these estimates.*

Steadily declining costs of distributed energy technologies will further offset electric load growth. For solar photovoltaic (PV) systems, for example, analysts project that prices from 2014 to 2020 will fall 16% to 33% for residential systems and 26% to 36% for utility-scale systems, or between 3% and 12% per year.[71] Solar PV systems are increasingly competitive with retail rates in several states.[72] Costs also are falling for technologies that can adjust loads up and down through real-time information and control and automation systems.[73]

Altogether, investments in energy efficiency and consumer- or third-party-owned DERs are contributing to stagnant, or even declining, electricity sales in some jurisdictions. The EPSA Side Case projects retail electric sales growth of just 0.58% per year from 2014 to 2040.

## 1.3 Other Trends for Energy Efficiency and DERs

In addition to costs, other trends that will affect the adoption levels of energy efficiency and DERs in the future include the following:

- Grid modernization – The traditional grid architecture is based on large-scale generation remotely located from consumers, hierarchical control structures with minimal feedback, limited energy storage, and passive loads. DOE's objectives for a modern grid include greater resilience to hazards, improved reliability, enhanced security from an increasing and evolving number of threats, greater affordability to maintain economic prosperity, better flexibility to respond to the variability and uncertainty of conditions including a range of energy futures, and increased sustainability through additional clean energy and energy-efficient resources. As summarized in DOE's Grid Modernization Multi-Year Program Plan, "The future grid will solve the challenges of seamlessly integrating conventional and renewable sources, storage, and central and distributed generation. It will provide a critical platform for U.S. prosperity, competitiveness, and innovation in a global clean energy economy. It will deliver resilient, reliable, flexible, secure, sustainable, and affordable electricity to consumers where they want it, when they want it, how they want it."[74] Such grid modernization efforts are likely to influence advances in energy efficiency and DER technologies, market strategies, and policies, regulations, and programs.

- Changing roles of electricity system participants – The electric sector of the future is likely to have higher levels of end-use efficiency and DERs, new market participants, and changing relationships between many consumers and utilities. Planners and regulators will need to take these developments into account.

- Strategies enabling consumer choice and engagement –Traditional demand response programs provide consumers an incentive payment for shifting or adding consumption to lower demand periods—for example, by allowing the utility to directly control the household's water heater. Where advanced metering infrastructure has been deployed, utilities increasingly are augmenting these incentive-based programs by offering time-based rates for residential utility customers, which better align prices with the actual costs of producing or procuring electricity,[a] reduce peak demand, and enable customers to better manage electricity use and costs.[b]

  Consumer-automated control technologies offer consumers ways to choose and control how and when they use electricity and can improve the effectiveness of these programs. These devices enable automated responses to price or control signals to change the timing and level of electricity consumption. For residential customers, these technologies include load controllers for air conditioners, water heaters, and swimming pool pumps and programmable communicating thermostats (PCTs). These thermostats, primarily for controlling air-conditioner thermostat settings, let consumers "set it and forget it," using automation to execute strategies based on pre-programmed consumer preferences to time-based electricity prices and temperatures.

  A combination of time-based rates, enabling technologies, and recruitment strategies were recently tested in consumer behavior studies analyzed by LBNL. Among the findings, estimated demand reductions for utility customers on time-based rates are higher with PCTs—27% to 45%—compared to -1% to 37% for customers without PCTs. In addition, enrollment in time-based rates was much higher when utilities made the rate the default option ("opt-out" recruitment) than when they required consumers to proactively sign up for the rate ("opt-in" recruitment)—93% versus 24%, respectively. The recruitment approach had little impact on customer retention; attrition rates were minimal in all cases. Not surprisingly, customers who opted into the rate provided larger load reductions. But, the sheer increase in participants

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[a] In general, as demand for electricity increases, higher-cost power plants must be brought online to accommodate the additional demand. In addition, the transmission and distribution system must be sized to meet peak consumer demand.
[b] See Chapter 6 for additional discussion of time-based rates.

recruited through an opt-out approach results in far higher aggregate-load impacts and lower customer-acquisition costs.[75]

Other technologies facilitating consumer choice and engagement include in-home displays and web portals that show current electricity prices and consumption, prepaid ("pay as you go") meters that allow consumers to budget for and pay for electricity as they use it and see how much energy they use each day, and a host of new software and data applications, such as Green Button.[76]

Another consumer-engagement strategy, behavioral feedback (e.g. home energy reports) programs, is increasingly common. These periodic reports provide a household with a comparison of its energy use relative to similar households and offer customized energy-saving tips. While accounting for only about 6% of total residential savings in LBNL's dataset of utility efficiency programs,[a] behavioral programs show promise for achieving greater electricity savings cost-effectively. LBNL estimated the savings-weighted average total cost of these programs at 5.7 cents per kWh,[b] assuming that the electricity-saving actions taken by customers would last about 1 year—the condition of regulators' approval for the pilot or new program. Using instead a measure lifetime of 3.9 years based on a recent meta-analysis of studies of behavior-feedback programs,[77] the savings-weighted average total cost of behavioral feedback programs that LBNL analyzed is just 1.7 cents per kWh.[78]

- "Other" end uses – Electricity consumption by these end uses is growing rapidly in both the residential and commercial sectors. In the residential sector, these end uses include audiovisual equipment, telephones, miscellaneous kitchen and household devices (e.g., toaster ovens, hair dryers), fans, pool and spa heating, and pumps. In the commercial sector, these end uses include equipment such as elevators, escalators, medical and other laboratory equipment, laundry, communications equipment, security equipment, transformers, and miscellaneous electrical appliances not counted as office equipment or computers. See Appendix Table 7.5.

- Data access and information and communication technologies (ICT) – These technologies are capable of enabling networks that connect the electric grid from end to end, facilitating communications throughout the system. Example applications include advanced sensors and controls in buildings to detect and eliminate energy waste, advanced metering infrastructure that enables automated response to electricity prices according to settings (e.g., for thermostats) pre-set by consumers, and distribution management systems that support enhanced value from DERs. Information and communication technologies can improve the reliability, resiliency, flexibility, and efficiency of the electricity system through real-time monitoring and control of grid systems. One meta-analysis estimated that the effective use of ICT has the potential to reduce total U.S. energy consumption by 12% to 22% by 2020.[79] While ICT devices consume electricity, they also increase economic productivity and can improve energy efficiency. For every kWh consumed by ICT systems, it has been estimated that 10 kWh are saved elsewhere in the economy.[80] However, deployment of ICT, advanced metering, and grid communication infrastructure also raise issues concerning data privacy, ownership, and access.

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[a] This refers to programs funded by customers of investor-owned utilities from 2009 to 2013.
[b] This is based on LBNL's 2009 to 2013 dataset of 32 programs (excluding pilots and other programs for which no savings are claimed) that are funded by customers of investor-owned electric utilities. For comparison, for three behavioral programs sponsored for multiple years by U.S. utilities reported a cost range of $0.032 to $0.044 per kWh See *The Short-Run and Long-Run Effects of Behavioral Interventions: Experimental Evidence from Energy Conservation* by Allcott and Rogers (2014).

- Regulatory activities – Lower growth rates for retail electricity sales due to increasing adoption of energy efficiency and DERs does have implications for the financial health of electric utilities. Retail rates are typically designed to raise revenues sufficient to cover both variable and fixed costs primarily through volumetric charges (in dollars per kilowatt-hour).[81] When sales decline, revenues drop without equivalent reductions in total costs, resulting in the potential for earnings erosion between rate cases. Changes in rate designs to address such erosion are being considered or adopted by many state regulators. Many states also have adopted incremental changes to traditional cost of service regulation to better align utility financial interests with increased adoption of energy efficiency, such as decoupling, shareholder incentive mechanisms, and lost revenue adjustments mechanisms (see Section 1.5, Barriers). A handful of states are considering more fundamental changes to utility regulatory and business models and the role of regulated utilities in the ownership, management, and operation of electric delivery systems. For example, in its "Reforming the Energy Vision" (REV) proceeding,[82] the New York Public Service Commission is considering new market-based approaches and revenue streams enabled by utilities, a new ratemaking process that mitigates a utility's bias toward capital expenses compared with operating expenses, longer-term rate plans that allow more flexibility for utility planning and innovation, new performance standards for utilities, changes in retail rates that better signal value to utility customers and aggregators, and a distribution system planning process that reveals locational and temporal system values. Both incremental and fundamental changes to future electric utility regulation and business models have been addressed in numerous reports.[83]

- Market transformation – Market transformation for energy efficiency is "the strategic process of intervening in a market to create lasting change in market behavior by removing identified barriers or exploiting opportunities to accelerate the adoption of all cost-effective energy efficiency as a matter of standard practice."[84] The process requires strategic intervention in specific markets. Examples include accelerating market adoption of energy-efficient homes through marketing, recruitment, and training support, offering rebates to "upstream" or "mid-stream" providers of energy-efficient technologies, and labeling energy-efficient products. Market transformation is a key tenet of the Federal ENERGY STAR program, leveraged by many energy efficiency programs funded by States and utility customers. Other organizations facilitating market transformation for energy efficiency include the Northwest Energy Efficiency Alliance, with more than 140 northwestern utilities and energy efficiency organizations that work at a regional level to accelerate the adoption of energy-efficient products, services, and practices, and the Consortium for Energy Efficiency, an organization of U.S. and Canadian efficiency program administrators that work together to accelerate the development and availability of energy-efficient products and services at the national level.[a]

- Non-wires alternatives for transmission and distribution – Many utilities are facing the prospects of large capital investments in transmission and especially distribution system upgrades. According to The Edison Foundation, total U.S. distribution capital investments for the period 2010 to 2030 are projected to be $582 billion in nominal terms.[85] Geographically targeted energy efficiency and DERs have the potential to cost-effectively defer, reduce, or replace capacity upgrades for distribution and transmission systems by reliably reducing maximum demand in

[a] For more information, see Northwest Energy Efficiency Alliance, http://neea.org/, and Consortium for Energy Efficiency, https://www.cee1.org/.

specific grid areas. In addition to cost savings, potential benefits of non-wire alternatives include mitigating siting concerns related to transmission lines, engaging consumers and their agents (e.g., aggregators) in distribution and transmission solutions, gradual implementation (reducing the impact of incorrect load projections), improving reliability and resiliency through diversity of measures, and faster development time frames. These alternatives can be identified through distribution and transmission planning for specific geographic areas. The Bonneville Power Administration and some states (e.g., Maine and Vermont) and utilities (e.g., Consolidated Edison) have been early adopters in this area. Orders 890 and 1000 by the Federal Energy Regulation Commission require transmission providers to identify how they will treat energy efficiency and DERs on a comparable basis with traditional transmission solutions and how they will ensure comparability through their evaluation and selection of projects.[86] [87]

- Energy efficiency as an environmental compliance strategy –[88] Most air pollution-control devices are effective at reducing only a subset of the pollutants associated with fossil-fuel combustion. Energy efficiency reduces all types of power plant-related emissions simultaneously by avoiding the need to generate electricity in the first place. Energy efficiency can be used to address air pollution from greenhouse gases, acidifying substances, eutrophying substances, ozone precursors, and particulate matter or precursors. With enhanced methods for estimating and determining avoided emissions associated with electricity savings, energy efficiency programs are now being included in air quality improvement plans for a variety of pollutants, including greenhouse gas emissions. Environmental regulatory programs typically mandate specific technologies, practices, or policies to reduce emissions of individual pollutants, but also can use energy efficiency programs to reduce risks associated with air, water, solid waste, and hazardous waste discharges. For example, energy efficiency can mitigate risks related to water withdrawal and discharge for power plants and reduce vulnerability of electricity systems to reductions in availability of cooling water for thermal plants and availability of hydroelectric facilities during dry periods. Quantifying the benefits of energy efficiency as an environmental compliance strategy is becoming increasingly important to support emissions benefits in air pollution compliance plans for federal regulations.[89]

**Table 1.1. Crosscutting Policies, Regulations, and Programs for Energy Efficiency and DER[a] [b]**

| Crosscutting Categories | Description |
|---|---|
| (1) Resource standards | Local, state, and federal jurisdictions can establish standards for energy efficiency, DERs, and transportation electrification across all sectors. Common types of standards include renewable portfolio standards (energy or capacity targets), energy efficiency resource standards (energy or capacity savings per year), vehicle carbon emission standards (e.g., fleet standards that can encourage electric vehicle models), and environmental emissions standards (e.g., $SO_x$, $NO_x$, and $CO_2$ emission caps). |
| (2) Utility ratepayer-funded programs | Ratepayers (utility consumers) fund programs that promote or directly support the uptake of cost-effective measures in nearly all sectors of the economy. Utilities, third parties, or government agencies administer these programs. While these are typically associated with energy efficiency and demand response, other DERs such as solar photovoltaic (PV), distributed generation, and electrical vehicle infrastructure (e.g., charging stations) can also be supported. |
| (3) Building energy codes | State and local building energy codes reduce energy use in new buildings and major renovations by establishing minimum energy efficiency standards for building design, construction, and major remodeling. Such standards could also include provisions for demand response (e.g., requirements for smart thermostats) and potentially other DERs. |
| (4) Appliance and equipment (product) standards | These federal and state standards set minimum efficiency levels for products that consume significant amounts of energy and can include requiring products to have demand response-ready features. State and federal standards efforts often involve assessing efficiency levels with consideration of product efficiency criteria established by the Federal ENERGY STAR program. |
| (5) Financial incentives and tax policies | Federal, state, and local governments can establish policies that provide financial support for efficiency and DER investments, such as programs that provide low-cost financing, tax credits, rebates, and grants. |
| (6) Power sector regulations | Federal, regional, and state electricity regulators oversee a wide range of policies, regulations, and programs that influence energy efficiency and DER adoption. Regulations span all facets of the power sector, from generation, to transmission and distribution, to end-use technologies. Among the areas of particular importance are how electricity rates (both energy and demand charges) are set for utility retail customers, access to markets for energy efficiency and DERs, and rate structures for purchase of energy and capacity from distributed generation (e.g., net metering, value of solar tariffs, and feed-in tariffs). |
| (7) Federal and state lead by example programs | Federal and state lead-by-example programs improve the energy efficiency of their own facilities and operations, and may include demand response, distributed generation goals, and vehicle electrification. These programs can provide examples for private sector actors in addition to supporting public sector energy savings and other goals. |
| (8) Local government-led efforts | Cities and other local governments can establish policies, regulations, and programs for energy efficiency, DER, and transportation electrification through their role as owners of buildings and other assets, policy-makers, taxation authorities and, in some locales, operators of electric utilities. These initiatives can also have "lead-by-example" benefits. |
| (9) Performance contracting | Performance contracting mechanisms are a way for public and private entities to implement comprehensive energy-saving and DER projects using energy service companies (ESCOs) with energy savings guarantees. |
| (10) Voluntary efforts of businesses and consumers | Businesses and consumers can invest in energy-efficient equipment and processes, as well as DERs and transportation electrification, to achieve corporate and personal financial and sustainability goals. |

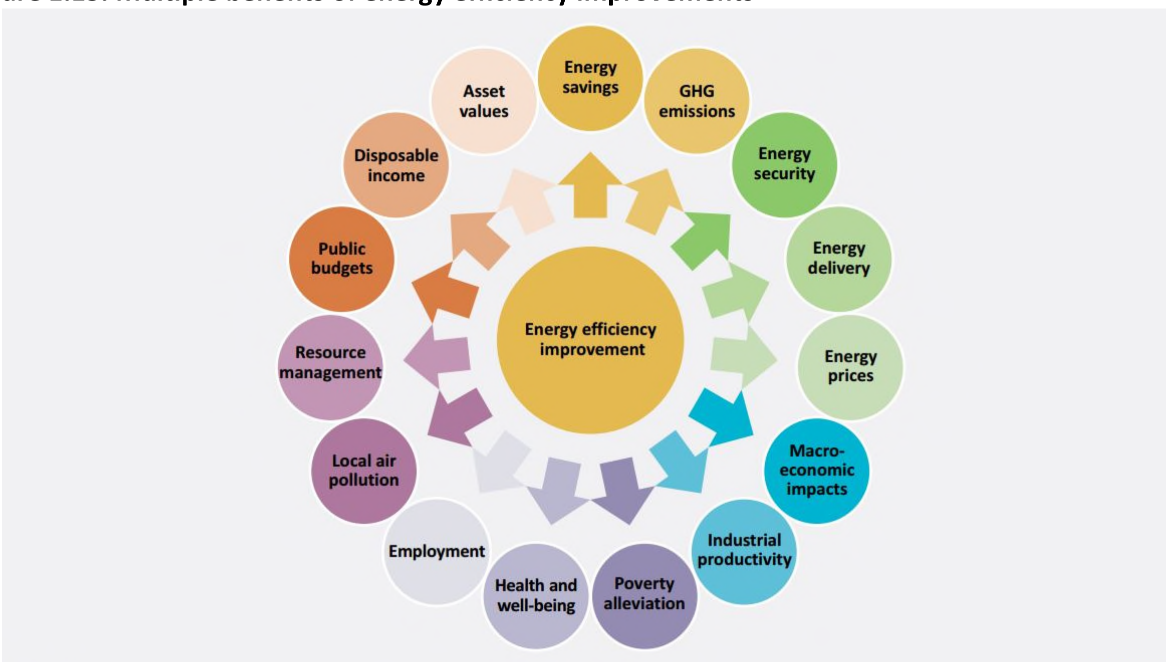
[a] For detailed discussion of policies, regulations, and programs, see Appendix 7.2.

[b] This categorization is based in part on the pathways described *in State and Local Energy Efficiency Action Network (SEE Action) Guide for States: Energy Efficiency as a Least-Cost Strategy to Reduce Greenhouse Gases and Air Pollution and Meet Energy Needs in the Power Sector*. (SEE Action, February 2016).

## 1.4 Energy Efficiency Benefits

Figure 1.15 is an illustrative, but not exhaustive, list of the most prominent benefits of energy efficiency. For the utility and utility customers, energy efficiency avoids costs for energy as well as generation, transmission, and distribution capacity; helps stabilize electricity market prices; reduces disconnections due to arrearages on bill payments; and improves system reliability.

**Figure 1.15. Multiple benefits of energy efficiency improvements[90]**




*Benefits include energy and non-energy benefits for individual participants, the electricity system, and society as a whole.*

Energy efficiency also supports a host of non-energy benefits for individual participants and society as a whole.[91] [92] For participants, these include such benefits as reduced energy bills and more disposable income, increased property values, improved comfort, lower maintenance costs, higher productivity, and positive health impacts.[93] For society as a whole, non-energy benefits include improved energy security and independence; reduced air emissions, water savings, and other environmental benefits; reduced costs to operate public facilities; jobs created and local economic development; and broad health benefits such as reduced asthma cases from cleaner air. Table 1.2 provides an example of the estimated monetary value of health benefits from energy efficiency for single-family and manufactured homes.

**Table 1.2. Weatherization Assistance Program—Health-Related Benefits of Weatherization[94]**

| Non-Energy Benefit (Present Value Per Unit) | Total | Total (Value of Life Excluded) |
|---|---|---|
| Asthma | $2,009 | - |
| Thermal Stress-Cold | $3,911 | $172 |
| Thermal Stress-Heat | $870 | $85 |
| Food Assistance Reduction | $832 | - |
| Reduction in Missed Days at Work | $201 | - |
| CO poisoning | $154 | $7 |
| Improvement in Prescription Adherence | $1,929 | - |
| Reduction in Use of Short-Term Loans | $71 | - |
| Home Fires | $831 | $175 |
| Increased Productivity at Work Due to Improved Sleep | $1,813 | - |
| Increased Productivity at Home Due to Improved Sleep | $1,329 | - |
| Reduction in Low-Birth Weight Babies from Heat-or-Eat Dilemma | $198 | - |
| Total by Tiers (Present Value Per Unit) | $14,148 | - |
| Total by Tiers (Present Value WAP Program) | $1,165,653,232 | - |

*The table summarizes the estimated monetary value for 12 non-energy benefits of the Federal Weatherization Assistance Program for single-family and manufactured homes. "Unit" is an individual single-family or manufactured home. Total values include prevention of deaths from thermal stress. The highest total benefit accrues from preventing thermal stress due to low home temperatures.*

Jobs are a key economic benefit of energy efficiency. Most spending in the energy efficiency services sector goes to insulation jobs (including envelope insulation to meet building energy codes and mechanical insulation to optimize equipment performance and achieve energy savings), work by Energy Services Companies (including energy savings performance contracting by ESCOs), and utility ratepayer-funded activities and associated market activity. For every million dollars spent on these activities nationally, LBNL estimated that the resulting person-years of employment[a] required is 8.9 for insulation, 2.5 for ESCO work, and 6.2 for ratepayer-funded efficiency activities and associated market activity.[95]

[a] One person-year of employment equals one person working full-time for a year.

## 1.5 Barriers

Despite all of these benefits, a host of well-known barriers impede the adoption of all cost-effective energy efficiency and DER, including the following:

- Information and awareness – Consumers have imperfect information about efficiency and DER measures, including available options and performance.
- First costs – Energy efficiency and DER products and services may cost more up-front but provide savings over time. Individual decision-makers generally dislike having to pay up-front for future benefits, in part because of uncertainty in how long they will own or lease the property where improvements will be made.
- Materiality – Energy costs are a small share of expenses for most households and businesses, so it is hard to get them to pay attention to energy efficiency and DERs.
- Limited access to capital – Consumers and businesses may be cash and credit constrained and may not be able to take on debt to finance efficiency upgrades.
- Transaction costs – Energy efficiency improvements and DERs may be time-consuming to understand, arrange, and execute.
- Split incentives – Building owners may not have an incentive to invest in energy-efficient equipment and DERs if their tenants pay the utility bills. Tenants may not want to make such investments in properties they do not own.
- Price signals – Electricity prices are set to recover utility and electricity service supplier costs, not to reflect the true social cost of electricity consumption. In addition, retail rate structures may discourage customer investments in energy efficiency and DERs.
- Insufficient research and development (R&D) – Market sectors may underinvest in technical innovation and R&D for energy efficiency and DER technologies.

In addition, inherent in traditional cost of service regulation for utilities are several incentives, or biases, affecting energy efficiency and DERs. First is the throughput incentive:

> [I]n general if utility sales go down, revenues and profits decline. Because the utility's return is embedded in the rate per unit for electricity … each incremental sale brings incremental profit, and each lost sale costs the utility net income…. But in the short run … the only significant change in utility costs as sales go up or down is the variable cost of producing or purchasing more or less power. Because incremental sales produce revenue that usually exceeds incremental expense in the short run, a utility has a strong motive to increase its throughput. If sales go up, the existing investment in power plants and power lines is spread out over a larger number of units, so the utility is getting more revenue out of them.[96]

Ratemaking tools, such as decoupling and lost revenue adjustment mechanisms, mitigate the impact of energy efficiency and DERs on utility profitability. These tools are discussed further in Appendix 7.2.10. Decoupling breaks the link between utility revenues and energy sales. Specifically, it is a price adjustment mechanism that ensures the utility recovers its allowed revenue, as determined by the state public utility commission, regardless of the utility's actual energy sales.[97] Under lost revenue adjustment mechanisms, rates are adjusted periodically, such as annually, to specifically address revenue loss resulting from energy efficiency, and potentially, DERs. In addition, some states provide shareholder performance incentives to reward utilities for reaching goals specified by their regulator. Some mechanisms also impose a penalty for performance below these goals.[98]

Going beyond performance incentives, comprehensive performance-based regulation also includes multiyear rate plans that encourage utility management efficiency and cost containment. Performance incentives may apply to such measures as service quality and customer service, as well as energy efficiency and DERs.[99]

Two other incentives inherent in cost of service regulation also are relevant to utilities' behavior with respect to energy efficiency and DERs:

- *The Averch-Johnson Effect*, the tendency to overinvest in capital instead of labor. The opportunity to earn a rate of return on investment encourages more capital investment than is optimal. Thus, utilities generally prefer to invest in assets rather than increase energy efficiency programs, and to own generating facilities instead of buying energy from independent power producers.
- *Rent seeking*, the tendency to protect markets through law or regulation or imposing costs on competitors. For example, utilities may make it difficult for third parties to use utility networks to provide value-added electricity services.

In addition, some utilities lack staff experience or capacity in emerging DER areas.

Barriers also exist for energy efficiency and DER participation in markets in restructured regions. First-order barriers to participation of energy efficiency and DERs include eligibility of these resources and the length of the term. Other barriers include the difficulty in measuring energy efficiency compared to other resources, small individual transaction size, non-dispatchability for energy efficiency (energy efficiency is always "on" for the affected electricity uses), and complexity of market rules.[100] [101]

# 2 Residential Sector

This section discusses electricity usage and electric efficiency in the U.S. residential sector. Data on the residential sector generally comprise all "living quarters for private households,"[102] including single-family and multifamily buildings of all kinds, but excluding institutional living arrangements (which are considered part of the commercial sector). The Residential Energy Consumption Survey (RECS), a key data source for details on electricity consumption by households, classifies housing types by the number of units (see, for example, Figure 2.5). All of the data sources cited in this section of the report include housing units in large, multi-unit buildings. However, some policies and programs define the boundary between residential and commercial differently. For example, residential buildings with four or more floors must comply with commercial building energy codes, and energy efficiency program administrators generally address large residential buildings under their commercial programs if they do not have dedicated programs to address such buildings. Except where noted, "projections" in this section refer to the EPSA Side Case (see the introduction to this report for more details).

## 2.1 Key Findings and Insights

### 2.1.1 Levels and Patterns of Residential Electricity Consumption through 2040

*Findings:*

- Growth in national residential electricity sales has slowed significantly, but slow positive growth is projected through 2040 (Figure 2.1).
- Electricity is a large (> 40%) and growing share of national energy use in the residential sector (Figure 2.2).
- Electricity usage per capita and per square foot are declining (Figure 2.3 and Figure 2.4).

*Insight:* Electrical productivity is improving as measured by various metrics cited above. However, as overall load is still increasing, energy efficiency markets and policy have a key role to play in meeting energy resource and environmental goals.

*Findings:*

- Miscellaneous uses (largely plug loads) and air conditioning in the residential sector are growing end uses of electricity, while lighting and space heating are declining (Figure 2.7).

*Insight*: Residential efficiency programs and policies will need to evolve to address the drivers of future electricity consumption, which are not the same as the drivers of past consumption.

Findings:

- Low-income households spend a much greater share of their income on electricity than other households (Figure 2.11).
- The South Census Region uses more electricity per household than other regions (Section 2.2.3), and this region uses electricity for space and water heating much more than other Census regions (Figure 2.9).

*Insight*: Resolving the particular barriers to energy efficiency uptake in the South Census Region and among low-income households throughout the U.S. offers significant potential for achieving energy savings and improving the equity of cost burdens across consumers.

### 2.1.2 Status of Electric Efficiency Deployment

*Findings:*

- Heat pumps are a small but growing share of space-conditioning and water-heating equipment that can generate much more heat per unit of electric input than electric resistance heating. Heat pumps are most efficient in regions where winter temperatures are mild, but new technology has extended their viability into regions that reach temperatures below zero degrees Fahrenheit (Section 2.4.1).
- The South Census Region uses electricity for space and water heating much more than other regions (Figure 2.9).

*Insight*: Heat pumps offer a significant opportunity for electric efficiency improvement. Continued technological progress on heat pumps could facilitate even greater savings.

*Findings*:

- Highly advanced building envelope designs and materials exist (Figure 2.14 and Figure 2.15), but market penetration is very low. Conventional designs and materials show more incremental progress (Section 2.4.1).
- Appliance efficiency is improving, but there is still a sizeable gap between stock average efficiencies and best available technologies (Figure 2.16).
- Substantial opportunities for improving efficiency of electronics exist (Table 2.1).
- Penetration of controls and automation in the residential sector is quite low (Section 2.4.5).

*Insight*: Significant efficiency improvements are available through greater adoption of technologies that are available today, though cost-effectiveness of advanced technologies is often a barrier to their more widespread adoption.

*Findings:*

- The lighting market is transforming to much lower electricity usage due to light-emitting diodes (LEDs). A U.S. Department of Energy (DOE)-sponsored forecast projects LEDs will grow to 83% of installations and 84% of sales in 2030, saving a cumulative 25% of residential lighting electricity usage, relative to a no-LED baseline (Section 2.4.2).

*Insight*: A combination of technology and policy efforts has achieved great success in the lighting market, which may hold lessons for other markets for products powered by electricity. Lighting has been a mainstay of programmatic efforts. With the market in transition, the best end uses for energy efficiency programs to target will be different going forward.

### 2.1.3 Other Trends

*Findings*:

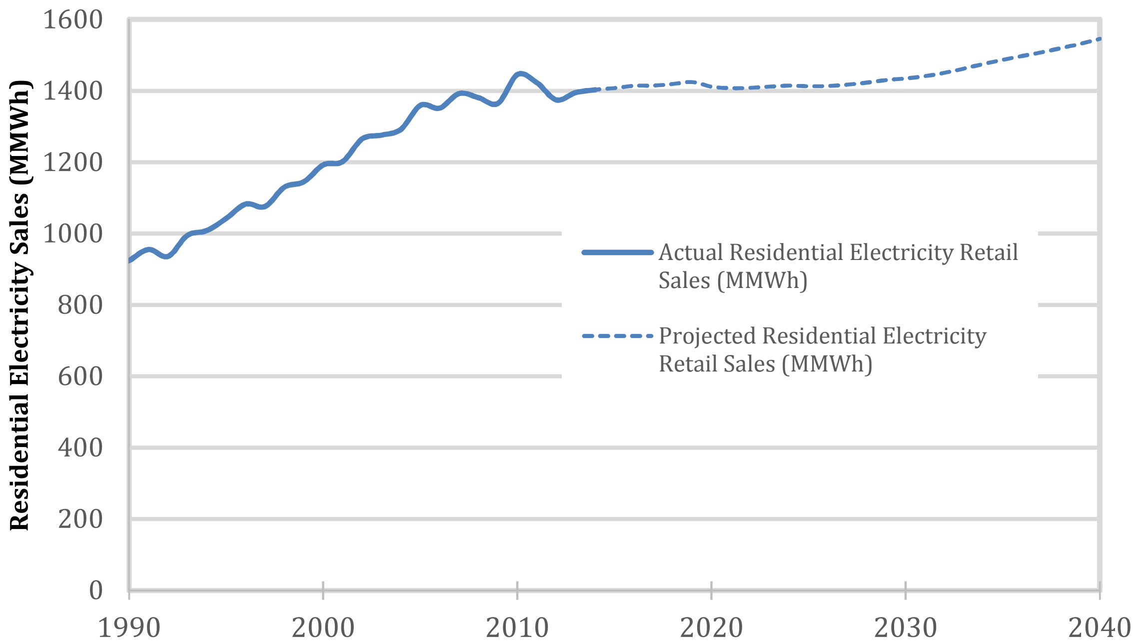
- The U.S. population is shifting to the South and West Census Regions (Section 2.2.3).
- The South Census Region, in particular, uses considerably more electricity per household than other Census regions (Figure 2.8 and 2.9).

*Insight:* Internal population migration is one driver of the slow but steady increase in total electricity consumption.

## 2.2 Characterization

Total residential electricity use generally has grown steadily since 1990 (Figure 2.1). That growth slowed in the mid-2000s,[a] [103] [104] and residential retail sales are currently lower than their peak in 2010. The *Annual Energy Outlook* (AEO) projects growth in total residential electricity sales going forward; however, the projected growth rate is lower than during the 1990s and early 2000s. The AEO projections show residential electricity sales do not reach the 2010 level again until 2032.

**Figure 2.1. Residential retail electricity sales, 1990–2014 (actual) and to 2040 (projected)[105] [106]**



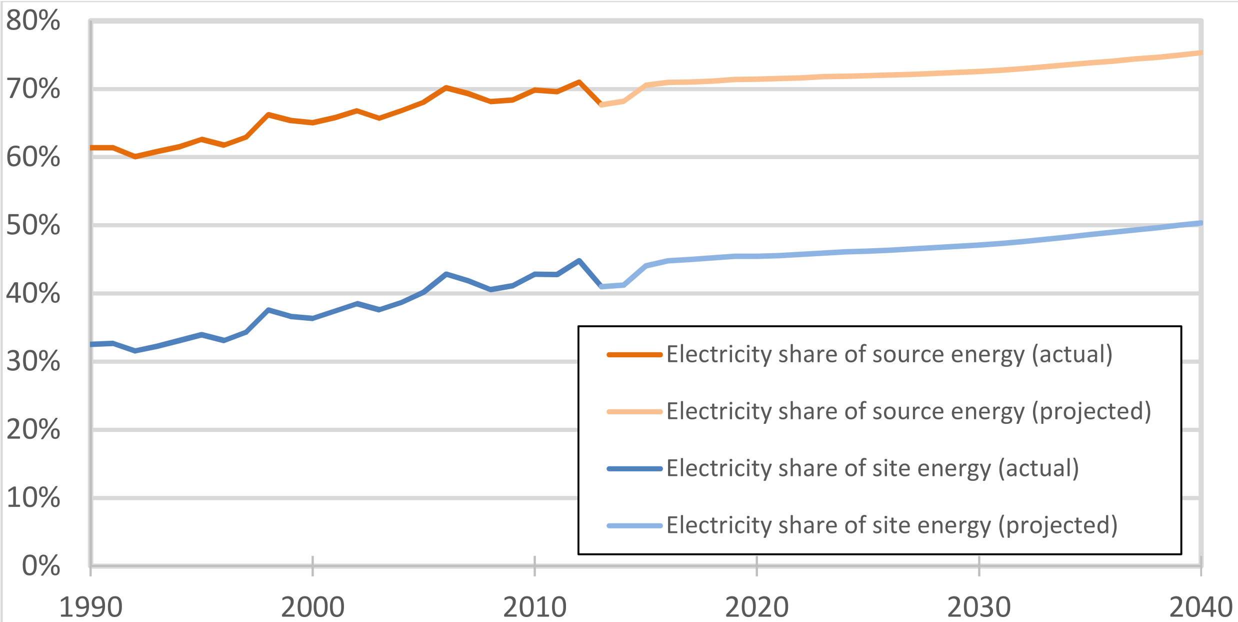

*Sales grew steadily until the mid/late-2000s, when volumes rose and fell by year. Sales in the residential sector are projected to grow very slowly until the mid-2020s, then somewhat faster through 2040.*

Electricity's share of total residential energy usage has also grown steadily and is projected to continue to do so (Figure 2.2). This suggests that electric end uses are growing more quickly in aggregate than end uses that are mostly powered by fuels.[b] [107] [108] [109]

[a] The economic slowdown was likely a key driver of declining consumption in 2008 and 2009. Growth had arguably begun to decrease before the slowdown, and it cannot account for falling consumption after 2010. Other potential explanations include mild weather patterns and improvements in efficiency of electric equipment and building shells

[b] Another explanation could be that space heating and water heating—the two largest end uses where electricity and other fuels are both options—are becoming increasingly dominated by electricity. However, data from the RECS do not show a clear upward trend in the fraction of space heating or water heating energy generated by electricity. The EPSA Side Case projects an increasing share of electricity for these two end uses, but the change is very modest and could explain only a small fraction of the total change in electricity share shown here.

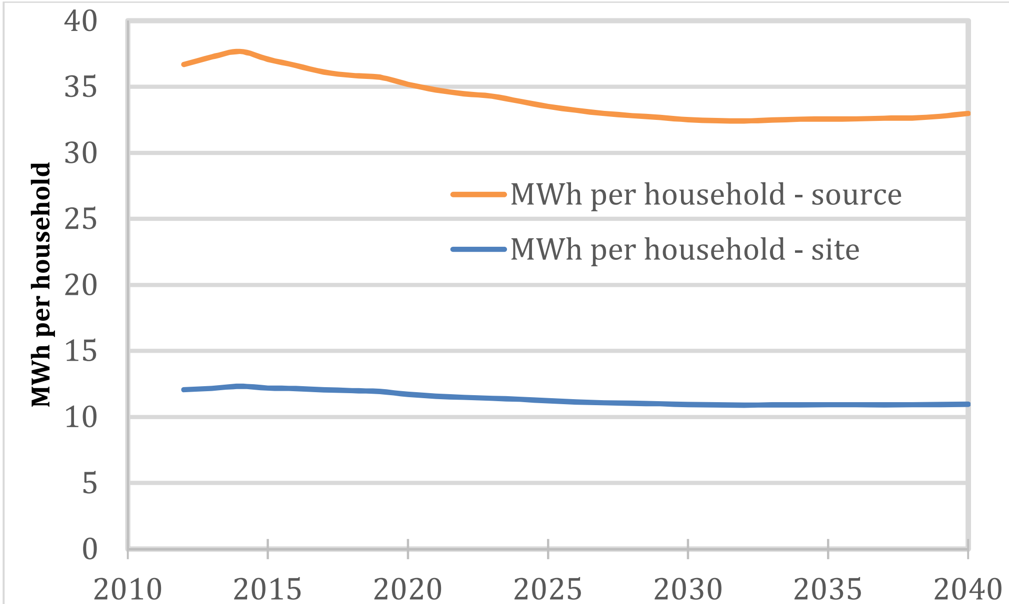
**Figure 2.2. Electricity as a share of total energy use in the residential sector, 1990–2013 (actual) and to 2040 (projected)[110]**




*Measured as site energy (energy delivered to the building), electricity's share of energy consumption has grown over the past 25 years from about 30% to about 40% of residential energy use. Measured as source energy (including generation and line losses), the share is much higher—growing from 60% to 70% over the same time. By 2040, the electricity share of residential energy consumption is expected to exceed 50% in site terms, 75% in source terms.*[111] [112]

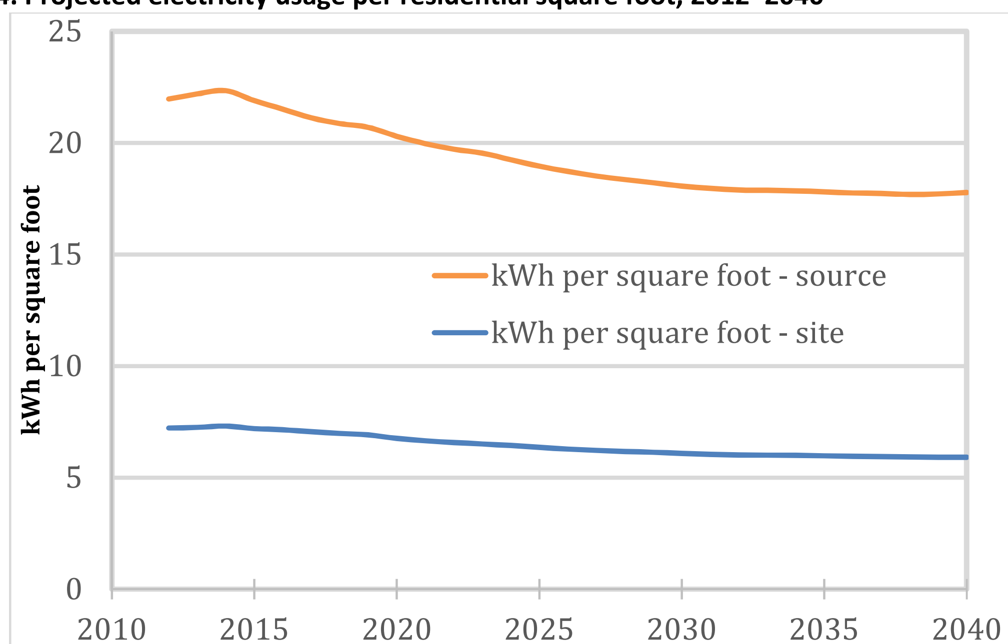
The number of U.S. households has been increasing and is projected to continue to increase. As a result, total residential electricity use is projected to rise even as electricity usage per household is projected to decline (Figure 2.3). The average size of a housing unit is also projected to increase, so electricity usage per square foot declines somewhat more rapidly (Figure 2.4). Electricity use per capita also declines, but slightly more slowly than the per-household decline, as the average household size is projected to decrease slightly. On the whole, 2040 electricity usage is projected to be 10% lower than 2013 per household, 8% lower per capita, and 18% lower per square foot.[113] By these metrics, electrical productivity in the residential sector is increasing and is projected to increase further despite growth in total electricity use.

**Figure 2.3. Projected electricity usage per household, 2012–2040**[114]




*Electricity usage per household is projected to decline slightly in site terms, and more steeply in source terms (due to lower electricity production and line losses in the future).*

**Figure 2.4. Projected electricity usage per residential square foot, 2012–2040**[115]



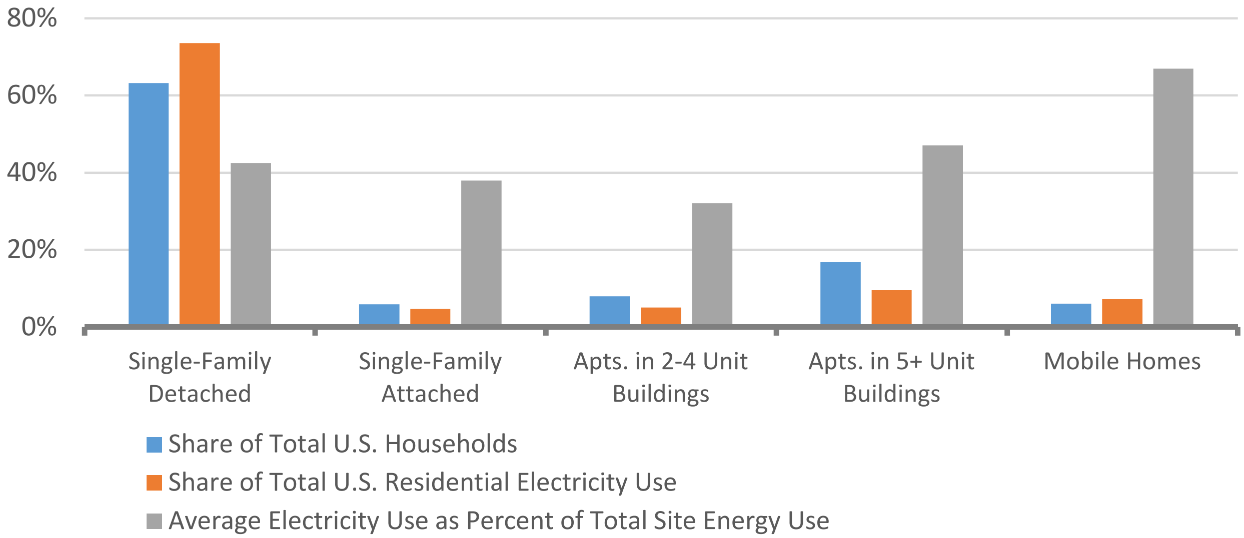

*Housing units are getting larger, so, expressed per square foot, declines in electricity usage are somewhat more rapid.*

### 2.2.1 By Housing Unit Type and Year of Construction

Single-family detached homes are by far the most common housing unit in the United States, comprising 63% of households. They also use more electricity per housing unit than most other housing types (Figure 2.5). As a result, single-family detached homes use 74% of the electricity consumed in the residential sector.[116]

Collectively, apartments in buildings with five or more units consume the second-largest share of electricity. However, even though these buildings comprise 17% of housing units, they use only 9% of total electricity. Manufactured housing is the most electricity-intensive type of housing unit. Electricity represents more than two-thirds of site energy consumed in manufactured housing. However, as manufactured housing represents a small share of the housing stock, they only consume 7% of residential electricity.

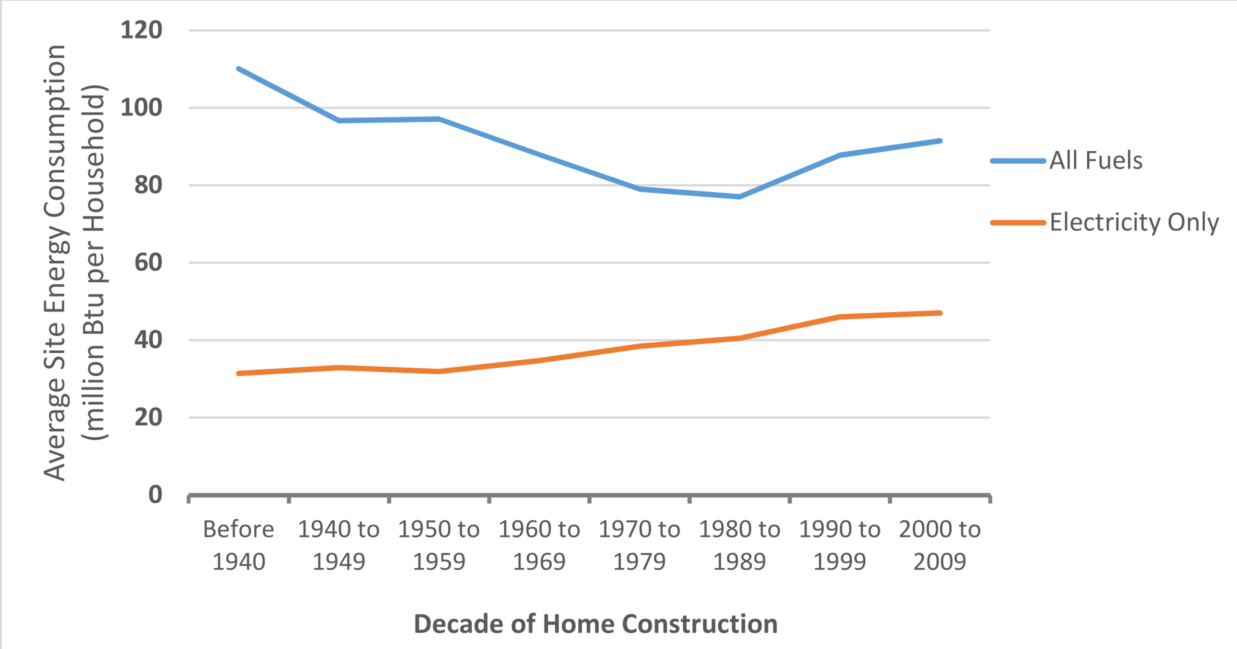
**Figure 2.5. Share of Total U.S. Household and Electricity Usage, by Housing Type, 2009** [117]




*Single-family detached homes use more than 70% of residential electricity. All other housing types use less electricity per household, except manufactured housing (referred to as mobile homes in the Residential Energy Consumption Survey data), for which electricity comprises a large share of total energy use. Large apartment buildings are also fairly electricity-intensive but still use much less electricity per household than single-family detached homes.*

While there is no clear trend in overall *energy* usage by year of construction, newer homes clearly use more *electricity* (Figure 2.6). New homes use more energy for air conditioning, appliances, electronics, and lighting than do old homes—all categories where electricity is the dominant fuel used.[118] Conversely, new homes use less energy for space and water heating, where other fuels are common. This likely explains the trends in Figure 2.6.

**Figure 2.6. Energy and electricity usage per household by year of construction**[119]



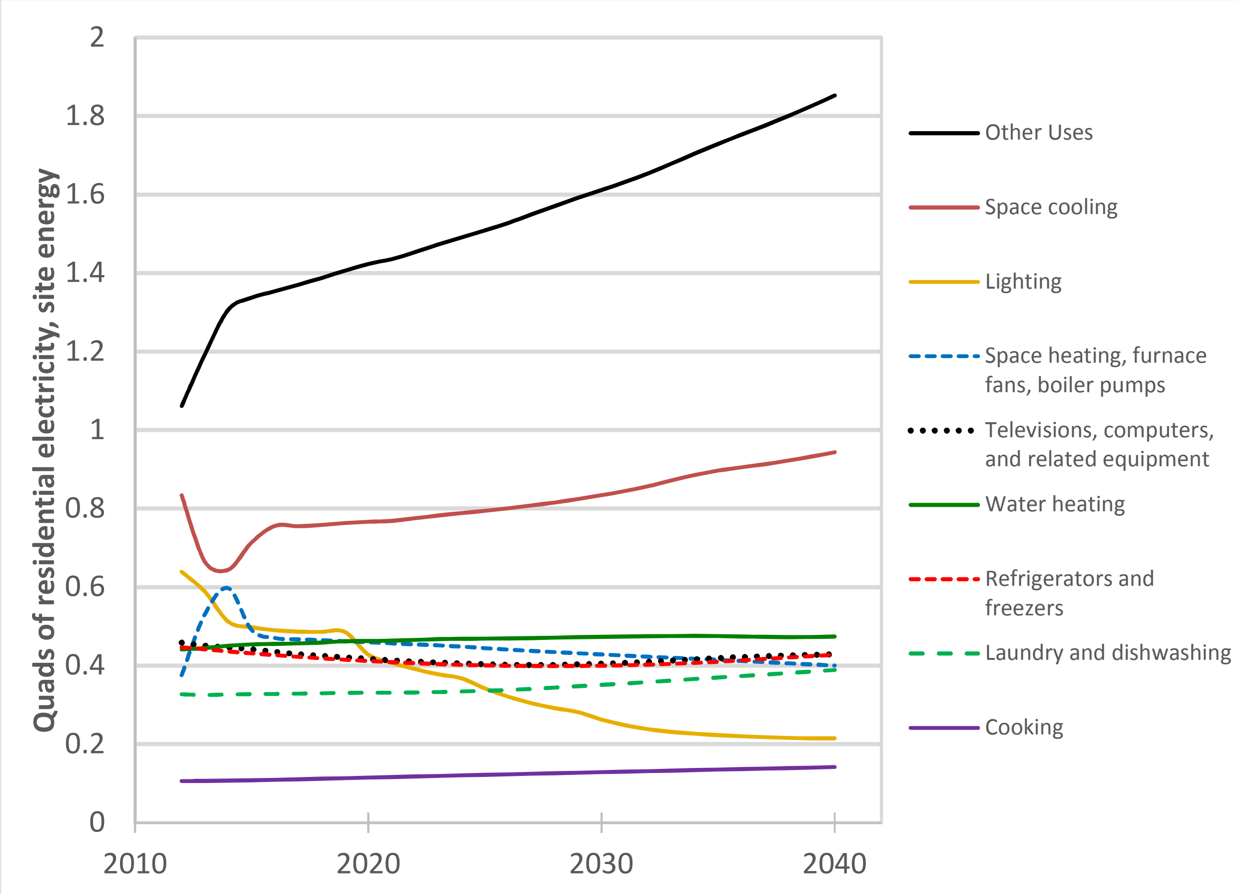

*There is no clear trend in overall energy use, but electricity use is increasing with year of construction.*

### 2.2.2 By End Use

In the U.S. Energy Information Administration's (EIA's) classification of electricity uses, "Other" uses of electricity collectively represent the largest residential electricity end use. This category is mostly miscellaneous small electronic devices, although it also includes items like fans and pool heaters (for more on Other residential end uses, see Section 2.4.4). Space cooling, space heating, and lighting are the next-largest residential end uses. Note that, for natural gas and other fuels, this distribution looks very different. These fuels are mostly used for space heating and water heating and are not commonly used for cooling, lighting, or Other uses. Also note that electricity used for home electric vehicle (EV) charging is not included in EIA's classification of residential end uses; rather, this usage is attributed to the transportation sector. For more on EV charging and residential electricity use, see Section 2.7.

Figure 2.7 shows that use of electricity for Other and space cooling is projected to grow substantially in the future. Electricity usage for space heating and lighting is projected to decline; the latter by more than half by 2040 due to increasing penetration of highly efficient lighting technologies. Expected population migration to the South and West Census Regions—regions with high cooling loads—drives much of the anticipated increase in space cooling (Section 2.3). [120] The continued profusion of miscellaneous electric loads (MELs) drives projected increases in Other uses.[121] Note that some MELs are outside the Other category in Figure 2.7. Televisions (TVs) and computers comprise their own category, and their electricity usage is projected to rise only slightly. Increased penetration of highly efficient screen technologies is reducing electricity usage from TVs and monitors, though larger screens are offsetting some of these gains in the case of TVs.[122]

**Figure 2.7. Projections of residential electricity usage by end use**[123]

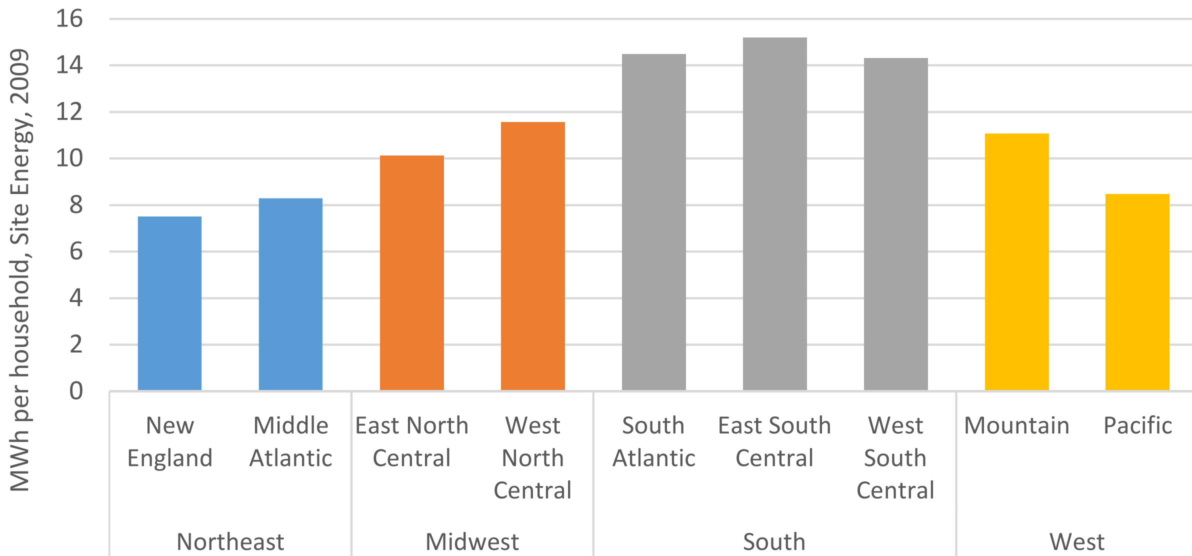



*Air conditioning and Other Uses are the largest shares of electricity usage and by far the fastest growing. Lighting consumption is projected to fall by more than half. Space heating consumption is projected to decline as well.*

### 2.2.3 By Region

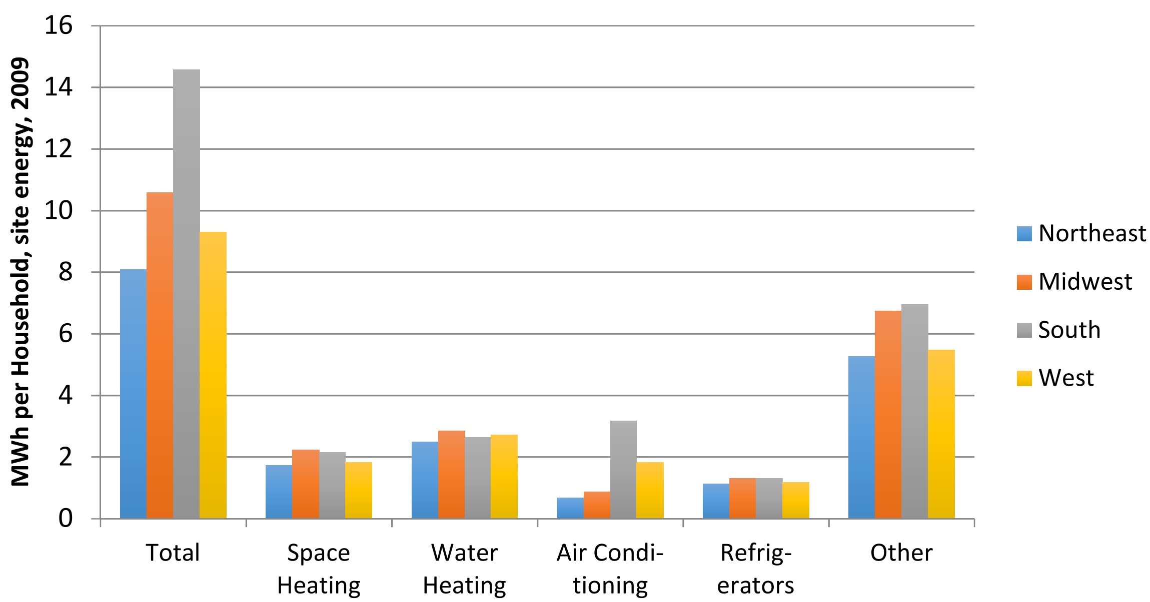
As Figure 2.8 shows, electricity usage varies substantially by region. The South Census Region uses more electricity per household than other regions, while the Northeast Census Region and the Pacific Census Division use less. Much of the variation in usage can be explained by disparities in specific end uses across Census regions (Figure 2.9). The South, and to a lesser extent the West, Census Regions have high cooling loads. Moreover, the South Census Region uses electricity for space heating much more than other regions do. Differences in housing type may also help explain these discrepancies (see Figure 2.5). The Northeast Census Region, which has low electricity consumption per household, has relatively more single-family attached homes and apartment units and fewer single-family detached homes and manufactured homes than other Regions. The Midwest Census Region, with moderate electricity consumption, is dominated by single-family homes and has few large apartment buildings. The South Census Region, with high consumption, has many manufactured homes and fewer single-family detached and small apartment buildings than other Regions. And the West Census Region, with moderate to low consumption, has a housing distribution broadly comparable to the nation as a whole.[124]

**Figure 2.8. Electricity usage per household, by Census Divisions, 2009** [125]




*Usage varies significantly. An average household in the East South Central Division using more than twice as much electricity as the average New England household, driven by weather and by the share of household energy use that comes from electricity.*

**Figure 2.9. Residential electricity usage (MWh per household) by Census Region and end use, 2009**[126]

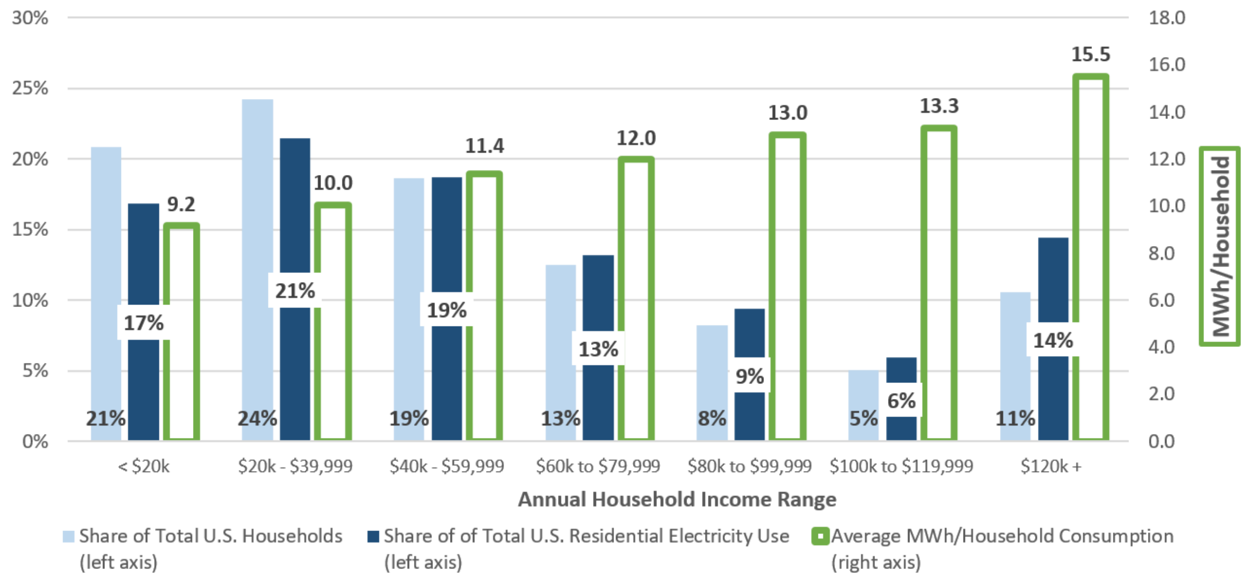



*Variation in air conditioning and Other usage is significant between regions. However, the South Census Region uses a similar amount of electricity per household for space and water heating as other regions despite milder winter temperatures. Note that averages for end uses are based on the households that use electricity for that end use. For example, households that use natural gas for space or water heating are not included in the averages for those end uses.*

### 2.2.4 By Occupant Demographics

Electricity usage increases steadily with household income (Figure 2.10 and Figure 2.11). Households with incomes above $120,000 use about 70% more electricity per household than households with incomes less than $20,000. However, low- and moderate-income households are much more numerous and collectively account for a large share of residential electricity use. Households with incomes below $60,000 collectively consume more than 60% of residential electricity.

**Figure 2.10. Electricity consumption and share of U.S. households by income, 2009**[127]

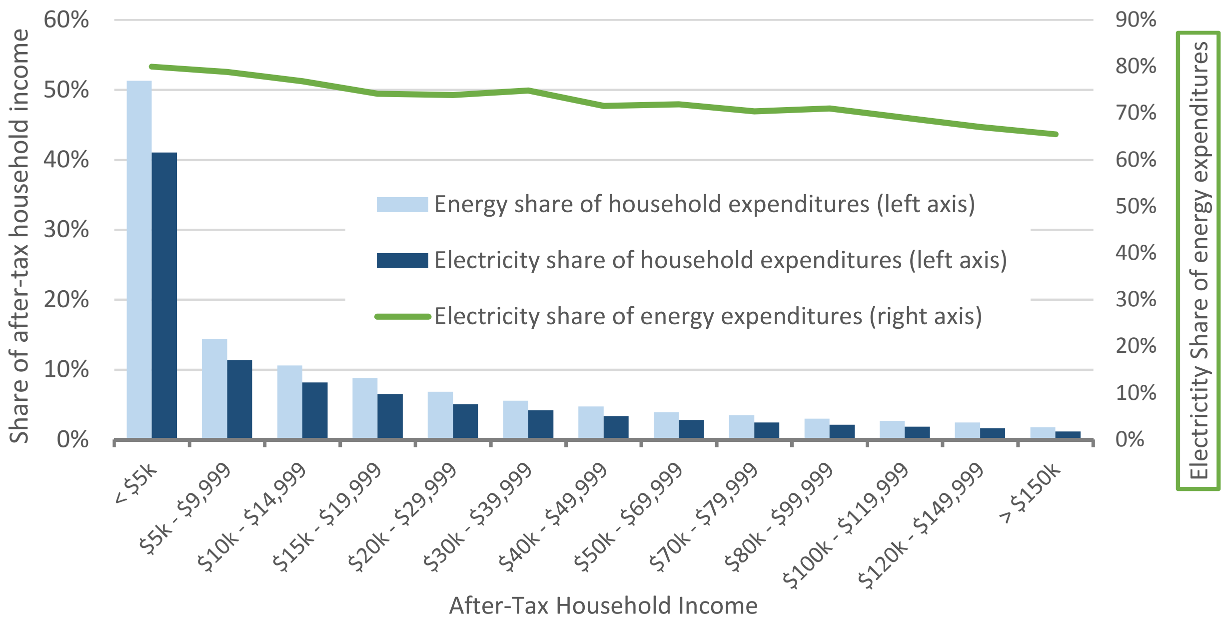



*Site electricity use per household rises steadily as income increases. Households at the highest income level account for a significant share of total electricity use in the United States. Due to the large number of low- and middle-income households, households with less than $60,000 in income use more than 60% of U.S. residential electricity. Note that these data are not normalized by square footage of households in each income category.*

Households with more members use more electricity than do smaller ones. However, electricity consumption per person declines with household size. This reflects the fact that additional housing unit occupants have relatively little impact on many electricity end uses, such as space conditioning and some appliances.

On average, 3.6% of annual U.S. household income after taxes ($2,075 per household) goes toward energy and 2.5% ($1,484 per household) toward electricity specifically. Households with incomes below $20,000 pay a higher share of after-tax income for energy (9.0%, $1,571 per household) and electricity (6.2%, $1,082 per household) (Figure 2.11). Moreover, electricity's share of household energy costs is highest for low-income households and declines steadily as income increases. It is also important to note that, per household, renters pay 26.7% more on energy expenditures per sq. foot compared to homeowners.[128]

**Figure 2.11. Energy and electricity expenditures as a fraction of after-tax income, by household income level**[129]




*Lower-income households spend a greater share of their income on energy and a greater share of their energy expenditures on electricity. Income includes public assistance such as social security income, food stamps, and unemployment and veterans' benefits.*

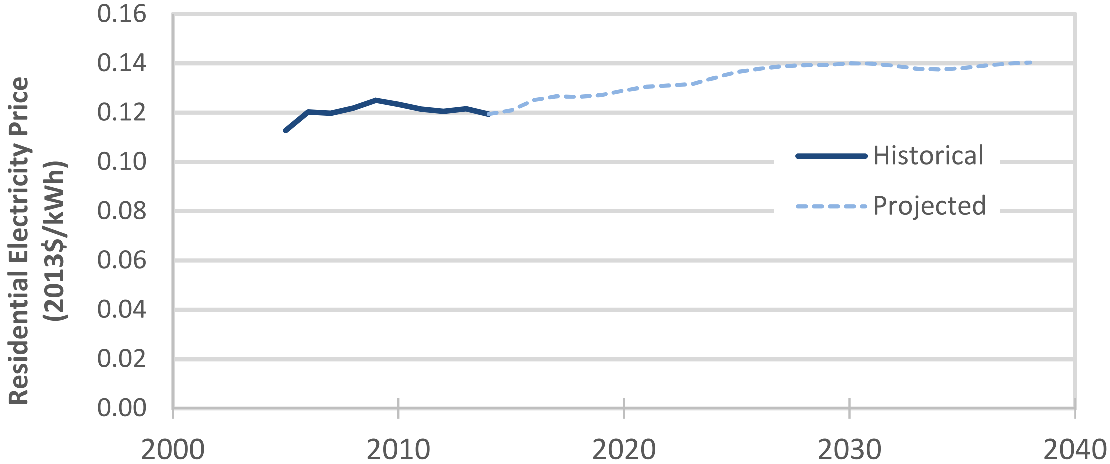
Regional differences in electricity's share of household expenditures also exist, especially with regard to the South Census Region. Electricity expenditures are on average 2.0% of household after-tax incomes in the West, 2.2% in the Northeast, 2.3% in the Midwest, and 3.3% in the South Census Regions. Drivers of this difference are discussed above.

## 2.3 Metrics and Trends

Section 2.2 covered trends in residential electricity use overall (Figure 2.1), as a share of total energy use (Figure 2.2), per household (Figure 2.3) and per square foot (Figure 2.4), by household vintage (Figure 2.6), and by end use (Figure 2.7).

Electricity prices are an important driver of electricity usage and of the economic attractiveness of efficiency measures. Figure 2.12 shows the trend in average electricity prices, which have been mostly flat over the last 10 years but are expected to rise slowly but steadily to 2040. The "average price" shown is total utility revenues divided by total electricity sales, but the actual prices utility customers pay vary due to many factors. Prices are different in different parts of the country. The average price per kilowatt-hour is different for different customers of a given utility based on their electricity usage and income level. In addition, in a small but growing number of cases, residential electricity prices also vary by the time of usage. See Section 2.6.5 for more on residential electricity rate design. The Residential Appendix includes historical prices for the residential sector since 1990 (See Figure 7.16).

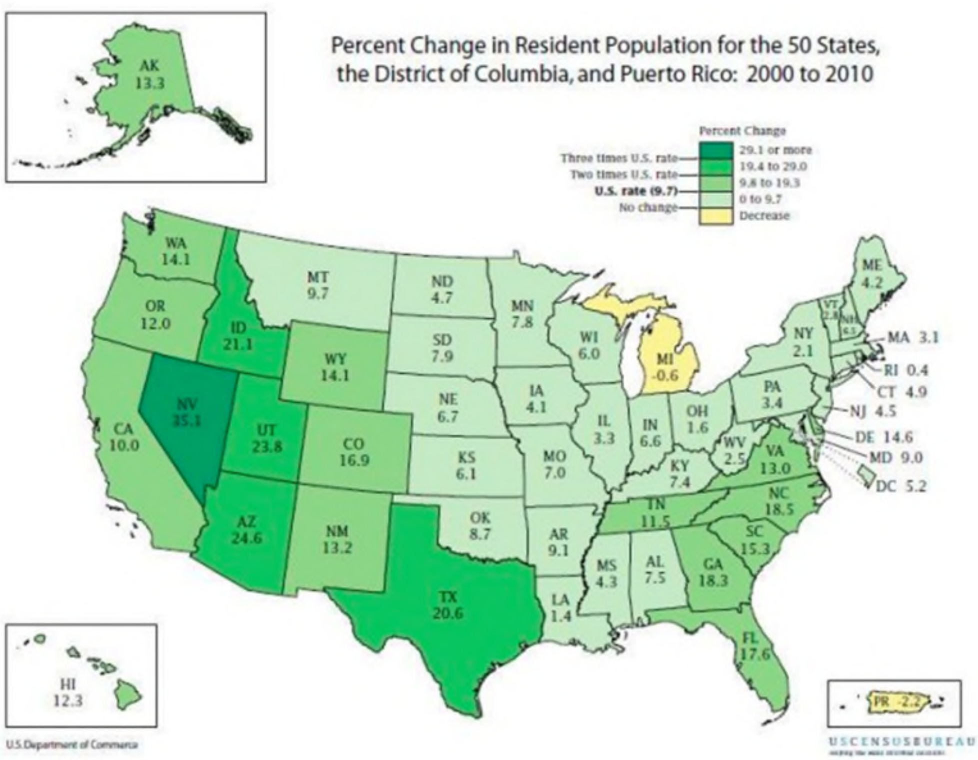
**Figure 2.12. Trends in average residential electricity price (revenue from residential customers divided by utility sales from residential customers), 2005–2013 (measured) and to 2040 (projected)[130] [131]**




*While prices have been mostly flat over the past 10 years, they are projected to increase steadily to 2040.*

Finally, population movement is a driver of several of the trends affecting residential electricity use. As Figure 2.13 shows, population growth (including immigration and internal migration) has been highest in the South and West Census Regions and lowest in the Northeast and Midwest Census Regions. As discussed in Section 2.2.3, the West and South Census Regions use more electricity than other regions, due to high cooling loads and in the South to greater use of electricity as a home heating fuel.

**Figure 2.13. Population growth by state, 2000–2010[132]**




*Growth has been high in the South and West relative to the Northeast and Midwest Census Regions.*

## 2.4 Residential Energy Efficiency Technologies and Strategies

This section provides an overview of the current and projected state of play for energy efficiency technologies in residential buildings, with a focus on those technologies that are currently deployed. Chapter 5 of the *Quadrennial Technology Review* (QTR) provides much more detail on energy technologies in buildings.

### 2.4.1 Space Conditioning

Overall, space conditioning represents a declining share of electricity consumption. However, as noted in Section 2.2.2, the trends diverge for heating and cooling; electricity use is projected to fall for heating but rise for cooling.

Two major factors influence electricity demand for space conditioning: the building envelope (including doors, windows, insulation, and air-flow control) and the efficiency of heating and cooling units (furnaces, boilers, room and central air conditioning units, heat pumps, and the distribution system for the conditioned air). Generally, separate units provide heating and cooling, although these units often share duct systems. Heat pumps can provide both heating and cooling services with a single unit.

In the case of heating, most households can access other fuels—primarily natural gas and, less often, fuel oil, propane, or wood. Electricity usage for heating and water heating is substantially driven by the relative economics of the available options, although the high fixed costs of switching between fuels mean that long-run shifts in those relative economics are more important than short-term changes.[a] Because of issues such as fuel-switching and migration to regions with different fuel mixes, changes in national electricity usage for heating do not necessarily reflect changes in the efficiency or usage of devices or efficiency of building envelopes. As of 2009, 33.5% of U.S. housing units used electricity as the primary heating source. About half of these households (16.8% of all households) used central warm-air furnaces, 26% (8.6% of all households) used heat pumps, and the remainder (8.2% of all households) used other electric heating technologies, mostly built-in or portable electric units.[133] Some 24% of all households use secondary electric heaters.

Conversely, electricity powers essentially all space-cooling technologies, so space-cooling electricity usage is directly determined by usage and device efficiency. As of 2009, 87% of U.S. households had air conditioning equipment. Nearly three-quarters (73%) of those households (61% of all households) had central air conditioning; 19% of central air conditioning units were heat pumps. Nearly a third (29%) of households with air conditioning had one or more window or wall units.[134]

Little technological improvement is possible in electric resistance heating, which is 98% to 99% efficient in converting site electricity to heat. Heat pumps, however, can generate two to four times as much heat per unit of electric input as electric resistance heating.[b] As temperatures drop, the performance advantage of air source heat pumps over electric resistance heating decreases. Ground-source heat

[a] Policy also may play a role. For example, California's Title 24 building standards no longer allow electric-resistance heat as a primary heating source except in certain, unusual circumstances.

[b] Electric resistance heat uses electricity to *generate* heat. A heat pump, however, uses electricity to power a mechanical compressor and refrigerant system that *moves* heat from where it is needed to where it is not. Heat pumps extract heat from outdoor air to warm a home (or extract heat from indoor air to cool a home). At most temperatures, this process yields substantially more heat energy than the electric energy used to power the system.

pump efficiency is less affected by ambient temperatures. Until recently, air source heat pumps were only considered appropriate technology in regions where temperatures rarely drop well below freezing, most notably the South. Newer heat pump technologies are improving performance at lower temperatures and may facilitate the penetration of air source heat pumps in other parts of the country. Air source heat pumps are projected to comprise 13.3% of main space heaters by 2040, up from 8.6% in 2012, while electric resistance heaters decline from 26.1% to 23.4% of main heating units. Ground-source heat pumps comprise 0.8% of space heating units in 2012 and are projected to increase to 1.3% in 2040.[135] Uptake of ground-source heat pump is limited by high installed cost at present. They also require a suitable underground location for burial. Space may not be available for some housing units. The Residential Appendix provides details on expected improvements in performance of space conditioning equipment between now and 2040 (Table 7.3).

Heat pump technology is also available in water heaters and offers similar performance advantages over electric resistance water heaters. New standards for electric water heater efficiency adopted in 2015 (Section 2.6.1) will effectively require heat pumps for electric water heaters with storage capacity between 55 and 120 gallons[a] that are not grid-enabled.[b] DOE has identified continued research on heat pump technologies as a major priority for energy efficiency in buildings.[136]

The building envelope affects cooling as well as heating efficiency in electrically heated buildings. Housing units that comply with current building energy codes regulate heat gains and losses much better than older homes, many of which are not well sealed, not insulated, and have single-pane windows. Modern building envelopes allow for significant downsizing of heating and air conditioning units. Beyond heat gains and losses, the building envelope also influences the amount of solar heat gained by the home, especially through windows and roofs.

As Figure 2.14 and Figure 2.15 show, advanced envelope technologies available today can dramatically reduce or entirely eliminate the need for space conditioning in many climates.[c] The challenge is to make these technologies cost-competitive with conventional alternatives, to manage potential moisture accumulation brought on by tight building envelopes,[d] [137] and to provide equivalent or superior amenities.[e] [138] As noted in Section 2.5, research on retrofit-friendly technologies that can easily be deployed in existing buildings is another research priority for DOE.[139]

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[a] This standard will cover water heaters with tanks that serve some single housing units. However, small housing units may have tank sizes smaller than this, while water heaters that serve multiple units may be larger than this.

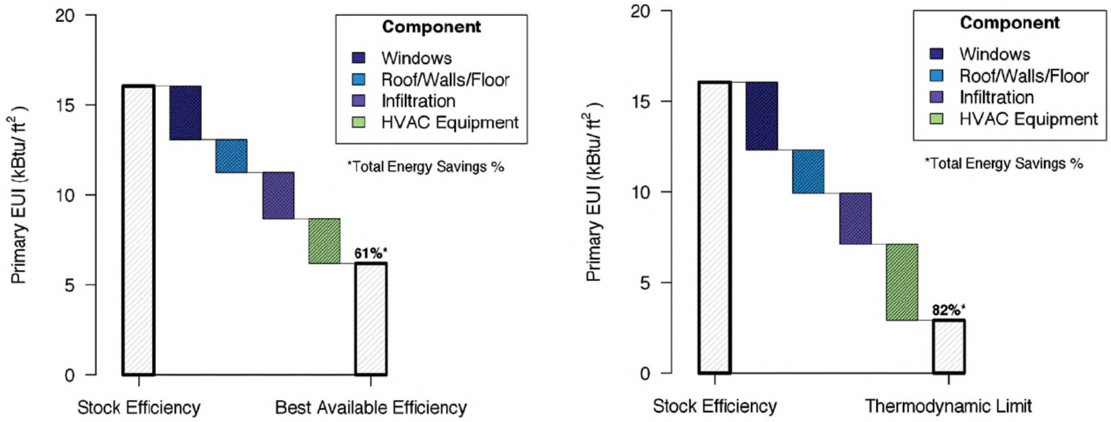
[b] Some electric utilities are deploying grid-integrated water heaters for demand response, as they offer storage by heating water during off-peak hours. Efficiency standards for grid-enabled water heaters are lower to enable greater demand response.

[c] In the case of space heating, these efficient envelope technologies would reduce demand for natural gas and other home-heating fuels, not just for electricity.

[d] "[A]advanced envelope systems are rarely selected by building designers. Current solutions are expensive and/or unfamiliar to many designers, builders, contractors, and code officials and therefore perceived as risky. Furthermore, the dominant perceived risk is durability specifically related to condensation and moisture accumulation in building assemblies."

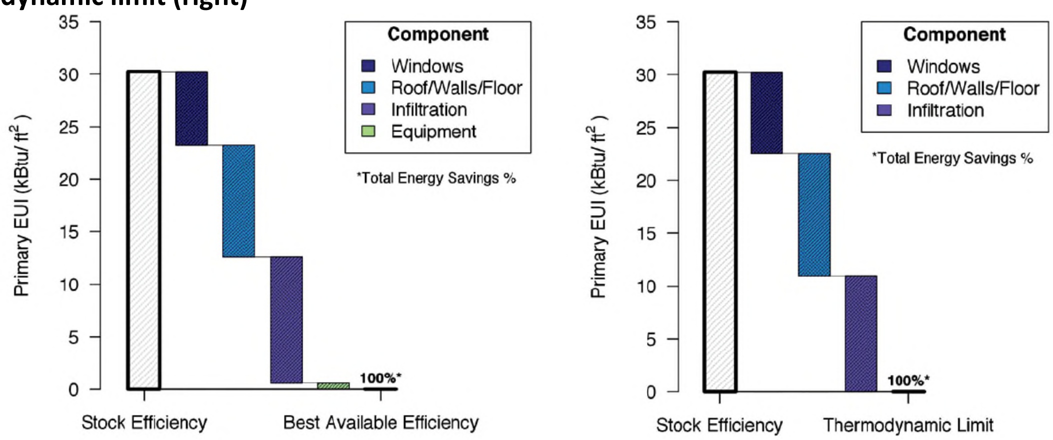
[e] For example, very tightly constructed houses with low air-exchange rates can feel stale and create indoor air-quality issues; mechanical ventilation can ameliorate these problems.

**Figure 2.14. Potential for reductions in residential cooling, using best available technology (left) and thermodynamic limit (right)** [140]




*Use of the most efficient wall, window, and HVAC equipment now available could reduce residential cooling 61% (left). The theoretical limit is an 82% reduction (right).*

**Figure 2.15. Potential for reductions in residential heating, using best available technology (left) and thermodynamic limit (right)** [141]




*Use of the most efficient wall, window and HVAC equipment now available could eliminate the need for residential heating. Note that much of space heating energy consumption in the U.S. is not electrically powered, so the potential reductions shown here pertain only partly to electricity.*

### 2.4.2 Lighting

As Figure 2.7 earlier in this chapter suggests, the residential lighting market is in the midst of a significant transition to more efficient technologies that are projected to dramatically reduce lighting's share of residential electricity use. A DOE-sponsored forecast[142] projects that LED lighting will grow from < 1% of installations and 3% of sales in 2013 to 83% of installations and 84% of sales in 2030, saving a cumulative 25% of residential lighting electricity usage, relative to a no-LED baseline. This projection assumes continued price and performance improvements in LED lighting technology. LEDs have been rapidly increasing in efficiency of light production per electricity input and decreasing in price.[143]

### 2.4.3 Appliances

Most major home appliances (refrigerators, freezers, clothes washers, and dishwashers) are powered by electricity. Clothes dryers, stoves, and ovens can be gas or electric, but electric units represent the significant majority (81% for clothes dryers; 61% for cooking equipment) in each case.[144] As with space heating, future electricity consumption depends on fuel choice, as well as equipment efficiency and both adoption and usage rates.

Electricity usage of refrigerators, freezers, and clothes washers depends significantly on the design of the unit. For example, refrigerators with top-mounted freezers (average consumption 407 kilowatt-hour (kWh)/year for a typical 2013 model) are considerably more efficient than those with bottom-mounted freezers (540 kWh/year) or side-mounted freezers (596 kWh/year);[a] [145] all three have significant market share.[b] [146] Front-loading clothes washers are considerably more efficient than top-loading models, both of which also have significant market share.[c] [147]

In terms of usage, stoves and refrigerators are near ubiquitous, and some homes have second refrigerators and freezers. Some 59% of households have dishwashers, 82% have clothes washers, and 79% have clothes dryers.[148] Increasing household adoption of these units—in addition to second refrigerators—will increase residential electricity use even as improved unit efficiency decreases it.

Refrigerators, freezers, and clothes washers are expected to see moderate improvements in efficiency through 2040. Efficiency of dryers is not expected to improve much; while heat-pump clothes dryers that are about 50% more efficient than electric resistance dryers are available in the U.S. market, the projected "typical" unit remains an electric resistance dryer through 2040.[149] Figure 2.16 shows projected improvements in the stock average efficiency for several major electric space-conditioning devices and appliances, with 2012 stock efficiency normalized to 1. Note that different metrics apply to different pieces of equipment, so these trajectories are not directly comparable to one another.

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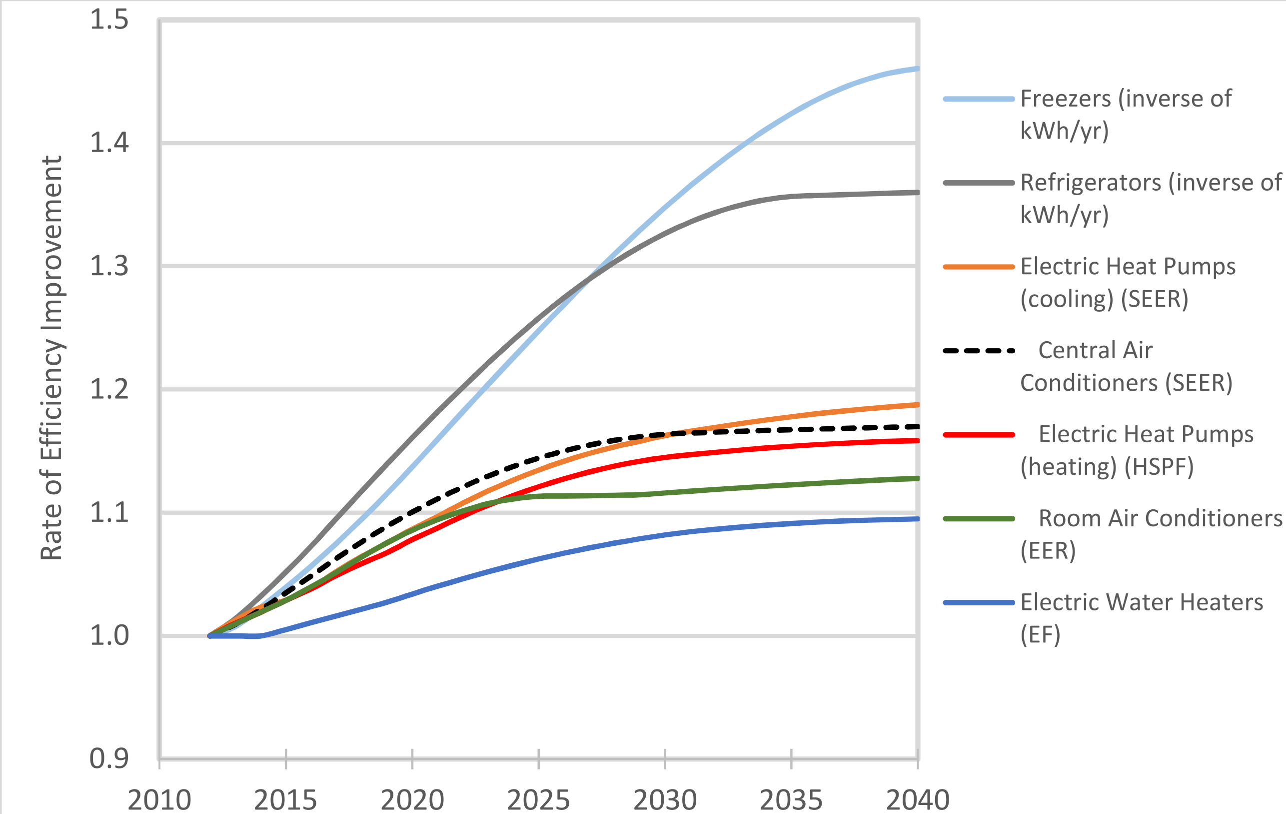
[a] Different standards apply to each of these product designs, reflecting the fact that the inherent efficiency of each design is different. Standards also vary based on whether an icemaker is present and whether defrost is automatic, as well as with the volume of the unit.

[b] Each of the three technologies accounted for at least 20% of shipments in 2012.

[c] Each technology comprised almost exactly half of electric clothes-washer shipments in 2012.

**Figure 2.16. Projected improvements in stock efficiency of selected electric equipment and appliances**[150]




*All equipment is projected to improve in efficiency. Note that different efficiency metrics apply to different pieces of equipment, and rates of improvement are not directly comparable across metrics.*

### 2.4.4 Electronics and "Other" loads

This section discusses computers, televisions, and related equipment, as well as a wide variety of uses that fall into the Other category in EIA data: audiovisual equipment, telephones, small appliances (e.g., dehumidifiers), fans, pool and spa heating, and pumps.

The electric loads in this section are generally referred to as MELs. (The term *plug load* is also used, though this term is more ambiguous since some appliances are also plugged in.) The term MELs is generally understood to include TVs, computers, and related equipment, as well as the Other uses mentioned above.[a]

Table 2.1 shows that the best available, current technology uses only a fraction of the electricity of the average television and computing unit, suggesting that improved efficiency can offset greater penetration of these technologies. Indeed, as Figure 2.7 shows, computer and TV electricity usage is projected to increase only slightly by 2040. Set-top boxes[b] account for about 28% of TV- and computer-related electricity use,[151] more than all computer-related equipment combined. Currently available technology provides less opportunity to reduce consumption in this category through stock turnover

[a] See Appendix Table 7.5 for list of example MELs.

[b] Set-top boxes are devices that convert an external signal into one that can be displayed on a television set. Common examples are cable TV converter boxes, satellite TV converter boxes, Ethernet devices, and video game consoles.

than in computers and TVs, suggesting a potential target for research and development. A DOE rulemaking to establish standards for set-top boxes was recently withdrawn after manufacturers reached a voluntary agreement. The agreement requires that by 2014, 90% of new set-top boxes meet ENERGY STAR standards, [152] representing an efficiency improvement of 10 to 45 percent, depending on box type, by 2017.[153]

**Table 2.1. Efficiencies of Selected Electronic Devices[154]**

| Devices | Current stock (kWh/yr) | Best available (kWh/yr) | Max tech (kWh/yr) |
|---|---|---|---|
| TVs | 213 | 63 | 24 |
| Residential computers | 158 | 34 | N/A |
| Commercial computers | 336 | 34 | N/A |
| Set-top boxes | 142 | 86 | 65 |

*There is tremendous potential to increase efficiency of these devices through stock turnover and further innovation, although less so in the case of set-top boxes.*

“Other” uses are considerably harder to address. Given that this group of uses is so varied, it is difficult to find crosscutting technological solutions. However, advances in power management and efficient electrical circuitry may decrease electricity consumption of MELs across the board.[155] Understanding these uses and making them more efficient are major research priorities given their rapidly growing importance.

### 2.4.5 Controls, Automation, and “Smart” Homes

Home controls and automation have significant potential to improve residential electric efficiency. Per the 2015 QTR, building control systems can potentially:

- “Control room temperatures, humidity, ventilation rates, tunable windows, variable louvers, and dimmable lights
- Control major appliances—most devices are controlled by turning them off or on, but the new generation of appliances allows more sophisticated adjustment of operation
- Use weather forecasts to develop optimum strategies for preheating or cooling the structure
- Detect and identify component failures and look for signs that equipment is about to fail
- Adapt performance in response to communications from utilities using new rate structures to minimize overall system costs
- Learn and anticipate user behaviors including adjusting for holidays and integrate user preferences dynamically”[156]

Currently, most residential buildings are equipped to automate only a small fraction of these tasks. Programmable thermostats are widely available and are present in 37% of housing units, though only 53% of households with these thermostats use them to lower temperatures during the day, and only 61% use them to lower temperatures overnight.[157] “Smart” thermostats learn from occupant behavior and adjust schedules to minimize energy use. These devices can also enable automated demand response, adjusting thermostats during peak load events to shave usage.[158] However, they are not yet widespread. "Smart" power strips can control "phantom" loads,[a] [159]drawn by plugged-in electric devices even when they are powered off, but these are not widely used. Lighting controls are becoming common in commercial buildings, but they are much less widespread in residential buildings.

Smart meters, which measure electricity demand at 15-minute intervals or less, now represent about half of U.S. meters.[160] These meters are key enablers of demand response (discussed in Chapter 6) and may enable a wide variety of consumer engagement strategies, including the potential for more economical and less intrusive "remote auditing" technologies to identify energy efficiency improvements revealed by consumer load profiles. They have also raised privacy concerns.[161] Data gathered by these meters could reveal details on activities inside the home that are reflected in the temporal profile of their electricity usage. If inadequately protected, smart meters could also create cybersecurity vulnerabilities and create the potential for data theft.

Expanding use of these systems presents a significant savings opportunity. While residential estimates are not available, an estimate for commercial buildings suggests these systems can increase building efficiency by up to 30% without any other equipment replacement.[162]

### 2.4.6 Zero-Energy Homes

In concept, zero net energy homes (and zero net energy buildings in general) either (1) consume no grid electricity, or (2) offset the entirety of their grid electricity consumption over some time period (e.g., a year) though surplus on-site electricity generation that flows back to the grid. Policy that encourages zero-energy homes increases demand for not only energy efficiency but also distributed energy resources (DERs) such as distributed generation and battery storage (discussed in Chapter 6). High levels of market penetration could have significant impacts on the grid, reducing overall grid electricity consumption. More distributed generation driven by zero-energy targets can potentially lead to higher levels of demand response.

California has announced a target of making all new residential buildings zero net energy by 2020.[163] It is likely that a significant fraction of existing residential buildings would struggle to attain zero energy on-site due to roof angles, poor insolation[b], insufficient roof area (particularly in the case of high-rise buildings), and other factors. This may place a premium on finding a way to procure off-site sources to offset whatever amount of site energy remains.[164]

## 2.5 Markets and Market Actors

This report identifies four markets related to residential electric efficiency: new build, equipment replacement, renovation/retrofit, and housing unit sale/rental.

New build includes the commissioning and construction of new housing units. This is a critical market for electric efficiency, especially for electrically heated buildings and buildings in areas with high cooling loads. It is generally far less expensive to build a new, efficient building than to upgrade an existing one to an equivalent efficiency level. However, diffusion of best practices in the new housing market can be slow; the National Association of Home Builders Research Center has noted that it can take from 10 to 25 years for new technology to achieve full market penetration.[165]

[a] "Phantom" loads may account for nearly 10% of residential electricity use.
[b] Insolation is the measure of incoming solar radiation on an object or surface.

Building energy codes (Section 2.6.1), ENERGY STAR and other home-certification labels (Section 2.6.2), and financial incentives for efficient construction (Section 2.6.3) all aim to improve the efficiency of new residential buildings. Important actors in new build markets include homebuilders (particularly those that develop many housing units at once in new communities), materials manufacturers, architects, contractors, investors in home development, and building inspectors. New build markets vary in activity by region, with higher rates of new housing units in the South and West than in other parts of the country (see Sections 2.2.3 and 2.3).

Renovation/retrofit involves significant upgrades to existing buildings, whether motivated by electric efficiency concerns or not. These projects represent the other opportunity to improve building shells and, potentially, appliances and lighting, depending on the nature of the project.

Table 2.2 shows typical payback periods for common retrofitting activity. As the table makes clear, building shell retrofits are generally carried out on older buildings that were constructed before building energy codes and may have little or no insulation, single-paned windows, and poor air and duct sealing. On the other hand, lighting and appliances are regularly replaced in all types of buildings; these activities are discussed in the equipment replacement section below.

**Table 2.2. Typical Payback Periods for Residential Retrofitting Measures [166]**

| Measure | Payback Period, Old Homes | Payback Period, New Homes | Discussion |
|---|---|---|---|
| **Lighting** | 1–2 years | 1–2 years | Almost always cost-effective |
| **Air sealing and duct sealing/insulation** | 0–8 years | Generally N/A | Cost-effective in most old homes; paybacks are climate-dependent |
| **Insulation (walls, attic, floors)** | 1–18 years | Generally N/A | Most cost-effective in cold and hot climates; depends on climate and date of construction |
| **Windows** | 8–20+ years | 20+ years | Most cost-effective in cold or hot climates; long paybacks in more temperate zones |
| **ENERGY STAR appliances and equipment** | 5–20+ years | 5–20+ years | Generally cost-effective when replacing broken or obsolete equipment; generally not cost-effective when the existing equipment is still functional |

Considerable policy and programmatic efforts are directed at encouraging efficiency retrofits and increasing the savings each retrofit delivers. These include programs that encourage energy audits to identify interventions (Section 2.6.2), programs that compare a building's usage to other similar buildings to motivate energy-use reduction (Section 2.6.2), grants and rebates for whole-building retrofits (Section 2.6.3), and financing to spread out the up-front cost of these projects (Section 2.6.4). Often, programs wrap all these interventions together. Despite this effort, it has proven challenging to motivate retrofits, specifically in pursuit of improved efficiency. While good data on efficiency retrofits are not available, most experts believe that considerably less than 1% of U.S. residential units receive an efficiency retrofit each year.[167] Raising this rate is a central concern of efficiency policy.[168] Injecting efficiency considerations into renovations that are not efficiency retrofits *per se* but still afford substantial opportunities for savings is perhaps just as important an objective.

The most important actors in the renovation/retrofit market are housing-unit owners and contractors (both dedicated efficiency retrofit providers and general contractors). Renters are important actors as well especially since renovation of rental units can be disruptive to tenants. Additionally, if the tenants pay the electric bills, owners will be less likely to make efficiency improvements since it is the tenant who would see the benefit. Energy efficiency retrofit programs that have achieved significant market share typically develop strong partnerships with contractors and craft programs and financial products that make contractors motivated to sell projects.[169] There is also an active market in developing financial solutions that can improve on thin project margins, and substantial private capital is beginning to engage,[170] though it is not clear that any dominant solution has yet emerged. Finally, retrofit-friendly materials and techniques could lower costs.

Equipment replacement is distinct from the previous category in that it generally involves changing out equipment. Equipment replacement projects often occur when equipment fails. While each project is smaller than a renovation/retrofit, the number of transactions in this market far exceeds those in the renovation/retrofit market. One important aspect of equipment replacement is proper equipment installation. Poor installation can reduce the efficiency of installed equipment.

Key policies affecting the equipment replacement market include equipment labels (Section 2.6.2) and rebates (Section 2.6.3). Many of these products are financed through vendors and contractors. Efficiency financing programs (Section 2.6.4) for equipment replacements need to be designed without long underwriting processes since many decisions are made quickly in the face of equipment failure.[171]

Important actors for the equipment replacement market are housing unit owners, contractors and vendors, equipment repair companies (these professionals are often the point of engagement for equipment failures), and equipment manufacturers. Housing-unit occupants who are not owners also make some consequential decisions on equipment, notably on lighting and electronics, which are important drivers of residential electricity use (see Section 2.2.2).

Housing unit sale/rental often motivates renovation or equipment replacement. Independent of the primary motivation for this action, this market is important because these transactions potentially capitalize energy efficiency into sale prices. Evidence suggests this capitalization varies by market, but that it often does occur in significant magnitudes for homes that meet various “green home” certifications.[172]

Little existing policy addresses this issue. Energy efficient mortgages allow homebuyers to finance larger amounts for properties that meet certain efficiency standards, but their take-up has been very low. Building rating and labeling schemes (see Section 2.6.2) seek to standardize the definition of a “green home” or an energy efficient home to reduce confusion in the real estate market, though their usage is not yet routine. Some jurisdictions require disclosure of energy information at point of sale, or require specific energy upgrades at time of sale. These requirements also are not yet widespread.

Important market actors are homebuyers and sellers; renters and landlords; mortgage lenders, appraisers, and real estate agents; and home energy raters.

Finally, while less of a market in a traditional sense, housing unit operations is another area of growing activity. Operations involve a myriad of choices about how and how often to use electrical devices and features in homes. Key actors are housing-unit occupants (who often face principal-agent issues[a] in

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[a] As noted in the renovation/retrofit section above, tenants generally do not make choices about appliances, space conditioning, and water heating in their housing units and may not be able to lower their electricity usage as much as they might wish to.

attempting to control electricity usage [see Section 2.6]), as well as regulators who set retail electricity prices.

## 2.6 Barriers and Policies, Regulations, and Programs That Address Them

Energy efficiency policies, regulations, and programs in the residential sector attempt to address well-known barriers, including the following:

- Information and awareness – Homeowners, renters, and homebuyers have imperfect information about the energy performance of housing units and about the costs and benefits of high efficiency appliances, equipment, and building shells, as well as potential efficiency improvements.
- First costs – More efficient homes[a] and equipment cost more initially but provide savings over time. Individual decision makers generally dislike having to pay up front for future benefits.
- This is particularly burdensome for low-income households who have less disposable income, despite the large share of their budget that is required to pay energy bills (Figure 2.11).
- Materiality – Energy costs are a small share of household expenses for most households (though not all; see Figure 2.11), so it is hard to get most homeowners and tenants to pay attention to energy efficiency.
- Limited access to capital – Many consumers are cash- and credit-constrained and may not be able to take on debt to finance efficiency upgrades.
- Transaction costs – Energy efficiency improvements, especially home retrofits, are time-consuming to understand, arrange, and execute.
- Split incentives – Building owners may not have an incentive to invest in energy efficient equipment if they do not pay utility bills, and tenants will not want to buy energy efficient equipment if they are planning to move out soon.
- Price signals – Electricity prices are set to recover utility and electricity service-supplier costs, not to reflect the true social cost of electricity consumption. In addition, tariff structures may discourage customer investments in energy efficiency.
- Insufficient research and development (R&D) – To the extent that efficient technologies do not realize demand from transparent, robust markets, companies will underinvest.[173] The housing sector significantly underinvests in technical innovation and R&D for energy efficiency—less than 0.4% compared to the industry average of 3%.[174]

Table 2.3 summarizes the major policies, regulations, and programs enacted to encourage efficiency in residential buildings, in addition to efficiency policies across all sectors such as an energy efficiency resource standard (see 7.2.1).

[a] Most new homes are mortgaged, potentially reducing the first-cost barrier. However, efficient homes are more expensive to build, increasing the amount that must be mortgaged if their lower operating costs are not taken into account in mortgage underwriting—which they often are not. This may lead prospective homeowners who don't want to or cannot take on larger mortgages to refrain from investing in efficiency.

**Table 2.3. Major Policies, Regulations, and Programs to Address Barriers to Energy Efficiency in the Residential Sector**

| Policy, Regulation, or Program | Description and Implemented Examples | *Principal Barriers Addressed* |
|---|---|---|
| Codes and standards | • Mandatory prescriptive or performance energy codes that regulate building envelopes<br>• Minimum performance standards for appliances and equipment<br>• Voluntary "green" or "reach" codes | *Information/awareness, materiality, split incentives*<br>• Standards set a minimum level of performance, guarding against uninformed or inattentive purchase of inefficient devices and limiting the impact of split incentives. |
| Clean energy mandates and target-setting | • Energy efficiency resource standards that mandate levels of savings across a sizable jurisdiction (e.g., across the entire state or all regulated utilities in a state)<br>• Other mandates (e.g., a mandate by a state public utility commission to achieve all cost-effective energy efficiency) | *Price signals, lack of private incentive for R&D, various others*<br>• These policies are generally enacted for clean energy policy reasons, meaning they are primarily intended to serve as a proxy for social costs of carbon emissions and other non-energy benefits. |
| Grants and rebates | • Payments to consumers that reduce or offset the incremental cost of efficient technologies, such as those offered by utility customer-funded programs<br>• Most are technology-specific; some are offered based on whole-building energy savings achieved | *First costs, price signals, materiality, information/awareness*<br>• Rebates lower the incremental up-front cost of efficient technologies, serving as a proxy for non-priced social benefits of energy efficiency adoption. |
| Resource planning | • Utility integrated resource planning (IRP) to ensure system reliability that appropriately factors in energy efficiency | *Price signals*<br>• IRPs can ensure efficiency is valued appropriately in utility planning for energy and capacity. |
| Informational interventions | • Programs that encourage or subsidize home energy audits<br>• Information and awareness campaigns run by utilities and other program administrators or government agencies<br>• Product energy labels (e.g., ENERGY STAR, Energy Guide<br>  • Building energy labels and ratings (e.g., ENERGY STAR, Home Energy Rating System )<br>• Demand side management (DSM) programs that leverage consumer behavior to save energy | *Information/awareness, materiality*<br>• Consumers may lack capacity to identify opportunities for energy-saving improvements.<br>• Data on energy usage may not be transparent.<br>• Efficiency may not be adequately salient to consumers due to lack of information or the lack of focus on energy. |
| Rate design | • Tiered (inclining block) rates | *Price signals*<br>• Tariff structures may discourage customer investments in energy efficiency. |

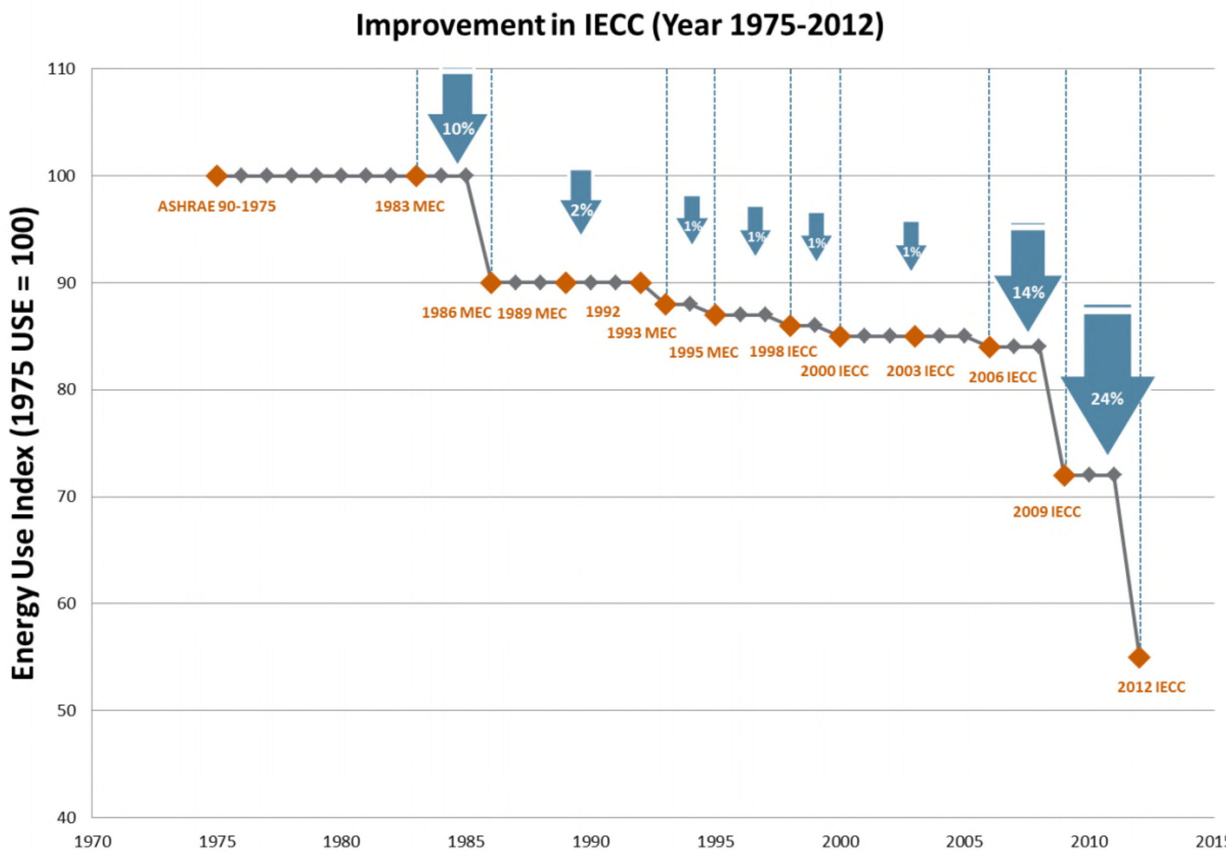
| | | |
|---|---|---|
| RD&D for end-use technologies | • Direct support for RD&D<br>• Prizes, contests, and other manufacturer incentives | *Lack of private incentive for R&D*<br>• In general, and particularly in the energy industry, RD&D is undersupplied absent policy intervention. |
| Financing | • Utility DSM financing programs<br>• Financing offered by state energy offices, green banks, or by programs that are largely private (e.g., property assessed clean energy [PACE] programs) | *Lack of capital, first costs, transaction costs*<br>• Financing programs extend capital and often eliminate entirely up-front cost to consumers.<br>• Financing is often packaged with other programmatic offerings and potentially removes the need to seek out a source of capital, which can otherwise be a barrier to program participation. |
| Tax incentives | • Personal income tax credits (federal/state)<br>• Sales tax incentives (state)<br>• Property tax incentives (state or local) | *Price signals*<br>• Like rebates, tax incentives can be a proxy for non-priced social benefits. |

### 2.6.1 Building Energy Codes and Appliance and Equipment Standards

State building energy codes reduce energy use in new homes and major renovations by establishing minimum energy efficiency standards for building design, construction, and remodeling. These codes address wall, ceiling, and duct insulation; window and door specifications; heating, ventilating, and air-conditioning equipment; and lighting fixtures. States are generally responsible for adopting residential building energy codes,[a] while local governments are generally responsible for enforcing the codes.

Most state codes are based on the national model code, the *International Energy Conservation Code®* (IECC), often with state-specific revisions. The IECC is updated every 3 years to keep current with new technology and market norms. In recent years, the codes have become significantly more efficient. Homes built per the 2009 IECC, for example, are 14% more efficient compared to the 2006 IECC, and homes built per the 2012 IECC are 24% more efficient compared to the 2009 IECC (Figure 2.17). In May 2015, DOE estimated that homes built per the 2015 IECC will be 0.98% more efficient compared to houses built to the 2012 IECC.[175]

**Figure 2.17. Code-on-code savings estimates for International Energy Conservation Code model codes[176]**

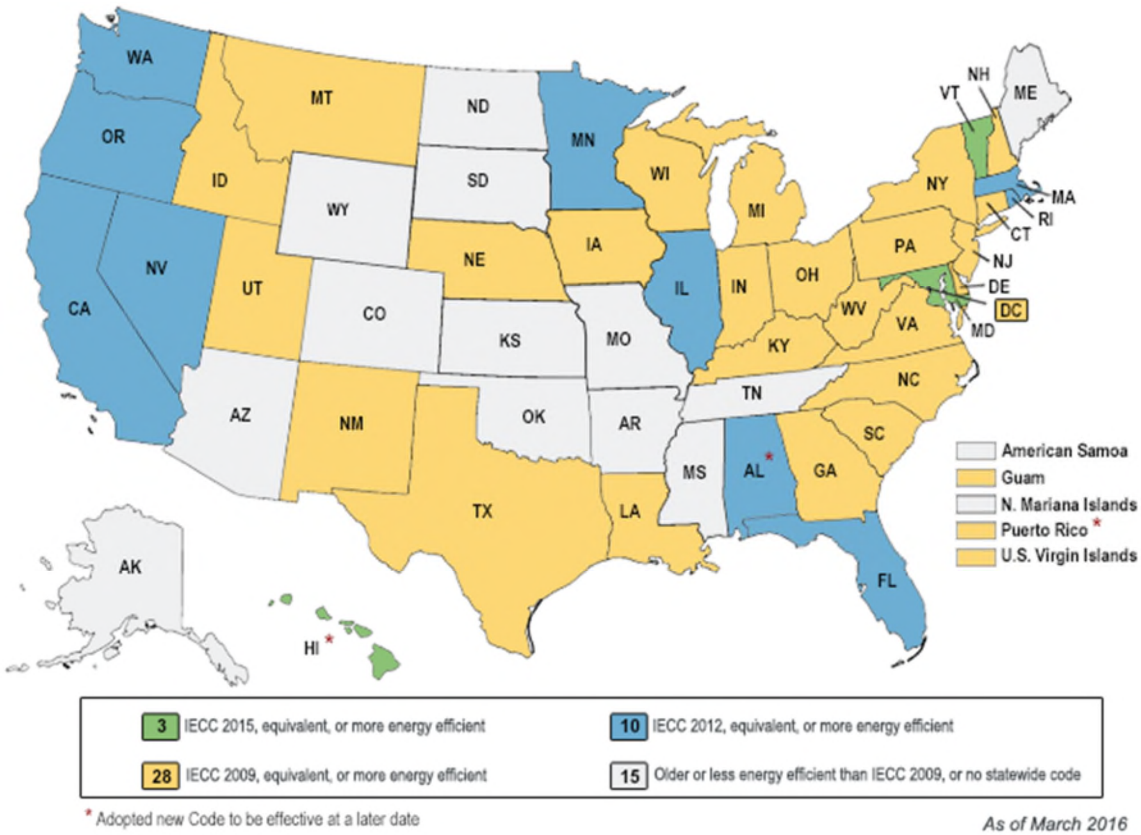



*Advances in the stringency of the model code have been irregular. The 1986, 2006, and 2009 codes tightened significantly.*

[a] Local governments occasionally adopt codes, particularly when their states do not.

Three states have codes in place that are equivalent to, or are more efficient than, the 2015 model code; 13 states have adopted residential building energy codes at least as stringent as the 2012 model code; and 41 states have codes as strong as the 2009 model code (Figure 2.18).

**Figure 2.18. State-by-state adoption of residential building energy codes[177]**




*Some 41 states or territories have adopted a code at least as stringent as the 2009 national model code—International Energy Conservation Code*.

Local building inspectors enforce codes by checking construction sites and reviewing building plans. *Code compliance* refers to meeting the requirements specified by the code and demonstrating that the requirements have been met. It is through code compliance that actual energy savings are enforced.

In 2012, the United States saved an estimated 11 billion kWh of residential site electricity through building energy codes (compared to baseline 1992 codes).[178] Between 2013 and 2040, if current trends in adoption and compliance continue, the cumulative electricity savings from residential codes in post-2012 new construction are estimated at 2,100 billion kWh.[179] A 2014 Pacific Northwest National Laboratory study estimates that, in 2030, code development, adoption, and compliance efforts could reduce residential electricity consumption in the United States by more than 4% compared to 2012.[180]

DOE issues standards for consumer products and lighting products. It is required to review each standard at least once every 6 years and to set standards at levels that achieve the maximum improvement in energy efficiency that is technically feasible and economically justified. Once an appliance or piece of equipment is covered by a standard, manufacturers must test, rate, and certify all such products they produce for compliance with the standard per mandated testing procedures, and they cannot distribute any product that is not in compliance with the standard.[181] Federal end-use standards reduced U.S. energy consumption (all fuels) by an estimated 4% in 2014, compared to usage absent the standards.[182] In some cases (see Residential Appendix, Table 7.4. Status of Consumer Product and Lighting Standards that Impact Residential Electricity Use, states have adopted residential standards in advance of the federal standards. Many of the products now covered by national standards were first addressed by state standards. Once a federal standard exists, it preempts state standards.[a]

As Residential Appendix Table 7.4 shows, DOE recently updated standards for many consumer products, including air conditioners, heat pumps, clothes washers, clothes dryers, refrigerators, and freezers, as well as lighting. Additional products that consume significant amounts of energy, including computers, are not yet covered by a federal standard. (DOE is currently working on standards for a number of products.)

A study by the Appliance Standards Assistance Project and the American Council for an Energy-Efficient Economy (ACEEE) found that average savings from new standards are more than four times greater than average incremental costs to the consumer. They found the average payback for increased efficiency was 3.3 years.[183] For example, the California Energy Commission estimates that state and federal equipment efficiency standards saved California 2.4 million megawatt-hours (MWh) in 2013.[184]

### 2.6.2 Labeling and Other Informational Interventions

Labeling provides energy-related information to consumers on homes and equipment that would otherwise be difficult and time-consuming to obtain. Two national labeling schemes, EnergyGuide and ENERGY STAR, provide point-of-sale information about energy use for consumer products.

EnergyGuide labels are required on most major appliances. The labels provide information on energy usage and approximate annual cost of using the product. The Federal Trade Commission administers EnergyGuide.

ENERGY STAR labels cover a broad range of consumer products, including electronics, computers and related equipment, windows and doors, heating and cooling devices, water heating, and lighting. ENERGY STAR and ENERGY STAR Most Efficient are certification labels, denoting products that meet or exceed a specific level of performance. ENERGY STAR updates these performance levels periodically as product efficiencies improve.[b] The U.S. Environmental Protection Agency administers ENERGY STAR.

Information barriers extend beyond product choice. It is difficult to identify potential interventions and the energy and cost savings they might yield absent professional assistance. As a result, many programs offered by utilities and other program administrators offer subsidized or free energy audits. Approved private contractors generally conduct these audits and perform the follow-on work. The Home Performance with ENERGY STAR program takes a whole-home approach to retrofitting.

Building energy labels and ratings are another potential informational tool to encourage capitalization of energy performance and are under development in several states and cities[185] as well as at the federal level. The ENERGY STAR Homes label certifies new homes that use 15% to 30% less energy than typical new homes.[186] DOE's Zero Energy Ready Home program promotes and labels homes that use 40% to

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[a] States can only set standards for appliances that are not currently covered by a federal standard unless they obtain a waiver to do so.

[b] These updates are not directly tied to changes in the appliance and equipment standards discussed in the previous subsection.

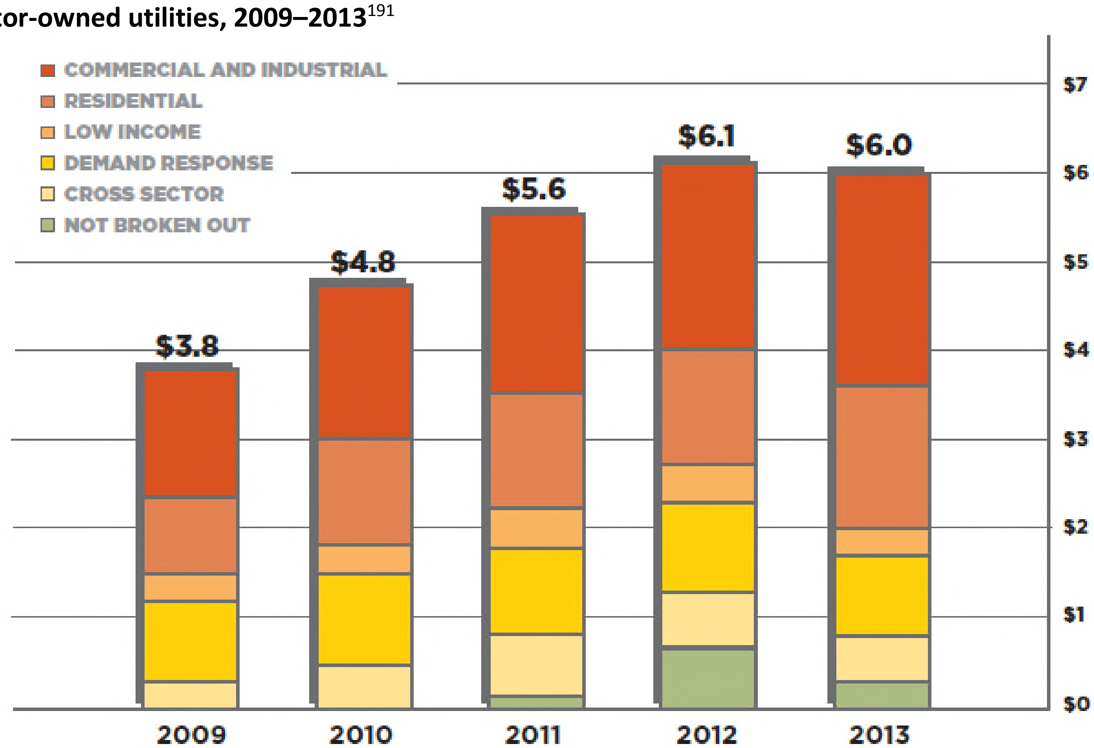
50% less energy than typical new homes and can be readily retrofitted with solar energy panels.[187] The Home Energy Rating System scores a home's energy performance and has been adopted by some whole-home programs (such as Energy Upgrade California, offered by California's investor-owned utilities) as a method for qualifying for performance-based savings.

Recently, utilities and other program administrators have begun to offer informational programs that leverage consumer behavior to reduce energy use. Home energy reports, which compare a customer's utility bills to those of similar customers, are growing in popularity. These reports are now sent to about 15 million utility customers' homes[188] and are generating energy savings[189] at a relatively low cost.[190] Behavioral approaches are expanding to include demand response programs that seek to reduce electricity usage at peak times. While home energy reports generally serve single-family residences, a growing number of jurisdictions are employing benchmarking practices for multifamily buildings, which also compare these buildings against their peers to identify and motivate savings opportunities. See Section 3.6.2 for more on benchmarking.

### 2.6.3 Grants and Rebates

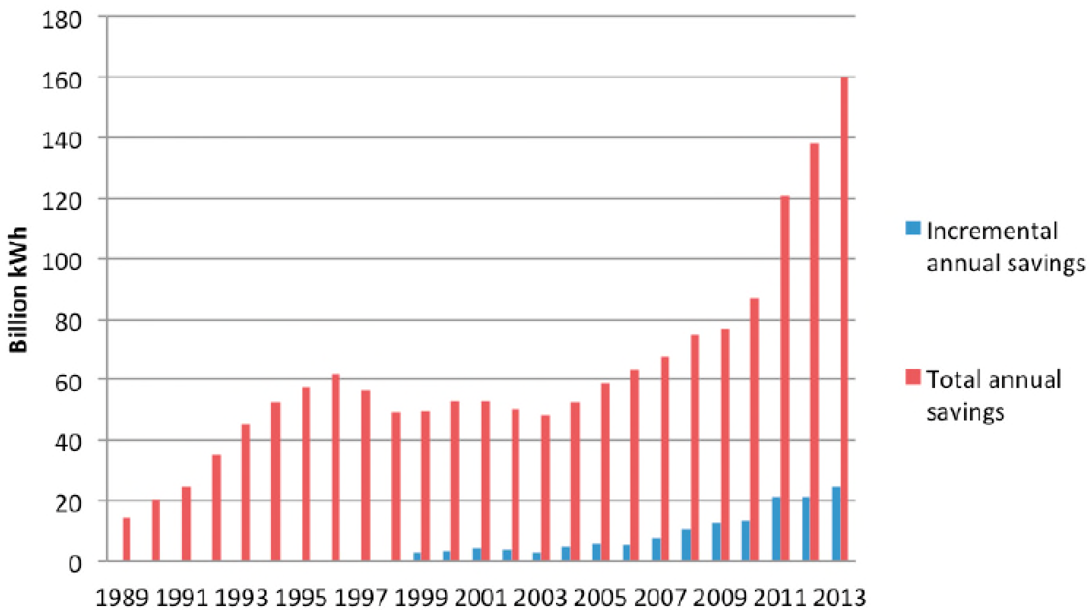
Programs funded by utility customers and run by utilities and other program administrators offer many rebates for the purchase of energy-efficient products. Programs funded by utility customers have grown substantially in recent years, both in terms of dollars spent (Figure 2.19) and energy savings achieved (Figure 2.20). Note that these programs comprise many activities other than rebates, although rebates account for more than half the spending (Figure 2.21).

**Figure 2.19. Growth in spending ($ billion) on energy efficiency programs funded by customers of investor-owned utilities, 2009–2013**[191]



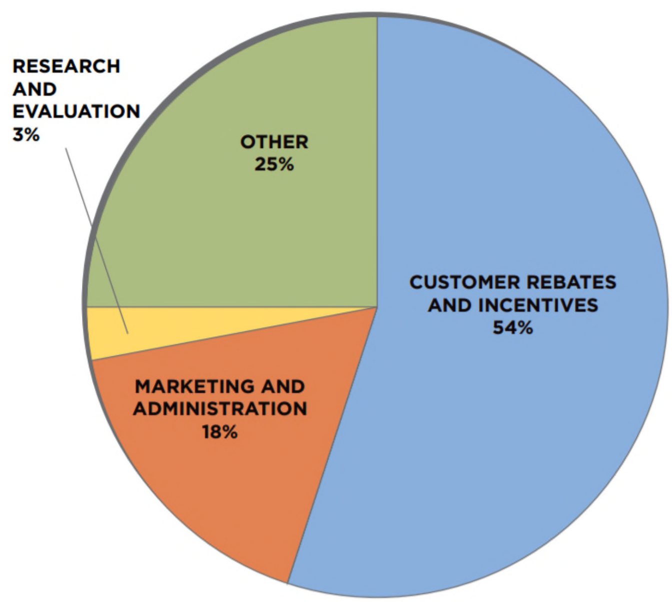

*Like other energy efficiency programs, residential programs have expanded substantially. Municipal and rural cooperative utilities also fund energy efficiency programs.*

**Figure 2.20. Electricity savings from energy efficiency programs funded by utility customers, 1989–2013** [192]




*Savings have grown from the mid-2000s, especially in the past several years. Incremental annual savings are savings from measures installed that year. Total annual savings are those achieved in a year from measures installed that year and in prior years (for those measures still providing savings based on estimated measure life).*

**Figure 2.21. Utility customer-funded energy efficiency program spending, 2013**[193]




*More than half of spending goes toward rebates and other incentives.*

Rebates are provided for equipment that meets efficiency levels specified by the program. Many rebates are provided to utility customers, either at point of sale or by submitting documentation to the program administrator after purchase. Other rebates are offered to manufacturers or retailers for producing or stocking efficient equipment. Some programs are developing performance-based rebates, which depend on the actual energy savings achieved, as an alternative approach to rebates for predicted energy savings for whole-home retrofitting programs.

Federal grant programs are largely targeted at low-income consumers, for whom energy costs are a large share of expenditures (See Figures 2.10 and 2.11). DOE's Weatherization Assistance Program [194] offers grants covering the full cost of efficiency upgrades to income-qualified households, up to a defined spending limit. Beyond air sealing, the Weatherization Assistance Program also can pay for insulation, heating and cooling systems, and appliance replacement. The U.S. Department of Health and Human Services' Low-Income Home Energy Assistance Program pays a portion of a qualifying household's energy bills and can also provide partial funding for weatherization.

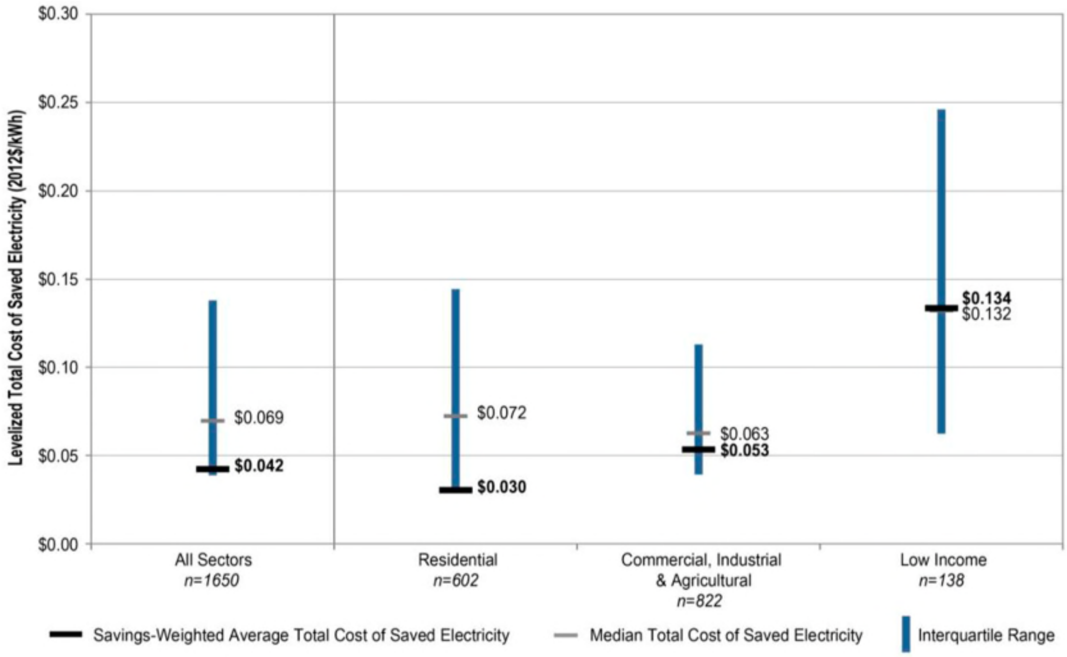
Low-income households have proven difficult and expensive to engage on efficiency upgrades. For example, one study showed that weatherization services from the Weatherization Assistance Program (which are free to low-income homeowners) were taken up by less than 1% of eligible households. With substantial additional marketing efforts, the participation level rose, but it was still less than 6%.[195] Utilities also run programs that target low-income households, and these programs cost substantially more per dollar saved than do other program types (Figure 2.22). In some cases, these higher costs may reflect non-efficiency measures that had to be addressed in the process of making efficiency improvements, such as required asbestos mitigation or gas-leak repair.

Low-income programs that work through community organizations that are trusted messengers have tended to elicit relatively strong participation.[196]

Utility programs support these federal and community efforts. One example is utility efficiency programs for manufactured housing. About three-quarters of manufactured home residents have an income below $40,000.[197] Among these programs, Tennessee Valley Authority, through its affiliated utilities, pays the incremental cost to upgrade to ENERGY STAR-qualified manufactured homes. More than half of the manufactured homes shipped to Tennessee in 2014 qualified for the program.[198]

Some utilities also offer direct-install programs that are free to all customers. These programs typically accompany energy audits and install low-cost, short-payback measures (at no cost to the customer). Typical measures include efficient lighting, water conservation measures, and air and duct sealing.

**Figure 2.22. Energy efficiency program costs by market sector, 2009–2014**[199]




*Residential programs during this period had the lowest cost per kilowatt-hour saved, on a savings-weighted basis, of any market sector. Programs targeting the hard-to-reach, low-income market are more costly than other market sectors. Data include both direct program costs (e.g., the cost of rebates) and utility administrative and overhead expenses.*[a]

### 2.6.4 Financing

Programs that offer financing for residential energy efficiency upgrades have grown substantially in recent years. Common offerings include the following:

- Conventional loans offered by utility, state, or third-party energy efficiency programs, generally unsecured loans
- On-bill loans that are repaid via a dedicated charge on an energy bill[200]
- Property assessed clean energy (PACE) programs that fund efficiency upgrades via an assessment on a property tax bill.[201]

Financing spreads the higher up-front cost of efficient products over time, in many cases allowing such measures to self-finance via energy bill savings that cover the loan or assessment payments. Depending on program design, on-bill loans and PACE assessments can potentially transfer with ownership of a home, eliminating a common split-incentive problem that deters homeowners from investing in longer-payback improvements.

Residential PACE programs in California have grown dramatically in the past few years, financing nearly $1 billion of clean energy investments since 2009.[202] California PACE programs finance energy efficiency improvements and distributed renewable resource systems. Most of that investment has been delivered by the Home Energy Renovation Program, which operates in multiple California counties. The Federal

[a] In some cases, costs borne by third-party program administrators may not be fully reflected in these data.

Housing Finance Agency has directed Fannie Mae and Freddie Mac, the agencies that back most U.S. residential mortgages, not to purchase mortgages for homes with PACE assessments where these assessments are senior[a] to the mortgage lender. This action has stalled senior lien residential PACE programs, except in California. The California Alternative Energy and Advanced Transportation Financing Authority established a $10 million loan loss reserve to protect mortgage holders in the event of reduced recoveries from defaults on PACE-encumbered mortgages. To date, there have been no claims on the reserve.[203] States also can develop residential PACE programs using eligible subordinate lien structures under forthcoming guidelines from the Federal Housing Administration.[204] Residential PACE programs in Maine, Vermont, and Rhode Island subordinate PACE repayments to the mortgage lender; these programs have not delivered loan volumes on the scale of the California programs.

Some financing programs funded by utility customers and run by utilities or third-party administrators have also achieved significant lending volume. In 2014, these financing programs, including utility, on-bill, PACE, and state energy office programs, loaned more than $500 million for residential energy efficiency upgrades.[205]

### 2.6.5 Rate Design

Electric utility tariff structures may affect customer investments in energy efficiency. Improving rate design can encourage (or at least not discourage) such investments:[206]

- Tiered (inclining block) rates – Inclining block rate structures charge a higher rate for each incremental block of electricity consumption. They are common in the U.S. for residential customers and are based in part on the theory that higher usage typically is associated with consumption during times of peak demand, when generation and delivery costs are higher than non-peak periods.[207]
- Time-varying rates – The underlying costs of providing electricity vary hourly and seasonally. Tying rates more closely to the actual cost of providing electricity can give customers more economically efficient incentives to reduce usage during costly periods. Current penetration of time-varying rates is low in the residential sector, and many residential customers who have opted into these rates are EV owners who can take advantage of inexpensive nighttime rates for vehicle charging. However, these rates may become more prevalent in the future. For example, the California Public Utilities Commission is planning to introduce time-varying rates for residential customers as the default tariff in 2019, with the option for customers to opt out to a rate that does not vary by time of use.[208]
- Fixed and volumetric charges – Electric utilities in many states are proposing raising the fixed customer charge—a set dollar amount each billing period regardless of energy usage—and decreasing volumetric (per-kWh) rates. Such a change would lower incentives for electric efficiency. As of yet, few state public utility commissions have adopted significantly higher fixed charges.[209]
- Low-income rates and other assistance – Most utilities offer lower electricity rates for households that fall below defined income thresholds. Households on low-income rates consume less electricity; it is not clear whether the rate structure impacts their usage.[210]

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[a] Seniority refers to the order in which debt is repaid in the event of sale or bankruptcy.

## 2.7 Interactions with Other Sectors

This section briefly outlines several points of connection between the residential sector and the other sectors covered in this report.

Data servers – Residential computing usage drives electricity consumption in data servers that are part of the commercial sector. This means that residential demand will partly drive the growth of future commercial electricity-server consumption.

Electric vehicle charging – EVs displace petroleum fuel use in the transportation sector and increase electricity use in the residential sector (as well as the commercial sector), creating a potential conflict between energy efficiency and increasing load from plug-in electric vehicle (PEV) charging. While EV penetration is currently low, these vehicles are a significant electricity end use for those who own them. Assuming the need to recharge 30 vehicle miles per day and an EV that uses 0.3 kWh/mile (equivalent to a 2015 Nissan Leaf, the most common EV in the United States), an EV user would consume 9 kWh per day if all charging is done at home. This is equivalent to 29% of an average U.S. household's electricity usage. Therefore, as EV penetration increases, EVs may come to represent a significant source of residential electricity use.[a]

Telecommuting and e-commerce – Telecommuting and e-commerce redirect electricity consumption from the commercial sector to the residential sector. Telecommuting is on the rise: The percentage of workers who work at home at least 1 day per week increased from 7.0% to 9.5% from 1999 to 2010, and 4.3% of U.S. workers worked the majority of the week from home in 2010.[211] Telecommuting raises residential electricity usage for computing, lighting, and space conditioning. Telecommuting also may expand residential floor space to provide dedicated work space; the reverse is true of commercial impacts.[212] A study of telecommuting in Japan finds that telecommuting can reduce net energy usage in the buildings sector overall if commercial floor area is decreased through space sharing among telecommuters; however, it can increase net energy usage if commercial floor space is not reduced.[213]

R&D – Most of the technologies used in residential buildings—in building shells or products used within—are not unique to the sector. Innovations in technologies for residential and commercial sectors, in particular, readily spill over to each other, driving both improvements in electric efficiency and increases in demand for electricity-powered services.

## 2.8 Research Gaps

Following are key research questions and research gaps related to electricity consumption and energy efficiency in the residential sector:

- What policies or methods of consumer engagement can be employed to increase the rate of household energy efficiency retrofits? Candidates include:
    - Financing products that motivate contractors to sell more energy efficiency projects
    - Ordinances requiring a home energy audit, rating, or label at time of sale and disclosure of results to prospective buyers
    - Building energy labels that enable home prices to reflect energy performance

[a] From a grid-management perspective, however, EVs may be helpful as they add base load during off-peak hours, can provide grid services, and help to preserve utility revenues through additional kWh sales. See section 5.5.6 for more on these topics.

    - Training, outreach, and incentives to contractors and community groups on the benefits of efficiency for their consumers
    - Development of retrofit-friendly technologies to lower costs
- What policies or methods of consumer engagement can be employed to specifically reach low-income households who have proven challenging to engage, and for whom electric efficiency can ease budget pressures?
- How can policy best facilitate adoption and quality installation of efficient technologies while managing related moisture, comfort, and indoor air quality issues?
- What are the best methods to improve building energy code compliance?
- How can data be gathered and reported to eliminate confusion and competition between electricity usage reduction through efficiency and electricity usage increase for electric transportation?
- What technologies and policies can best control electricity usage from MELs?
- What are the potential electricity savings and relative cost-effectiveness of various innovative policy approaches, including
    - Home automation
    - Zero energy homes
    - Behavior-based programs
    - Innovative financing products
    - Building energy label

# 3 Commercial Sector

In this report, the *commercial sector* refers to nonresidential buildings and excludes energy transportation demands for the sector, such as commercial vehicle fleets or delivery trucks. The U.S. commercial buildings market comprises 87 billion square feet ($ft^2$) of floor space.[214] Buildings are of all sizes, ages, and construction; have locations in all climate zones; and serve a variety of purposes. Commercial buildings account for approximately 18% of total U.S. energy consumption, 35% of U.S. electricity consumption, and 18% of the nation's carbon dioxide ($CO^2$) emissions.[215] In 2013, the United States spent nearly $180 billion to provide energy services to these existing commercial buildings.[216] From 2008 to 2012, more than 300,000 new commercial buildings were constructed, comprising more than 5.7 billion $ft^2$.[217]

New building construction in each state must meet the building energy codes for that state (Section 3.6.1). These are statutory requirements that specify minimum building construction standards for components such as insulation and windows. End-use services in the commercial sector include heating, cooling, water heating, ventilation, cooking, lighting, refrigeration, personal computer (PC) and non-PC office equipment, and a category denoted "miscellaneous end-use loads" or "Other" end uses to account for all other, minor, end uses such as elevators, escalators, and medical/lab/security equipment.[a] Many end-use equipment types are subject to federal energy efficiency standards for appliances and equipment, which cover about 60% of commercial building energy use.[218]

Building categories in the commercial sector are assembly, education, food sales, food services, inpatient health care, outpatient health care, lodging, office buildings, mall-based mercantile, non-mall mercantile, services, warehouse and storage, public assembly, public order and safety, religious worship, Other, and vacant buildings.[b] "Other" buildings include airplane hangars, laboratories, telephone-switching facilities, agricultural facilities with some retail space, manufacturing or industrial facilities with some retail space, some data centers or server farms, and some water utility facilities and wastewater treatment plants.[c] The commercial sector thus includes the municipal government, state government, universities and colleges, kindergarten through grade 12 schools, and health care including hospitals category (Table 3.1).

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[a] These "Other" end uses are included in CBECS. The *2015 Annual Energy Outlook* includes the following additional end uses in the "Other" sector: distribution transformers, municipal water services, lift trucks, and forklifts.

[b] See the CBECS Building Type Definitions for a description of building categories (accessed November 5, 2015): https://www.eia.gov/consumption/commercial/building-type-definitions.cfm.

[c] The allocation of some buildings between the commercial and residential sectors and the commercial and industrial sectors can be challenging to define. Electricity consumption data reported by EIA for the commercial sector are based on survey data from electricity suppliers (e.g., utilities), which are typically based on number of customer utility accounts. Thus, a mixed-use building with a single master meter that is on a commercial electricity rate is classified as a commercial building even if it has some residential units, while a mixed-use building, which has individually metered retail and residential units, will count toward both residential and commercial electricity consumption. A large data center or wastewater treatment plant that is connected to the grid at a high voltage is reported as an industrial site and not a commercial building.

**Table 3.1. Commercial Sector Building Types**

| Building Type | Included in MUSH Sector?* |
|---|---|
| Education | Yes |
| Food Sales | |
| Food Service | |
| Health Care: Outpatient | Yes |
| Health Care: Inpatient | Yes |
| Lodging | |
| Mercantile (Enclosed/Strip Malls) | |
| Mercantile (Non-Mall Retail) | |
| Office | Government office buildings included |
| Other | |
| Public Assembly | |
| Public Order and Safety | Yes |
| Religious Worship | |
| Service | |
| Vacant | |
| Warehouse and Storage | |

*Municipality, University, School, Hospital (MUSH) buildings include government-owned buildings and thus could include some buildings from additional building types (e.g., vacant, warehouse, and storage buildings).*

## 3.1 Key Findings and Insights

*Findings:*

- Growth in electricity sales in the commercial sector has slowed significantly in the last decade, and slow growth (about 0.7% per year) is projected through 2040 (Section 3.3).
- Electricity consumption is expected to comprise a slightly higher share of energy used in the commercial sector in 2040 compared to 2015 (55% vs. 53%) (Section 3.3).

*Insight*: While electricity intensity (kWh/ft$^2$) in the commercial sector is projected to slightly decrease, overall load is still projected to increase, pointing toward the need for continued attention to electricity efficiency.

*Findings*:

- "Other" is the fastest growing electricity end use in the commercial sector, followed by non-PC office equipment. Electricity consumption for lighting is declining (Section 3.3).

*Insight*: Efficiency policies and programs targeted at the commercial sector will need to evolve to address the drivers of future electricity consumption, which are not the same as the drivers of past consumption.

*Findings:*

- As in the residential sector, the lighting market is transforming to much lower electricity usage due to compact fluorescent lamps (CFLs) and LEDs. A DOE-sponsored forecast projects that LEDs will grow to 82% of commercial-sector lighting market share in 2030, saving a cumulative 18% of commercial lighting electricity usage from 2013 to 2030, relative to a no-LED baseline (Section 3.4.1).

*Insight*: A combination of technology and policy efforts has achieved great success in the lighting market. Lighting has been a mainstay of efficiency programmatic efforts. With the market in transition, energy efficiency programs and standards will shift to LED lighting as the dominant lighting technology.

*Findings:*

- Energy management control systems (EMCS) for heating, ventilation, and cooling (HVAC) are installed in only 12% of buildings smaller than 25,000 $ft^2$. These buildings represent about 35% of overall commercial floor space (Section 3.4.4).
- EMCS for lighting are installed in only 3% of buildings smaller than 25,000 square feet ($ft^2$) (Section 3.4.4).

*Insight*: EMCS in smaller buildings offer a significant opportunity for energy efficiency improvements. Understanding and overcoming adoption barriers are critical in this market segment.

*Findings:*

- Best available technology for heating, cooling, ventilation, lighting, water heating, refrigeration, and PC and non-PC equipment is estimated to save 46% of building energy intensity (primary energy per unit area). Of the remaining energy intensity, almost 50% is from Other uses (Section 3.3).
- With proper design, overall costs of new zero net energy buildings (ZNEBs) in the commercial sector can fall within the same range as conventional new construction projects (Section 3.4.3).
- Buildings designed for whole-building performance using advanced system-level modeling software often outperform buildings designed using less quantitative approaches, such as prescriptive guidelines (Section 3.4.4).

*Insight*: The Other category is a major opportunity for energy savings. In addition, careful building design using advanced system-level modeling can achieve high performance and greater cost-effectiveness.

*Findings:*

- The U.S. population is aging. The fraction of the population older than 65 years of age will increase from 14.9% in 2015 to 21% in 2040 (Section 3.3).

*Insight*: With an aging population, healthcare-building floor space is projected to grow at a faster annual rate (1.2%) between 2015 and 2040 than average floor space growth in the commercial sector (1.0%)

*Findings*:

- Retail electricity prices for the commercial sector are projected to rise from about $0.102/kWh in 2014 to about $0.114/kWh by 2040 (Section 3.4).

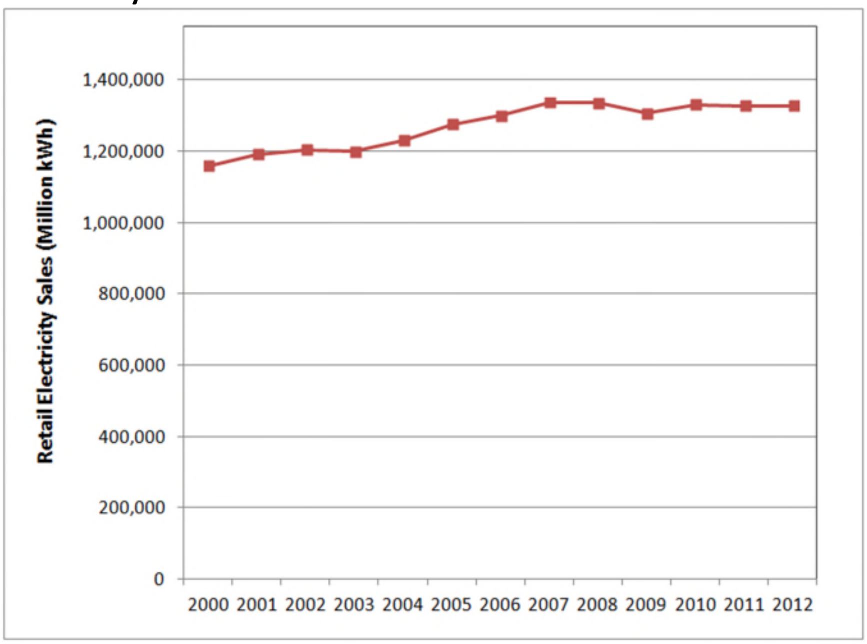
*Insight*: Increases in projected retail electricity prices for the commercial sector are modest, with a less than 13% increase in prices projected in 2040.

## 3.2 Characterization

Figure 3.1 shows retail electricity sales in the commercial sector since 2000. Sales have been flat in recent years, with higher sales growth tracking overall economic growth in the early 2000s. Recent analysis indicates that the major contributing factors to the change in commercial electricity consumption from 2008 to 2013 were savings from appliance and equipment standards and utility energy efficiency programs.[219]

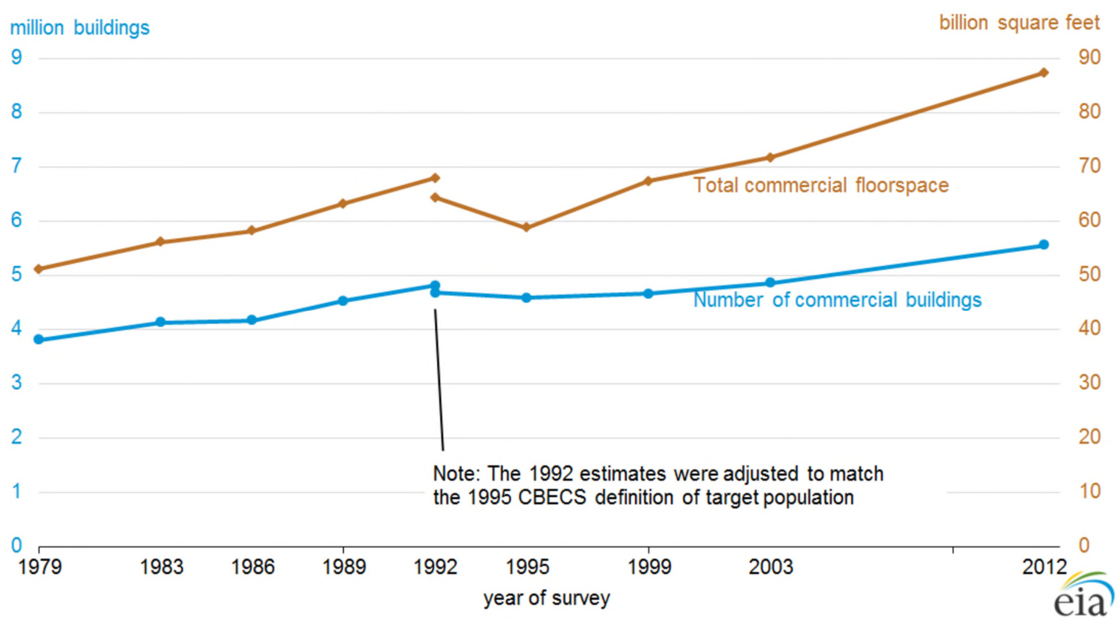
Floor space has increased more rapidly (2.2% per year from 2003 to 2012, as Figure 3.2 shows). In part, this is because new commercial buildings are larger, on average, than old commercial buildings (Commercial Appendix, Figure 7.17). Thus, overall electricity intensity (in kWh/ft$^2$) dropped by 8% from 2003 to 2012, largely driven by more energy-efficient end uses.

**Figure 3.1. Retail electricity sales in the commercial sector from 2000 to 2012**[220]




*Commercial electricity sales have been fairly flat since 2007 after sharp periods of growth in the 1990s and mid-2000s.*

**Figure 3.2. Floor space trends and number of commercial buildings from 1979 to 2012**[221]




*Total floor space grew by 2.2% a year from 2003 to 2012, outpacing growth in new buildings.*

### 3.2.1 By Building Category

Table 3.2 shows a breakdown of electricity consumption by building category and end use, highlighting the diverse nature of the commercial sector. The top row of the table shows the end-use fraction of consumed electricity for 2012, while the second row shows the same for 2003. The lower portion of the table provides the percent share of electricity consumption in 2012 for each building category and end-use pair. The right column shows the share of electricity consumption in 2012 by building category.

Office buildings and mercantile (including both malls and non-mall retail) each make up about 20% of electricity consumption, followed by education at 10%. Five building categories have between a 5% and 10% share of electricity consumption: health care (both inpatient and outpatient), lodging, warehouse and storage, food service, and public assembly (e.g., community centers, gymnasiums, and theaters).

The second line of Table 3.2 shows the percentage of total consumption by end use in 2003. The share of lighting has dropped by more than 20% and space heating share by 2.7%. Lighting consumption has dropped in large part because of "increasing use of CFLs and LED bulbs as replacements for lower-efficiency incandescent bulbs," while the large decrease in heating demand is "likely because of the warmer than average winter during the reference year (2012) and federal equipment standards."[222] Figure 3.3 shows the percentage of electricity consumption by building category from 1992 to 2012, and Commercial Appendix Table 7.6 has a summary of electricity consumption data by building category from EIA's Commercial Buildings Energy Consumption Survey (CBECS) 2003 and CBECS 2012.

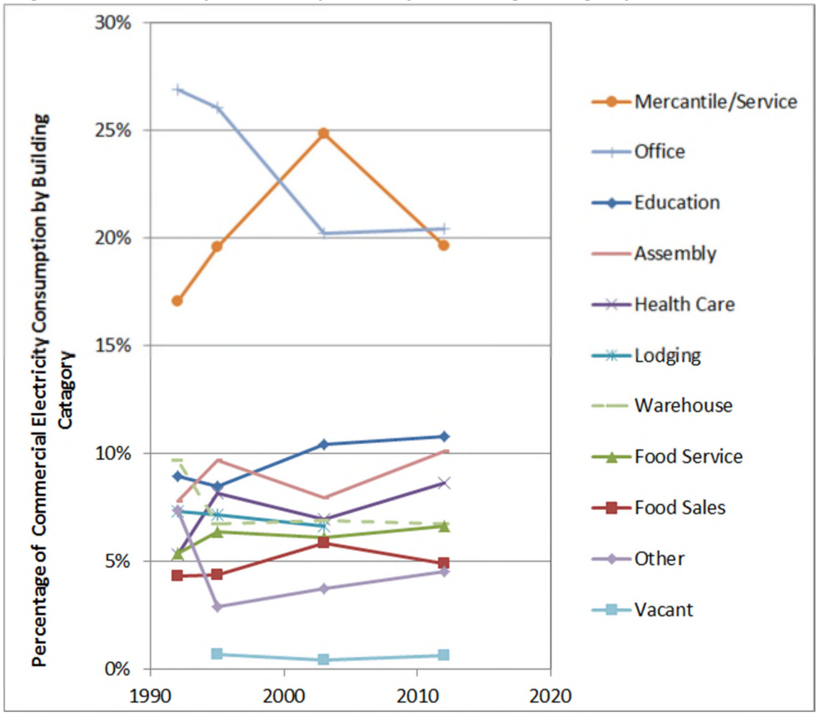
**Table 3.2. Share of Electricity Consumption in the Commercial Sector by Building Category and End-Use Service, 2012** [223]

| | Other | Lighting | Refriger-ation | Ventil-ation | Cooling | Compu-ters | Office Equipment | Cooking | Space Heating | Water Heating | Total by Building |
|---|---|---|---|---|---|---|---|---|---|---|---|
| % of Total Consumption (2012) | 18.1% | 17.1% | 15.8% | 15.8% | 14.9% | 9.5% | 4.1% | 2.2% | 2.0% | 0.5% | |
| % of Total Consumption (2003) | 11.8% | 37.8% | 10.8% | 12.3% | 13.6% | 4.4% | 1.6% | 0.6% | 4.7% | 2.4% | |
| % of Total Consumption, by Building Type and End Use (2012) | | | | | | | | | | | |
| Office | 3.1% | 3.5% | 0.7% | 5.0% | 2.7% | 3.9% | 0.9% | 0.0% | 0.4% | 0.0% | 20.4% |
| Mercantile | 2.2% | 3.3% | 4.5% | 2.9% | 2.1% | 0.5% | 0.4% | 0.1% | 0.3% | 0.2% | 16.6% |
| Education | 1.6% | 1.8% | 0.9% | 1.6% | 2.1% | 1.8% | 0.5% | 0.1% | 0.2% | 0.1% | 10.8% |
| Health care | 1.7% | 1.4% | 0.4% | 1.9% | 1.6% | 0.8% | 0.4% | 0.2% | 0.1% | 0.0% | 8.6% |
| Lodging | 1.7% | 0.9% | 0.8% | 1.2% | 0.9% | 0.1% | 1.0% | 0.2% | 0.2% | 0.1% | 7.2% |
| Warehouse and storage | 1.8% | 2.0% | 1.1% | 0.3% | 0.8% | 0.4% | 0.1% | 0.0% | 0.1% | 0.0% | 6.7% |
| Food service | 0.5% | 0.4% | 2.7% | 0.7% | 0.7% | 0.1% | 0.2% | 1.1% | 0.1% | 0.1% | 6.6% |
| Public assembly | 1.7% | 0.8% | 0.6% | 0.6% | 1.9% | 0.4% | 0.2% | 0.1% | 0.2% | 0.0% | 6.5% |
| Food sales | 0.3% | 0.4% | 3.5% | 0.3% | 0.1% | 0.0% | 0.0% | 0.2% | 0.0% | 0.0% | 4.9% |
| Other | 1.2% | 0.9% | 0.4% | 0.4% | 0.6% | 0.9% | 0.0% | 0.0% | 0.1% | 0.0% | 4.5% |
| Service | 0.9% | 0.9% | 0.1% | 0.3% | 0.4% | 0.2% | 0.1% | 0.0% | 0.1% | 0.0% | 3.0% |
| Religious worship | 0.7% | 0.2% | 0.1% | 0.3% | 0.4% | 0.1% | 0.1% | 0.0% | 0.1% | 0.0% | 1.9% |
| Public order and safety | 0.5% | 0.4% | 0.1% | 0.1% | 0.4% | 0.2% | 0.1% | 0.0% | 0.0% | 0.0% | 1.7% |
| Vacant | 0.3% | 0.1% | 0.0% | 0.1% | 0.0% | 0.0% | 0.0% | | 0.0% | 0.0% | 0.6% |

Legend: > 20% (green); 10%-20% (orange); 5%-10% (yellow); 1%-5% (grey); 0%-1% (white)

*The Other end use was the largest in the commercial sector, followed by lighting, refrigeration, ventilation, and cooling. Office buildings, mercantile (including both malls and non-mall retail) and education make up almost 50% of total electricity end use.*

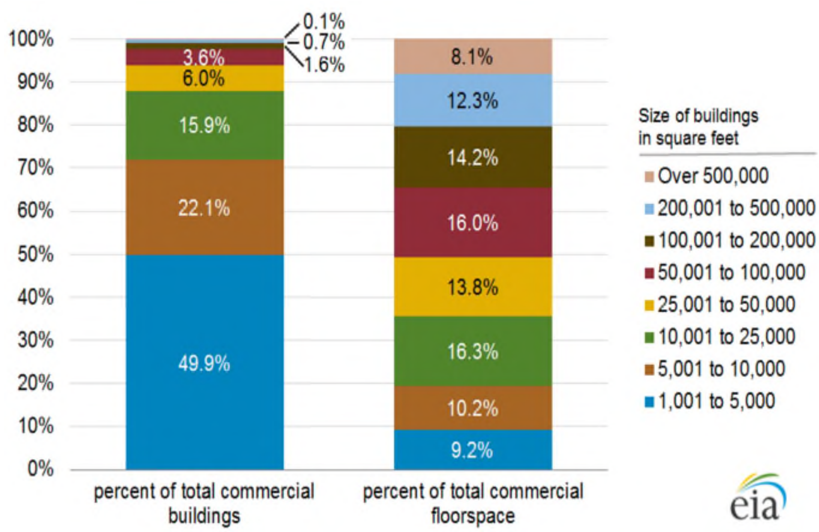
**Figure 3.3. Percentage of electricity consumption by building category from 1992 to 2012[224]**




*Office buildings and mercantile/service buildings make up about 40% of overall consumption. Mercantile/service demand reduction from 2003 to 2012 was driven by a 14% reduction in mall floor space.*

Figure 3.4 shows the distribution of buildings by floor space. Half of all commercial buildings are quite small—5,000 ft$^2$ or less—accounting for less than 10% of total commercial floor space. While buildings with more than 25,000 ft$^2$ account for almost two-thirds of commercial floor space, they make up only 12% of the total building population. [225]

**Figure 3.4. Commercial building sizes, 2012 [226]**




*Buildings 5,000 square feet (ft$^2$) or less account for half of all commercial buildings but comprise less than 10% of total commercial floor space. Buildings greater than 25,000 ft$^2$ account for only 12% of commercial buildings but comprise about two-thirds of total commercial floor space.*

Table 3.3 shows the percentage of floor space by building type and age. For several building types, 15% to 20% of floor space was built before 1946. A large fraction of building floor space for many building types was built between 1990 and 2007. In the municipalities, universities, schools, and hospitals (MUSH) category, a large fraction of building floor space (41%) in the education sector was built prior to 1969. Most health care and office building floor space was built after 1970. [227]

**Table 3.3. Percentage of Total Floor Space by Building Type and Vintage.[228]**

| Principal building activity | Total floorspace (million square feet) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Before 1946 | 1946 to 1959 | 1960 to 1969 | 1970 to 1979 | 1980 to 1989 | 1990 to 1999 | 2000 to 2007 | 2008 to 2012 | >46 yrs old | 26-45 yrs old | 3-25 yrs old |
| **Education** | **11%** | **12%** | **18%** | **10%** | **10%** | **14%** | **19%** | **7%** | **41%** | **20%** | **39%** |
| Food sales | 0% | 0% | 0% | 0% | 13% | 23% | 0% | 0% | 0% | 13% | 23% |
| Food service | 17% | 10% | 9% | 13% | 17% | 17% | 10% | 0% | 37% | 30% | 27% |
| **Health care** | **5%** | **9%** | **9%** | **21%** | **14%** | **15%** | **15%** | **13%** | **23%** | **35%** | **42%** |
| Lodging | 6% | 6% | 13% | 14% | 20% | 18% | 15% | 7% | 26% | 34% | 40% |
| Mercantile | 6% | 6% | 9% | 14% | 20% | 18% | 19% | 8% | 21% | 34% | 45% |
| **Office** | **16%** | **8%** | **9%** | **13%** | **25%** | **13%** | **12%** | **4%** | **33%** | **38%** | **29%** |
| Public assembly | 18% | 9% | 16% | 11% | 11% | 16% | 13% | 6% | 43% | 21% | 35% |
| **Public order and safety** | **0%** | **0%** | **0%** | **0%** | **0%** | **29%** | **0%** | **0%** | **0%** | **0%** | **29%** |
| Religious worship | 15% | 13% | 15% | 8% | 12% | 14% | 17% | 0% | 44% | 20% | 31% |
| Service | 14% | 7% | 11% | 14% | 19% | 17% | 13% | 5% | 33% | 33% | 35% |
| Warehouse and storage | 9% | 6% | 11% | 11% | 17% | 17% | 21% | 8% | 25% | 29% | 46% |
| Other | 0% | 0% | 0% | 0% | 14% | 14% | 12% | 0% | 0% | 14% | 26% |
| Vacant | 21% | 11% | 9% | 14% | 22% | 14% | 0% | 0% | 41% | 36% | 14% |

*Building types that include buildings in the MUSH sector are in bold;[a] the decades with the highest percentages are shaded. Note: Some rows do not sum to 100% because of missing data in the Commercial Buildings Energy Consumption Survey.*

### 3.2.2 Municipal and State Governments, Universities, Schools, and Hospitals

The MUSH subsector includes all buildings under the control of municipal and state governments, universities and colleges, schools, hospitals, and healthcare facilities. These entities generally have control over many buildings and tend to have a longer-term perspective on investments. Some MUSH buildings (e.g., health care facilities) also are high energy users. Table 3.4 and 3.5 characterize floor area and electricity consumption in the MUSH subsector. Overall, MUSH floor space comprises an estimated 24% of total commercial floor space.[229] End-use electricity consumption is similar to the overall mix of total commercial sector end uses (Table 3.2), with lighting, ventilation, and cooling making up about two-thirds of electricity consumption. Kindergarten through 12th grade (K–12) schools, state and local government buildings, and health care facilities make up about 80% of the total floor area of large MUSH buildings in the United States (owner-occupied[b] facilities larger than 50,000 $ft^2$).[230]

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[a] The percentages for office buildings are an approximation for the percentages of office buildings in the MUSH subsector. The CBECS data set does not split out office buildings into MUSH versus non-MUSH segments.

[b] While not owner-occupied, large public-housing projects are included.

**Table 3.4. Floor Area in the MUSH Subsector for Large, Owner-Occupied Buildings More Than 50,000 square feet, 2003**[231]

| Market Segment | Floor area 2003 (million $ft^2$) | % floor area |
|---|---|---|
| K–12 Schools | 5,113 | 42.3 |
| State/Local | 2,326 | 19.2 |
| Health Care | 2,244 | 18.6 |
| Universities/Colleges | 1,354 | 11.2 |
| Public Housing | 1,057 | 8.7 |

**Table 3.5. End-Use Electricity Consumption in the MUSH Subsector, 2003**[232]

| End Use | % End-Use Electricity Consumption, 2003 |
|---|---|
| Lighting | 31 |
| Ventilation | 19 |
| Cooling | 17 |
| Other | 10 |
| Heating | 8.4 |
| Computer Use | 5.9 |
| Refrigeration | 4.2 |
| Water Heating | 3.6 |
| Office Equipment | 1.4 |
| Cooking | 0.3 |

*Lighting, ventilation, and cooling dominate, constituting two-thirds of overall electricity consumption in the MUSH subsector.*

### 3.2.3 By Electricity End Use

Generally, population and gross domestic product (GDP) growth are factors that drive increases in commercial-sector electricity consumption. Slower economic growth and tightened building energy codes and appliance and equipment standards have led to flat overall consumption in the past few years (Figure 3.1).

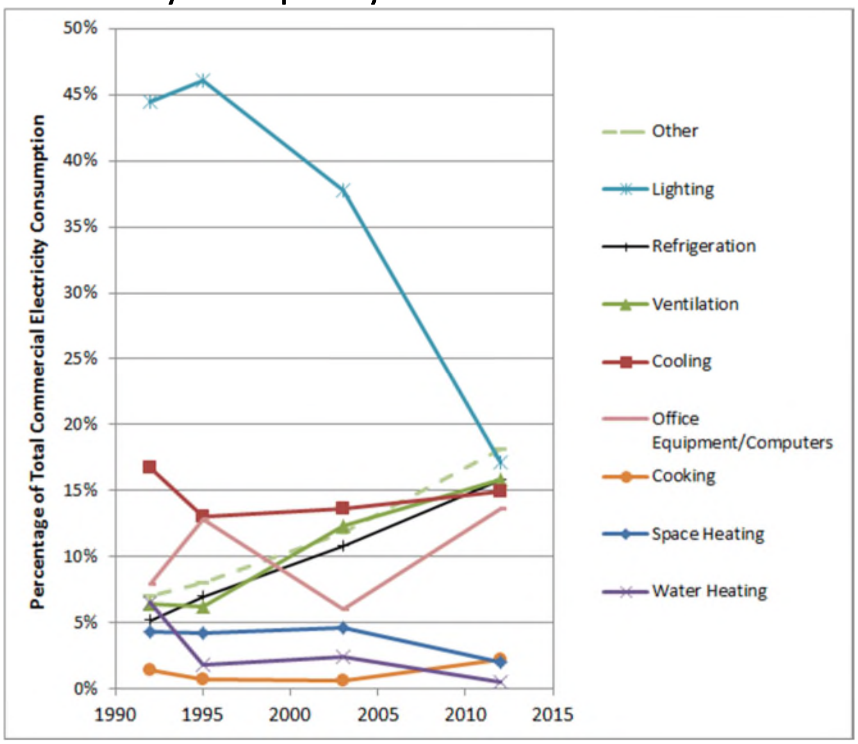
The most consumptive end uses in 2012 were Other end uses, lighting, refrigeration, ventilation, and cooling (Table 3.2). Lighting has historically been the largest end use in the commercial building sector, but the lighting share of total electricity in commercial buildings dropped from 46% in 1995 to 17.1% in 2012 (Figure 3.5) via continued improvements in lighting efficiency and controls. Electricity consumption in ventilation and Other end uses[a] has increased by 153% and 125% compared to their 1995 shares, respectively. The importance of technology development and energy efficiency standards for lighting, cooling, and Other end uses is highlighted in Section 3.34. Note that the commercial sector end use consumption data from the EPSA Side Case used in this chapter has been adjusted. The supply- and

[a] "Other" end uses include equipment such as elevators, escalators, medical and other laboratory equipment, laundry, communications equipment, security equipment, transformers, some municipal water service, non-road electric vehicles, and miscellaneous electrical appliances not counted as office equipment or computers. See Appendix Table 7.5.

consumption-side data discrepancy adjustment is separated from the Other end use category and proportionally re-allocated to the remaining end uses (see appendix 7.4.1).

Some water distribution and wastewater treatment end uses are included in the Other end-use category but are not included in EIA's CBECS. A recent study on the representation of miscellaneous electric loads in DOE's National Energy Modeling System (NEMS) found that about 0.5% of annual electricity use in the commercial sector is used for water distribution and about 3.5% for wastewater treatment.[a] [233]

**Figure 3.5. Trends in electricity consumption by end use from 1992 to 2012**[234]

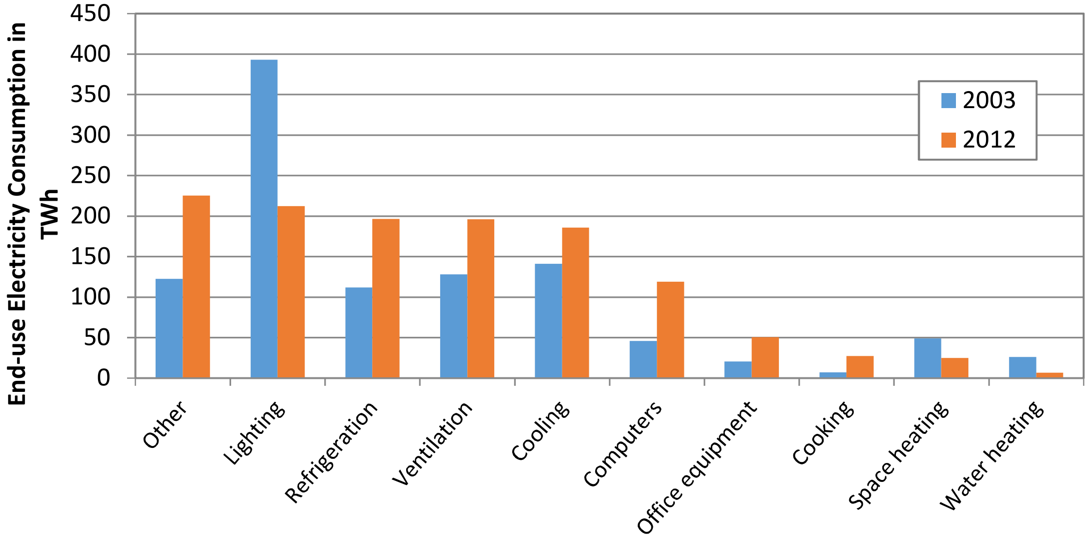



*The lighting, cooling, ventilation, and Other categories made up 75% of total use, with a sharp drop in lighting share and large increase in ventilation and refrigeration.*

Comparison of end-use electricity consumption in terawatt-hours (TWh) for CBECS 2003 and CBECS 2012 is shown in Figure 3.6 below. Lighting and space heating dropped by about 50% each, but they were offset by large increases in Other, refrigeration, computers, and office equipment, which increased by 84%, 76%, 160%, and 149%, respectively.

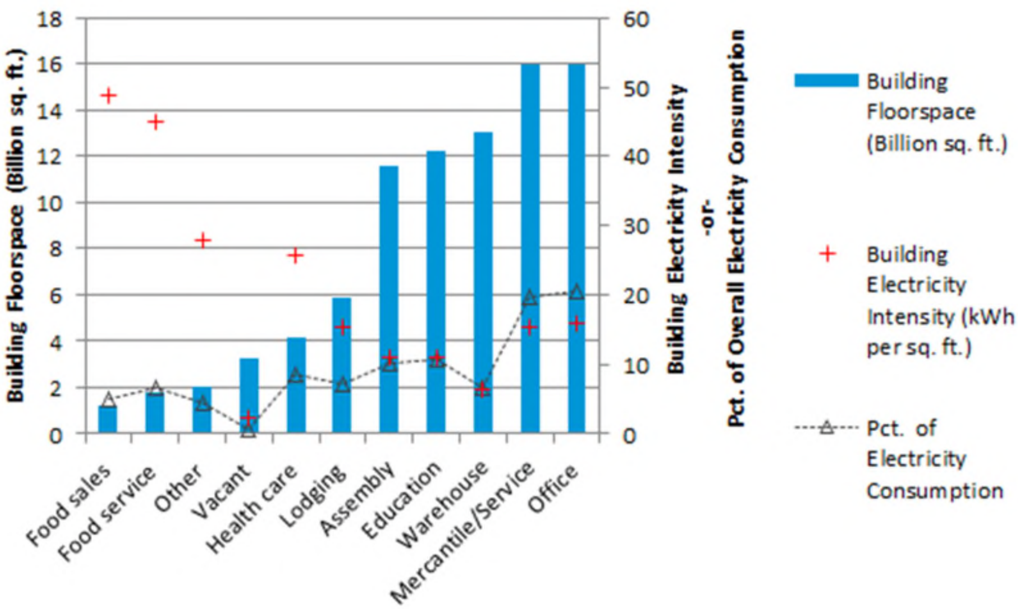
[a] While water systems may only account for a small portion of national-level annual electricity use, they may represent the largest single electricity usage (and expense) for a local government.

**Figure 3.6. End-use electricity consumption in TWh, 2003 and 2012**[235]




*Other, computer, and office equipment end use is up sharply while lighting consumption has dropped by almost 50%. Total electricity consumption was estimated at 1,043 TWh in 2003 and 1243 TWh in 2012.*

**Figure 3.7. Building floor space, building electricity intensity, and overall fraction of electricity consumption in 2003 by building category**[236]




*Buildings with the highest electricity intensity account (food sales, food service, and health care) have less floor space; buildings with more floor space have lower electricity intensity. Mercantile/service and office buildings represent large amounts of floor space and have moderately high electricity intensity, together accounting for about 40% of overall electricity consumption in the commercial sector. "Assembly" includes three building categories: public assembly, public order and safety, and religious worship.*

Figure 3.7 presents a synthesis of the above data sets. Building categories with the highest electricity intensity (food sales, food service, and health care)—due to high electricity demand for refrigeration, lighting, and plug loads around the clock—have low overall floor space, while building categories with the highest floor space (e.g., mercantile/service and office buildings) have moderate electricity intensity. This plot highlights the importance of mercantile/service, office, and health care building types, which are among the faster-growing by floor space.

## 3.3 Key Metrics and Trends

This section presents key metrics and trends in the commercial sector. Primary data sources are the U.S. Energy Information Administration (EIA),[a] CBECS, and EPSA Side Case.[237] Projected trends reflect the EPSA Side Case unless otherwise noted. Overall, end-use electricity consumption in the commercial sector is projected to grow about 22% from 2025 to 2040, primarily driven by Other end uses.

Figure 3.8 shows overall end-use energy consumption in the commercial sector. Electricity consumption has been increasing since 1992, while consumption of natural gas and other fuels (dominated by natural gas) has been flat. The electricity share of total energy consumption has increased from 23% in 1994 to 26% in 2012 and is projected to stay flat at 26% to 2040. Direct consumption of natural gas and other fuels dropped from 27% to 23% between 1994 and 2012 and is projected to comprise 22% of energy consumption in 2040. The increase in electricity consumption from the mid-1990s is consistent with increased use of existing types of electrical equipment and introduction of new types of equipment in commercial buildings such as computers (PCs, work stations, and servers), office equipment (printers, copiers, and fax machines), telecommunications equipment, and medical diagnostic and monitoring equipment.[238]

Note that Figure 3.8 does not take into account fuel switching from natural gas and other fuels to electricity. An example of this is moving from natural gas-fired water heaters to heat-pump water heating in small commercial buildings. If policies and technologies evolve to favor widespread fuel switching as a mechanism to achieve deep decarbonization in buildings, end-use electricity consumption in the commercial sector (blue line) could be higher than shown, and end-use fuel consumption (red line) lower, in the next 25 years.

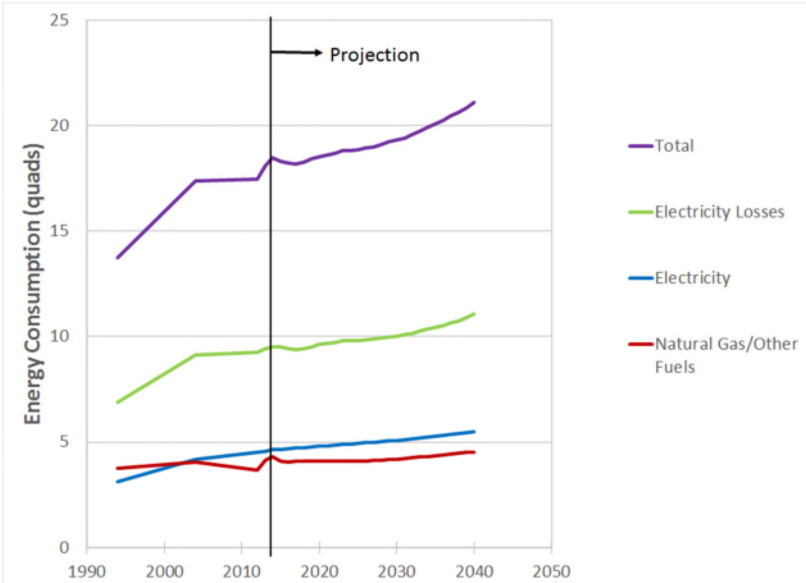
End-use electricity consumption in the commercial sector is projected to increase by 0.7% annually from 2015 to 2040, from 1.365 TWh to 1.615 TWh, a combination of a projected 0.3%-per-year decrease in electricity intensity and 1%-per-year increase in floor space (Figure 3.9). Floor space projections in the MUSH subsector are shown in Figure 7.21. End-use electricity in the sector is projected to increase by a total of about 18%. Figure 3.10 shows that the increased consumption is largely driven by Other uses.[b] Lighting and consumption continue to drop with improved technology (Section 3.2.3) and tighter federal energy efficiency standards, while non-PC office equipment, ventilation, and space cooling continue to increase. Consumption by Other end uses grows by 73% from 2015 to 2040 and by 72% for non-PC office equipment. Non-PC office equipment growth is largely driven by growth in consumption from data servers. A 2013 EIA study projected that electricity consumption from data center servers would grow 160% from 2015 to 2040, from 36 terawatt-hours TWh/year to 95 TWh/year,[239] but as noted

[a] The Commercial Demand Module (CDM) in National Energy Modeling System (NEMS) projects the reference case consumption by fuel and electricity at the Census-division level using prices from the NEMS energy supply modules, macroeconomic variables from the NEMS Macroeconomic Activity Module (MAM), and external data sources for technology characterizations and other inputs. Energy demands are projected for 10 end-use services for 11 building categories in each of the nine Census divisions. Detailed assumptions for the CDM are found in AEO 2015 CDM.

[b] An adjustment to the AEO 2015 Other end-use category was made according to the procedure described in an earlier LBNL report (Brown et al. 2008, p 2) to account for the residual electricity attributable to the commercial buildings sector but not assigned directly to specific end uses.

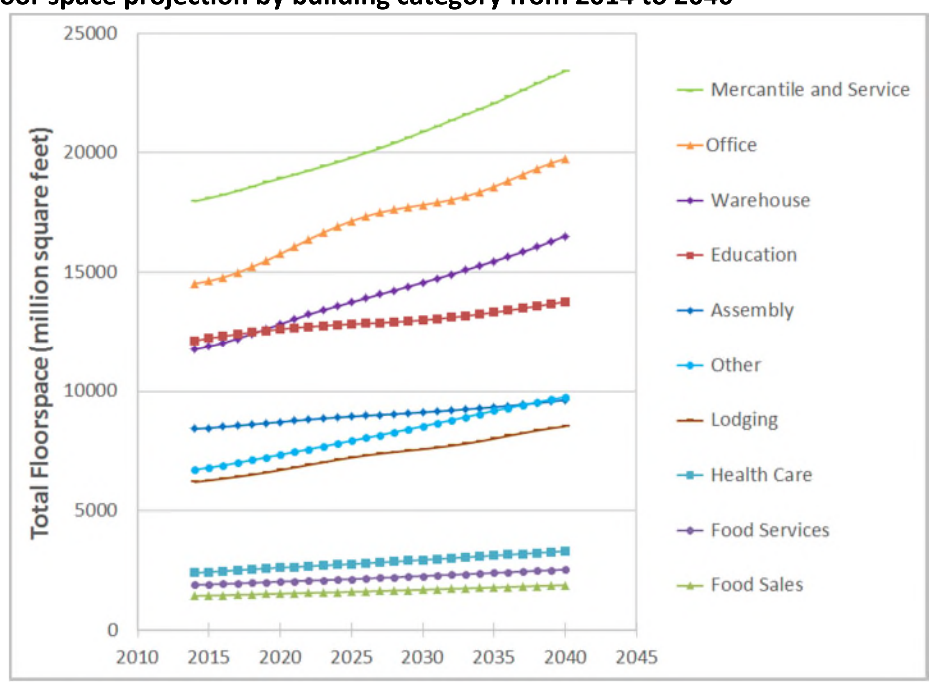
above, some large server farms would be classified in the industrial sector. The growth of data servers also increases energy requirements for building cooling and ventilation.

**Figure 3.8. Energy consumption trends in the commercial building sector[240]**



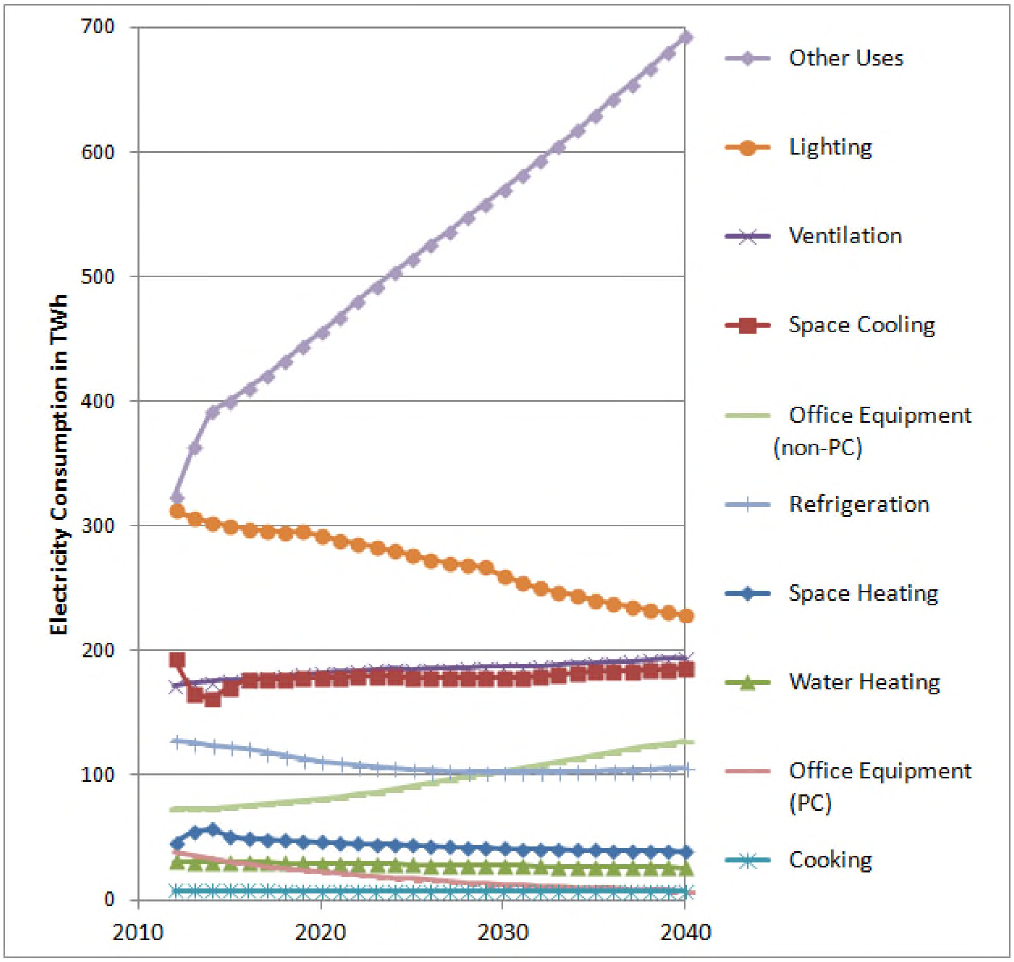

*End-use electricity consumption has exceeded consumption of natural gas and other fuels since the early 2000s, largely driven by the increase in plug loads and the Other end-use category, and it is projected to grow steadily for the next several decades. "Electricity losses" refer to the thermal losses due to electricity generation, transmission, and distribution.*

**Figure 3.9. Floor space projection by building category from 2014 to 2040[241]**




*Overall, floor space in the commercial sector is projected to increase by 1.1% per year. "Other," warehouses, health care, and lodging are growing fastest, at an annual rate of 1.2% to 1.5% per year.*

**Figure 3.10. Projected commercial electricity consumption by end use**[242] [a]




*The largest demand is expected from "Other," lighting, and ventilation. Overall end-use electricity consumption in the commercial sector is expected to increase by 0.7% annually (~0.3% drop in electricity intensity in kWh/ft² with ~1% increase in floor space per year)—about 18% from 2015 to 2040, driven primarily by Other uses. Lighting and refrigeration consumption is expected to continue to drop. Non-PC office equipment, ventilation, and space cooling are projected to increase.*

The largest demand overall comes from Other end uses, lighting, and ventilation. Future demand in the Other category may grow even more from greater workplace charging of PEVs. The growth in non-PC office equipment and Other end uses is addressed in Section 3.4.3, highlighting both direct approaches (e.g., standards for more efficient equipment and devices) and indirect approaches (e.g., management protocols) to increase energy efficiency.

A small (8.8%) reduction in electricity end-use intensity (kWh/ft²) from 2015 to 2040 is projected in the commercial sector (Figure 3.11). Other, lighting, ventilation, and space cooling are expected to be the most electricity-intensive end uses, making up 75% to 80% of commercial-sector electricity intensity. The intensity of Other uses is expected to trend significantly upward. Lighting is expected to trend significantly downward. Refrigeration and several other end uses also trend downward, due to more stringent appliance and equipment standards.

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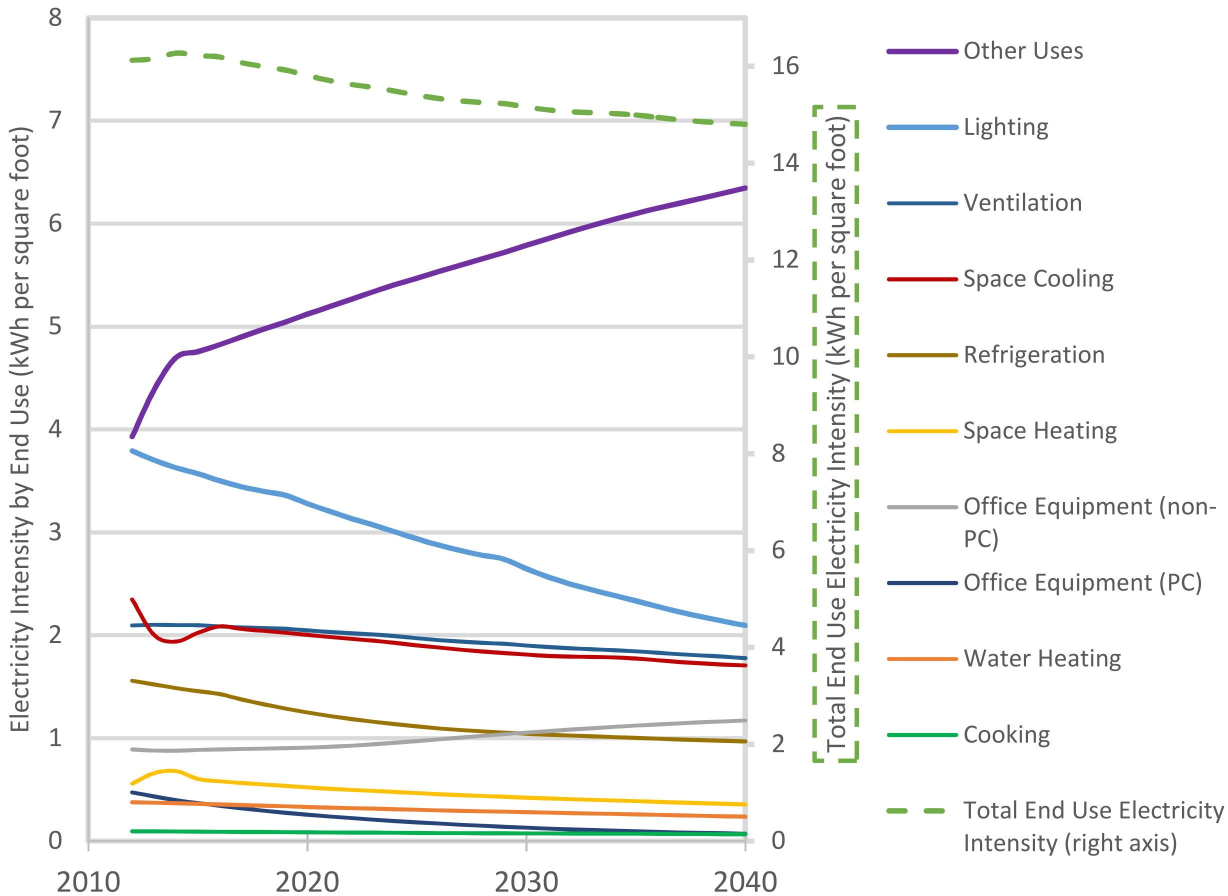
[a] Note that consumption data from CBECS 2012 was not available as an input to the EPSA Side Case. Thus the starting electricity consumption values by end use in 2012 from the EPSA Side Case are not identical to values from CBECS 2012.

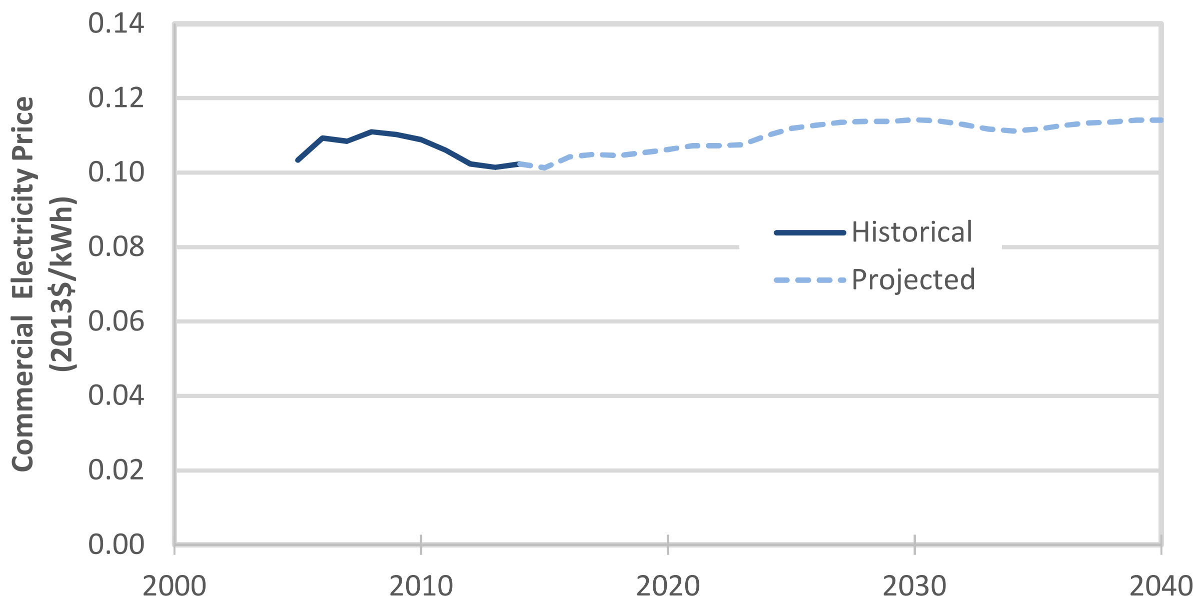
Electricity consumption for water distribution is projected to increase at a faster rate than the demand for water, as more energy is needed to distribute water from harder-to-reach places (e.g., wells of greater depth and sources of water farther away). Similarly, electricity consumption for wastewater treatment may increase at a faster rate than the increase in wastewater demand if wastewater treatment requirements are made more stringent and wastewater recycling increases.[243] Desalination could play a larger role in some coastal areas with reduced water supply from conventional sources and prolonged drought, and it could be a driver for new electricity demand. Figure 3.12 shows projected electricity prices for the commercial sector. The projected annual growth rate is a modest 0.5% per year through 2040. Between 1990 and 2014, commercial sector electricity prices increased 46%, remaining relatively stable between 1990 and 2000 at about $0.075/kWh, and then rising to $0.107/kWh by 2014. Electricity prices for the commercial sector are higher than industrial sector prices but lower than residential sector prices (Figure 7.24).

**Figure 3.11. Electricity intensity in the commercial sector by end use: Projection to 2040[244]**




*Electricity end-use intensity is projected to decline slightly (8.8%) from 2015 to 2040. Other, lighting, ventilation, and space cooling are expected to make up 75% to 80% of commercial sector electricity intensity. The intensity of the Other category is expected to trend significantly upward and lighting significantly downward.*

**Figure 3.12. Historical electricity prices and projected electricity prices per kWh in the commercial sector, 2005 to 2040**[245]




*Electricity prices for the commercial sector are projected to grow modestly, at 0.5% per year.*

Table 3.6 shows projected population growth from 2015 to 2040. Annual growth of 0.7% is projected for the overall population, but annual growth for the population aged 65 and over is projected to grow by three times that rate—2.2% annually. Senior citizens made up about 15% of the U.S. population in 2015. This share is projected to grow to 21% in 2040. In fact, most of the growth in population from 2015 to 2030 will be from senior citizens, representing 68% of the overall population increase. This shift in the population is expected to have an impact on the distribution of commercial building types. For example, with an aging population, health care floor space is expected to increase more rapidly than the Other building type.

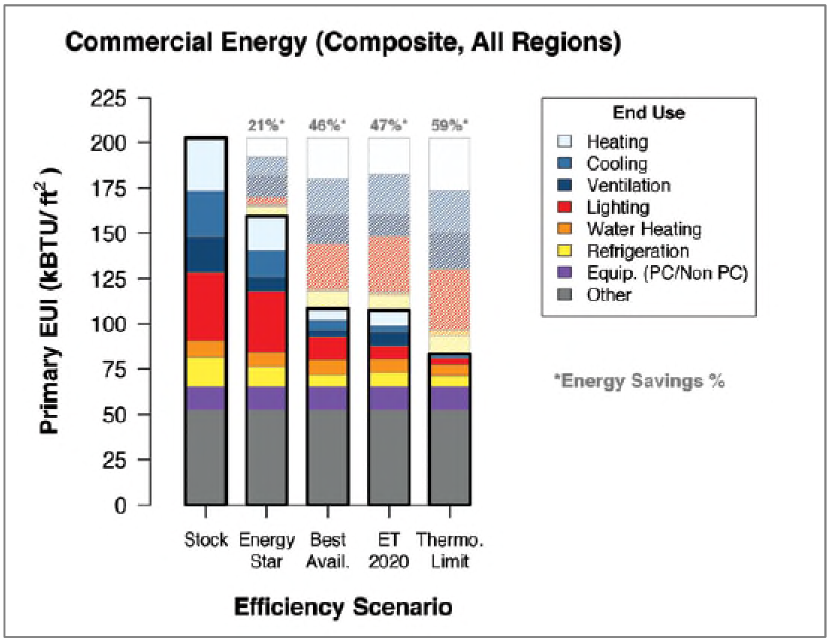
**Table 3.6. U.S. Population Projections from 2015–2040**[246]

| Population and Employment (millions) | 2015 | 2030 | 2040 | Annual Growth (%) | 2030 increase from 2015 (M) | 2040 increase from 2015 (M) |
|---|---|---|---|---|---|---|
| Population, with Armed Forces Overseas | 321.5 | 358.6 | 380.0 | 0.7 | 37.1 | 58.5 |
| Population, aged 16 and over | 255.9 | 287.7 | 307.3 | 0.7 | 31.8 | 51.4 |
| Population, aged 65 and over | 48.0 | 73.0 | 79.8 | 2.2 | 25.0 | 31.9 |
| Employment, Non-farm | 141.6 | 158.6 | 168.5 | 0.8 | 17.0 | 26.9 |
| Employment, Manufacturing | 12.0 | 10.7 | 9.7 | -0.7 | -1.3 | -2.3 |
| % of Population aged 65 and older | 14.9% | 20.4% | 21.0% | | 68% | 54% |

## 3.4 Energy Efficiency Technologies and Strategies in Commercial Buildings

The 2015 QTR estimates the ultimate potential of energy savings in the commercial sector by end use (Figure 3.13). If the stock of commercial building in 2013 were improved by 20%, the savings would be approximately 3.6 quads of total energy and $36 billion in costs.[247]

**Figure 3.13. Potential improvements in commercial building energy intensity[248]**




*For example, energy intensity can improve by an estimated 21% with ENERGY STAR equipment and 46% with best available technology. No improvement was assumed for the Other end-use category, which becomes dominant in scenarios with high levels of energy savings.*

### 3.4.1 Lighting

Lighting in mercantile buildings, followed by lighting in office buildings, is the largest electricity end use in commercial buildings.[249] Linear fluorescent lighting is commonly used with about 72% of overall lighting energy.

LED and solid-state lighting (SSL) technology[a] through R&D programs since the mid-2000s. LEDs have a much longer lifetime than CFL or incandescent lighting and can improve the performance and value of lighting through enhanced controllability and new functionality. LEDs also are highly energy efficient and can decrease wattage by 75% or more.[250]

Solid-state lighting (SSL) sources are inherently dimmable, instantaneously controllable, and can be readily integrated with sensor and control systems. That enables additional energy savings through occupancy sensing, daylight strategies, and local control of light levels.[251]

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[a] LEDs are a solid-state lighting technology based on semiconductor electronics to generate light, as opposed to a radiant tungsten-filament light source in incandescent lighting or a gas-discharge light source in fluorescent lighting. Solid-state lighting includes LEDs, organic LEDs, and polymer LEDs.

A DOE-sponsored forecast projects LEDs will grow to 84% of market share in 2030 in the commercial sector, saving a cumulative 18% of commercial lighting electricity usage from 2013 to 2030, relative to a no-LED baseline. The same study projects that by 2030, total indoor lighting shipments (in lumen-hour units) will be 82% LED-based in 2030, compared to 2% in 2013. LED market share of lighting shipments for outdoor lighting, including parking lots and building exterior lighting, is projected at 99% in 2030, compared to 9% in 2013. The study estimates that "SSL could account for nearly half of all lighting shipments in the U.S. (measured in terms of light-production capacity in lumen-hours) and approximately 40% of the installed base (in lumen-hours) by the year 2020."[252]

Still, there are remaining market barriers to adopting advanced lighting technologies. They include first cost, with a price premium for new technologies over conventional technologies, for both new and retrofit applications. However, adoption of LED-based products in many commercial sector applications has accelerated as the payback period declines to one or two years.[253] Another market barrier is the added complexity and variation in product performance for new lighting technologies.

Organic LED or larger-area, more-diffuse, lighting technology[a] could be widely deployed in offices and other commercial buildings, offering a great variety of possible designs and product implementation. The technology is still in early commercialization but is a key area for both public and private R&D.[254]

Another priority for DOE-sponsored R&D is to capitalize the unique controllability, dimmability, and directionality of LED lighting through smart controls and sensors, including: (1) investigating interoperability of lighting control, communication, and sensor platforms, and (2) developing systems for real-time energy monitoring and feedback.[255]

### 3.4.2 Cooling

Cooling accounts for 15% of electricity consumption in the commercial sector, ranking as the third-highest end use.[256] Cooling systems in commercial buildings often provide humidity control, and careful system design and regular maintenance are essential for energy-efficient operation, particularly in humid climates such as the Southeast.

Traditional cooling approaches use vapor-compression heat pumps to both cool the air and remove moisture for greater comfort. Commercial central air conditioners and heat pumps (often called rooftop units) are commonly used for small and mid-sized commercial buildings. Most large commercial buildings use central chillers to cool water and transfer heat from water to air closer to the occupied spaces.[257] Activities to improve HVAC efficiency involve efforts to optimize internal loads to reduce cooling requirements, improve the efficiency of cooling systems, and develop technology that can efficiently remove moisture from air without cooling energy.[258]

Electricity consumption for cooling is projected to stay fairly constant through 2040 from its 2012 level of 200 TWh.[259] Growth in cooling demand from higher GDP and population are thus counteracted by greater energy efficiency of building shells and more energy-efficient cooling equipment. For example, updated federal standards for commercial air-cooled central air-conditioners and heat pumps issued in 2015 (and effective in 2018 and 2023, depending on product type) will yield lifetime energy savings estimated at 14.8 quads from 2018 to 2048, a savings of 24% relative to the energy use of these products in the no new standards case. Cumulative net savings are estimated at $15.2 billion to $50

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[a] Organic LEDs (OLEDs) are made of organic compounds, while conventional LEDs are made of semiconductors. OLEDs provide thin films of material that emit light, as opposed to "point-source" lighting provided by LEDs.

billion.[260] Commercial chiller performance is addressed in the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) standard 90.1-2013, with a greater focus on part-load performance of systems, specifically part-load "off-design" point efficiency where most of the operating hours occur. The latest version includes a 10% increase in required part-load efficiencies.[261]

Heat pump and air-conditioning systems using vapor-compression technology typically employ hydrofluorocarbon refrigerants (working fluids) that have a far higher global warming potential (GWP) than $CO_2$. The development of alternative, lower-GWP refrigerant substitutes is an intensive area of R&D, but current substitutes are more expensive, slightly toxic, or slightly flammable, or they require more expensive equipment.

Several promising cooling technologies can eliminate high-GWP refrigerants and increase system efficiency, but more development and demonstration is needed before these technologies can make a large impact. These include magnetocaloric, thermoelastic, electrochemical, and electrocaloric approaches. Thermally driven technologies using absorption and adsorption devices are another opportunity for performance improvement.[262]

One key source of uncertainty in cooling demand is the impact of climate change. The AEO 2015 projects a 12% increase across the United States in cooling degree days from 2012 to 2040, where "a 10% increase in cooling degree days would increase cooling consumption by about 12.5%."[263] While the AEO takes this into account in projections, there is considerable uncertainty in future climate and, in particular, the prevalence of more extreme weather—e.g., heat waves or peak demand periods with higher frequency, duration, and intensity.

### 3.4.3 "Other" End-Use Sector

The Other end-use category is a key area for reduced electricity consumption in the future, with projected growth in electricity demand in the commercial sector largely driven by growth in this category. Other end uses include miscellaneous end uses, plug loads, and additional uses that do not fall into specific end-use service categories (e.g., elevators, escalators, medical/lab/security equipment). Potential improvements in the Other end-use category include improving the efficiency of vertical transportation through greater equipment efficiency, more efficient operation, and improved building design—e.g., design and location of stairways versus elevators.[264]

Importantly, electricity consumption in the Other category is not projected to drop (Figure 3.13), due to a large increase in the number of devices.[265]

Recent studies on ZNEBs and ZNEB-capable[a] buildings underscore the growing importance of improving the efficiency of plug loads. According to a recent study, plug load fractions range from 35% to 49% for California Leadership in Energy and Environmental Design (LEED)-rated projects (depending on building-use type) and 32% to 45% for ZNEB-capable California projects.[266]

Reducing electricity consumption by Other uses includes the following direct and indirect approaches:[267]

- Direct (1) improved energy-efficiency devices and appliances and (2) power-management strategies through integrated control systems with improved controllability—for example,

[a] "ZNEB-capable" refers to a building that is capable of achieving zero net energy status with the installation of on-site renewable electricity generation but does not have on-site supply of electricity installed.

developing a separate circuit for plug loads that can be turned off globally if there is no building occupancy, or escalator/elevator sleep modes.

- Indirect (1) increasing the visibility of plug load energy usage to commercial building occupants and building operators,[268] (2) development of management protocols to address these miscellaneous loads, and (3) encouraging changes in behavior to minimize unnecessary power usage.

Separately metered receptacle circuits are another option to reduce plug load. The ASHRAE standard 90.1-2010 was the first to address plug loads by requiring sweep or occupancy controls on 50% of power outlets in open offices and computer classrooms.[269] States also are beginning to take action to address previously unregulated loads. For example, all new commercial buildings in California larger than 25,000 $ft^2$ must include separately metered receptacle circuits.[270] However, market barriers still exist in the application of plug-load savings opportunities, including lack of cost savings information, tenant/occupant buy-in, and integration with whole-building energy management and information systems.

### 3.4.4 Improved Controls for More Dynamic and Flexible Buildings

The market for building energy-management systems, sensors and controls, and load-management strategies for commercial buildings is large and growing.[271] A recent report by Navigant estimates the global building energy-management software market is expected to grow from $2.4 billion in 2015 to $10.8 billion in 2024.[272] Energy-management systems are increasingly able to control room temperatures, humidity, ventilation rates, plug loads, and dimmable lights, and in the future, they will control windows and louvers.[273] Similarly, lighting, windows, HVAC equipment, water heaters, and other building equipment are starting to be equipped with smart controllers and often wireless communications capabilities that enable demand response for peak load.[274]

Buildings perform most efficiently when an integrated system controls all energy-using systems. Well-designed control systems can increase building efficiency up to 23%.[275] Moreover, the greater use and effective utilization of sensors and controls will help to move today's building operations from fixed-schedule operations to more dynamic and flexible operation (e.g., for building facades, HVAC, and refrigeration systems) that is responsive to electricity price signals and utility and grid operator requests for load flexibility.

Advanced building-control systems will enable better building-to-grid integration and allow commercial buildings to participate in integrated energy efficiency and demand response programs, such as short-term frequency regulation and load shedding. Other potential benefits of advanced building-control systems include space-planning adaptation and optimization (based on occupancy, density, and scheduling), improved security, enhanced fault detection/diagnostics and response, emergency detection and management, and early identification of maintenance issues.

Sensors and controls enable valuable capabilities—greater visibility to energy usage, greater building information and control for the individual occupant at the whole-building level, and the opportunity for component-level response—i.e., exhaust fans, reheat, or one light at a time. In addition, the data enabled by these technologies can facilitate more whole-building control and potentially facilitate future building energy codes that may be based on actual energy use—e.g., requiring building monitoring for a specified period of time after the building has been occupied.[276] Key factors for the greater adoption of sensors and related equipment are interoperability, ease of installation and user interfaces, low cost, and integration with a diversity of end-use equipment.

Lighting provides an instructive example. As the largest single electricity end use in the commercial sector, lighting offers a significant opportunity for energy savings through sensors and controls. A recent meta-study on lighting controls by Lawrence Berkeley National Laboratory (LBNL) shows a wide range of potential savings—from an average of 24% using only occupancy sensors to 38% with daylighting and more sophisticated controls.[277] However, today's lighting controls can still be expensive, and it is difficult to build reliable occupancy sensors.[278] Progress is being made to make sensors more robust by coupling them with other data sources such as user activity (e.g., computer usage). Further improvements can be made to reduce cost, improve sensor quality, and enhance data algorithms.

One issue for achieving more energy efficiency and flexibility in the commercial sector is the difficulty of market adoption of EMCS[a] in small buildings. In 2012, more than 70% of all commercial buildings larger than 100,000 $ft^2$ had some kind of EMCS for HVAC, but only 12% of buildings smaller than 25,000 $ft^2$ used them.[279] Only 3% of buildings smaller than 25,000 $ft^2$ have EMCS for lighting. Thus, innovations are needed that greatly lower the cost and simplify the installation and operation of control systems and advanced control systems.

Other barriers and challenges to the adoption of control systems include the following:[280]

- Lack of capability to respond to price – Many commercial buildings are not capable of handling price and energy performance information.
- Lack of low-cost control networks and optimization functionality – Cost should be low enough for both large and small buildings, and systems should not disrupt the comfort of building occupants.
- Lack of accuracy and access to data – Sensors are needed to collect energy use and end-use performance data. Existing sensors may not be accurate enough or may not have the required granularity to participate in demand response programs.
- Lack of evaluation, measurement and verification (EM&V) technology – M&V technology and protocols are needed to track the performance of control systems and should be easy to install and reliable to operate. See Appendix 7.8.
- Lack of interoperability of proprietary or legacy systems with new technologies, services, tools, and DERs.

Security and privacy concerns related to increased data collection and data that are processed by external parties are another issue, and a possible barrier to the greater adoption of advanced control systems. Data-handling policies, guidelines, and protocols addressing consumer preferences and privacy concerns can remove this barrier to deploying programs that rely on more ubiquitous sensors and control systems.[281]

Prices for sensors and controls remain a barrier but are expected to come down by a factor of 10 in the next decade from lower cost, printed electronic substrates for circuits, sensors, antennas, solar photovoltaics (PVs), and batteries.[282]

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[a] Note that the terms energy management control systems and building automation systems are synonymous and may also be referred to as smart building controls. See "Guide to the 2012 CBECS Detailed Tables," accessed January 15, 2016, http://www.eia.gov/consumption/commercial/data/2012/guide.cfm.

Some building energy policies are expected to have an impact on facilitating the greater use of advanced controls and sensors. For example, California is developing building energy codes for net zero-energy new construction in the commercial sector for 2030. Such codes are expected to encourage builders to employ more advanced controls and sensors. Further advances in building energy codes, such as system-efficiency metrics, outcome-based energy codes, and periodic building retrocommissioning requirements, could encourage the greater use of advanced controls and sensors.

### 3.4.5 Zero Net Energy Buildings

The general concept of a ZNEB is that it produces as much energy on site as it consumes and, using clean generation sources, enables deep reductions in building energy use and energy-related air emissions. (See Section 2.4.6 for more discussion on the ramifications of ZNEBs in the residential sector.)

More precise definitions of such buildings depend on the treatment of site versus source energy,[a] energy imports versus exports, fuel equivalency offsets, and other factors. DOE recently defined a ZNEB as "an energy-efficient building where, on a source energy basis, the actual annual delivered energy is less than or equal to the on-site renewable exported energy."[283] Other definitions use site-energy-based criteria (a less-stringent definition than source-based) and time dependent valuation-based definitions,[284] which seek to assign a valuation of energy produced or consumed to better reflect the actual costs of energy, as adopted by the California Public Utilities Commission.[285]

The difficulty in meeting ZNEB criteria varies between definitions. Furthermore, the cost-effectiveness of ZNEBs is highly dependent on the type of building, location (climate), incentives (e.g., utility rebates), and the cost of renewable energy generation.

Recent studies demonstrate that many new ZNEBs in the commercial sector can be cost-effective, with overall costs falling within the same range as conventional new construction projects. The explicit goal of zero net energy throughout the design process is critical to minimizing construction costs.[286]

Table 3.7 shows key design steps toward achieving ZNEBs, including high-efficiency building envelopes, highly efficient end-use systems, building-management control strategies, energy recovery (e.g., waste heat recovery and minimizing re-heating of previously tempered air), use of sufficient renewable resources to meet remaining building load, and monitoring and management of building energy during actual building occupancy and operation.

In California, for example, many commercial buildings are technically feasible to be ZNEB using a time dependent valuation-based definition.[287] However, several building categories, such as sit-down restaurants, hospitals, and large offices cannot reach ZNEB designation using rooftop solar though they might reach that designation using parking lot PV systems. Available roof space for on-site PV often is a challenge. Contracting with off-site renewable energy systems or participation in community-scale solar projects provide greater flexibility for buildings to be ZNEB or ZNEB-ready.[b] This is an active area of policy discussion.

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[a] Site energy is energy delivered to the building; source energy includes production and line losses.

[b] A *Zero Energy Ready* home is a high-energy-performance home that enables a renewable energy system to offset all or most of the home's annual energy consumption. See "Zero Energy Ready Home," U.S. Department of Energy, http://energy.gov/eere/buildings/zero-energy-ready-home.

Other barriers to the adoption of ZNEBs are the lack of integrated design practices, cost barriers, lack of skilled and knowledgeable workforce in design and construction,[288] additional design and construction cost, and integration of solar PV, either as part of the building construction process or as a parallel step during that process.

**Table 3.7. ZNEB Design Steps and Sample Technologies[289]**

| Design step | Sample technology options |
|---|---|
| 1. Reduce building energy loads with improved envelopes and the use of passive systems | Superinsulation, daylighting, exterior shading, natural ventilation |
| 2. Install high-efficiency systems to address primary building energy loads | Heating, ventilation, and air-conditioning systems (including distribution), water heating, appliances/equipment |
| 3. Install systems to manage building energy loads with effective control strategies and other mechanisms | Energy management systems, plug-load control strategies, feedback to users and occupants |
| 4. Incorporate energy recovery mechanisms to minimize energy losses | Energy recovery ventilation, heat-pump water heaters |
| 5. Use renewables to meet remaining building loads | Rooftop and other photovoltaic energy systems |
| 6. Monitor and manage building energy use post-occupancy | Monitoring-based commissioning, occupant engagement |

*Source:* Arup et al. 2012; NBI 2014

*Energy recovery mechanisms, building management, and control strategies are critical design and operation strategies beyond energy-efficient building shells, equipment, and renewable energy.*

### 3.4.6 Integrated Design/Whole-Building Modeling for New Construction and Major Retrofits

Integrated design and whole-building modeling represent the evolution of component-level optimization to system-level design and whole-building efficiency. To do this requires advances in modeling tools, sensors and building controls, data collection, and cost-effectiveness.
Similar to ZNEBs, integrated design includes the following activities:[290]

- Minimizing plug and process loads using efficient and efficiently used equipment
- Maximizing use of natural light while minimizing the negative thermal impacts of fenestration
- Minimizing unwanted envelope heat losses and gains through both conduction and infiltration/exfiltration
- Ventilating with outside air more effectively and selectively
- Recovering heat from exhaust air and waste water
- Reusing energy within the building and exchanging energy with buildings in a complex or campus
- Using hybrid HVAC systems that reduce overall energy consumption
- Using thermal and electrical storage
- Using renewable energy sources
- Using sensing and responsive automation to provide thermal and visual comfort to meet actual rather than pre-programmed occupant demand
- Using building automation and advanced system controls and diagnostics for commissioning and continuous commissioning to maintain system health and as-designed operation.

Buildings designed for whole-building performance using advanced system-level modeling software often outperform buildings designed using less quantitative approaches, such as prescriptive guidelines. They also often achieve this performance at a lower up-front cost because they help identify those areas where energy efficiency investments will be most effective.[291]

Whole-building energy modeling also can add value after construction, to maintain and improve building energy performance during occupancy and optimize control strategies to respond to weather forecasts, building-use predictions, and price signals from utilities, grid operators, and aggregators. Energy models can harmonize building operation between flexible load, energy storage, and on-site generation to optimize services to the grid.

Whole-building energy modeling has become more capable, robust, and application vendor-friendly, bolstered by DOE investment in the open-source modeling engine EnergyPlus and the open-source modeling software-development kit OpenStudio. Although continuous improvement is needed—especially in support of emerging building operation application, the adoption of building modeling remains another key challenge. Today, only about 55% of new commercial buildings use modeling at any time during the design process,[292] and the general consensus is that more than half of those use modeling at the end of the project for code-compliance or LEED certification, rather than early in the project for informing the design itself. Meanwhile, model-driven building commissioning and operation is an emerging area with a growing number of commercial actors but low levels of market penetration, with most activity focused on very large buildings and campuses.

Demand for integrated design could come from both regulatory and market sources. The next revision to the commercial national model energy code (ASHRAE 90.1-2016) may include system efficiency metrics that encourage more comprehensive efficiency approaches and previously unregulated loads. Outcome-based energy codes—which require absolute rather than relative energy performance levels—could also increase demand for integrated design, as well as for post-construction modeling to maintain intended performance levels.[293] Energy efficiency programs that provide incentives for whole-building design and integrated approaches to building design and operation also can drive demand. Key challenges include aligning incentives for market actors to support the integrated design and operations approach and adoption of supporting programs, regulations, and policies. Education and training in integrated design and construction is also needed.[294]

### 3.4.7 Some Cost Estimates for Commercial Building Energy Efficiency Retrofits

Table 3.8 summarizes cost estimates for major types of commercial building energy efficiency retrofits. Retrocommissioning can offer payback times of less than two years with source energy savings of up to 20%. Energy service company (ESCO) projects span a range of payback times, with paybacks for public buildings typically being 7 to 12 years. Retrofits with integrated design can have a similar payback period, while net zero energy retrofits are the most costly but achieve the highest energy savings. There are few data points for net zero energy retrofits, thus payback times and costs are less certain.

**Table 3.8. Simple Payback Times for Various Energy Efficiency Retrofits**[295]

| Energy Retrofit Type | % Source Energy Savings* | Simple Payback Times from Energy Cost Savings | Cost ($/ft$^2$)** |
|---|---|---|---|
| Retrocommissioning | 10 to 20* | 4 months to 2.4 years | $0.30 –.40 |
| ESCO | 20 to 40 | 3 to 12 years | $2.50 |
| Integrated Design | 30 to 60 | 7 to 12 years | $2.50 |
| Net Zero Energy | 50 to 90 | 8 to 20 years? | $10? |

** End-use electricity savings estimated at 2% to 5%.*
*** The cost per ft$^2$ varies widely among building types because the energy intensity for each type is different.*

A retrofit case study for Walmart stores[296] finds that lighting upgrades have a 3- to 5-year payback time, annual savings of 286,000 kWh, and installed cost between $72,000 and $121,000. HVAC measures utilizing waste-heat recovery have a payback greater than five years, depending on the climate, with annual savings of about 900 kWh and installed costs between $52,000 and $88,000. Refrigeration upgrades have a payback of 3 to 5 years, with annual savings of 521,000 kWh and installed costs between $208,000 and $346,000.

The decision to retrofit an existing building versus demolishing the building and constructing a new facility to achieve energy efficiency, carbon, or cost goals is generally highly building- and site-specific. Full life-cycle analysis comparing the two options typically includes operating energy as well as the embodied energy of materials and new construction. Other factors to consider include building location, density, transit proximity, infrastructure changes, occupant preferences, and other attributes such as indoor air quality and building safety.

Existing studies that compare new versus renovated commercial buildings are limited,[297] but studies generally show lifetime carbon emissions depend on operational energy efficiency and lifespan assumptions. New buildings with equivalent energy efficiency to retrofitted buildings show comparable lifetime emissions and gains of 1% to 16% for new buildings, with 30% higher energy efficiency than retrofit buildings.[298] These studies include building energy consumption and embedded energy, but do not examine cost-effectiveness and other factors such as density and transit proximity. In some cases, new buildings may be the preferred option—for example, if the existing building is too expensive to upgrade to meet current code requirements as may be the case for seismic upgrades; if technical issues prevent cost-effective energy efficiency upgrades (e.g., some older buildings cannot be easily insulated); if the older building requires a new addition that negates the cost advantage; or if the existing building cannot meet functional requirements or has a large disadvantage in another area such as density or transit proximity.

## 3.5 Markets and Market Actors

Market actors in the commercial sector vary according to factors such as type of building, building size, new versus existing buildings, and ownership model. Table 3.9 illustrates lists key market actors as a function of the building life-cycle phase, from pre-construction to design, modeling, and construction to building operation and building type (new and existing). In the pre-construction phase, local and state officials develop building energy codes that set minimum performance and efficiency standards, typically on a three-year cycle. For new buildings, the design, modeling and construction phase involves developers, architects, and builders, as well as financing agents. After construction, permitting entities, appraisers and, in high performing buildings, commissioning[a] agents test and measure building performance and energy efficiency. During building operation, key market actors include building owners and tenants, property management companies, real estate professionals, contractors for maintaining and replacing equipment, equipment suppliers, energy service suppliers, building auditors, and retrocommissioning[b] agents. Intelligent control system providers are emerging market actors, competing with or augmenting existing control system providers.

**Table 3.9. Key Market Actors and Roles for New and Existing Commercial Buildings**

| Building Phase or Area | New Buildings | Existing Buildings |
|---|---|---|
| **Pre-Construction** | | |
| | *Code officials* | |
| | *Policymakers, regulators and program* | |
| | *Developers, architects, designers, builders* | *Builders/contractors* |
| | *Capital providers, investors, corporate finance* | *Capital providers, REITs* |
| **Construction Phase** | | |
| | *Builders/contractors* | |
| | *Commissioning agents, permitting entities, appraisers* | *Permitting entities, retro-commissioning agents, building auditors* |
| **Operational Phase** | | |
| | *Owners, tenants, property management firms, real estate marketing and sales professionals Software solution providers (intelligent control systems, building management software)* | |
| Energy Services | *Utilities and grid operators* | |
| | *Electric industry regulators* | |
| | *Distributed energy resource providers (equipment,* | |
| | *Energy Service Companies (for larger buildings)* | |
| | *Energy Management System providers* | |

| Equipment/ Appliance Installation and Sales | |
|---|---|
| | *Federal and state officials promulgating standards and labeling* |
| | *Administrators of utility incentive programs* |
| | *Builders, designers, developers, and contractors* |
| | *Equipment retailers and installers* |
| | *Manufacturers* |

*Commercial buildings involve a diverse set of market actors and roles that vary during the life-cycle of the building (pre-construction; design, modeling, and construction; and building operation) and type of building (new and existing). REIT stands for real estate business trust.*[299]

Each market actor faces various competing factors that enable or discourage energy efficiency investment in the commercial sector. See the following section (3.6) for more details on these factors. Additionally, while many of these market actors are well established, some have been growing rapidly over the past several years, and some are anticipated to grow rapidly in the coming years. The diversity and impact of these factors and the development of these market actors indicate the need for new building energy codes and equipment standards to remove barriers and align interests to increase

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[a] When a building is initially commissioned it undergoes an intensive quality assurance process that begins during design and continues through construction, occupancy, and operations. Commissioning ensures that the new building operates initially as the owner intended and that building staff are prepared to operate and maintain its systems and equipment.
[b] Retrocommissioning is the application of the commissioning process to existing buildings to resolve problems that have developed throughout the building's life. In all cases, retrocommissioning improves a building's operations and maintenance procedures to enhance overall building performance.

energy efficiency of commercial buildings. In addition to new standards and codes, other evolving regulations, governmental and corporate policies, and newly available commercial technologies will continue to affect the growth of these market actors, expand the importance of building designs, and increase market adoption.

Already energy-efficient construction, maintenance, and operation of commercial buildings are on the rise. In the United States, the market share of high-performance green buildings grew from 2% of new construction starts in 2005 to 44% in 2012. In a recent survey of U.S. architecture, engineering, and real estate firms, the number of firms that report heavy engagement in green building projects (over 60% of total projects) will increase from 16% to 53% between 2009 and 2015.[300] The motives behind investment in more sustainable buildings, especially in the commercial sector, have shifted from regulation-based drivers to building owners' interest in cost and energy consumption reduction, as well as market differentiation. According to a 2013 study, 83% of leaders in the largest U.S. companies view overall sustainability practices as consistent with their profit mission. This is up from only 58% in 2006.[301] High-performance buildings are increasingly factoring into tenants' decisions about leasing space and buyers' decisions about purchasing properties.

**Energy Savings Performance Contracting (ESPC)**

Energy service companies (ESCOs) can integrate multiple measures and mitigate technical and performance risks for energy efficiency projects, and bundle them with other facility upgrades. Typically, these arrangements are structured as energy savings performance contracts. Performance contracting is a partnership with an ESCO to design, construct, maintain, and conduct evaluation, measurement, and verification for energy-saving projects. The client pays a percentage fee to the ESCO based on the total project cost. Performance contracting also provides a financial guarantee to the lender that the energy savings generated will cover debt service on the project. Performance contracting can pay for today's facility upgrades with tomorrow's energy savings, with service fees distributed across the term of the performance contract.

A typical performance contract reduces annual energy use by 15% to 30%.[302] Electricity accounts for an estimated two-thirds of the energy savings for public and institutional (e.g., university and hospital) ESPC projects.[303]

Municipalities, universities, schools and hospitals (MUSH) market consumers accounted for about three-quarters of U.S. ESCO industry savings during the period from 2003 to 2012.[304] Private sector projects made up only 8% of ESCO industry revenues in 2011. Private sector companies in the United States generally have higher barriers to energy efficiency investments and much shorter payback time requirements (one to two years) than the MUSH market.[305]

In 2011, 84% of ESCO revenues were from the MUSH[a] market (including the federal government) and 64% from non-federal MUSH buildings.[306] Gross revenues are projected to double from an estimated $6.4 billion in 2013 to $10.6 billion to $15.3 billion in 2020. Median estimates of market penetration in the U.S. range from 10% in health care facilities to 42% in kindergarten through 12th grade (K–12) schools. Of the remaining estimated $100 billion market potential for ESCOs, about two-thirds is in the non-federal MUSH sector, led by health care and K–12 schools.[307]

[a] Municipal and state government, university, school, and hospital sector.

## 3.6 Barriers, and the Policies, Regulations, and Programs That Address Them

Energy efficiency policies, regulations, and programs in the commercial sector attempt to address well-known barriers.[308] Performance contracting can address some of these barriers.

- Information/awareness and transparency – Market actors have imperfect information about the performance of energy-efficient technology and equipment, practices that can save energy, and cost effectiveness. Energy savings can be difficult to measure and separate by end use.
- First costs and short payback times – More efficient devices cost more, and typically, businesses require a short payback period (e.g., one to two years), severely restricting opportunities to invest in more energy efficient equipment.
- Risk aversion – A building owner or operator may be risk-averse to new or unfamiliar building construction technologies, new end-use technologies, new operating procedures, or business practices.
- Materiality – When energy costs are small, relative to other costs, it is hard to get building owners to pay attention to energy efficiency.
- Limited access to capital – Companies have limited capital investment budgets, and energy sometimes is not a consideration for renovations.
- Lack of monetization of non-energy benefits and price signals – Electricity prices are set to recover utility and electricity service supplier costs, not to reflect the true social cost of electricity consumption. In addition, tariff structures may discourage consumer investments in energy efficiency.
- Transaction costs – Energy efficiency improvements and building retrofits are time-consuming to understand, arrange, and execute.
- Split incentives – Commercial building owners may not have an incentive to invest in energy-efficient equipment if they do not pay utility bills, and tenants will not want to buy energy-efficient equipment if they are planning to move out soon.
- Tax treatment – Energy bills are a deductible expense, and capital costs for energy-efficient equipment may be subject to long depreciation schedules.
- Workforce development – The availability of a skilled workforce is a barrier in some regions due to inadequate training, experience, or certification (e.g., lack of technical expertise on energy-efficient technology options and lack of familiarity with various local incentive programs).
- Other market failures and imperfections – These include externalities (e.g., health and environmental costs of fossil energy production) and imperfect competition (e.g., lack of a fully competitive market for energy efficiency that may enable lower prices for products and services).

Following are key policies, regulations, and programs enacted to address these barriers in the commercial sector. Overarching policies such as an energy efficiency resource standard are discussed in Appendix 7.2 in this report. Table 3.10 summarizes the major policies, regulations, and programs enacted to encourage efficiency in commercial buildings.

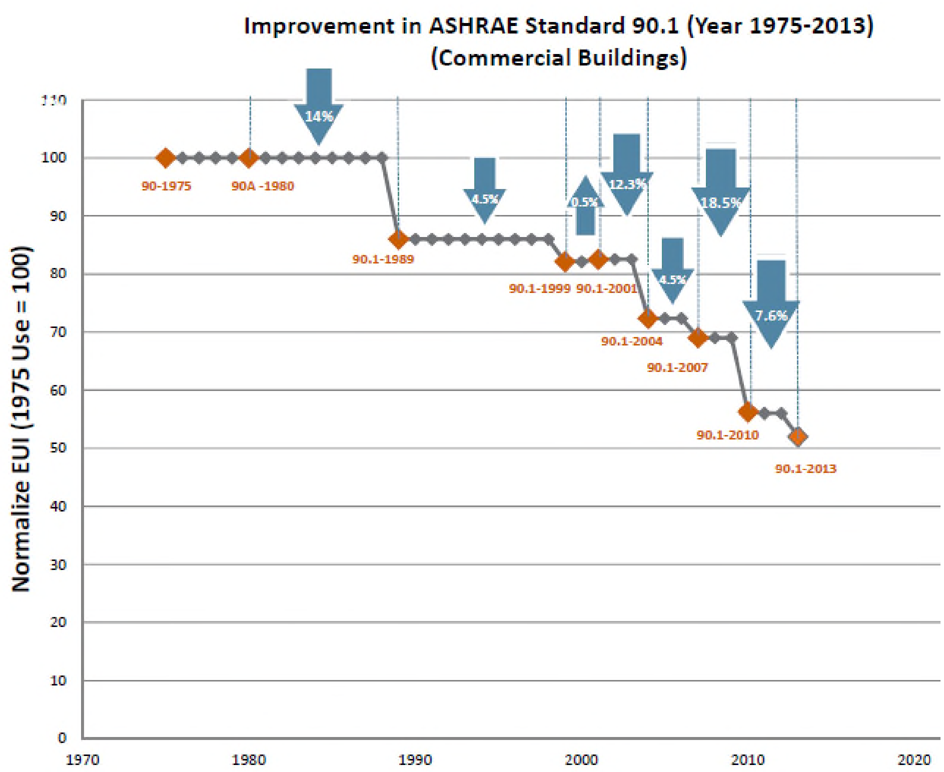
### 3.6.1 Building Energy Codes and Appliance and Equipment Standards

Codes and standards set a minimum level of energy efficiency performance, guarding against uninformed or inattentive purchase of inefficient devices and limiting the impact of split incentives. These policies have the goal of cost-effectively reducing energy consumption to meet long-term energy goals and to address barriers related to information and transparency, materiality, and split incentives.

- Building energy codes are mandatory prescriptive or performance-based codes that regulate building energy efficiency in new construction, major renovations, and remodels. National standards typically are updated every three years. ASHRAE 90.1-2013 is the most recent update (Figure 3.14). The ASHRAE 90.1-2010 or ASHRAE 90.1-2013 building energy code has been adopted in 22 states (Figure 3.15). Building energy codes also may include voluntary "green" or "reach" building energy codes.
- Appliance and equipment standards enact minimum performance requirements for appliances and other end-use equipment. Federal energy efficiency standards currently cover 14 types of commercial equipment (See Table 7.7), 11 of which are electricity-powered (e.g., air conditioning and refrigeration equipment). Some states have adopted additional commercial equipment standards beyond the federal standards. For example, several states have adopted standards for hot food-holding cabinets and water dispensers (California, New Hampshire, District of Columbia, Maryland, Oregon, Washington, Rhode Island, and Connecticut).

A recent LBNL study showed that energy efficiency standards adopted from 1987 through 2014 for appliances and equipment have saved 5 quads of primary energy from commercial and industrial standards and 7.8 quads from lighting products.[a] [309]

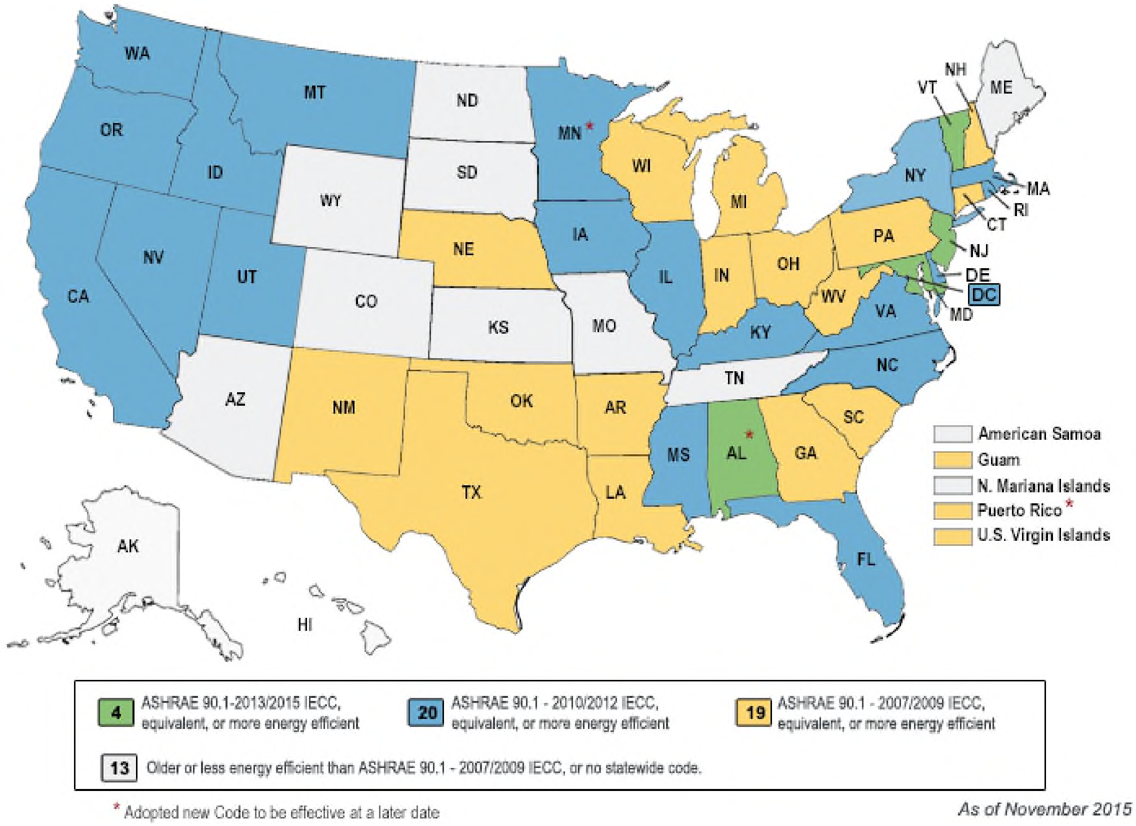
**Figure 3.14. Energy savings from commercial building energy codes relative to the 1975 base code[310]**




*About 8% energy-use intensity savings are achieved through adoption of the ASHRAE 90.1-2013 standard compared to 90.1-2010, about 30% savings have been achieved since 2004, and almost 50% savings are achieved from the initial standard set in 1980.*

[a] Note: the referenced study does not distinguish savings from the commercial sector alone.

**Figure 3.15. Adoption of state energy codes for commercial buildings, as of 2015** [311]




*Three states have adopted ASHRAE 90.1-2013, 20 states have adopted 90.1-2010, 20 states have adopted ASHRAE 90.1 – 2007/2009 IECC, and 7 states have a building energy code older than ASHRAE 90.1 – 2007/2009 IECC or no statewide code.*

### 3.6.2 Informational Interventions

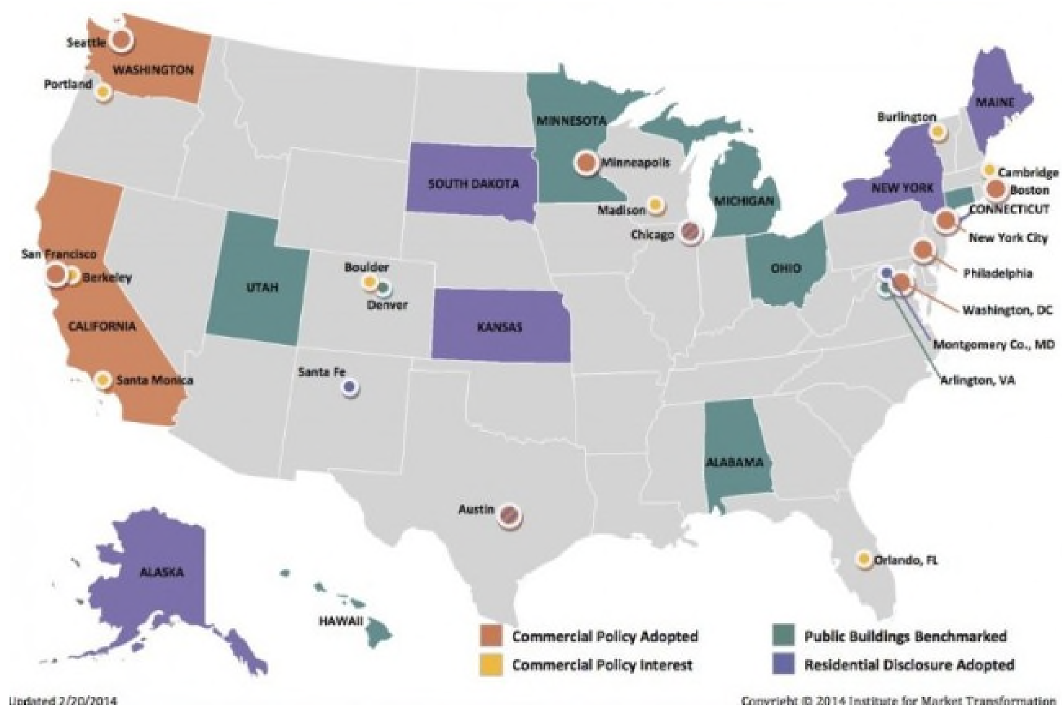
Building owners and operators often have inadequate information about the performance of high-efficiency technologies and energy-efficient operations. Stakeholders lack robust ways to assess, compare, and validate building energy performance. This leads to the perception that investing in efficiency is too expensive, complicated, or risky, making it difficult to gain access to capital. Without the appropriate information, tools, and platforms, building owners and managers are not able to accurately track their energy consumption, assess and compare their buildings, make timely decisions on upgrades and maintenance, or properly value their investments.

Inadequate information also leads to uncertainty in valuation of energy-efficient commercial buildings by the real estate community. The design, construction, appraisal, and underwriting processes do not fully account for the value that increased energy efficiency can bring to a building. When building owners are uncertain about their ability to recoup energy efficiency investments through rent or resale, they are more hesitant to make those investments. Informational interventions have been designed to alleviate or remove these barriers.

These include programs that encourage or subsidize building audits, programs promoting energy management and information systems, product labels (ENERGY STAR, EnergyGuide), or building designations (ENERGY STAR Buildings) that provide better information and disclosure about energy costs. These programs have the goal of encouraging greater energy and cost savings by addressing barriers related to information, awareness, and materiality. Building owners and occupants may lack capacity to identify opportunities for energy-saving improvements, data on energy usage may not be transparent, and consumers may lack information or focus on energy.

Building energy benchmarking and transparency policies (Figure 3.16) require reporting of building energy performance to raise building owners' knowledge base of properties' energy usage; they provide greater transparency for current and prospective tenants; they highlight cost-effective, energy-saving opportunities; and they provide market data to allow for enhanced deployment of efficiency efforts on the part of relevant agencies.[312] Building benchmarking and auditing data provide a database of information over time that support better valuation of energy efficiency measures in commercial buildings for future owners and investors. Regulations that require building energy benchmarking, periodic energy audits, corrective actions (e.g., retrocommissioning), or point of sale disclosure or upgrades (or both) for commercial buildings have been adopted by 8 states and 14 cities.

**Figure 3.16. U.S. building benchmarking and disclosure policies, as of 2014**[313]




*A growing number of states and communities are adopting building information transparency policies. These include building energy benchmarking, periodic energy audits, corrective actions (e.g., retrocommissioning), and point of sale disclosure or upgrades (or both).*

### 3.6.3 Incentives and Rebates

Incentives and rebates have the goal of increasing the market adoption of energy efficiency measures by lowering their incremental up-front cost. These approaches address barriers of first costs, short payback requirements, lack of monetization of non-energy benefits, materiality, and information and awareness.

Incentives and rebates are payments to end users that reduce or offset the incremental cost of energy efficient technologies, such as those offered by utility customer-funded programs. Currently, there are more than 300 of these programs nationwide targeting the commercial sector. Most programs are technology-specific; some are offered based on whole-building energy savings achieved. In December 2015, the U.S. Congress extended the commercial building tax deduction through 2016. The deduction is applicable for expenses incurred for energy-efficient building expenditures made by a building owner and is capped at $1.80 per ft$^2$.[314]

### 3.6.4 Financing

Energy efficiency financing programs have the goal of facilitating greater adoption of efficiency measures by providing capital at attractive terms for such investments. Financing is often packaged with other programmatic offerings, such as rebates, to help drive demand. Financing programs address such barriers as lack of capital, first cost, transaction costs, and performance risk.

- Utility demand-side management financing programs – For example, for on-bill financing, the utility makes a loan to a customer for energy efficiency improvements, and the utility collects the loan payment on the customer's bill.
- Financing offered by state energy offices – According to the National Association of State Energy Officials, more than $2 billion in state energy office-administered financing is available for energy efficiency and renewable energy projects in 44 states.[315] For example, many state energy offices administer loan programs (e.g., using general obligation bonds or revolving loan funds) offering low-interest loans for energy efficiency improvements.
- Energy investment partnerships and green banks – These entities are stand-alone public or quasi-public entities created to use existing sources of public funds (e.g., ratepayer funding, greenhouse gas allowance proceeds) to attract private capital for clean energy projects. The entities emphasize the idea of "leverage"—seeking to attract multiple dollars of private investment for every dollar of public investment—as a way to increase private market activity in energy efficiency today and ultimately transition to a model that relies solely on private investment. Rather than make direct loans with their own funds, green banks focus on strategies that attract private capital, such as offering loan loss reserves or other forms of credit enhancement. A recent report by DOE provides an overview of state energy investment partnerships.[316]
- Property-PACE programs – PACE programs finance energy efficiency improvements in the commercial sector (as well as the residential sector). Through third-party financing, local governments finance the up-front costs of these investments, and property owners repay the costs as a line item on their property tax bills.
- Energy-saving performance contracting – Performance contracting is a partnership with an ESCO to design, construct, maintain, and conduct M&V for energy-saving projects (see appendix 7.9). Performance contracting provides a financial guarantee to the lender that the energy savings generated will cover debt service on the project.
- Capacity markets for energy efficiency investments – Capacity markets offer another market for energy efficiency resources in regions of the United States with restructured electricity markets. A capacity market procures capacity resources one to three years in advance of delivery for future load-serving entity requirements. Capacity resources can include energy efficiency as well as other qualifying resources. For example, PJM's capacity market cleared 923 megawatts (MW) of energy efficiency resources for delivery in 2015-2016 (at clearing prices of $136 to $357/MW per day), an increase from 569 MW in 2012-2013. Energy efficiency resources in the ISO New England forward capacity market averaged 229 MW from 2011 to 2014 (at recent clearing prices of about $130/MW per day).[317]

### 3.6.5 Rate Design

Electric utility tariff structures may affect customer energy consumption and investments in energy efficiency by addressing barriers such as information and materiality. Improving rate design can encourage (or at least not discourage) such investments:[318]

- Tiered (inclining block) rates – Inclining block rate structures charge a higher rate for each incremental block of electricity consumption. They are common worldwide and are based, in part, on the theory that higher usage typically is associated with consumption during times of peak demand. The effectiveness of this structure depends partly on the customers' knowledge of this rate structure and awareness of their consumption.[319]
- Demand charges – These are monthly charges based on a customer's maximum usage in an hour or shorter period of time. Charges may be based on a customer's highest load coincident with the electric system's peak demand, or the customer's non-coincident peak—the highest load during the billing period regardless of when it occurs. The theory is that the customer's own peak drives the sizing and costs of grid equipment closest to the customer, and coincident peak loads are correlated with peak needs for generation, substations, and transmission. The level and structure of demand charges can influence customer interest in energy efficiency measures, demand response programs, and on-site generation that reduce the customer's maximum demand on the grid. However, charges based on non-coincident demand may not track underlying electricity costs well and may encourage customers to shift loads in a manner that does not reduce system costs.
- Time-varying rates – The underlying costs of providing electricity vary hourly and seasonally. Tying rates more closely to the actual cost of providing electricity can give customers more economically efficient incentives to reduce usage during costly periods. In addition to encouraging energy efficiency measures that affect consumption during peak periods, time-varying rates also can increase customer use of sensors and controls and energy management systems and interest in demand response programs.

### 3.6.6 RD&D for End-Use Technologies

RD&D in energy efficiency is undersupplied because many energy efficiency technologies cannot find sufficient demand from transparent, robust markets.  Direct support for RD&D may include incentives for manufacturer incentives, such as ongoing DOE support for SSL. The QTR provides more detail on federal RD&D activities related to end-use technologies.

### 3.6.7 Workforce Training

The Federal Energy Management Program provides in-person and online training for energy managers and other energy workers on how to construct, operate, and maintain facilities in an energy-efficient and cost-effective manner. Several government agencies (National Science Foundation, U.S. Department of Labor, and DOE) fund many specific training courses in energy services and manufacturing across the U.S. at community colleges and universities. In addition, DOE works with industry partners such as the National Institute of Building Sciences to develop training and certification guidelines. With the development of the Better Buildings Workforce Guidelines, a voluntary national program, DOE is helping to improve the quality and consistency of the training and certification programs offered to the buildings workforce for four key energy-related jobs: building energy auditor, building commissioning professional, building operations professional, and energy manager.

**Table 3.10. Major Policies, Regulations, and Programs to Address Barriers to Energy Efficiency in the Commercial Sector**

| Policy, Regulation, or Program | Description and Implemented Examples | Principal Barriers Addressed |
|---|---|---|
| **Codes and standards** | • Mandatory prescriptive or performance-based energy codes that regulate building energy efficiency (ASHRAE 90.1 2010 or higher standards in 22 states)<br>• Minimum performance standards for appliances and end-use equipment (commercial equipment federal energy efficiency standards for 14 product types, 11 of which are electric)<br>• Voluntary "green" or "reach" codes | *Information/awareness, materiality, split incentives*<br>• Standards set a minimum level of performance, guarding against uninformed or inattentive purchase of inefficient devices and limiting the impact of split incentives. |
| **Clean energy mandates and target-setting** | • Energy efficiency resource standards that mandate levels of savings across a sizable jurisdiction (e.g., across the entire state or all regulated utilities in a state)<br>• Other mandates (e.g., a mandate by a state public utility commission to achieve all cost-effective energy efficiency) | *Price signals, lack of private incentive for R&D, various others*<br>• These policies are generally enacted for clean energy policy reasons, meaning they are primarily intended to serve as a proxy for the social benefits of saving energy and other non-energy benefits. |
| **Grants and rebates** | • Payments to consumers that reduce or offset the incremental cost of efficient technologies, such as those offered by utility customer-funded programs (currently more than 300 commercial energy efficiency programs nationwide)<br>• Most grant and rebate programs are technology-specific; some are offered based on whole-building energy savings achieved. | *First costs, short payback requirements, non-energy benefits, materiality, information/awareness*<br>• Rebates lower the incremental up-front cost of efficient technologies, serving as a proxy for non-priced social benefits of energy efficiency adoption. |
| **Resource planning** | • Utility integrated resource planning (IRP) to ensure system reliability at least cost and risk that appropriately factors in energy efficiency. | *Price signals, non-energy* benefits<br>• IRPs can ensure efficiency is valued appropriately in utility planning for energy and capacity. |

| Policy, Regulation, or Program | Description and implemented examples | Principal barriers addressed |
|---|---|---|
| **Informational interventions** | • Programs that encourage or subsidize building audits<br>• Programs promoting energy management systems<br>• Regulations that require energy disclosure for comparative benchmarking (8 states and 14 cities with commercial policy adopted)<br>• Product (e.g., ENERGY STAR, EnergyGuide), building (e.g., ENERGY STAR), and utility Demand Side Management (DSM) programs | *Information/awareness, materiality*<br>• Building owners and occupants may lack capacity to identify opportunities for energy-saving improvements.<br>• Data on energy usage may not be transparent.<br>• Efficiency may not be adequately salient to consumers due to lack of information or the lack of focus on energy. |
| **Rate design** | • Tiered (inclining block) rates<br>• Time-varying rates<br>• Demand charges | *Price signals, non-energy benefits*<br>• Tariff structures may discourage customer investments in energy efficiency. |
| **RD&D for end-use technologies** | • Direct support for RD&D; prizes/contests/other manufacturer incentives (e.g., ongoing DOE support for solid-state (LED) lighting through contests, product testing support, stakeholder workshops, etc.) | *Lack of private incentive for R&D*<br>• In general, and particularly in the energy industry, RD&D is undersupplied absent policy intervention. |
| **Financing** | • Mostly utility DSM financing programs<br>• Some financing offered by state energy offices, green banks, or by programs that are largely private (e.g., PACE programs)<br>• Programs that facilitate and encourage energy savings performance contracting | *Lack of capital, first costs, transaction costs, performance risk*<br>• Financing programs extend capital and often eliminate up-front cost entirely. Financing is often packaged with other programmatic offerings and potentially removes the need to seek out a source of capital, which can otherwise be a barrier to program participation. Performance contracting transfers energy performance risk to the energy services company. Performance contracting also provides technical expertise and lowers transaction costs. |
| **Tax incentives** | • Personal income tax credits (federal/state)<br>• Sales tax incentives (state)<br>• Property tax incentives (state or local) | *Non-energy benefits, price signals*<br>• Like rebates, tax incentives can be a proxy for non-priced social benefits. They also alter depreciation timescales that otherwise do not accurately portray equipment lifetime and help compensate where energy cost is deductible and therefore subsidized. |

## 3.7 Interactions with Other Sectors

Commercial interactions with the residential and transportation sectors – The commercial sector interacts with the residential sector in mixed-use developments with both residential and commercial units. The commercial sector interacts with the transportation sector in integrated land and transportation-planning policies such as SB 375 in California.[320] This policy sets regional targets for greenhouse gas (GHG) pollution reduction from passenger vehicle use in 2020 and 2035. California SB 375 is projected to save 3.0 million metric tons of $CO_2$ equivalent by 2020. Each region of the state must prepare an integrated land use, housing, and transportation strategy that, if implemented, would allow the region to meet its GHG emission-reduction targets. Such mixed use and transit-oriented development is designed to centralize activities, reduce passenger-vehicle miles traveled, and promote greater use of public transportation. Future commercial developments may feature more PEV-charging infrastructure and possibly better accommodation for car sharing. Recent programs in California (e.g., South Coast Air Quality Management District Rule 2202)[321] provide options for employers to reduce mobile source emissions generated from employee commutes, to comply with federal and state Clean Air Act requirements and include credits for low-emission vehicles. If adopted nationally, these types of programs may contribute to an increased demand for workplace charging infrastructure.

Development patterns and urbanization will have system-wide impacts (e.g., across economic development, construction, energy, and water), and interactions among the commercial, residential, transportation, and DER sectors. Greater urbanization affords additional opportunities for more energy-efficient systems such as district energy systems. Leading strategies include ambient heat-pump loops thermally connecting multiple urban/dense buildings and districts enabling load sharing, load diversity, and economies of scale. Microgrids and shared renewable energy resources also become more cost-effective at larger district scales.

Telecommuting and e-commerce – Greater adoption of telecommuting by office workers is expected to reduce office electricity use and increase electricity use in the residential sector. A greater degree of e-commerce could shift the distribution of buildings from retail stores to more warehouses. This could impact HVAC loads by reducing retail floor space. More e-commerce could increase the electricity demand for information technology equipment. Regular work-at-home telecommuting is projected to increase from 2.9 million workers in 2011 to 4.9 million in 2016[322] (11% annual growth), and the number of workers who telecommute at least occasionally is projected to reach 63 million in 2016.[323] E-commerce sales are projected to grow to about $450 billion by 2018 with a 10% annual growth rate.[324]

### 3.7.1 Distributed Energy Resources

*Distributed generation* – According to a recent study, the technical potential[a] for combined heat and power (CHP) in the U.S. commercial sector is 68 gigawatts (GW) by 2020, compared to 11.0 GW of CHP installed in the sector in 2012.[325] Also promising are higher-density developments or multi-building distributed heating and cooling systems. For example, a CHP system powering a nonresidential facility may provide district heating to neighboring residences, thereby lowering fuel demands for residential

[a] Technical potential is the total market potential where, in this example, CHP technologies have the capability to meet a customer's energy needs. It is not constrained by cost, capital availability, owner interest, fuel availability, or other factors. Economic potential considers three cases: (1) payback time more than 10 years, (2) payback time between 5 and 10 years, and (3) payback time less than 5 years. The Hedman et al. 2013 study does not break out economic potential by industrial and commercial sectors. The three economic potential cases are quoted at 81.7, 35.3, and 6.4 GW, respectively. A commercial sector share of about 50% of the economic potential would yield about 41, 17.5, and 3.2 GW, respectively.

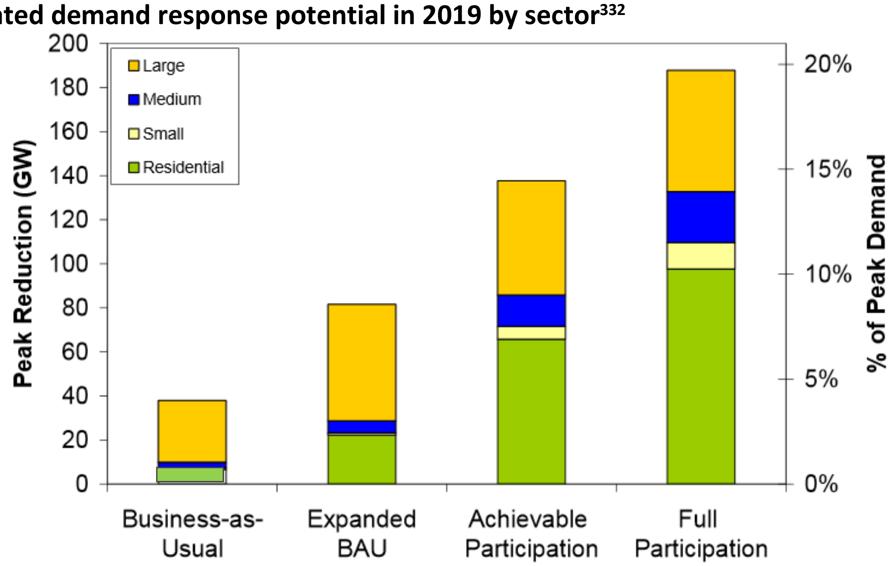
heating. Properly designed, these integrated system approaches may offer the prospect of greater efficiency and lower cost.[326]

The market for PV rooftop systems for commercial buildings is expected to grow. "Community solar" enables commercial building tenants as well as owners of commercial buildings that do not have a sufficient solar resource to buy or lease a portion of an off-site solar PV system. Shared solar is an emerging area with potential ramifications to expand the flexibility of buildings to meet ZNEB goals.[327]

*Demand response and distributed energy storage (see Chapter 6 for additional information)* – The commercial and industrial sectors account for 55% of total achievable potential for peak demand-reduction capacity in the United States in 2019 (Figure 3.17). Demand response in these sectors is forecast to achieve a peak demand reduction capacity in 2019 of about 8%.[328] Commercial buildings with demand-shifting using thermal mass, thermal storage, or battery storage can provide load leveling and reduce peak demand.[329] Thermal energy storage is a proven technology[330] and can be used to pre-cool buildings at times when electricity demand and prices are lower.

Distributed energy storage is rapidly expanding with declining costs. Most of the market growth appears to be in commercial buildings or for utility grid support. Current operational capacity of distribution-side storage is 180 MW, with 162 MW under construction, contracted, announced, or under repair. Median storage system capacity is 151 kW. Thermal storage (e.g., chilled water, ice) has the largest share at 37%.[331] Growth in distributed storage is in part driven by a mandate in California to add 1.3 GW of storage (both distributed and grid-connected) by 2020, compared to 2013. The growth of battery storage through sales of PEVs is another key driver in lowering the cost of distributed battery storage.

**Figure 3.17. Estimated demand response potential in 2019 by sector[332]**




*The expanded business-as-usual (BAU) scenario represents the extension of traditional programs to states that have little to no participation. The achievable participation scenario includes dynamic prices. The full participation scenario is an estimate of how much cost-effective demand response would take place if advanced metering infrastructure were universally deployed and all customers were on dynamic pricing tariffs and use enabling technology where it is cost-effective. Large, Medium, and Small refer to commercial and industrial sites.*

## 3.8 Research Gaps

Following are key research questions and research gaps related to electricity consumption and energy efficiency in the commercial sector:

- How will U.S. demographic and social trends, and trends in the commercial sector, affect the future distribution of commercial floor space and energy use intensity by building category and size? Demographic trends include aging population, shrinking family/household size, continuing immigration, shifts between large and medium size urban centers, changes in the distribution of income and wealth, and increasing leisure time. Commercial sector trends include increased e-commerce and flexible employment location.
- What is the opportunity to use decision and behavioral science[a] to reduce energy consumption in the commercial sector? Do existing policies, regulations, and programs (e.g., building energy codes, equipment standards, technical assistance, financial incentives) successfully address the behavior of commercial consumers and split incentives (landlord-tenant, utility-ratepayer, and builder-owner)? If not, what changes might be required? Relatedly, how should building energy codes take into account the impact of building occupants and operators on energy use? Should energy efficiency activities take advantage of social learning by emphasizing leaders (technical and financial assistance to early adopters), or should we focus more on incentives to the laggards for faster following?
- How can we better characterize commercial buildings with large opportunities for efficiency improvements? What policy and program options could better address energy efficiency in small commercial buildings?
- What analytical framework should be adopted to prioritize particular commercial sector end-use categories that offer the greatest benefits at least cost?
- How can energy-efficient commercial-sector building designs be better integrated with benefits that may be hard to quantify and monetize? These include the following:
    - Impact on primary energy[b] saved or generated from commercial sector operations
    - Impact on water consumption
    - Impact on GHG emissions, other air pollutants, and water pollutants during building operation on a life-cycle basis
    - Impact on other sectors (e.g., residential, transportation)
    - Impact on energy security
    - Impact on occupant health, productivity, and satisfaction
    - Impact of electric transportation when workplace charging systems are incorporated.
- How can we close the gap between modeled and designed building efficiency and actual performance over time? Closing this gap requires more detailed information about actual building occupancy, use, and as-built conditions, as well as advances in building energy-modeling calibration. More accurate input data could come from enhanced measurement and monitoring capabilities through sensors and data collection or from M&V for outcome-based building energy codes and outcome-based efficiency programs. Programs that achieve energy efficiency savings through operational, behavioral, and energy auditing activities are being pursued in some states.

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[a] Decision science involves research on how people make judgments and decisions and how they interact with one another.
[b] *Primary energy* refers to the upstream direct energy input that is required for end-use energy consumption. For example, a thermal power plant typically requires three units of energy or fuel to make one unit of end-use electricity consumed at a customer's site.

- How can the cost effectiveness of zero net energy buildings be improved, and how can greater flexibility of distributed energy supplies be achieved? More studies are needed on the cost-effectiveness of new ZNEBs considering an integrated package of energy efficiency measures rather than analysis of discrete measures, as well as a better understanding of the cost-effectiveness of ultra-low energy or ZNEB retrofits. Some of the key consumer adoption issues that need to be resolved for “shared solar” or offsite renewable generation include a lack of uniformity and standardization of consumer contracts, rate design, and program structure,[333] and the need for a framework to track and match off-site renewable resources to specific buildings claiming an offset.[334] Thus, an analysis of the policy choices, impacts, and cost implications of ZNEB generation would be helpful.

# 4 Industrial Sector

This section discusses electricity usage and electric efficiency in the U.S. industrial sector. Manufacturing accounts for 83% of total industrial-sector electricity consumption, with machine drives accounting for half of that.

The data summarized in this section are from several sources. Historical data (1990 to 2014) use EIA's Monthly Energy Review[335] and Bureau of Economic Analysis[336] datasets. Forecast data to 2040 primarily use the EPSA Side Case described in the introduction to this report. EPSA Side Case data also are used when most-recent (2014) metrics are reported as a single year or are plotted with future projections. Doing so ensures consistency between current and forecasted metrics. Overlapping years between historical data and data modeled for forecasts are not necessarily equal. Historical data are revised periodically as EIA gathers better information over time, while forecasted cases, which report a few historical years, do not change once they are released to the public. In addition to the EPSA Side Case, this section also presents several forecasts produced by EIA, utilizing NEMS. These side cases provide ranges in industrial-sector electricity-consumption forecasts under several high-level assumption scenarios[a] (e.g., high versus low economic growth, high versus low fossil energy supplies, high versus low technology adoptions).[337]

## 4.1 Key Findings and Insights

### 4.1.1 Levels and Patterns of Electricity Use

*Findings:*

- Industrial electricity supply is dominated by grid purchases, accounting for 89% of the supply in 2014. Electricity consumed in the industrial sector is primarily for manufacturing (83%), with mining (8%), construction (6%), and agriculture (3%) accounting for the remainder (Figure 4.1).
- Industrial electricity sales were relatively flat from 1990 to 2014 (Figure 4.2)
- In 2014, manufacturing provided the largest industrial-sector contribution to U.S. GDP (74%), followed by construction (16%), mining (6%), and agriculture (4%) (Figure 4.3).
- The industrial sector's electrical productivity (the amount of economic output per unit of energy input) nearly doubled (89% growth) between 1990 ($3.97/kWh) and 2014 ($7.48/kWh) (Figure 4.4).
- Within manufacturing, metal-based durables consumed the most electricity in 2014 (21%), followed by bulk chemicals (16%), paper (9%), refinery (8%), food (8%), aluminum (6%), and iron and steel (6%). Manufacturing's CHP-based electricity is primarily produced in the bulk chemicals, paper, and refinery subsectors (89%) (Figure 4.5).
- Electric motor-driven system end uses dominated the manufacturing sector's 2010 electricity consumption (50%), followed by process-heating end use (11%) (Figure 4.6). Motor-driven system end uses have dominated consumption in all previous manufacturing surveys dating back to 2002 (Figure 4.7).
- Drives are the largest share of electric motor-driven system end-use consumption (37%), followed by pumps (30%), compressed air (17%), and fans (15%) (Figure 4.6 and 4.7).

*Insight*: Electrical productivity in the industrial sector has improved rapidly over the last 15 years; persistent attention to efficiency will be needed to continue this trend. High-energy-consuming sectors (e.g., metals and chemicals manufacturing) and end uses (e.g., motor systems) present opportunity for targeted efficiency developments.

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[a] These scenarios do not include the updated technology costs and policies represented in the EPSA Side Case.

### 4.1.2 Energy Efficiency Opportunities

*Findings:*

- Energy efficiency opportunities in the industrial sector span a wide range of end-use categories, technologies, and subsectors. In addition, optimizations of the entire industrial sector, through innovative technologies such as "smart manufacturing" and supply-chain efficiencies, process intensification, and circular economy, offer additional efficiency-improvement opportunities, although their magnitudes have yet to be fully understood.
- The forecasted increase in electrical productivity ($/kWh) is lower in the EPSA Side Case (Figure 4.11) than it is in historical trends (Figure 4.4).
- Thermodynamic efficiency losses during the conversion of energy into work account for about half of total manufacturing energy consumption, excluding feedstocks. Thermodynamics often limit the recovery of efficiency losses. Materials also can limit the cost-effective recovery of efficiency losses.
- Waste heat-recovery potential within the iron and steel, glass, aluminum, and cement and lime industries alone equates to 26% of the manufacturing sector's 2010 CHP generation measured in kWh.

*Insight*: While materials and thermodynamics limit the efficiency of many industrial processes, waste-heat recovery can provide significant industrial energy efficiency improvements. Moreover, industrial sector-wide optimization of supply chains and materials recycling can also significantly contribute to efficiency improvements.

### 4.1.3 Technology and Market Factors

*Findings*:

- DOE's industrial sector RD&D is currently focused on 14 key technology areas that offer industrial energy-efficiency improvements (Table 4.2), many of which have crosscutting ties to nonindustrial sectors (Table 4.6).
- Electricity consumption forecasts show that efficiency improvements in nonindustrial sectors influence industrial sector consumption (Section 4.2).

*Insight:* Industrial electricity consumption is intertwined with all economic sectors, and therefore, efforts to improve efficiency in any sector should consider economy-wide impacts.

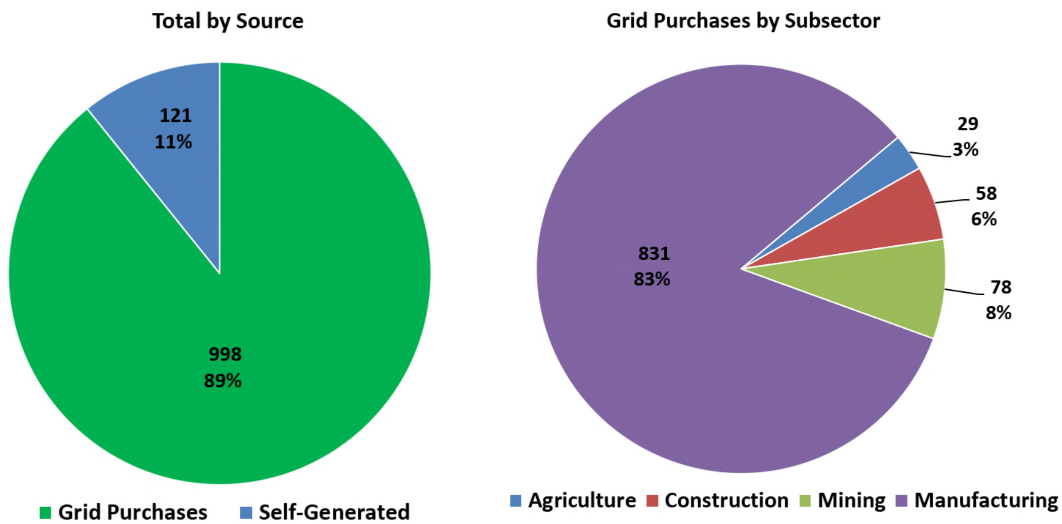
## 4.2 Characterization

### 4.2.1 Electricity End-Use and Supply Snapshot

Following the EIA's categorizations, the U.S. industrial sector consists of agriculture, construction, mining, and manufacturing subsectors. These subsectors comprise facilities with wide-ranging production scales and energy-consuming processes. Electricity constituted 15% of the industrial sector's end-use consumption in 2014.[338] Electricity for the industrial sector is supplied by electric grid purchases and its CHP capacity. Some CHP-generated electricity is consumed on-site (self-generation); some is sold off-site (grid sales).

Figure 4.1 shows 2014-estimated electricity consumption in the U.S. industrial sector. The left chart shows grid purchases and self-generation, and the right chart shows the quantity of grid purchases for the four major industrial subsectors—manufacturing, mining, construction, and agriculture.

**Figure 4.1. U.S. industrial electricity consumption in 2014 (TWh)** [339]



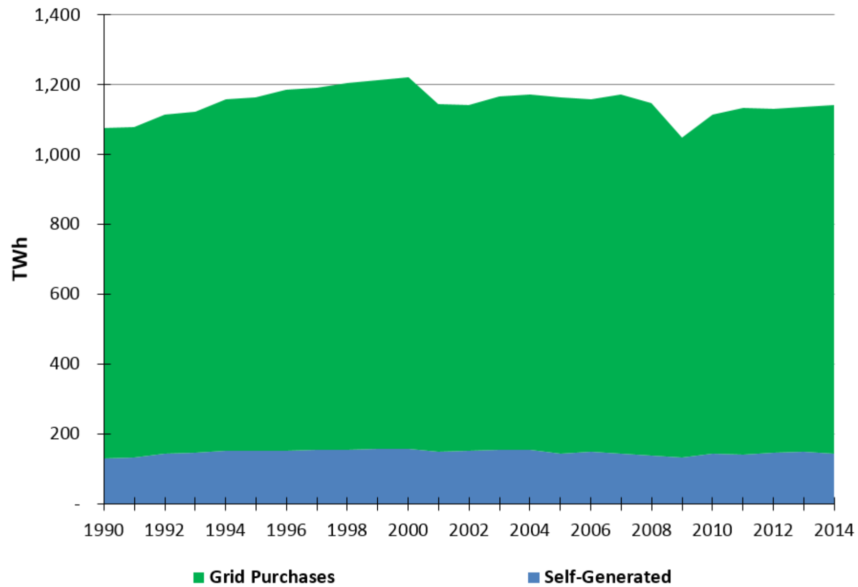

*The left chart shows the industrial sector's purchased electricity consumption, CHP self-generation, and the right chart shows purchased electricity by industrial subsector.*

In 2014, the industrial sector purchased 998 TWh from the electric grid; it self-generated and consumed 121 TWh, and it generated 28 TWh, which it then sold back to the grid.[340] This equates to 89% of the industrial sector's electricity needs being supplied through grid purchases and the other 11% being self-generated. The majority of the sector's purchased electricity is consumed by the manufacturing subsector (83%), followed by mining (8%), construction (6%), and agriculture (3%).[341] Within the manufacturing sector, energy-intensive manufacturing (defined by EIA as aluminum, bulk chemicals, cement and lime, food, glass, iron and steel, paper, and refining) consumed 56% of its electricity use in 2014, and metal-based durables manufacturing consumed 20%. Thus, this portion of the report focuses primarily on the manufacturing subsector, though efficiency advances within manufacturing systems can yield benefits to other industrial subsectors.

### 4.2.2 Historical Trends in Electricity Use

Figure 4.2 shows the U.S. industrial sector's end-use electricity (grid purchases and self-generated) for the years 1990 to 2014.[342] Electricity consumption in the industrial sector was relatively flat during this period. The vast majority of electricity consumed in the industrial sector was purchased from the electric grid. The amount of self-generated electricity remained flat from 1990 to 2014.

**Figure 4.2. Total industrial electricity consumption from 1990 to 2014**[343]




*Electricity consumption in the industrial sector was relatively flat from 1990 to 2014.*

Grid-purchased electricity gradually increased from 1990 until it peaked in 2000 at 1,064 TWh (13% above 1990 levels, accounting for 28% of total U.S. electricity consumption). Self-generation grew by 20% between 1990 and 2000 and peaked at 156 TWh. A decline in U.S. economic activity began in 2000, and although the economy quickly recovered and continued to grow through the early to mid-2000s, electricity consumption in the industrial sector remained relatively flat until the recession in 2008. Industrial-sector electricity use has historically been sensitive to economic conditions as the industry responds to changing demand for goods.[344] In 2009, grid purchases fell below 1990 levels, but returned to roughly 1,000 TWh by 2011 and remained around this level.[a] Self-generation declined after 2000, rising only to 1% above 1990 levels in 2009. By 2011, self-generation recovered some of its growth but remained below 150 TWh through 2014.[b]

### 4.2.3 Historical Trends in Value of Shipments by Industrial Subsector

Value of shipments (VOS) is a measure of the industrial sector's economic output that contributes to total GDP. It is a metric used to evaluate electrical productivity, which is discussed in the next subsection. Specifically, it is the value received for the industrial subsector's products, and it does not include excise taxes, freight or transportation charges, or installation charges.[345]

Figure 4.3 shows that the VOS in the industrial sector grew between 1997 and 2014.[346] It also shows the industrial sector's and manufacturing subsector's contribution to total U.S. GDP (lines and right axis). Despite the economic slowdown in 2008, manufacturing is, by far, the largest contributor to total industrial VOS. Manufacturing contributed 77% of the total industrial sector's value of goods and 45% of total U.S. GDP in 1997. Despite an increase in manufacturing's VOS between 1997 and 2014, its contribution fell to 72% of the industrial sector's total value of goods and 36% of total U.S. GDP.

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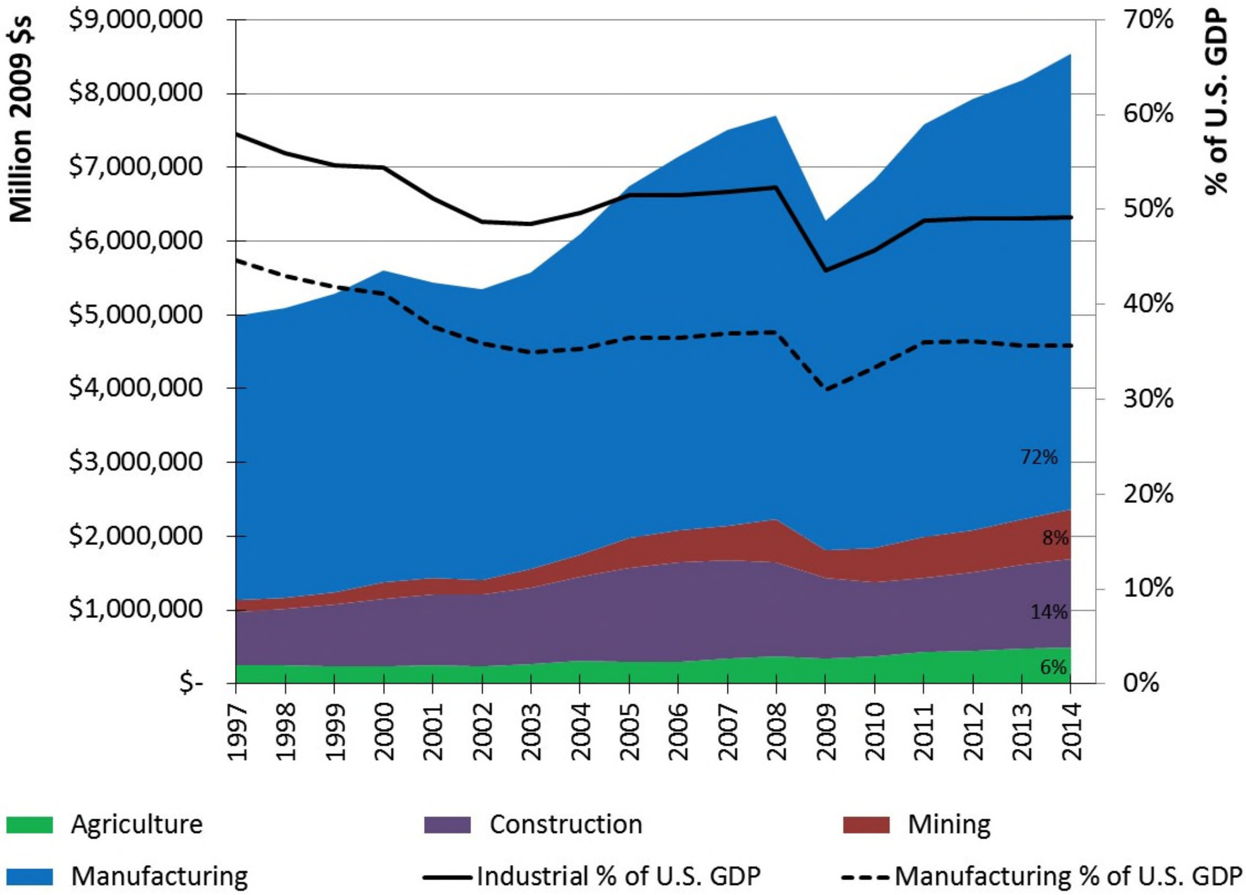
[a] In 2014, grid purchases were 1% higher than 1990 levels.

[b] Note: The *Monthly Energy Review* (EIA 2014) reports industrial sector electricity end-use consumption of 1,076 TWh in 1990 and 1,141 TWh in 2014. The 2015 *Annual Energy Outlook* (AEO) reports this metric as 1,251 TWh (EIA 2015). The roughly 10% percent difference is because the Monthly Energy Review is a record, while the AEO is a forecast.

**Figure 4.3. Industrial sector value of shipments (VOS), 1997 to 2014**[347]



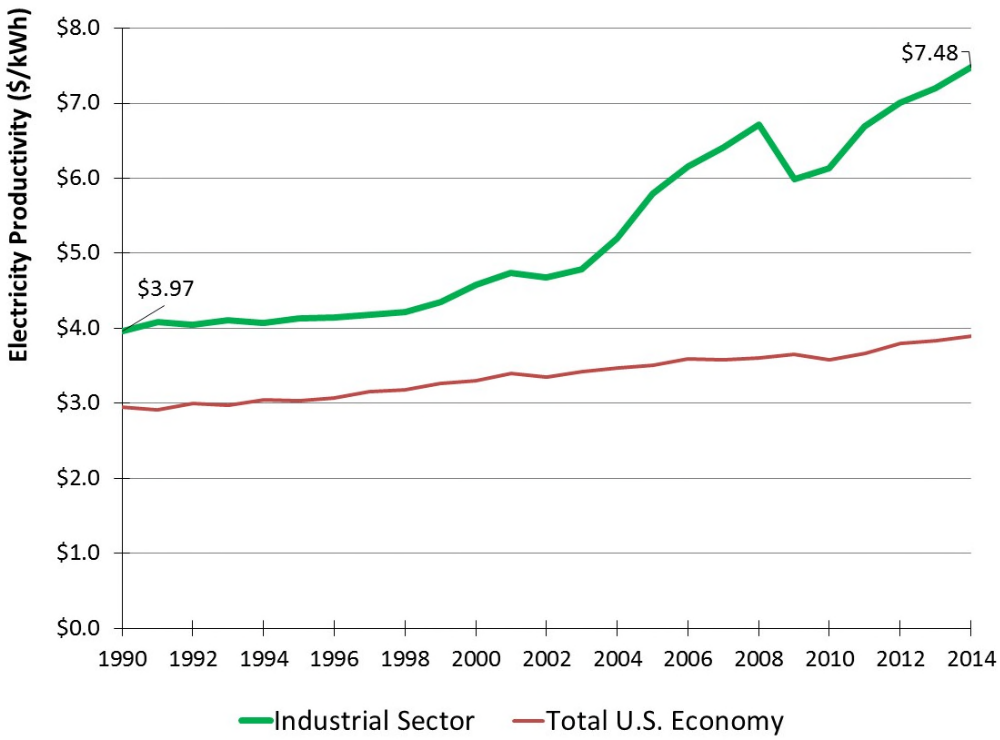

*Manufacturing is the largest contributor to the total industrial value of shipments. Manufacturing contributed 72% of total industrial value of shipments in 2014, followed by construction (14%), inming (8%), and agriculture (6%).*

### 4.2.4 Historical Trends in Electrical Productivity

*Energy Electrical productivity* is a metric of the amount of economic output per unit of energy input.[348] It can be used to measure the efficiency of the economy. In his 2013 State of the Union address, President Obama called for a doubling of electrical productivity by 2030. Specifically, industrial electrical productivity is defined as the ratio of the VOS (in 2009 U.S. dollars) to electricity consumption (in kWh): $VOS/kWh. Figure 4.4 shows nearly a doubling of industrial electrical productivity between 1990 and 2014, from $3.97/kWh in 1990 to $7.48/kWh by 2014.[349 350]

For comparison, U.S. national electrical productivity is also shown in Figure 4.4 and is calculated as the ratio of GDP to total U.S. electricity consumption. Both productivity curves are in 2009 dollars.

**Figure 4.4. Electrical productivity from 1990 to 2014**[351]




*Industrial electricical productivity nearly doubled by 2014 relative to 1990. Industrial sector values are calculated as value of shipments per kWh of consumption ($/kWh in 2009$s), while total U.S. values represent national GDP per kWh of national consumption ($/kWh in 2009$s).*

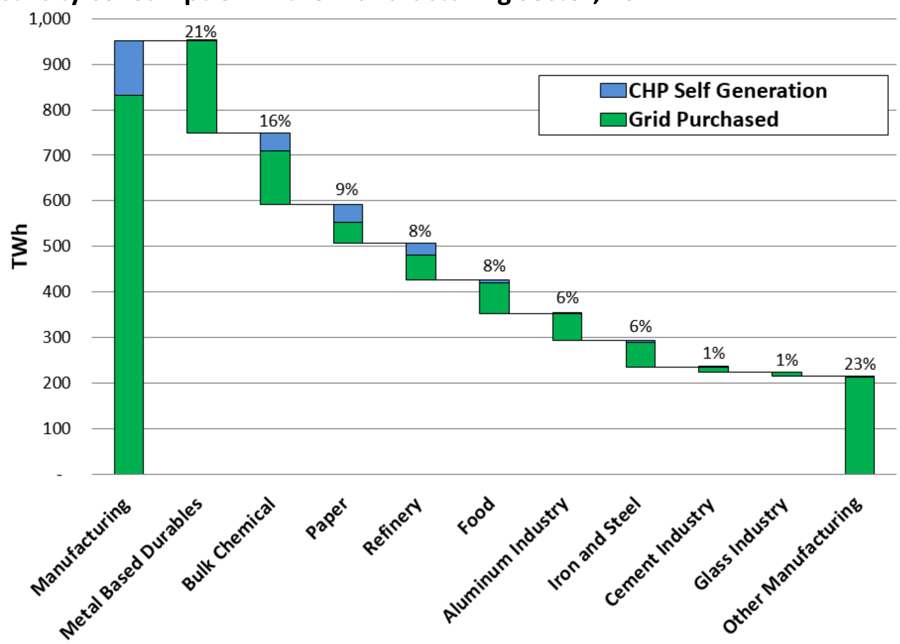
While growth in electrical productivity may indicate structural changes to less electricity-intensive manufacturing, it can also be indicative of the growth in industrial electricity efficiency, especially in electricity-intensive industries like metal-based durable goods. As Figure 4.3 shows, industrial electricity consumption remained relatively flat between 1990 and 2014, while industrial VOS grew.

### 4.2.5 Electricity Consumption in Manufacturing by Subsector

Recognizing that the U.S. manufacturing sector covers a wide range of industrial specializations, EIA's NEMS and Industrial Demand Module (IDM) estimate energy consumption for several classifications of industrial products or subsectors.[352] In addition to agriculture, construction, and mining, the IDM models and estimates energy consumption for the following energy-intensive manufacturing subsectors: food, paper, bulk chemicals, glass, cement, iron and steel, aluminum, metal-based durable goods (consisting of fabricated metal products, machinery, computers, and electrical equipment), and other manufacturing (consisting of wood products, plastics, and "balance of manufacturing").[353] Petroleum refining is also tracked individually in NEMS, but it is modeled in the liquid fuels market module.[354]

NEMS projects energy use for each of the main industrial subsectors (agriculture, construction, mining, and manufacturing), as well as manufacturing subsectors (listed above), including purchased electricity and CHP (for self-generated electricity and grid sales electricity). Figure 4.5 shows EPSA Side Case 2014 electricity consumption for high-energy-consuming manufacturing subsectors. NEMS energy forecasts for all industrial subsectors (NEMS output Tables 35–43 and 139–140) do not inherently sum to the industrial totals (NEMS output Table 6) for various reasons that are difficult to trace. To account for this, numbers for industrial-subsector energy consumption throughout this report have been scaled to match industrial total outputs. The method used to scale these numbers is described in the Industrial Appendix 7.5.1.

**Figure 4.5. Electricity consumption in the manufacturing sector, 2014**[355]




*Total manufacturing sector estimated electricity use (including CHP self-generation) was 95.1 TWh, with metal-based durables the single largest electricity-consuming group (21% of the manufacturing sector's electricity consumption).*

The other manufacturing subsector aggregates all manufacturing that is not delineated by one of the high-energy-consuming classifications presented in Figure 4.5. Other manufacturing consists of a large number of low-electricity consumers. The metal-based durables subsector is the highest-electricity-consuming group within manufacturing. Although the subsector is a major consumer of electricity, it does not have significant CHP capacity. Metal-based manufacturing processes are not typically suitable for CHP capacity due to their low demand for thermal energy and lack of low-value fuel co-products. The next three highest-electricity-consuming subsectors are bulk chemical, paper, and refinery—each of which has large operating CHP capacities. These subsectors have CHP systems that convert low-value co-products (e.g., liquefied petroleum gases, refinery gases, and wood residues) into useful thermal energy and electricity, the majority of which (81%) is consumed on-site as self-generation, and the remainder of which is sold to the grid.

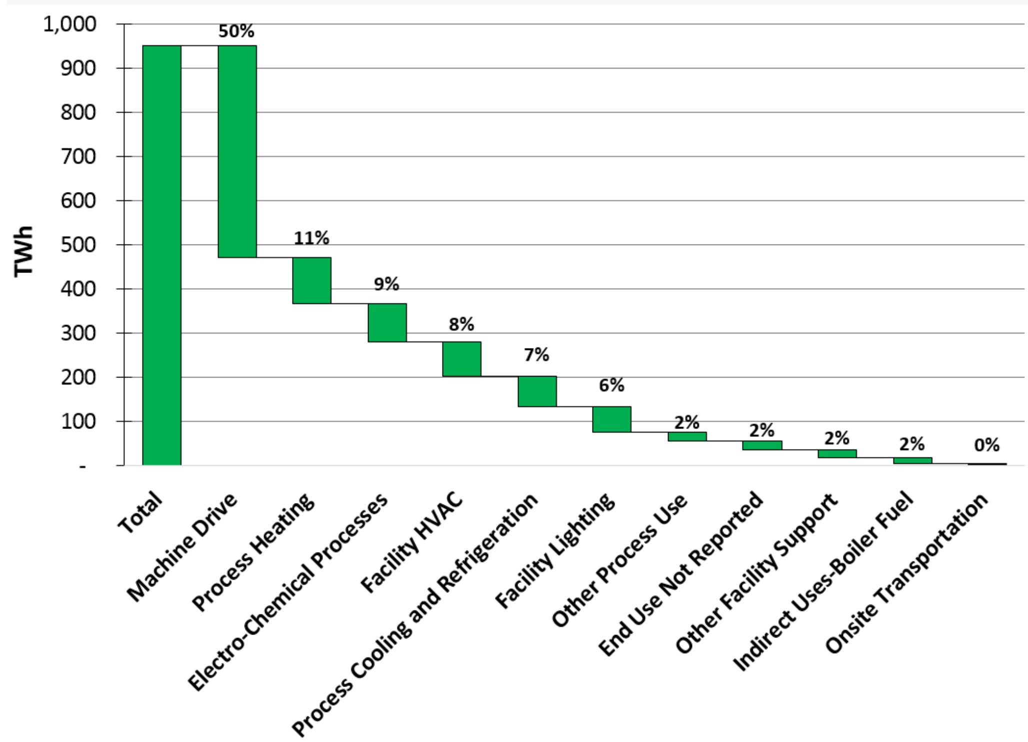
### 4.2.6 Manufacturing End-Use Electricity by End-Use Categories

Although the AEO does not report industrial electricity consumption disaggregated by end-use, the IDM is predicated on EIA's quadrennial Manufacturing Energy Consumption Survey (MECS) reports, which do specify electricity consumption by end-use and by industrial subsector. For these surveys, EIA performs modeling of high-energy-consuming manufacturing sectors in addition to collecting reported data, and therefore, AEO results for total energy consumption do not match MECS reports.[356]

The most-recent publicly available MECS data set is for the year 2010.[357] The MECS data classifies end uses by: (1) indirect uses (boiler fuels, conventional boiler use, CHP and/or cogeneration), (2) direct uses: process (heating, cooling, and refrigeration; machine drives; electrochemical processes; other process use), and (3) direct uses: non-process (facility HVAC, facility lighting, other facility support, on-site transportation, conventional electricity generation, other non-process uses, and end uses not reported). These classifications are defined below. However, indirect uses typically mean that electricity is used to produce steam, which is then directly used by steam end uses.

Figure 4.6 shows the sum of end-use electricity estimates by multiplying MECS 2010 end-use percentages by the total manufacturing-sector electricity reported in the EPSA Side Case.[a] The figure indicates that machine drives (i.e., motors and the process systems they drive) are the largest electricity end-use category in manufacturing and offer the largest opportunities for electricity-efficiency improvements. As shown in Figure 4.7, MECS end-use percentages have remained approximately constant since 2002.

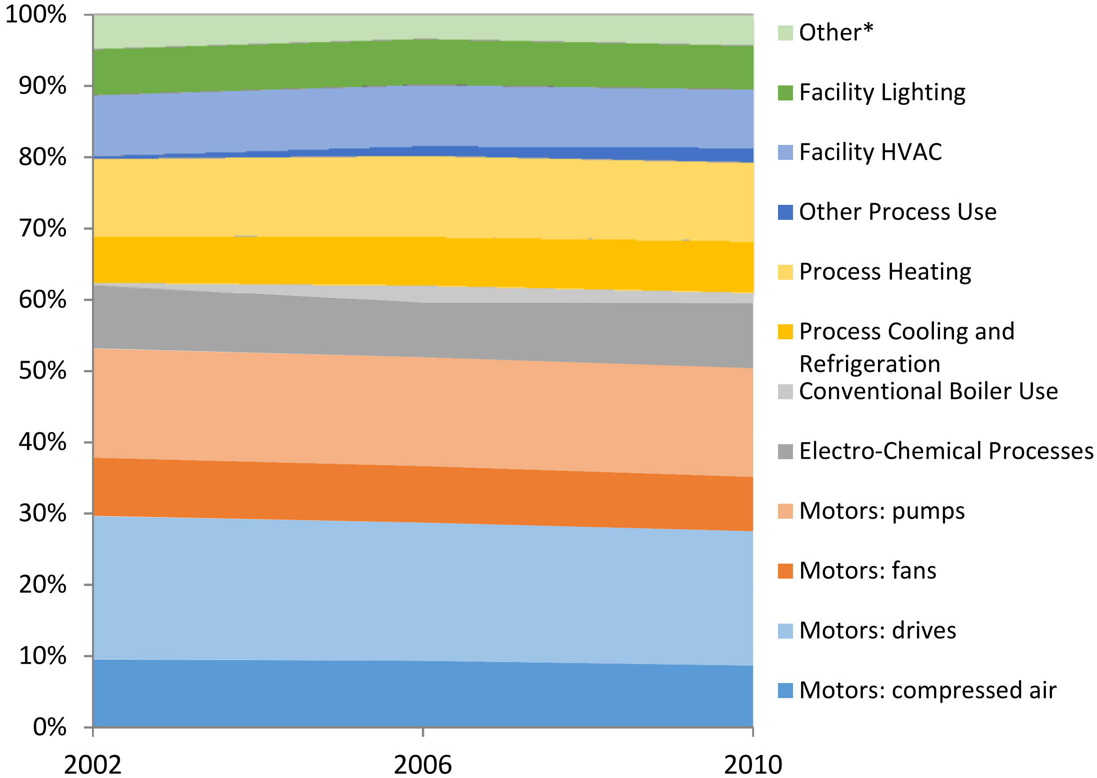
**Figure 4.6. Manufacturing sector's end-use electricity consumption in 2014 based on MECS percentages[358] and EPSA Side Case sum of grid-purchased and self-generated electricity[359]**




*Machine drives consume the most end-use electricity in the manufacturing sector (50% of total manufacturing sector consumption).*

[a] MECS 2010 manufacturing subsector's total electricity end use is 845 TWh. The EPSA Side Case year 2010 manufacturing subsector's total electricity end use is 831 TWh. The ratio of each end use's MECS-reported electricity to MECS-reported total electricity is then multiplied by the total manufacturing sector electricity reported in the EPSA Side Case.

**Figure 4.7. Major end-uses and their percent of manufacturing sector's electricity consumption from three sets of MECS data**[360]




*The breakdown of electricity used for various manufacturing end uses has remained relatively constant between 2002 and 2010. MECS 2010 definitions can be found in Appendix 7.5.2. The 'Other' category in this figure includes: CHP and/or Cogeneration Process; Conventional Electricity Generation; Onsite Transportation; Other Non-process Use; Other Facility Support, and End Use Not Reported.*

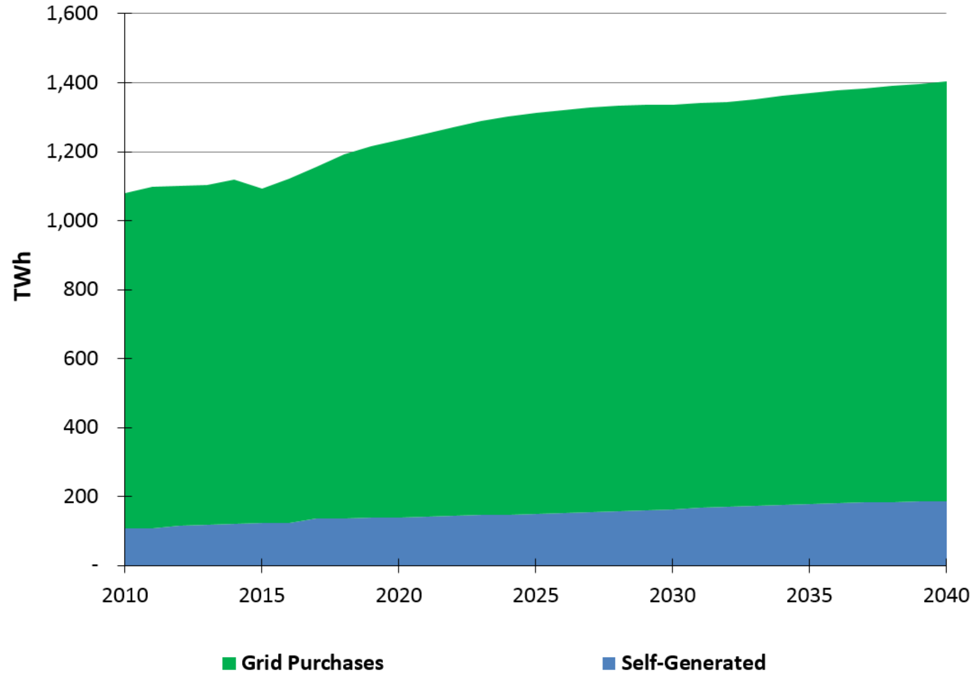
## 4.3 Metrics and Trends

This section presents key metrics, trends, and future projections for the industrial sector. All data are from EIA as well as the EPSA Side Case.

### 4.3.1 End-Use Electricity Forecasts:

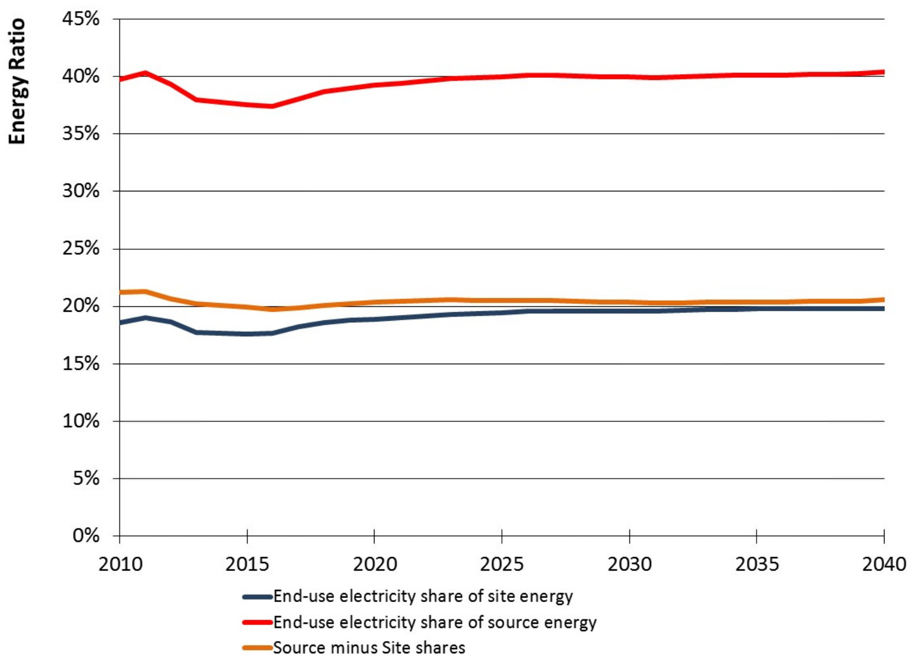
Figure 4.8 shows forecasts of end-use electricity consumption (grid purchases and self-generated) in the industrial sector for the years 2010 to 2040 using the EPSA Side Case.[361] Grid-purchased electricity increases rapidly from 2015 until 2025, after which growth slows to 2040, when it reaches its maximum level of 1,218 TWh—25% above the 2010 level of 971 TWh, accounting for 23% of total U.S. electricity consumption in 2040. Self-generation remains a small portion of total end-use electricity, although its growth is projected to be faster than the growth in grid-purchased electricity. Self-generation reaches its maximum level in 2040 of 187 TWh (73% above its 2010 level of 108 TWh). Growth in electricity consumption is largely driven by strong economic growth assumptions in the EPSA Side Case—an average annual GDP growth rate of 2.4% from 2013 to 2040 results in a doubling of GDP between 2010 and 2040. At the same time, industrial-sector end-use efficiency reduces end-use electricity-demand growth. Figure 4.9 shows end-use electricity's share of total site and source energy consumption in the industrial sector.

**Figure 4.8. Industrial end-use electricity, 2010 to 2040**[362]




*Electricity consumption in the industrial sector is expected to grow modestly. Note: Grid purchases and self-generated electricity are additive.*

**Figure 4.9. Industrial electricity ratios (percent of total industrial site and source energy), 2010-2040**[363]




*The electricity share of total industrial site and source energy remains relatively flat over this time period with some fuel switching.*

Shares of both site and source energy remain relatively flat between 2010 and 2040. Electric grid efficiency improves by 5% between 2010 and 2040 (efficiency in this case is measured by electric grid "electricity-related losses" divided by "purchased electricity," which is 211% in 2010 and 201% by 2040). Source minus site shares declines by 3% between 2010 and 2040. The smaller decline in this value, compared to electric grid-efficiency improvements, indicates that some fuel switching is occuring in the EPSA Side Case. EIA's MECS reports indicate fuel-switching opportunities[364] and highlight, in particular, opportunities for the chemical industry.[365] A better understanding of industry's potential to switch from fuels to electricity end uses is important because of the impacts on future electricity consumption versus direct consumption of fuels in the industrial sector.

Switching from fuels to electricity potentially[a] transfers the thermodynamic losses from the end-use facility (downstream) to the electric grid (upstream). Fuel-switching from fuels to electricity could increase net efficiency of the combined electric grid and industrial end-use systems if the grid-based production is more efficient than the end-use systems. However, the heterogeneity of the U.S. electric grid mix of fuels and generation capacity requires a careful analysis of the net savings, considering both upstream and downstream impacts. The net analysis is necessary to fully assess the benefits of fuel-switching and to shape any future policies intended to encourage switching from fuels to electricity.

### 4.3.2 Value of Shipments Forecasts by Subsector

The VOS in the industrial sector grew between 2010 and 2040, but at slower rates than GDP.[b] Agriculture's VOS grew the least of the four industrial subsectors, at only 11% above 2010 levels by 2040, followed by mining at 39% percent, construction at 73%, and manufacturing at 87%. Combined, growth in the VOS for the industrial sector as a whole was 78%. The manufacturing sector not only has the largest forecasted growth of the four industrial subsectors, it also remains the largest contributor to total industrial VOS—$11,443,105 million (2009$) in 2040 (Figure 4.10). In 2040, agriculture contributes 3%, mining 5%, construction 16%, and manufacturing 76% to industry's total value. The industrial sector's contribution to real GDP declines from 43% in 2010 to 38% by 2040.

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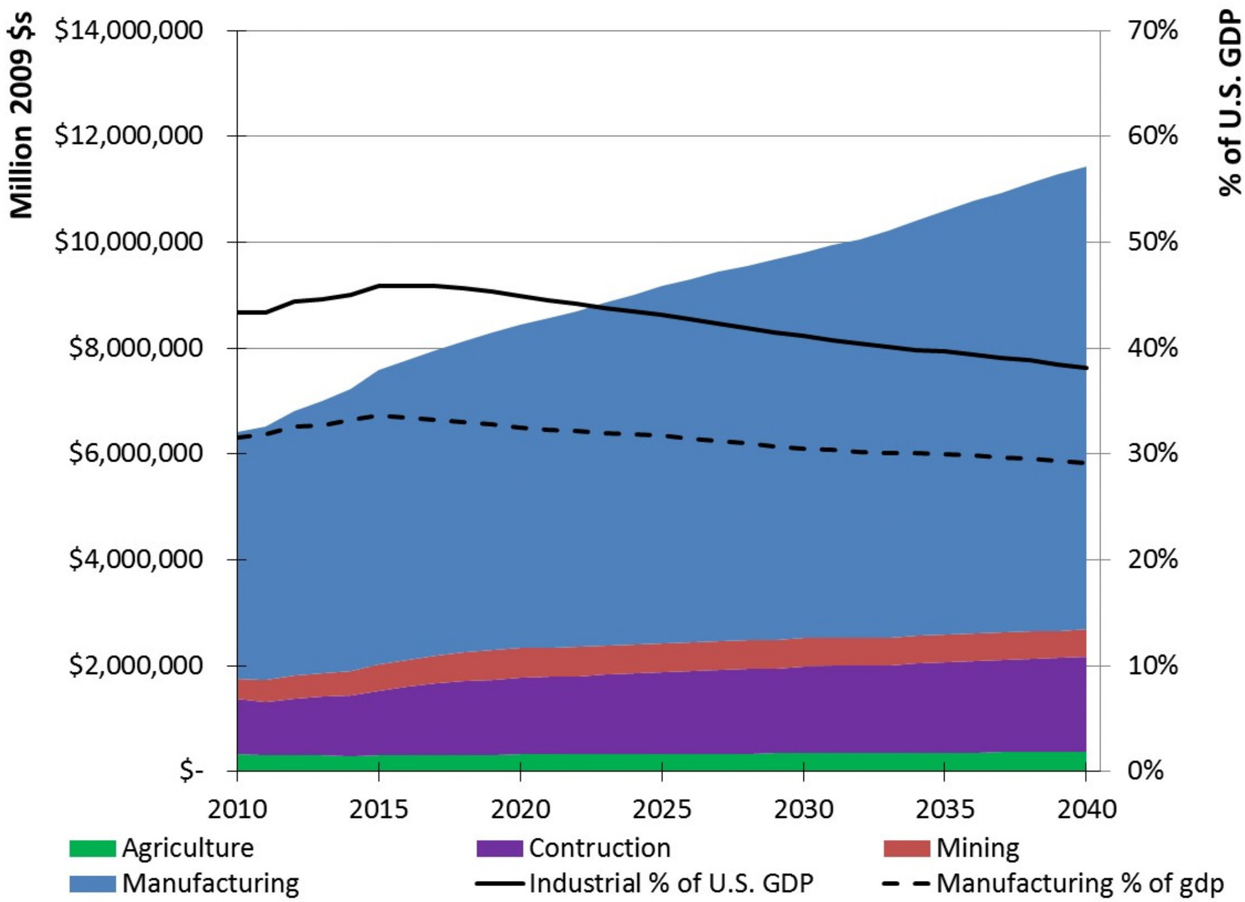
[a] An exception would be when fuel-switching from fuels to electricity is combined with on-site generation capacity.
[b] GDP growth assumptions and NEMS-forecasted industrial value of shipments are handled in the NEMS macroeconomic activity module. Assumptions for this module are at http://www.eia.gov/forecasts/aeo/NEMS/documentation.

**Figure 4.10. Industrial sector value of shipments, 2010 to 2040[366]**

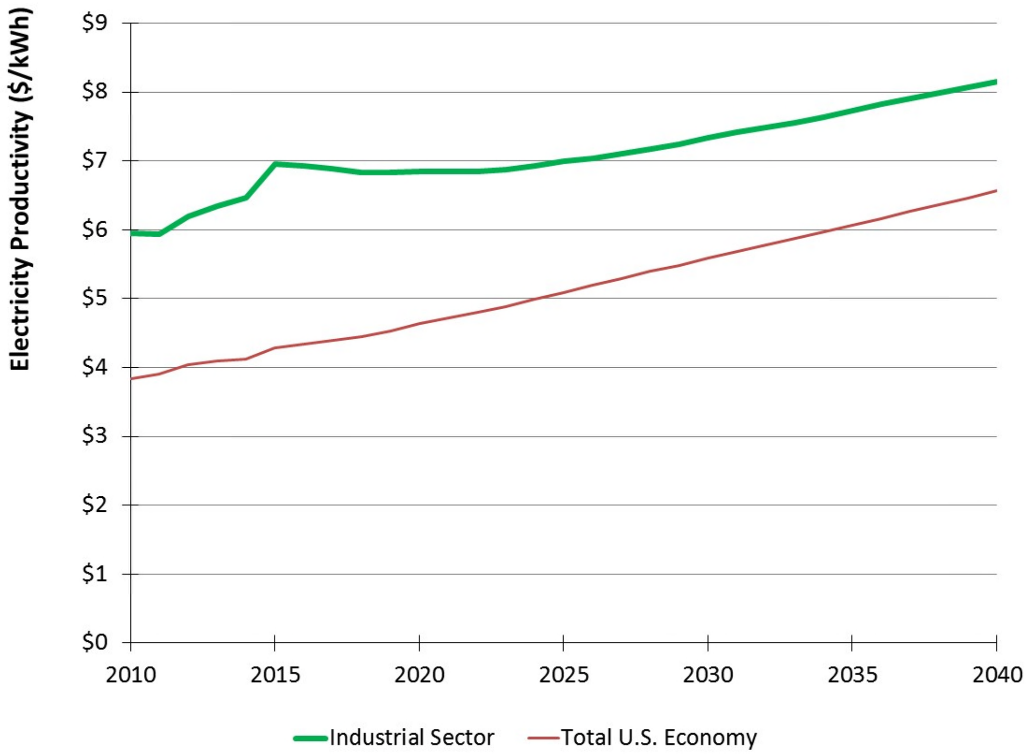



*Manufacturing continues to contribute the most to the industrial sector's value of shipments through 2040.*

### 4.3.3 End-Use Electrical Productivity Forecast

*Energy productivity* indicates economic output per unit of energy input.[367] *Industrial end-use electrical productivity* is defined as the ratio of the VOS (in 2009 U.S. dollars) to end-use electricity consumption (in kWh): $VOS/kWh. Figure 4.11 shows industrial electrical productivity between 2010 and 2040. Electrical productivity grows, but at a slower rate than historical trends (Figure 4.4).

**Figure 4.11. Electrical productivity from 2010 to 2040**[368]




*Electricity Electrical productivity grows, but at a slower rate than that shown by historical trends. Industrial sector values are calculated as value of shipments per kWh of consumption, while total U.S. values represent national GDP per kWh of national consumption.*

### 4.3.4 Overview of Forecast Cases

The AEO includes forecast cases representing sensitivities to high-level assumptions about the future.[369] AEO cases inform the metrics and trends forecast out to 2040.[a] The AEO 2015 forecast provides data for five cases: Low Economic Growth, High Economic Growth, Low Oil Price, High Oil Price, and High Oil and Gas Resource. In addition to these cases, the AEO 2014 forecast provides three technology cases: frozen technology, best-available technology, and high technology. Assumptions and model inputs to NEMS are extensive.[370] Table 4.1 provides the major assumptions underlying the AEO side-case projections as listed by the EIA. Assumptions for the EPSA Side Case are discussed in the introduction of this report.

[a] This report uses the EPSA Side Case as a reference case in lieu of the AEO reference case. See "Description of Energy Models".

**Table 4.1. AEO and EPSA Forecast Cases and the Major Assumptions Underlying the Projections**[371]

| Case | Major Assumptions Underlying Projections† |
|---|---|
| | *EPSA* |
| EPSA Side Case | Takes into consideration a broad range of existing policies, such as the recently extended Production and Investment Tax Credits and environmental regulations such as the Mercury and Air Toxics Standards and the Clean Power Plan. In addition, the EPSA Side Case relies on updated technology cost assumptions. The EPSA Side Case also relies on the same oil and gas prices as the AEO reference case. |
| | *Annual Energy Outlook* 2015 |
| Low Economic Growth | Same assumptions as the Reference Case, but with GDP growing at an average annual rate of 1.8% |
| High Economic Growth | Same assumptions as the Reference Case, but with GDP growing at an average annual rate of 2.9% |
| Low Oil Price | Considers demand for petroleum and other liquids in nations outside the Organization for Economic Cooperation and Development and level of global supply. On the supply side, the Organization of Petroleum Exporting Countries (OPEC) increases its liquids market share from 40% in 2013 to 51% in 2040. Costs of other liquids-production technologies are lower than in the Reference Case. Brent crude oil prices remain around $52/barrel (2013 dollars) through 2017 and then rise slowly to $76/barrel in 2040. |
| High Oil Price | OPEC's liquids market share averages 32%, and non-OPEC crude oil expands more slowly in the short- to mid-term, relative to the Reference Case. Brent crude oil prices rise to $252/barrel (2013 dollars) in 2040. |
| High Oil and Gas Resource | Assumes the estimated ultimate recovery (EUR) of shale gas, tight gas, and tight oil is 50% higher, and well spacing is 50% closer than in the Reference Case. In addition, tight oil resources are added to reflect new plays or the expansion of known tight oil plays, and the EUR for tight and shale wells increases by 1% per year more than the annual increase in the Reference Case to reflect additional technology improvements. This case also includes kerogen development; undiscovered resources in the offshore Lower 48 states and Alaska; and coalbed methane and shale gas resources in Canada that are 50% higher than in the Reference Case. |

| *Annual Energy Outlook* 2014[372] | |
|---|---|
| Frozen Technology | Future residential and commercial purchases are based only on the range of equipment available in 2013; commercial and existing residential shell efficiency is held constant at 2013 levels; and energy efficiency of new industrial plants and equipment is held constant at the 2014 level. |
| Best Available Technology | Future residential and commercial purchases are limited to the most efficient models available in a particular year, regardless of cost; all residential building shells for new construction are built to the most efficient specifications; existing residential shells have twice the improvement of the Reference Case; commercial building shell efficiencies improve 50% more than the Reference Case by 2040; and the industrial and transportation sector assumptions are the same as the Reference Case. |
| High Technology | Earlier availability, lower costs, and higher efficiencies for more advanced residential and commercial equipment; improvements to new residential building code compliance and building shell efficiencies, which meet ENERGY STAR requirements by 2023; existing residential building shells exhibit 50% more improvement than the Reference Case after 2013; new and existing commercial building shells improve 25% more than in the Reference Case by 2040; the industrial sector has earlier availability, lower costs, and higher efficiency for more advanced equipment and a more rapid rate of improvement in the recovery of biomass by-products from industrial processes; and more optimistic assumptions about incremental improvements in fuel economy and costs of light-duty vehicles, including battery electric vehicle costs, and more improvement in fuel efficiency of freight trucks, air, rail, and shipping. |
| † Other assumptions not specified here are the same as in the Reference Case. | |

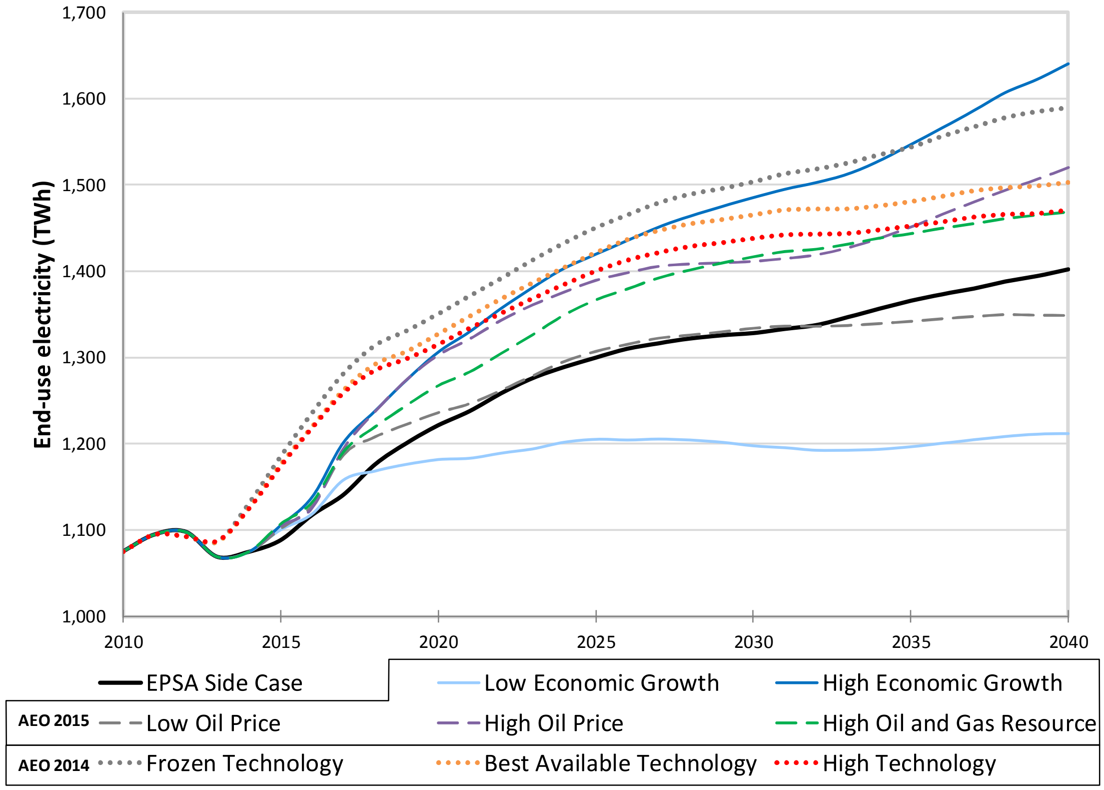
*The ranges produced by the AEO cases provide insights into how high-level assumptions influence the forecast results.*

### 4.3.5 Comparison of Forecast Cases

Figure 4.12 shows the ranges in EPSA and AEO cases for end-use electricity forecasts for the industrial sector to 2040. The graph contains the nine forecast cases described in Table 4.1 above. Total end-use electricity consumption is the sum of purchased electricity and self-generation (CHP) electricity. The data exclude grid sales (CHP electricity that industrial facilities sell to the grid). Similarly, Figure 4.12 shows the ranges in QER and AEO cases for electrical productivity forecasts for the industrial sector to 2040.

The four major energy-consuming sectors across the U.S. economy (residential, commercial, industrial, and transportation) are linked through energy markets and are modeled in NEMS through the Electricity Market Module. This module models 22 geographical regions (based on North American Electric Reliability Corporation regions and sub regions) with heterogeneous electricity prices that reflect each region's power plant dispatch and operational constraints. Each of the end-use demand modules (e.g., Residential Demand Module) includes price elasticities—responses to price changes that can result in increased or decreased electricity consumption. The market relationships between sectors have an effect on electrical productivity in the industrial sector.

**Figure 4.12. Aggregate industrial electricity consumption forecasts to 2040 for the EPSA Side Case and eight AEO side cases [373]**




*These AEO cases provide a wide range in industrial end-use electricity forecasts—a 26% difference between the AEO 2015 Low and High Economic Growth Cases.*

The range in industrial electricity-consumption forecasts is driven by the economic growth metric that AEO uses more than it is by the technology assumptions. The economic growth cases use the same assumptions as in the Reference Case, except economic growth is higher in the High Economic Growth Case (2.9% average growth per year), and lower in the Low Economic Growth Case (1.8% average growth per year), as compared to the Reference Case (2.4% average growth per year). As discussed in the introduction of this report, many of the assumptions between the AEO 2015 Reference Case and the EPSA Side Case are the same.

The Frozen Technology Case assumes the same economic growth rate as the EPSA Side Case, but restricts residential and commercial purchases to the range of equipment available in 2013 and holds industrial efficiency constant at 2014 levels. The resulting electricity end-use forecast for the Frozen Technology Case (which has the same economic growth rate as the EPSA Side Case) is similar to the High Economic Growth Case. The difference between the Frozen Technology and EPSA Side Case highlights the role that energy efficiency is anticipated to play in reducing industrial electricity end-use consumption and boosting industrial electrical productivity. In the EPSA Side Case, industrial electricity consumption is 29% of the total U.S. electricity consumption in 2040. In the Frozen Technology Case, industrial electricity consumption is 28% of total U.S. electricity consumption in 2040.

The lowest electricity consumption case (i.e., the Low Economic Growth Case) assumes an industrial efficiency adoption rate that is similar to the EPSA Side Case, but slower economic growth keeps industrial electricity consumption relatively flat. The difference between the High and Low Economic Growth Cases, with the same efficiency assumption in both cases, is nearly 500 TWh, or a 26% lower electricity demand in 2040 relative to the High Economic Growth Case.

Comparison of the Best Available Technology with the EPSA Side Case provides an estimate of the net effect on industrial-sector electricity consumption when the residential and commercial sectors reduce their electricity demand. The Best Available Technology Case assumes that the most efficient technologies are purchased in the residential and commercial sectors, regardless of price; while the industrial and transportation sector assumptions are the same as in the EPSA Side Case. In addition, the Best Available Technology Case assumes all new residential building shells are built to the most efficient specifications. (By 2040, residential building shells are twice as efficient as in the EPSA Side Case, and commercial building shells are 50% more efficient than the EPSA Side Case.)

Within the NEMS model, these assumptions reduce residential and commercial electricity demand, which lowers the net cost of electricity and, consequently, electricity prices; this, in turn, results in increased electricity consumption in the industrial sector based on the sector's price elasticities. Moreover, the Macroeconomic Activity Module also registers slightly higher economic growth due to lower energy prices—an indirect, positive feedback loop to the industrial output and energy/feedstock inputs in the IDM. Industrial electricity consumption increases by 105 TWh by 2040 in the Best Available Technology Case relative to the EPSA Side Case. See the Industrial Appendix for historical and projected electricity prices in the industrial sector.

## 4.4 Industrial Energy Efficiency Technologies and Strategies

### 4.4.1 Non-Process End Uses

*Non-process* end uses in the industrial sector include buildings, lighting, HVAC, and water and wastewater handling. Efficient building shells and glazing offer energy savings in industrial facilities, as does improved controls for dynamic and flexible buildings. Energy efficient facility lighting technologies and strategies include LED and SSL technology, as well as natural lighting through skylights and light-scattering window glazing. Facility HVAC efficiency involves efforts to optimize internal loads to reduce cooling requirements, improve the efficiency of cooling systems, and develop technology that can efficiently remove moisture from air without cooling energy.[374] See the commercial section in this report (Chapter 3) for more information on many of these technologies and strategies.

Industrial sector and manufacturing subsector water use and consumption is poorly documented. Industrial and manufacturing facilities often self-supply their own water and/or lack meters to accurately measure their water use and its associated electricity demands. As a consequence, assessing electricity efficiency opportunities for industrial and manufacturing water use is also poorly understood. In light of this, DOE's Advanced Manufacturing Office (AMO) has recently started to assess water use and its efficiency opportunities, as well as the technologies necessary to achieve greater efficiencies.[375] It is anticipated that there are significant opportunities to reduce the electricity consumed by water and wastewater systems. For example, water distribution systems can use small, modular hydropower systems to recover excess energy. In addition, wastewater treatment plants can increase energy efficiency and even produce enough energy on-site to become zero net-energy facilities.

### 4.4.2 Process End Uses

The following section focuses on electricity efficiency technologies and strategies for *process* end uses, in the industrial sector, particularly the following end uses:

Process heating – While electricity supplies a small fraction of process- heating demand in the U.S. manufacturing sector, electric process-heating techniques such as microwave, ultraviolet, and other electromagnetic-processing methods offer promising efficiency opportunities, although assessing their net efficiency requires an evaluation of electric-grid efficiency. Electric process heating can increase the proportion of useful heat energy delivered to the product by delivering energy directly where it is needed rather than heating the environment.[376] In addition, electric process-heating techniques are flexible, and process parameters (e.g., electromagnetic frequency, energy input, and spatial extent) can often be monitored and actively controlled. Because the interaction of electromagnetic energy with matter varies from material to material, electromagnetic processing techniques can enable entirely new or enhanced manufactured products.

Process cooling and refrigeration – Electricity efficiency technologies and strategies for process cooling and refrigeration rely on many of the same technologies available to commercial-sector HVAC systems—namely, heat pumps and large-scale chillers. See the commercial section of this report (Chapter 3) for more information on some of these technologies and strategies. Most applicable to the industrial sector is the application of cooling technologies that utilize waste heat through thermally activated cooling systems, such as absorption chillers, adsorption chillers, solid and liquid desiccant dehumidifiers, and ejector refrigeration systems.[377]

Machine drives – Machine drives associated with motor-driven systems consume roughly half of the industrial sector's electricity demand. Efficiency-improvement opportunities for motor-driven systems include the motors themselves and the systems they drive.[378] [379] The largest efficiency-improvement opportunity for motor-driven systems is improving overall system designs (62% of estimated potential savings), followed by adopting variable-speed drives (25%) and upgrading motors to newer, high-efficiency technologies (13%).[380] [381] New, higher-efficiency motors, along with state-of-the-art motor controls such as variable-speed drives, can improve motor efficiencies. However, in many instances, greater efficiency improvements are associated with redesigning the system that the motor is driving, rather than the motor itself.[382] [383] [384] Often, those systems are poorly designed (overdesigned or designed for greater throughput than normally operated, with excess throughput throttled by process controls that result in efficiency losses). Next-generation motor-driven systems will benefit from the development of improved wide-bandgap semiconductors, which are expected to enable more cost-effective and higher-efficiency variable-speed drives. Information technology is enabling more intelligent power use and more integrated and intelligent motor systems that can increase facility productivity.

AMO is sponsoring an assessment of motor systems in the United States in order to better understand the state of motor systems and their efficiencies in the U.S. industrial sector. [385]

Electrochemical processes – Electricity consumption for electrochemical processes mostly takes place in the primary metals manufacturing subsector, especially in aluminum processing, and, to a lesser degree, in the chemicals subsector. The use of electrolysis (an example of an electrochemical process) is a relatively mature technology in aluminum smelting, introduced in the late 1880s. Recycling aluminum is the most effective option available to reduce electricity consumption in the aluminum subsector, reducing the energy used per unit of aluminum by an order of magnitude.[386] Other options include use of prebaked carbon anodes, which have lower resistance than traditional Søderberg anodes, and recovery of waste heat generated in the electrolyte and anode.[387]

*Waste Heat Recovery Potential for Additional On-Site Electricity Generation*

The AMO's Manufacturing Energy and Carbon Footprints analyses estimate that 7,229 trillion British thermal units (TBtu), or 51% of the 14,064 TBtu of total delivered energy to the U.S. manufacturing sector, was wasted as efficiency losses in 2010.[388] This estimate includes losses for on-site steam and electricity generation (1,417 TBtu, or 10%), steam distribution losses (870 TBtu, or 6%), process energy consumption (4,368 TBtu, or 31%), and non-process energy consumption (574 TBtu, or 4%). Process energy is commonly consumed by process-heating equipment (e.g., furnaces, ovens, heaters, kilns, and dryers), which produces waste heat that could be captured and converted into electricity.
Barriers to self-generation from waste process heat include both technical components (e.g., innovative materials needed for high-temperature and highly corrosive environments that are commonly found in large industrial facilities) and cost components (e.g., high capital costs, high maintenance costs, and competition with industrial electricity prices).[389] Based on 2010 MECS data, an estimated 300 TBtu per year of potentially recoverable heat is available within the iron and steel, glass, aluminum, and cement and lime industries alone. This equates to roughly 28 TWh—assuming an average electricity generation heat rate of 10,500 Btu/kWh, consistent with typical Rankine cycle generators—or 24% of the industrial sector's self-generated supply in 2014.

### 4.4.3 Quadrennial Technology Review's Advanced Manufacturing Chapter

U.S. manufacturing has diverse and often interrelated layers of subsectors, specializations, and technologies. MECS end-use categorizations do not necessarily capture this complexity. Chapter 6 of the 2015 QTR examines the status of the science and technology associated with advanced manufacturing.[390] That chapter presents efficiency opportunities that correspond to three levels of manufacturing system integration:

- Manufacturing/unit operations – Equipment used for individual manufacturing process and non-process unit operations (similar to MECS end-use classifications)
- Production/facility systems – Equipment, process flow, and energy strategies that comprise a goods-producing facility (e.g., a petroleum refinery)
- Supply chain systems – A network of facilities and operations involved in moving materials through industry, from extraction of raw materials to the production of finished goods (i.e., the larger industrial ecosystem)

Efficiency-improvement opportunities exist for state-of-the-art end-use equipment at the unit operations level. One example is more-efficient electric motor-driven systems. Other efficiency opportunities are available through better integration of facility systems, such as integrating heat transfer between product flows to reduce steam demand and associated electrical energy for boiler feedwater pumps. In addition, efficiency improvement opportunities exist across the entire supply chain of material flows through industry. An example is reducing waste materials through advanced manufacturing processes that enable electricity savings across the whole material supply chain associated with a reduction in material inputs.

The QTR proposes that an effective technology RD&D portfolio balances: (1) high-efficiency manufacturing equipment and approaches, (2) advanced technologies to improve energy and resource use at manufacturing facilities, and (3) next-generation products with potential for energy impacts throughout the economy. The portfolio must also include a mixture of developmental timescales, including both short-term projects and longer-term projects that push technological boundaries or involve transformational new approaches. The QTR highlights 14 key technologies that have the potential to reduce overall energy intensity and environmental impacts in the manufacturing sector; both direct and indirect (from a life-cycle perspective).

**Table 4.2. Key Efficiency Improvement Opportunities in U.S. Manufacturing, by Technology[391]**

| Key Technology Area | Industrial Sector: Electricity Efficiency Improvement Opportunities |
|---|---|
| Critical Materials | Critical materials alternatives allow material substitution in electronic systems that improve efficiency, costs, or both |
| Direct Thermal Energy Conversion Materials, Devices, and Systems* | Recovering waste heat as electricity through direct thermal energy conversion |
| Wide Bandgap Semiconductors for Power Electronics | Smaller-footprint electronics with reduced cooling requirements<br>More efficient variable-frequency drives and motor-speed controls |
| Materials for Harsh Service Conditions | Enables thermoelectric adoption in harsh service conditions<br>Extends sensing, control, and energy-management systems to harsh environments |
| Advanced Materials Manufacturing* | Advanced materials formulations for all electric systems (both electricity generation and consumption) |
| Additive Manufacturing* | Advanced components for CHP system-performance efficiencies<br>Thermoelectric device fabrication |
| Composite Materials | Lightweight materials manufacturing for life-cycle energy savings |
| Roll-to-Roll Processing | Thermoelectric device fabrication<br>Advanced battery designs |
| Process Intensification | Real-time data acquisition and modeling for process control<br>Enterprise-wide operations optimization<br>Optimized heat and mass transfer in reaction, separation, heating, and cooling applications |
| Process Heating | Better integration with CHP systems<br>Reduce process heating ancillary electricity loads<br>Fuel switching from furnaces to electric-based process heating (when coupled with cleaner electricity generation) |
| Advanced Sensors, Controls, Platforms, and Modeling for Manufacturing | Integrated sensors and controls that maximize efficiency and minimize waste<br>Improved controls for process unit grid integration<br>Increasingly referred to as “smart manufacturing” |
| Waste Heat-Recovery Systems* | Enhanced heat recovery for CHP<br>Novel energy-conversion materials, devices, and systems for waste heat to power |
| Combined Heat and Power* | Modular and standard designs for easier installation and operations<br>Improved controls for grid integration |
| Sustainable Manufacturing: Flow of Materials through Industry | Waste minimization and recycling reduces raw material processing energy |

**Indicates opportunities to improve electricity-generation-related technologies*
*The Quadrennial Technology Review covers a wide range of technologies and opportunities for improving energy efficiency in U.S. manufacturing.*

### 4.4.4 Industrial Energy Efficiency Technology Costs

Industrial energy efficiency technology costs vary widely by subsector, end use, and technology type. Table 4.3 broadly categorizes the various levels of energy efficiency investments, from simple no-cost energy saving behaviors to total facility replacement. Non-process energy consumption (e.g., lighting, HVAC) can be reduced using technologies that are most often utilized in the commercial sector, with some variations. For example, high-intensity fluorescent lighting is uniquely applicable to industrial applications, with typical installments costing around $185 per fixture and saving up to 50% of electricity, for a payback period of less than 3 years.[392] [393] Common process-related efficiency technologies include: high-efficiency motors, with payback periods of 0.6–7.9 years, depending on motor size and load; variable-speed drives on motors, with 22%–83% energy savings and payback periods of 0.9–3.7 years; and variable-speed drives on pumps, with payback periods of less than a year.[394]

**Table 4.3. Energy Efficiency Action and Investment Examples[395]**

| Level of Investment | Action/Investment |
|---|---|
| **No- to low-cost** | • Turning off lights and other equipment when not in use<br>• Behavioral/operational change (e.g., switching to low-rate overnight power)<br>• Strategic energy management (SEM)* |
| **Lower cost** | • Replacement lights with high-bay fixtures<br>• Variable-frequency drive motors, new pumps<br>• SEM* |
| **Medium cost** | • Heating, ventilating, and air conditioning replacement<br>• New boilers, refrigerators<br>• Back-up generator replacement<br>• SEM* |
| **Higher cost** | • Process equipment upgrades and selective equipment replacement<br>• Combined heat and power<br>• SEM* |
| **High cost** | • Replacement of complete production lines<br>• New power generation units, if off-grid; on-site energy generation |
| **Highest cost** | • New plant, new facility |

***SEM is a broad approach and can incur varying levels of cost depending on how it is implemented by the company.***

## 4.5 Markets and Market Actors

The industrial sector covers a diverse range of markets and market actors that make up the agriculture, construction, mining, and manufacturing subsectors. However, building-related electricity end uses (e.g., building lighting, HVAC, plug loads, etc.) in these four subsectors are similar to those in the commercial sector (see Chapter 3). The following text focuses on markets and market actors that are unique to the four industrial subsectors.

Within the IDM in NEMS, agriculture is categorized by: (1) crop production, (2) animal production, and (3) all remaining agricultural activities, which are primarily composed of forestry and logging. Agriculture's energy mix is dominated by liquid fuels necessary for farming equipment such as tractors and trucks. Electricity end-use equipment in the agricultural subsector includes a variety of both common equipment (e.g., irrigation systems that rely on pumps) and specialty equipment (e.g., cotton gins). Primary market actors for electricity-consuming equipment in the agricultural subsector are agricultural producers that make equipment investment choices and agricultural equipment manufacturers and vendors. Purchased electricity in the agriculture subsector remains approximately 15% of total agricultural site-energy consumption between 2015 and 2040, although the electrical productivity of the subsector nearly doubles over this time period.[396]

The construction and mining subsectors are also dominated by non-electricity fuels. Their respective electricity shares of site-energy consumption are expected to remain fairly constant between 2015 and 2040—construction increases from 14% in 2015 to 16% by 2040, and mining drops from 12% in 2015 to 9% in 2040. Electrical productivity increases between 2015 and 2040 (construction by 50%, mining by 147%).[397] Equipment efficiency improvements add to increasing electricity productivities, as do other structural changes (e.g., the mining subsector's increased oil and gas extraction result in higher VOS). Key market actors for construction are infrastructure planners (engineers and project managers) and building-construction equipment manufacturers. Electricity end-use equipment in the construction industry is dominated by building-construction equipment. Mining uses specialized equipment for material grinding and underground activities. Key market actors for mining are production managers and equipment manufacturers; regulators also are involved in regulating mining equipment.

Within the manufacturing subsector, producing cost-competitive products and satisfied customers is the primary driver in capital investment decisions, and technology expertise is a competitive advantage within industrial and manufacturing organizations. A diverse range of market actors make decisions about improving efficiencies in manufacturing. Table 4.4 provides an overview of the market actors and the roles they play in the decision-making process.

**Table 4.4. Electric Efficiency-Infrastructure Decision Makers in the Manufacturing Sector**

| Market Actors | Description |
|---|---|
| **Internal Industrial and Manufacturing Organizations** | |
| Corporate planners | Strategic decisions about capital investment |
| Engineers | Designing Design of products and manufacturing facilities |
| Facility managers | Management of operational activities |
| Solution Providers | |
| Analytical consulting | Strategic analytics for manufacturing decisions |
| Engineering, consulting | Detailed engineering, construction, and project management of industrial and manufacturing facilities |
| Demand Side Management providers | Aggregation of loads, software, and controls providers; energy systems managers |
| **Equipment Manufacturers** | |
| General equipment | Manufacturers of crosscutting equipment (e.g., pumps, compressors, control systems) |
| Specialty equipment | Manufacturers of industry-specific equipment (e.g., electric arc furnaces, paper machines, combined heat and power systems) |
| **Regulatory Oversight** | |
| U.S. EPA | Permitting of pollutant-emitting equipment |
| U.S. DOE Appliance and Equipment Standards | Efficiency standards for single-speed motors |
| U.S. Occupational Safety & Health Administration | Permitting of equipment for occupational safety |
| Local and State Business Development Agencies | |
| Chambers of commerce | Negotiations for incentive packages for facility locations and zoning |

| Market Actors | Description |
| --- | --- |
| **Education and Research Organizations** | |
| University engineering and technology-focused research and development programs | Developing Development of new processes, materials, and innovative technologies |
| Science, technology, engineering and mathematics education programs | Training for workers and decision makers of the future |
| Research laboratories | Developing Development of science-based solutions for long-term problems that private industries do not yet find profitable to solve on their own |

## 4.6 Barriers and the Policies, Regulations, and Programs That Address Them

Energy efficiency policies, regulations, and programs for the industrial sector attempt to address well-known barriers:

- Information/awareness and transparency – Market actors have imperfect information about the performance of energy-efficient technology and equipment, practices that can save energy, and cost-effectiveness. Energy savings can be difficult to measure and separate by end use.
- Stranded capacity/sunk costs/assets and opportunity costs – For many industries, process equipment is a major capital investment, and existing equipment tends to be utilized for long lifespans. Even if newer, more-efficient technologies are available, existing equipment is kept operating in order to recoup capital investments. Moreover, it can be difficult to justify replacing fully depreciated, functional equipment and any associated plant shutdowns.
- Need for short payback times – In some cases, more efficient technologies cost more. Typically, industry requires short payback periods (typically less than 2 years),[398] which tends to limit opportunities.
- Risk aversion – Faculty managers may be risk-averse to, or unfamiliar with, new efficient technologies, end-use technologies, operating procedures, or business practices.
- Materiality – When energy costs are small relative to other costs, energy efficiency can be a low priority.
- Limited access to capital – Companies have limited capital investment budgets, and energy efficiency might not be a priority.
- Lack of monetization of non-energy benefits and price signals – Electricity prices are set to recover utility and electricity service supplier costs, not to reflect the true social cost of electricity consumption. In addition, tariff structures may discourage customer investments in energy efficiency.
- Transaction costs – Energy-efficiency improvements and retrofits can be viewed as time-consuming to understand, arrange, and execute.
- Tax treatment – Energy bills are a deductible expense, and capital costs for energy-efficient equipment may be subject to long depreciation schedules.
- Workforce development – The availability of a skilled workforce is a barrier in some regions due to inadequate training, experience, or certification (e.g., lack of technical expertise on energy-efficient technology options and lack of familiarity with local incentive programs).
- Other market failures and imperfections – These include externalities (e.g., health and environmental costs of fossil energy production) and imperfect competition (e.g., lack of a fully competitive market for energy efficiency that may enable lower prices for products and services).

The DOE's 2015 report, *Barriers to Industrial Energy Efficiency,* documents energy efficiency deployment barriers and potential solutions.[399] Table 4.5 summarizes the types of policies, regulations, and programs related to industrial energy efficiency and the barriers they intend to address. The policies, regulations, and programs are implemented at a variety of geographical levels (federal, state, regional, and local).

Equipment, appliance, and lighting standards have been adopted for many products through national legislation and rulemakings, and over time, they have led to significant improvements in end-use energy efficiency. Standards require manufacturers to produce equipment that performs at set energy efficiency standards, with stringency of standards increasing over time. For example, a typical 1985 vintage 20-horsepower motor only operated at 87.5% full-load motor efficiency with 12.5% efficiency losses.[400] Standards resulting from the *Energy Policy Act of 1992* (with compliance beginning in 1997) raised full-load motor efficiencies to 91%, and compliance in 2016 requires a 93% full-load motor efficiency. This corresponds to a decrease in losses of about 44%.

The DOE's Appliance and Equipment Standards program covers products that represent about 29% of industrial energy end uses, compared to products that represent about 90% of energy use in homes and 60% of energy use in commercial buildings.[401] This difference in coverage is explained by three factors: (1) electricity accounts for a smaller fraction of energy use in industry relative to the residential and commercial sectors, (2) appliance and equipment standards only cover electricity end-use equipment such as motors, HVAC, and lighting (which represent approximately 65% of manufacturing electricity end use),[402] [403] and (3) industry often deploys specialized electric-powered equipment that is difficult to standardize. Historically, the majority of electricity savings in manufacturing has come from motors in pumps, fans, compressors, and machine drives. Although inverter-capable motors are included in appliance standards, variable-speed motors—that can only be operated with a variable-frequency drive (VFD)—are out of scope for the updated motors rulemaking.[404] [a] However, variable-frequency drive motors offer large efficiency-improvement opportunities. DOE has recently updated pump and fan rulemakings that consider the benefits and impacts of variable-frequency drives as part of the supporting analysis.

Many opportunities for energy efficiency improvements remain—both for physical systems and processes, and for business and operational processes that impact energy consumption. Despite the availability of improved manufacturing systems and processes and promising new technologies, the level of capital investment and planning required to make major upgrades in the physical plant of existing industrial facilities means that energy efficiency improvements are likely to continue to occur on an incremental basis.

[a] See 10 CFR 431.25. Inverter-only motors are listed at 10 CFR 431.25(l).

**Table 4.5. Industrial Sector Energy Efficiency Policies, Regulations, and Programs and Barriers Addressed**

| Policy, Regulation, or Program | Description and Implemented Examples | Principal Barriers Addressed |
|---|---|---|
| Codes and standards | • U.S. Department of Energy's (DOE's) Appliance and Equipment Standards<br>• ENERGY STAR labeling sets a minimum level of equipment performance.<br>• International Organization for Standardization 50001 Energy Management Standard<br>• Standardized Industrial Energy Management Systems (IEMS) protocols<br>• Standardized quantification methods for non-energy benefits for policies such as emissions reduction goals | *Information/awareness, management strategies, technology interoperability*<br>• Standards set a minimum level of performance, guarding against uninformed or inattentive purchase of inefficient devices.<br>• ENERGY STAR guards against uninformed or inattentive purchase of inefficient devices<br>• International Organization for Standardization 50001 guides implementation of technical and management strategies that reduce energy costs.<br>• Standardized IEMS protocols enhance technology interoperability.<br>• Co-benefits often are not considered, such as reduced maintenance and material use, as well as societal benefits of reduced energy consumption, water use, and emissions. |
| Auditing and Benchmarking | • Utility-sponsored benchmarking and efficiency auditing<br>• Determine cost-effective ways to submeter production lines | *Information/awareness, continued savings validation*<br>• Benchmarking can identify savings opportunities, and auditing can validate energy savings performance over equipment lifespans.<br>• Lack of disaggregated consumption data impedes identification and evaluation of energy efficiency opportunities. |
| Grants and rebates | • Many utilities and third-party administrators of utility consumer-funded programs offer rebates for industrial energy efficiency measures. | *First costs, non-energy benefits, materiality, information/awareness*<br>• Rebates lower the incremental up-front cost of efficient technologies. |
| Resource planning | • Industrial consumer participation in Integrated Resource Planning (IRP) | *Misaligned value of energy efficiency between utilities and industry*<br>• IRPs are critical for assuring that efficiency is valued appropriately in utility planning for energy and capacity. |
| Informational interventions | • Industrial technology assistance programs such as DOE's Better Plants Program, Better Plants Challenge, and Superior Energy Performance, as well as the U.S. Environmental Protection Agency's (EPA's) ENERGY STAR Industrial Program, which provides efficiency guides for selected industrial subsectors.<br>• Efficiency potential studies | *Information/awareness, materiality*<br>• Industrial technology assistance programs encourage energy efficiency capital investments where industrial facility management may lack capacity to identify opportunities for energy-saving improvements. |

| Policy, Regulation, or Program | Description and Implemented Examples | Principal Barriers Addressed |
|---|---|---|
| | | • Potential studies provide companies with information on opportunities for energy, capacity, and cost savings. They can also help improve workforce development. |
| Rate design | • Tariff structures that encourage consumer efficiency investments<br>• Increase collaboration between utility and industry where industry can adopt "self-direct" programs with rigorous verification of energy savings as an alternative to consumer-funded energy efficiency programs | *Price signals, incentivized pricing*<br>• Tariff structures may discourage consumer investments in energy efficiency (e.g., declining block energy charges, where higher levels of consumption are priced at a lower rate, or high customer charges).<br>• Lack of industrial participation in consumer-funded efficiency programs |
| RD&D for end-use technologies | • Direct support for research, development, and deployment (RD&D)<br>• Prizes, contests, and other manufacturer incentives | *Technology availability and deployment*<br>• Industrial RD&D often requires long time horizons. Direct support for RD&D can accelerate technology deployment. |
| Financing | • Financing programs through electric utility programs<br>• Industrial energy efficiency demonstration financing offered by some state energy offices<br>• Partnerships with financial institutions and equipment manufacturers to reduce project risk | *Lack of capital, first costs, transaction costs*<br>• Short utility program cycles relative to capital-planning schedule creates uncertainty.<br>• Responsibility for capital purchases, operations, and energy bills often are split among industrial business units. |
| Tax incentives | • Accelerated depreciation/changes in deduction schedules for energy efficiency capital investments | *Non-energy benefits, price signals*<br>• Tax incentives can be a proxy for non-priced social benefits. |

Ongoing informational interventions in support of industrial energy efficiency, typically including technical assistance, continue to be an important aspect of U.S. energy policy at both the state and national levels. Lack of industry familiarity with energy efficiency opportunities and technical resources creates informational barriers to efficiency. Some industries lack the in-house staff or technical expertise to identify long-term energy savings opportunities in their facilities. Energy management systems and submetering of facility equipment or production lines can also help identify opportunities and benefits of efficiency investments, while utility and other outreach and technical support can help inform industries about successful projects and participation processes.

Industry-specific energy management expertise is key to improving the efficiency, productivity, and resiliency of both industrial facilities. Considered broadly, insufficient knowledge and data concerning industrial needs and operational practices present a large barrier to more effective industrial energy management. Effective industrial program offerings tend to be targeted and require resource-intensive training, consulting, and coaching. Industrial programs and assistance that are not sufficiently targeted often result in major opportunities for improved energy efficiency being overlooked or industrial customers being discouraged from future participation. The emergence of strategic energy management (including International Organization for Standardization 50001 energy management standard and Superior Energy Performance®) as a technical assistance offering, which uses business processes to identify operational energy efficiency opportunities, further accentuates this need.

Another major barrier is the life cycle of a typical energy efficiency program offering for industry. Planning cycles for industrial capital projects are typically 2 to 5 years, which do not align well with 1- or 2-year efficiency program cycles. This has been a significant problem for national, state, and utility programs, with some improvement in recent years.

The DOE's Advanced Manufacturing Office (AMO) has an array of technical assistance offerings for U.S. industry.[405] Major offerings include the following:

- Better Plants – A voluntary pledge by a company to improve energy intensity by 25% over 10 years and to report progress. Participants receive coaching, tools, training, and recognition.
- Superior Energy Performance® – Facilities voluntarily achieve conformance with International Organization for Standardization 50001, an international energy-management system standard, and meet the American National Standards Institute (ANSI) and ANSI-ASQ National Accreditation Board-accredited Superior Energy Performance program requirements for third-party verified energy performance improvement. Extensive training, coaching, and software are provided to help facilities build internal capacity.
- Industrial Assessment Centers – Twenty-four universities provide energy assessments to small- and medium-sized manufacturers to identify opportunities to improve productivity, reduce waste, and save energy.
- Combined Heat and Power (CHP) Deployment – Regional CHP technical assistance partnerships help industrial companies and others consider CHP and waste heat to power in their facilities, including assisting project development from initial CHP screening to installation. The partnerships also provide information on CHP benefits and applications to industrial consumers, as well as state and local policy makers and regulators.
- Other Technical Resources – AMO offers other technical publications, training, webinars, software tools, and case studies.

- In addition, through a partnership between DOE and EPA, the SEE Action Network offers resources and technical assistance to state and local decision-makers on industrial energy efficiency, among other sectors.

EPA's ENERGY STAR industrial partnership program[406] offers a large variety of business-oriented tools that assist companies in engaging their full complement of managed plants and facilities in setting and meeting energy goals, including the following:

- Energy-management guidance and tools to help companies cost-effectively evaluate their current management practices and self-identify areas for improvement.
  - ENERGY STAR Guidelines for Energy Management provide a framework for continuous improvement and are compatible with the International Organization for Standardization 50001 standard.
  - ENERGY STAR sector-specific Energy Guides identify areas in plants where electrical and fuel savings unique to the plant type are possible and where there are potential savings.

- Plant Energy Performance Indicators are sector-specific energy-performance benchmarking tools to objectively score the performance of selected industrial plants and compare them to others in the same industry within the United States.
- Recognition for performance and improvement, including the Partner of the Year Award for excellence in corporate energy management, ENERGY STAR Plant Certification for plants that achieve top energy performance in an industry, and ENERGY STAR Challenge for Industry for reaching a basic goal of a 10% reduction in energy use at a plant.

A number of states and utilities also offer technical assistance to industry, most notably Washington, Oregon, Idaho, California, Texas, Colorado, Wisconsin, Minnesota, Indiana, Ohio, New York, Connecticut, Vermont, Kentucky, Pennsylvania, West Virginia, Maryland, and North Carolina.

Regulatory barriers to effective industrial energy management include rate structures that may discourage efficiency investments, incentive programs that are not well coordinated with industrial investment cycles. For example, some utilities have tariffs for industrial customers that include a declining block rate for electricity (i.e., the cost per kWh decreases as usage increases above a certain threshold). This type of rate may encourage industrial users to expand their output and could be a disincentive to energy efficiency. Some utilities also have rate designs that include either high fixed customer charges (for grid connection or access) or complex demand charges, which could also reduce a customer's incentive to invest in energy efficiency. These rate designs may result in industrial consumers making large electricity payments somewhat independently of their actual volumetric electricity consumption. Some states allow large industrial consumers to opt out of paying for utility customer-funded efficiency programs or allow them to "self-direct" their cost contribution to their own industrial facilities.[a]

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[a] Qualifying industrial customers can "self-direct" the fees toward energy efficiency investments in their own facilities instead of paying into an aggregated pool of funds the utility collects to fund all energy efficiency programs. Under a self-direct paradigm, industrial customers can choose to pay the fees to the utility or spend the fees in their own facilities to achieve energy savings. See: *Industrial Energy Efficiency: Designing Effective State Programs for the Industrial Sector*, U.S. Department of Energy, SEE Action, https://www4.eere.energy.gov/seeaction/publication/industrial-energy-efficiency-designing-effective-state-programs-industrial-sector.

Economic and financial barriers to energy efficiency are due in part to misalignment between utility program-planning cycles and industrial capital-investment cycles. Industrial consumers may not be able to plan around the open enrollment period for energy efficiency programs, which often have limited funds for rebates or incentives. Some industrial users also have high internal hurdle rates for investments, translating into requisite short payback periods (1 or 2 years). The need to invest capital up front is also a hindrance to companies that have more profitable uses for their own capital or do not wish to carry financing debt on their balance sheets. Corporate tax structures also may underestimate depreciation of assets while subsidizing energy costs, providing an incentive to hold onto inefficient equipment.

## 4.7 Interactions with Other Sectors

The U.S. industrial sector has significant interactions with all other sectors of the U.S. economy. From a macroeconomic perspective, industrial sector value-add translates into labor force wealth that is then used to purchase products in the other major sectors of the economy (residential, commercial, and transportation). In addition to providing labor force wealth, the industrial sector produces products that are used in homes and offices, manufactures equipment for all modes of transportation, and produces the infrastructure necessary for modern societies (e.g., roads, electric grid, and telecommunications). Table 4.6 summarizes some of the key industrial technology areas presented in the QTR and their interactions with buildings (commercial and residential), electric power (generating resources and the grid), fuels, and transportation.

**Table 4.6. Quadrennial Technology Review (QTR) Key Technology Areas and Their Crosscutting Connections to Nonindustrial Sectors**

| Key Technology Area | Cross-Sector Connections |
|---|---|
| Critical Materials | Buildings: *Phosphors for light-emitting diode (LED) lighting*<br>Electric Power: *Permanent magnets for wind turbines*<br>Transportation: *Dysprosium and other rare earths for motors; platinum for fuel cell catalysts* |
| Direct Thermal Energy Conversion Materials, Devices, and Systems | Buildings: *Thermoelectric heat pumps for heating, ventilation, and air conditioning (HVAC)*<br>Electric Power: *Water withdrawal for power plant cooling; waste heat recovery in power plants*<br>Transportation: *Direct thermal energy conversion for internal combustion engines* |
| Wide Bandgap Semiconductors for Power Electronics | Buildings: *Variable-speed drives for HVAC systems; Alternating current (AC)-to-direct current (DC) and DC-to-AC adapters*<br>Electric Power: *Solid-state transformers for power-flow control; inverters for renewable energy*<br>Transportation: *Power electronics for electric vehicles* |
| Materials for Harsh Service Conditions | Electric Power: *Radiation-resistant fuel cladding; high-temperature alloys for nuclear reactors and gas and steam turbines*<br>Fuels: *Corrosion in offshore drilling equipment; ash fouling in biomass-conversion equipment; hydrogen embrittlement in $H_2$ pipelines*<br>Transportation: *Corrosion-resistant lightweight materials* |
| Advanced Materials Manufacturing | Buildings: *Advanced building envelope materials*<br>Electric Power: *Materials genome techniques to screen materials for use in carbon capture and storage (CCS) applications*<br>Transportation: *Predictive design, modeling, and simulation for vehicle product development* |

| Key Technology Area | Cross-Sector Connections |
|---|---|
| Additive Manufacturing | Buildings: *Heat exchangers for HVAC systems; window frames*<br>Electric Power: *Custom electrical components in substations; complex parts for power plants; tooling for large castings for power plants*<br>Fuels: *Fuel cells*<br>Transportation: *Prototyping and tooling in automotive applications; fuel cells* |
| Composite Materials Manufacturing | Electric Power: *Lightweight wind turbine blades*<br>Fuels: *Hydrogen fuel storage*<br>Transportation: *Compressed gas storage for mobile applications; automotive lightweighting* |
| Roll-to-Roll Processing | Buildings: *Window insulation films*<br>Electric Power: *Flexible solar panels*<br>Transportation: *Battery electrodes* |
| Process Intensification | Buildings: *Membranes for dehumidification*<br>Electric Power: *Separations for CCS*<br>Fuels: *Natural gas and modular production*<br>Transportation: *Adsorbent systems for compressed gas storage* |
| Process Heating | *None—This is a manufacturing-specific technology* |
| Advanced Sensors, Controls, Platforms and Modeling for Manufacturing | Electric Power: *Advanced metering, sensors for power flow, grid integration*<br>Buildings: *Advanced sensors for lighting and HVAC*<br>Transportation: *Vehicles engine-control systems* |
| Waste Heat Recovery Systems | Electric Power: *Waste heat-recovery opportunities in electric generation*<br>Buildings: *Heat exchangers in HVAC systems*<br>Transportation: *Waste-heat recovery from internal combustion engines* |
| Combined Heat and Power | Buildings: *CHP in buildings*<br>Electric Power: *CHP for distributed generation*<br>*Refinery CHP* |
| Sustainable Manufacturing: Flow of Materials through Industry | Buildings: *Recycling and materials substitution/minimization*<br>Electric Power: *Management of water and energy resources* |

*Many of the key technology areas identified in the QTR 2015 have connections with other major sectors in the United States: electric power, fuels, buildings, and transportation.*

## 4.8 Research Gaps

The QTR identified several key RD&D opportunities in the industrial sector.[407] A crucial observation is that the way products are designed, fabricated, used, and disposed of affects energy consumption in nonindustrial sectors as well as in the industrial sector. With this perspective, manufacturing is critical to achieving greater efficiencies across the entire U.S. economy. The QTR identifies these issues and RD&D opportunities related to electricity consumption and energy efficiency in the industrial sector:

1. State-of-the-art technologies available today could provide energy savings, but many have not yet penetrated the market due to barriers such as high capital intensity and lack of knowledge. Opportunities exist to overcome these barriers and increase technology uptake.
2. Industrial-scale energy systems integration technologies, such as waste heat recovery and distributed energy generation, can reduce the manufacturing sector's reliance on the electric grid and increase industrial efficiency.
3. Data, sensors, and models can improve design cycles and enable real-time management of energy, productivity, and costs, increasing manufacturing efficiency while improving product quality and throughput.

# 5 Transportation Sector

In contrast to the residential, commercial, and industrial sectors of the U.S. economy, which are heavily electrified, the transportation sector currently uses virtually no electricity. In 2014, total transportation electricity consumption was about 26 trillion Btu (8 billion kWh), compared to total transportation energy consumption of about 27 quadrillion Btu.[408] In other words, electricity provides only about 0.1% of all transportation energy. Further, electricity consumption in the transportation sector represented only 0.2% of total U.S. electricity consumption in 2014.[409]

Most transportation electricity use—about 88%—is by transit, commuter, and intercity passenger rail.[410] Unless these rail modes increase usage significantly or other transportation modes become heavily electrified, electricity use for transportation will continue to play a very minor role in the U.S. electricity sector. This section will therefore focus primarily on the prospects for a major increase in transport electricity use through growth in the electrified modes and through electrification of modes now dependent on petroleum fuels. Due to the relative immaturity of markets for electric transportation technologies, projections of future consumption rates vary significantly. Therefore, this section does not attempt to project specific electricity consumption levels for transportation in the future. Rather, it is intended to provide a broad state of the industry, an overview of the major factors that may support or inhibit growth in electrified transportation, and the impacts that such growth may have on energy systems in the United States.

## 5.1 Key Findings and Insights

### 5.1.1 Current Status of Transport Electrification

*Findings:*

- In the U.S. transportation sector, electricity provides about 0.1% of all energy consumption; the sector remains dominated by petroleum fuels (Section 5.4).
- Most transportation electricity use—about 88%—is by transit, commuter, and intercity passenger rail. Transit rail is completely reliant on electricity, but intercity and commuter rail also rely heavily on diesel fuel (Section 5.4).

*Insight:* For electricity use in transportation to grow robustly, either the mode that is largely electrified—passenger rail—must grow or modes that are not currently electrified must switch from fossil fuels to electricity.

### 5.1.2 Predicting Future Electrification of Transportation

*Findings:*

- Among a fleet of about 230 million light-duty vehicles (LDVs) in 2014, about 280,000 were PEVs (Section 5.2.2).
- Competing projections of future penetration of EVs yield very different estimates, even when scenario assumptions are normalized among the projections (Section 5.8.5).

*Insight:* Because there are few data about why mainstream consumers may purchase PEVs, there is little basis for accurate long-term projections of future PEV sales. Models of future penetration of PEVs should be used cautiously, and preferably should be used to examine the relative impacts of different futures with different policies, degrees of technological success, oil prices, and other determining variables, rather than treating projections as robust predictors of likely PEV sales success.

### 5.1.3 Status of Battery Technology

*Findings:*

- Battery costs account for a quarter or more of total PEV costs, with variations depending on vehicle range and other factors (Section 5.3.2).
- Estimated PEV battery costs for industry leaders have been declining by about 8% per year since 2007 (Section 5.4.1).
- There is a robust battery R&D effort sponsored by both DOE and private industry, often in cooperation with the national laboratories and U.S. universities (Section 5.4.5).
- The initial high cost of PEVs is a primary barrier to their adoption (Section 5.6.1); limited utility for longer trips (unless limited range and long charging times can be overcome) is also likely to be a crucial barrier when batteries are the sole energy source, especially as the PEV market seeks to grow beyond early adopters.
- There are multiple pathways to increased battery performance and lower costs (Section 5.4.5).

*Insight:* It is highly likely that battery costs, and thus PEV prices, will continue to decline over time, especially if robust vehicle sales allow substantial gains in technology learning and economies of scale and a robust R&D effort continues. However, it is impossible to reliably project how low costs will go, or how much battery performance will improve. Battery performance, including rapid charging capability, must improve substantially if BEVs are to become full function vehicles.

### 5.1.4 Grid Impacts

*Findings:*

- Increased electrification of the LDV fleet will lead to both challenges and opportunities for power system operators (Section 5.5).
- Uncontrolled PEV charging can contribute to increased peak electricity demand and evening ramping requirements (Section 5.5.2).
- Controlled PEV charging can reduce costs for consumers, support grid reliability, and support the integration of variable renewable electricity generation (Section 5.5.2).

*Insight:* A comprehensive, modern power system that supports vehicle-to-grid communication and time-of-use pricing will be a vital component of a future where PEVs make up a large fraction of the total LDV fleet.

### 5.1.5 Policy Effectiveness

*Findings:*

- It is difficult to assess the relative effectiveness of specific policies and incentives for PEVs as technology costs and consumer perceptions are changing rapidly. Furthermore, most PEV policies are relatively young (Section 5.7).
- Policies to reduce the high up-front cost of PEVs and provide institutional support can promote early market growth (Section 5.7).

*Insight*: It is likely that PEV adoption can be most effectively supported through a combination of direct financial incentives, regulations and mandates, consumer awareness campaigns, and institutional support.

## 5.2 Characterization

### 5.2.1 Ultra-Light-Duty Vehicles

Motorcycles are generally defined as two- (or three-) wheeled vehicles powered by a motor and capable of carrying one or two riders. As of 2014, there are approximately 8.4 million registered motorcycles in the United States.[411] Although motorcycles are often characterized as fairly powerful vehicles, less powerful motor scooters and "motor bikes" also belong to this category. For example, motor scooters are a subgroup of motorcycles with a step-through frame and a platform for the feet. Motorcycles with engines less than 50 cc do not have to be registered but often can operate on the street. Motorized bicycles are also in this category and are generally not required to register, so motorcycle sales figures based on registration exclude these bikes.

There are already several manufacturers of electric motorcycles, including scooters, but U.S. sales currently number only a few thousand. Electric-motor assist bicycles[a] are also becoming quite numerous, though sales estimates vary. One industry estimate placed 2014 sales in the United States as high as 276,000[412] and another estimated 2013 sales at 173,000.[413]

### 5.2.2 Light-Duty Vehicles (LDVs)

**Table 5.1. Breakdown of 2014 Vehicle Stock (in Thousands)** [414]

| Vehicle Type | Cars | Trucks |
|---|---|---|
| Conventional Internal Combustion Engine (ICE) | 122,720 | 86,170 |
| Ethanol Flex-Fuel ICE | 2,970 | 10,390 |
| Hybrid Electric | 2,800 | 420 |
| Plug-in Hybrid Electric | 180 | 0 |
| Battery Electric | 84 | 14 |
| Other | 170 | 690 |
| **Total** | **128,910** | **97,690** |

*The large majority (92%) of existing cars and trucks are conventional vehicles that are powered entirely by conventional fossil fuels (some with up to 10% ethanol). Only a very small minority (0.1%) are plug-in electric vehicles (PEVs) powered by electricity from the grid.*

There currently are more than 200 million LDVs—passenger cars, minivans, crossover and sport utility vehicles (CUVs, SUVs), and pickup trucks—registered in the United States. However, definitional issues make precise numbers difficult to determine. According to EPSA Side Case (and in AEO 2015), there were 129 million passenger cars and 98 million light trucks in 2014,[415] while the Transportation Energy Data Book estimated 114 million passenger cars in 2013 and 120 million two-axle, four-tire trucks in that year.[416] The large majority of these (95% of cars and 88% of trucks) are conventional vehicles that rely entirely on internal combustion engines (ICEs) that are powered by gasoline or diesel fuels. Most of the "alternative-fuel vehicles" either are capable of using ethanol (although most of these are fueled primarily with gasoline) or are hybrid electric vehicles (HEVs), which use primarily conventional fuels and do not draw electricity from the grid. Only a small number of cars, approximately 264,000 in 2014, are

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[a] Also known as *e-bikes,* these generally allow propulsion via pedaling, pedaling plus motor assist, or motor alone.

PEVs—either BEVs or plug-in hybrid electric vehicles (PHEVs). Even fewer (approximately 14,000) trucks are PEVs. Table 5.1 displays these values.

According to EIA, LDVs consumed nearly 15 quadrillion Btu of energy in 2014, 56% of all energy consumed by transportation. Electricity accounted for a small fraction (3 trillion Btu) of that energy—roughly 0.02%.[417] There are several classifications of LDVs that utilize electricity in some form, as outlined in Table 5.2. A number following the classification (e.g., PHEV10) typically refers to the maximum electric-powered range in miles. For LDVs, the drivetrain options include pure battery electrics (electricity provides all motive power) and plug-in hybrids, where both fuel-powered engines and electric motors provide direct or indirect motive power.

Among PEVs, PHEVs that use both an engine and motor to drive the wheels have the smallest batteries—5 to 10 kWh of storage for existing models—and therefore the shortest electric range. For example, the 2015 Toyota Prius PHEV has an electric range of less than 10 miles.[a] Some PHEVs have battery capacities of about 10 to 20 kWh with electric ranges currently up to 75 miles and total (electric plus fuel-driven) ranges over 300 miles—for example, the 2016 Chevrolet Volt (53-mile electric range, 380-mile total range). These longer electric range PHEVs use only the motor to drive the wheels in most situations, with their ICEs used primarily as generators. Pure BEVs contain no ICE, and most have batteries larger than 20 kWh with EPA-rated electric ranges from 80 to as high as 265 miles according to fueleconomy.gov. The Tesla Model S has an EPA-rated range of 208 miles with a 65 kWh battery, or 265 miles with an 85 kWh battery. However, mass-market BEVs generally have ranges closer to 100 miles. For example, the 2016 Nissan LEAF has an EPA-rated range of 107 miles with a 30 kWh battery pack.[418] These ranges reflect the current state of technology; as batteries continue to improve, greater capacities and longer ranges will be achieved. This report refers to any vehicle that can be plugged in and charged by an external source as a PEV.

Despite their ability to run on gasoline, PHEVs may still electrify a very high percentage of miles driven. Idaho National Laboratory (INL) has shown that Chevrolet Volt drivers (2014 electric range of 38 miles) electrified 75% of their miles by recharging frequently (at home and, when available, at work or at public chargers).[b] [419] The 2016 Volt has a longer range (53 miles), which should increase the fraction of electrified miles. On the other hand, shorter-range PHEVs will electrify a smaller percentage of miles driven (the Ford C-Max Energi has 20 miles of electric range, and the 2015 Toyota Prius PHEV has 11 miles).[420]

However, the combination of a higher availability of public chargers in the future and the relatively short distances that most drivers travel most days may allow PHEVs to electrify a relatively large percentage of their miles even when their electric ranges are relatively short. The 2009 National Household Travel Survey showed that the average daily travel of rural and urban cars surveyed was 34.18 miles and 23.14 miles, respectively.[421] The Alternative Fuels Data Center estimates that a PHEV with 14 miles of electric range can electrify 50% of miles driven by the average driver with a daily recharge, based on data from the 2001 National Household Travel Survey.[422]

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[a] The EPA–rated range is 6 miles. This model has been discontinued, and the next version is expected to have a much longer electric range, with speculation about range varying from 15 miles up to about 30 miles.

[b] Because many of these drivers were "innovators" and "early adopters," it is not clear that mainstream purchasers would electrify the same percentage of their miles driven.

**Table 5.2. Primary Electric Classifications That Appear in This Report**

| Vehicle Type | Description | Example |
|---|---|---|
| Conventional Vehicle | Contains only an internal combustion engine (ICE) that is powered by gasoline or other fossil fuels. | |
| Fuel Cell Vehicle (FCV) | Uses the chemical reaction between hydrogen and oxygen to create electricity to power an electric motor. | Toyota Mirai, Hyundai Tucson |
| Ethanol Flex-Fuel Vehicle (FFV) | Contains an internal combustion engine that is powered by gasoline, ethanol (E85), or a mixture of the two. | Ford Focus FFV, Dodge Dart FFV |
| Hybrid Electric Vehicle (HEV) | Contains a battery and electric motor(s) as well as an internal combustion engine. The battery may be charged by the engine or through regenerative breaking to increase fuel efficiency but cannot be charged by an external source, i.e., HEVs use no grid electricity. | Honda Accord Hybrid, Toyota Prius |
| Plug-in Hybrid Electric Vehicle (PHEV) | Similar to an HEV, contains a battery, electric motor(s), and an internal combustion engine. The key distinction is that a PHEV has a larger battery and motor than an HEV and an electric range (currently) between 10 and 75 miles per charge and can also be charged by an external source. Typically, the combined electric and ICE range is over 300 miles. Some sources refer to PHEVs as only that group of plug-in hybrids that use both motors and ICE engines to drive the wheels, and which generally have short electric ranges of between 10–20 miles. In that nomenclature, vehicles that have longer electric ranges and use only the motor to drive the wheels in most driving situations are called Extended Range Electric Vehicles, or EREVs. This report uses the term PHEV for all plug-in hybrids. | Toyota Prius PHEV, Chevrolet Volt |
| Battery Electric Vehicle (BEV) | Does not contain an ICE; all power is provided by a battery that must be charged by an external source. Current BEVs have a U.S. Environmental Protection Agency (EPA) rated all-electric range between 50 and 265 miles. | Nissan LEAF, Tesla Model S |
| Plug-in Electric Vehicle (PEV) | Any vehicle that can be charged by an external source or through a plug. This umbrella term includes both PHEVs and BEVs. | |

A potential long-term roadblock to PHEVs is the cost of their dual drivetrains; some estimates project PHEV costs to remain significantly more expensive than ICE drivetrains even with projected battery cost reductions.[423] If this barrier could be overcome, prospects for significant increased market shares of these vehicles would improve considerably.

Although electric cars were introduced to the United States in 1890, and for a time afterwards electric cars were strong competitors to gasoline-fueled cars, the 2010 introduction of the Nissan LEAF (a BEV) and Chevrolet Volt (a PHEV) represented a new start for mass-market EVs. There are currently about 25 plug-in electric models available and, as of 2014, LDV stock of roughly 280,000 PEVs in the United States.[424] Virtually all of these vehicles are passenger cars, with CUV models recently introduced and no mass-produced electric passenger vans available. Some additional automakers are planning to introduce mass-market BEVs with a 200-mile range in the near future. For example, Chevrolet has stated it will introduce a 200-mile range crossover, the Bolt, in 2016 (as a 2017 model year vehicle). Appendix Table 7.9 lists the mass-market PEVs that are currently available for purchase, along with their fuel efficiencies.

### 5.2.3 Medium- and Heavy-Duty Vehicles

Freight trucks (greater than 10,000 pounds) are by far the largest freight carrier in the United States in terms of total tons carried. Freight trucks and rail are approximately equal in terms of ton-miles carried—1,247 billion ton-miles for trucks versus 1,212 billion for rail.[425] According to the 2012 Commodity Flow Survey, for freight carried by a single mode, trucks carried 8,060 million tons compared to rail's second-place 1,629 million tons.[426] Multimodal flows were much smaller, with combined truck and rail carrying only 213 million tons.[427] However, rail tends to dominate in transport of raw materials (especially coal), which often is shipped very long distances.

Freight trucks drove 268 billion vehicle miles in 2013, about 10% of LDV miles, but consumed 5.51 quads of energy, more than 33% as much energy as LDVs.[428] The largest of these trucks—Class 7 and 8 combination trucks (trucks with trailers)—account for about 2.4 million vehicles and 168 billion vehicle miles in 2013.[429] This large increase from 905,000 vehicles and 35 billion vehicle miles traveled (VMT) in 1970[430] was likely largely driven by economic growth. This class of trucks was also responsible for two-thirds of total freight truck energy use, with all single-unit (Class 3 through 8) trucks consuming the rest.[431]

Class 7 and 8 combination trucks drove an average of about 75,000 miles each in 2014, or about 250 miles per day assuming 300 driving days per year. Electrifying these trucks with current or readily foreseeable battery technology would be impossible without a massive network of fast chargers and willingness to stretch delivery schedules to allow several charging stops per day. However, for shorter-haul trucks, it may be possible to use a version of PHEV technology with diesel generators to electrify some of a truck's miles. FedEx has reportedly tested such a system.[432]

The only type of electrification that is being actively pursued for long-distance heavy trucks is for idle reduction. Drivers of long-haul trucks often idle their engines during rest stops or while waiting for delivery, with total idling losses estimated as high as 5% of total freight truck energy consumption.[433] One option to reduce idling is electrification of truck heating and cooling equipment combined with plug-in equipment at rest stops, or special equipment at rest stops that provide heating and cooling (as well as entertainment) services. Other options include a variety of onboard devices (e.g., auxiliary power units) that burn fuel, but at a much lower rate than the truck's engine.

Smaller trucks for freight hauling—delivery vans and smaller single-unit trucks (class 2 light-duty trucks, gross vehicle weight 6,001 to 10,000 lb., and classes 3 through 6 medium-duty trucks, gross vehicle weight 10,001 to 26,000 lb.)[a]—may be targets for electrification. Shifts in retail sales toward the Internet require considerable changes in goods delivery. Online retailers like Amazon are establishing multiple

[a] Typical vehicles are: Class 2, Ford F-250 pickup; Class 3, Ford F-350; Class 4, Dodge Ram 4500; Class 5, GMC 5500; and Class 6, Ford F-650.

distribution centers that ship goods fairly short distances. FedEx and UPS, as well as the U.S. Postal Service, have tested plug-in delivery vehicles (as well as hybrid electric and natural gas vehicles). Data on VMT and energy use for vehicles in these size classes are not readily available. Table 5.3 shows vehicle sales for smaller trucks. There currently is essentially zero penetration of electrified heavy-duty vehicles.

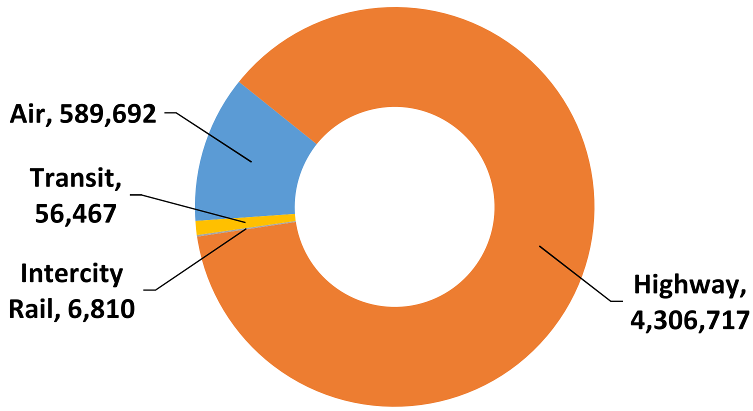
**Table 5.3. New Retail Truck Sales by Gross Vehicle Weight, 2000–2014 (in Thousands)[434]**

| Calendar Year | Class 2 6,001–10,000 lb. | Class 3 10,001–14,000 lb. | Class 4 14,001–16,000 lb. | Class 5 16,001–19,500 lb. | Class 6 19,501–26,000 lb. | Class 7 26,001–33,000 lb. | Class 8 ≥ 33,001 lb. | Total |
|---|---|---|---|---|---|---|---|---|
| 2000 | 2,421 | 117 | 47 | 29 | 51 | 123 | 212 | 8,965 |
| 2001 | 2,525 | 102 | 52 | 24 | 42 | 92 | 140 | 9,050 |
| 2002 | 2,565 | 80 | 38 | 24 | 45 | 69 | 146 | 9,035 |
| 2003 | 2,671 | 91 | 40 | 29 | 51 | 67 | 142 | 9,357 |
| 2004 | 2,796 | 107 | 47 | 36 | 70 | 75 | 203 | 9,793 |
| 2005 | 2,528 | 167 | 49 | 46 | 60 | 89 | 253 | 9,777 |
| 2006 | 2,438 | 150 | 50 | 49 | 70 | 91 | 284 | 9,268 |
| 2007 | 2,623 | 166 | 51 | 45 | 54 | 70 | 151 | 8,842 |
| 2008 | 1,888 | 135 | 36 | 40 | 39 | 49 | 133 | 6,680 |
| 2009 | 1,306 | 112 | 20 | 24 | 22 | 39 | 95 | 5,145 |
| 2010 | 1,513 | 161 | 12 | 31 | 29 | 38 | 107 | 6,137 |
| 2011 | 1,735 | 195 | 10 | 42 | 41 | 41 | 171 | 6,951 |
| 2012 | 1,811 | 223 | 9 | 55 | 40 | 47 | 195 | 7,544 |
| 2013 | 2,077 | 254 | 12 | 60 | 47 | 48 | 185 | 8,298 |
| 2014 | 2,275 | 264 | 13 | 67 | 52 | 54 | 220 | 9,154 |

### 5.2.4 Public Transit

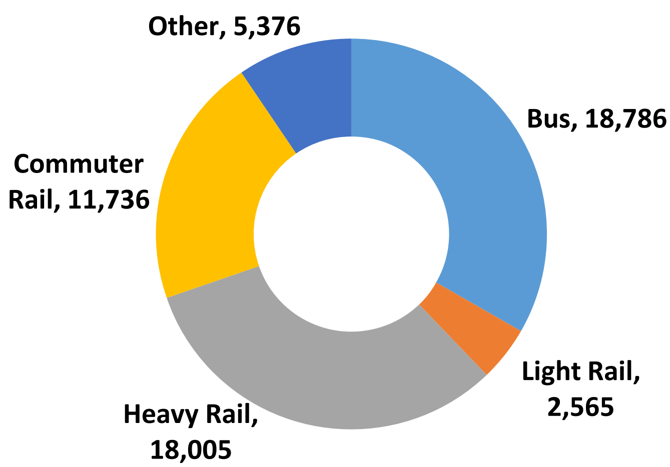
All public transit modes together provided 56.5 billion passenger miles (p-mi) in 2013, which is 1.1% of U.S. passenger travel in that year (Figure 5.1).[435] The preponderance of transit service came from heavy rail systems (18 billion p-mi), commuter rail (12 billion p-mi), and buses (19 billion p-mi); light rail systems (2.6 billion p-m) and trolley buses (0.2 billion p-mi) played minor roles (Figure 5.2).[436] Table 5.4 shows the multiple power sources of the U.S. transit system as of January 2014. Electricity is virtually the sole power source for light and heavy rail transit and trolleybus. Commuter rail systems with self-propelled cars are also essentially fully electric, but many commuter rail systems use traditional locomotives pulling unpowered cars. Aside from trolleybuses, which are dominantly electric but use some diesel for off-wire operation, non-rail transit (primarily bus systems) is powered by gasoline, diesel, and natural gas, with electricity providing only 0.1% of total energy.

**Figure 5.1. U.S. passenger miles by mode in 2013 (in millions)**[437]




*Highway travel accounts for the majority (87%) of passenger miles traveled in the United States, with air travel accounting for most of the remainder.*

**Figure 5.2. Breakdown of U.S. transit passenger miles (p-mi) for 2013 (in millions)**[438]




*Overall, rail travel accounts for 32,306 million of the 56,467 million p-mi traveled for transit, or 57% of the total.*

**Table 5.4. Vehicle Power Sources by Mode of Transportation, Public Transit Only, as of January 2014**[439]

| Public Transportation Mode | Electricity | Diesel or Gasoline | Hybrid | Other |
|---|---|---|---|---|
| Bus | 0.1% | 57.2% | 17.5% | 25.1% |
| Commuter Bus | | 97.8% | | 2.2% |
| Commuter Rail (Self-Propelled Cars) | 96.5% | 3.5% | | |
| Commuter Rail (Locomotives) | 4.1% | 95.9% | | |
| Demand Responsive Transit | | 82.4% | 1.9% | 15.6% |
| Ferryboat | | 60.5% | 39.5% | |
| Heavy Rail | 100.0% | | | |
| Hybrid Rail | | 100.0% | | |
| Light Rail | 100.0% | | | |
| Other Rail | 46.7% | | | 53.3% |
| Streetcar | 100.0% | | | |
| Transit Vanpool | 0.5% | 83.0% | | 16.6% |
| Trolleybus | 94.2% | | | 5.8% |

*Demand Responsive Transit is defined as "roadway service directly from an origin to a destination determined by the rider and not following a fixed-route."*

### *Buses*

There are approximately 72,000 transit buses in service in the United States (not including intercity and shuttle buses), virtually all of them fueled by gasoline, diesel, and natural gas.[440] In 2013, motor buses provided nearly 19 billion p-m of service.[441] Total transit bus energy use in 2014 was 107 trillion Btu, about 0.4% of total transportation energy use.[442]

Electric transit buses can either use overhead wires (trolleybuses) or onboard batteries for power. Trolleybuses are in common use in San Francisco but not elsewhere in the United States, and it seems unlikely that this will change. Battery electric buses are relatively new in the United States, with most serving as shuttle buses in airports. Some transit agencies use them in regular service—e.g., Foothill Transit in suburban Los Angeles. However, with current battery technology, most have short ranges—as low as 30 miles—that require frequent recharges. Some recent models by BYD and Proterra have ranges of 150 miles or more.[443] These buses offer the potential for electric buses to satisfy daily urban service without long pauses for charging, or even rural service with perhaps one charging event during service hours.

Another bus option, recently in service in China, uses ultracapacitors for power. These can store only modest amounts of electricity but can be recharged in a few minutes. The buses recharge at station stops every few miles by inserting a probe into an outlet. An alternative option, not yet introduced, is a bus with batteries plus ultracapacitors, enabling rapid recharging at stations to increase range.

Purchase costs for buses vary widely because of differences in size, features (including wheelchair and handicapped accessibility), and performance. Thus, data for identical buses are not readily available. Typical diesel-powered buses for transit service cost roughly $450,000; hybrid buses cost at least $100,000 more, and electric buses cost nearly twice as much.[444] Transit services contemplating the use of electric buses must account for charging station costs and scheduling issues associated with required charging times. Buses with greater electric range now becoming available will greatly reduce or eliminate this latter issue for most urban transit routes, as they could operate all day on a single charge and therefore would only be charged overnight. Also, electric buses will save large amounts on fuel and potentially on maintenance costs as well.

*Rail*

Transit rail systems, including both heavy and light rail, are virtually solely electrically powered. These systems are typically bidirectional at all times and operate primarily within urban centers, e.g., the Metro in Washington, D.C. There are 15 heavy rail systems in the United States, 5 hybrid rail systems, and 24 light rail systems.[a] [445] Heavy rail systems had 10,389 rail cars and nearly 2,300 miles of track in 2013, hybrid systems had 59 cars, and light rail systems had 2,054 cars and about 1,500 miles of track.[446] In 2013, transit rail consumed 16 trillion Btu of electric energy.[b] [447]

Commuter rail systems in 2013 included about 7,300 rail cars and 8,400 track miles.[448] Commuter rail systems use both electric and diesel locomotives. In contrast to transit rail, commuter rail systems tend to be heavily unidirectional, designed to serve suburban commuters heading into and out of the urban core, e.g., the MARC train that services Maryland and Washington, D.C. Commuter rail energy use in 2013 was 6.2 trillion Btu of electricity and 12.9 trillion Btu of diesel fuel.[449] In 2013, intercity rail service provided 6.8 billion p-mi of service, a little more than 0.1% of total U.S. p-mi traveled.[450] As opposed to transit and commuter rail systems, which typically serve a single metropolitan area, intercity rail systems provide service between major cities, e.g., the Amtrak or Acela trains with service between Washington, D.C., and New York City. Most intercity rail uses diesel locomotives. In 2014, electricity provided only 1.93 trillion Btu out of a total 19.29 trillion Btu of energy consumed by the intercity rail system, or roughly 10% (the electrified share of p-mi was higher, given the greater efficiency of that service).[451]

### 5.2.5 Freight Rail

Class I freight railroads consumed 466 trillion Btu in 2014, about 2% of total transportation energy use.[452] Essentially all of that energy was attributed to diesel locomotives, most with diesel-electric hybrid powertrains. Class I freight railroads operated 25,000 locomotives and 374,000 freight cars in 2013.[453] This represents a large shift away from rail and toward trucks over the past several decades, as there were 1,424,000 freight cars in operation in 1970—signaling a drop in freight car ownership of 74% during this period.[454]

Although several freight lines conducted studies of rail electrification in the 1980s and 1990s, a number of factors have stifled industry interest in electrification, including:[455]

- High capital costs of electrification and required system upgrades
- The need to replace signal systems
- Private ownership of freight rail systems
- Resulting limited density of freight operations on multiple routes
- Incompatibility of electric locomotives on non-electrified segments of track
- Moderated diesel fuel prices

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[a] Systems that combine diesel electric powertrains with a battery, allowing them to recapture braking energy.

[b] Assuming 3412 Btu/kWh; note that the total primary energy used to produce this electricity is larger by about a factor of 3 due to conversion and distribution losses.

However, rail electrification has several advantages, including more powerful locomotives, reduced maintenance of locomotives, and greatly reduced energy costs. Although private freight rail lines appear unlikely to electrify on their own, some combination of public incentives and requirements might stimulate electrification.

### 5.2.6 Charging Infrastructure

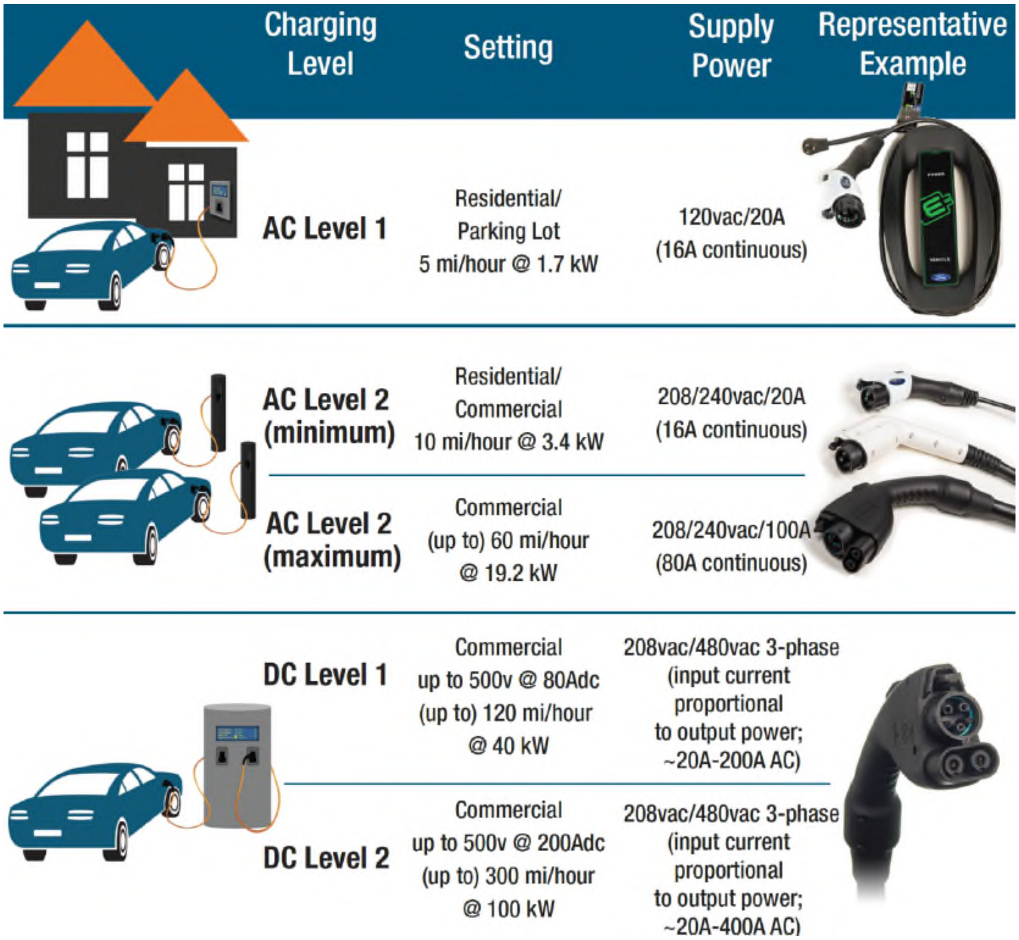
BEVs can use two types of charging infrastructure: (1) chargers for long-term charging at homes, in residential parking garages, or depots for buses and other vehicles and (2) public or workplace chargers that allow such vehicles to gain extra range when away from their home charger. Public chargers are open to all users while private chargers are limited to select vehicles. The relative importance and utilization of these resources will depend on the characteristics of individual PEV owners. For example, some households may use a BEV primarily for short trips to and from their home, while maintaining a separate vehicle for longer range travel. In this case the availability of pubic charging infrastructure may be less of a priority. On the other hand, for households that plan to maintain a BEV as their sole vehicle or that require all their vehicles to be multi-functional, the widespread availability of public charging infrastructure with short recharge times may be an essential consideration. There are three basic types of chargers (Figure 5.3):

- AC Level 1 chargers operate at ordinary U.S. current, 120 V AC. They can use extension cords or a protected charging device that connects to an ordinary socket on a dedicated electrical circuit. Most PEVs come with a cordset for Level 1 charging. One hour of Level 1 charging will add 2 to 5 miles of electrical range to a PEV.[456]

- AC Level 2 chargers operate at 240 V AC for home installations (208 V AC for commercial installations). These chargers require a separate charging installation and a dedicated circuit of up to 100 amperes, or amps (for high power commercial installations). Operation at 30 amps, which is typical for residential chargers, will deliver 7.2 kW of power; operation at 80 amps will deliver 19.2 kW. AC Level 2 charging adds about 10 to 20 miles of electrical range per hour. Future, higher-power AC Level 3 charging (up to 130 kW) will be possible using three-phase power at commercial and industrial locations.[457]

- DC Fast Chargers operate at up to 500 V DC and most can add 50 miles of range in about 20 minutes.[458] Tesla Motors states that its Supercharger can add up to 170 miles of range to a Tesla Model S in 30 minutes.[459] PEVs require special on-board connectors and charging equipment circuits to use such stations. Unlike AC Level 1 and 2 chargers, which have a common standard connector in the United States, SAE J1772, there are three competing couplers (connectors) for DC fast chargers: CHAdeMO and SAE J1772 Combined Charging System (CCS or Combo) couplers and the Tesla Super Charger connection. Over 500 U.S. charging stations use the CHAdeMO coupler. The SAE J1772 CCS design allows a single coupler to be used for AC Level 1 and 2 and DC fast charging, eliminating the need for two separate charge connectors on a vehicle, one for AC charging and one for DC charging.[460]

**Figure 5.3. Summary of the primary vehicle charging station categories**[461]



| Charging Level | Setting | Supply Power | Representative Example |
|---|---|---|---|
| AC Level 1 | Residential/ Parking Lot 5 mi/hour @ 1.7 kW | 120vac/20A (16A continuous) | |
| AC Level 2 (minimum) | Residential/ Commercial 10 mi/hour @ 3.4 kW | 208/240vac/20A (16A continuous) | |
| AC Level 2 (maximum) | Commercial (up to) 60 mi/hour @ 19.2 kW | 208/240vac/100A (80A continuous) | |
| DC Level 1 | Commercial up to 500v @ 80Adc (up to) 120 mi/hour @ 40 kW | 208vac/480vac 3-phase (input current proportional to output power; ~20A-200A AC) | |
| DC Level 2 | Commercial up to 500v @ 200Adc (up to) 300 mi/hour @ 100 kW | 208vac/480vac 3-phase (input current proportional to output power; ~20A-400A AC) | |

*Level 1 chargers can be integrated with a standard outlet, while Level 2 chargers require additional equipment. DC chargers are primarily used in commercial applications where rapid charging is an important priority. Other research found that home charging accounted for more than 80% of total energy transfers to PEVs by private owners* [462] *However, this fraction is decreasing over time as the availability of public chargers increases.*

Federal, state, and local governments have made a vigorous effort to roll out public charging networks, and a number of firms have promoted workplace charging as well as charging stations at retail shopping locations. Table 5.5 shows an estimate of the public and private chargers (not counting residential chargers for home use) currently available; availability of such chargers is increasing rapidly.

**Table 5.5. Number of Public and Private PEV Charging Stations in the United States**[463]

| | Stations | Outlets |
|---|---|---|
| Public | 12,543 | 31,363 |
| Private | 2,426 | 4,965 |

*Figures do not include residential chargers for home use.*

Although virtually all current charging systems use a cable connector, it is possible to charge wirelessly using an electromagnetic field. Some new charging systems use this "inductive charging," avoiding the need to physically plug vehicles into a charger. There are already a number of inductive (wireless) EV charging systems on the market, but most current offerings are relatively low power. Automakers such as Nissan, Toyota, Hyundai, and BMW currently are pursuing higher-power inductive charging options, as high as 22 kW; however, these are not yet commercially available.

Deployment of residential charging stations in rural and suburban areas is relatively straightforward because a large proportion of dwelling units are capable of co-locating vehicle parking and electrical access at moderate cost. In urban areas, developing successful residential charging networks is more complicated because PEV owners are likely to demand the ability to charge their vehicles at locations close to their residences and to access chargers at their convenience. This may be difficult to achieve in densely populated urban areas where many residences do not have a garage or an assigned parking place. This is also an environment where land is both expensive and scarce, and construction costs for charging stations will likely be high.

An extensive network of public charging stations can help to allay "range anxiety," the concern that a (pure battery electric) vehicle will lose its charge before reaching a desired destination, and to make such vehicles practical for longer trips. New business models have to be developed for these stations, but they cannot fully take the place of home charging. Although chargers are not capital intensive, land costs can be high, especially considering that even rapid charging can take a minimum of 20 minutes per vehicle. This may present an opportunity for business owners to recoup infrastructure investment through the increase in sales of goods and services, by adapting the current gasoline station model where the majority of profits are not realized from the direct sale of the fuel, but from the sale of consumables in the gasoline station. In the early years of PEV deployment, public charging stations may be underutilized, and the availability of home recharging will keep their utilization rather low even after significant numbers of PEVs are on the road.

Exacerbating the challenge, long-range travel is highly variable temporally and, given long charging times, major delays in accessing a charger could be a problem during peak travel periods unless substantial excess charging capacity is available. Also, extreme weather can greatly affect demand for public charging because high and low temperatures will both reduce PEV range and increase charging time.[a] Further study is warranted to better understand the relationship between charging infrastructure availability and PEV adoption rates.

Upgrades to the current electrical grid can help to support large-scale deployment of PEVs. In particular, many local distribution substations and feeders may need to be upgraded to be able to handle increased PEV charging loads required by AC Level 2 chargers and DC chargers. Many utilities are in the process of implementing optional time-of-use pricing programs that provide consumers with lower-cost electricity during periods of low demand and excess supply. These programs can be complemented by outreach and education to consumers to encourage them to achieve maximum cost savings by recharging during off-peak periods. Smart grid enhancements may also help improve the overall business case for EVs by allowing them to provide ancillary services to the grid, for example, by providing battery storage to smooth demand fluctuations. The section on Interactions with Other Sectors (Section 5.5) discusses these issues in more detail.

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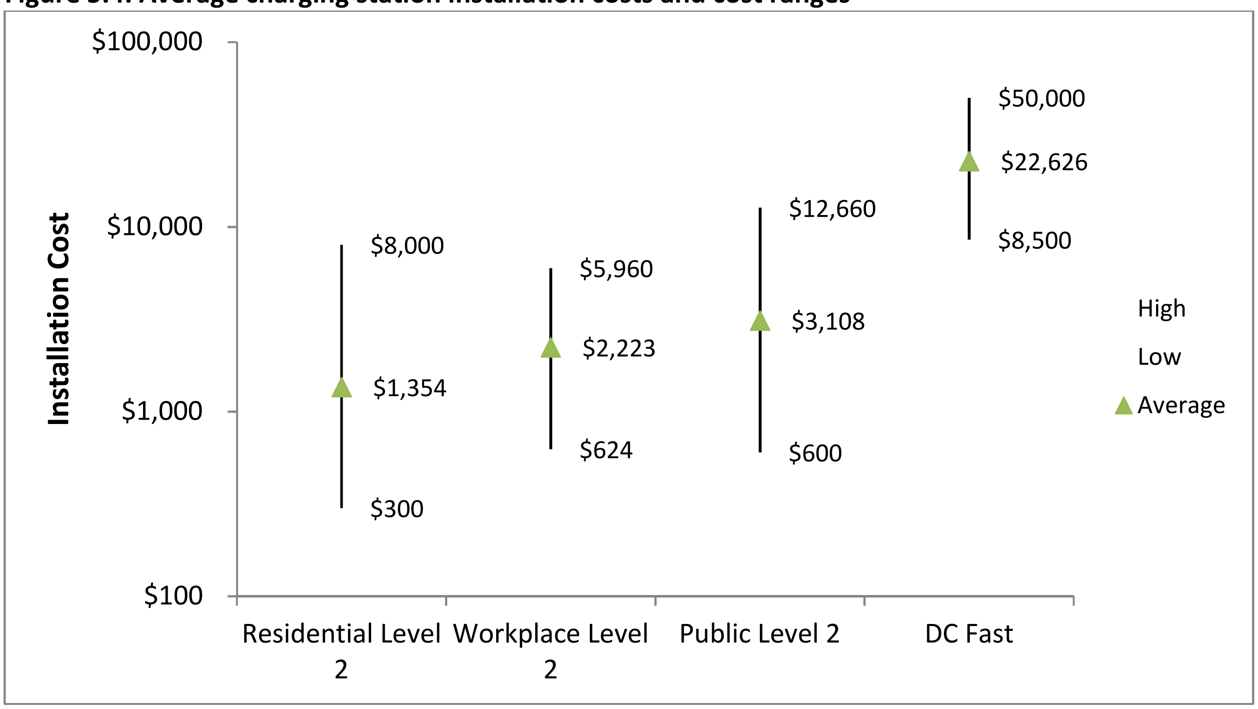
[a] American Automobile Association tests showed range reductions for 105-mile-range BEVs (at 75°F) to 43 miles at 20°F and 69 miles at 95°F; for fast charging, the LEAF owner's manual projects an increase from 30 to 90 minutes under cold temperatures and to 60 minutes under hot temperatures.

Charging station costs are highly variable and hard to predict due to permitting requirements that change with location, differences in accessibility of required electric service (for example, whether existing concrete must be removed and replaced to access electrical circuits), different features, and other factors (Figure 5.4). Also, costs have dropped over time, and equipment cost projections that are a few years old can be considerably higher than current projections. Currently, AC Level 2 home charging stations are available for as little as $500, with additional costs for installation and, if necessary, for installing a 240 V circuit. Public AC Level 2 stations are generally more expensive, as they require equipment to process payments (unless charging is free) and often require increased installation costs. Charger costs range from $2,300 to $6,000, but installation can be much more expensive.[464 465] Garage chargers can be wall-mounted, and installation may cost only a few thousand dollars, especially if wires can be wall-mounted (inside a protective cover). Chargers located next to on-street parking spaces will likely be located on pedestals, must be weather resistant, and may require extensive concrete work to connect the charger to the nearest breaker box. In both cases, co-location of multiple chargers will probably require upgrades to wiring, breaker boxes, and possibly also the local transformer. Workplace installations of AC Level 2 chargers have had lower average costs than public installations due to increased flexibility in installation locations.

DC fast chargers, particularly those with higher capacity, can cost far more than AC Level 2 chargers. If a new transformer is required, this can add $10,000 to $20,000 to the cost. Permitting is also expensive, possibly up to $10,000. Other installation costs are likely to be similar to those of AC Level 2 stations.

**Figure 5.4. Average charging station installation costs and cost ranges[466 467 468]**



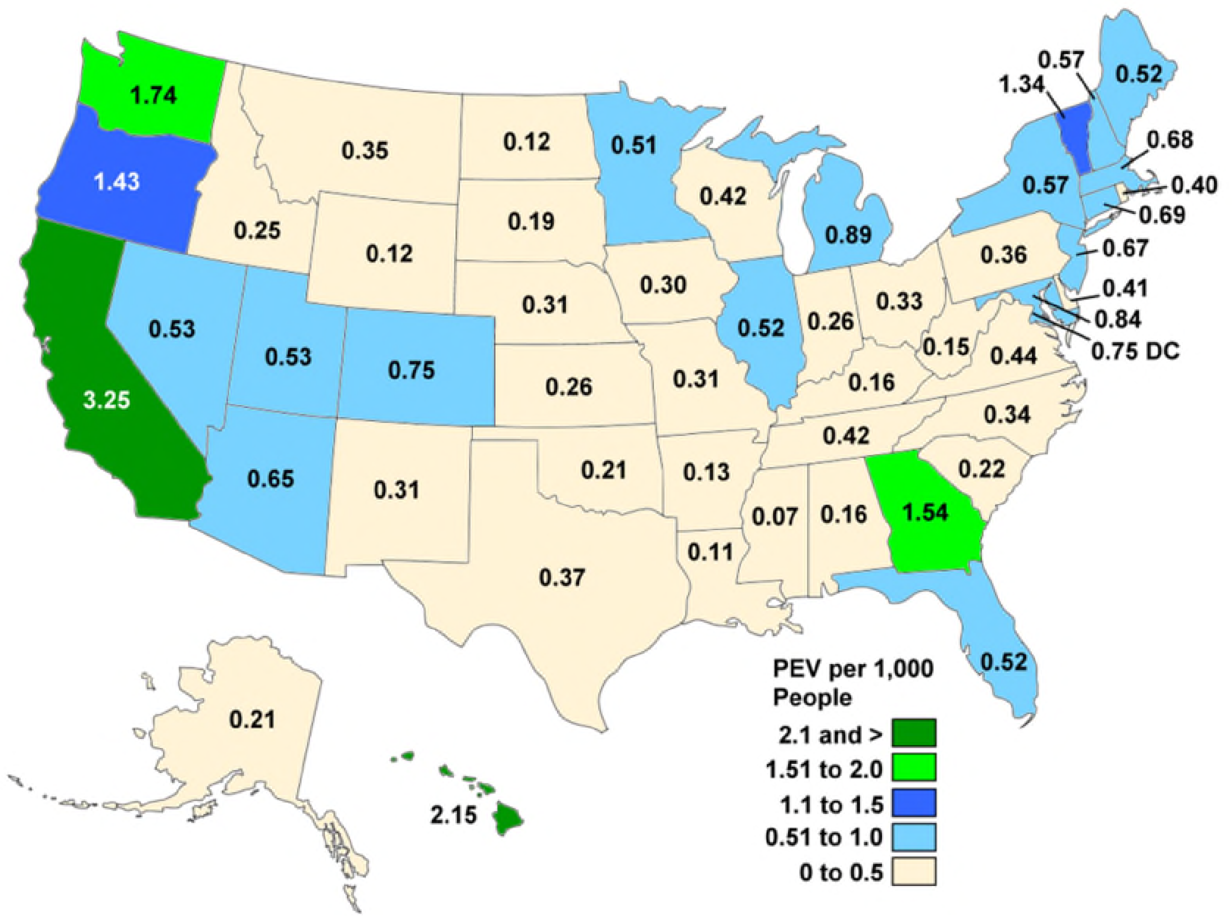

*Data are from the DOE EV Project and ChargePoint America Project, which together installed almost 17,000 Level 2 charging stations and over 100 DC fast-charging stations between 2011 and 2013.*

## 5.3 Metrics and Trends

### 5.3.1 Number and penetration of EVs

The first two mass-market PEV models, the Chevrolet Volt and the Nissan LEAF, were introduced into the U.S. market in December 2010, and 387,595 PEVs had been sold as of November 2015. Among these vehicles, 199,425 are BEVs and 188,337 are PHEVs. The PEV share of total car sales is about 1.4%, made up mostly by subcompacts, compacts, and large cars.[469] Because of the success of the large Tesla Model S sedan, and the sales dominance of the mid-size LEAF, BEVs are larger on average than PHEVs, which are primarily compacts and subcompacts. The fact that compliance BEVs[a] have been introduced in only a few states suggests a cost minimization strategy by many automakers. The general success of plug-in vehicles can be attributed primarily to shared success of multiple, nationally marketed models—the Plug-in Prius, the two Ford Energi PHEVs, the Volt, the LEAF, and the Tesla Model S.

**Figure 5.5. PEV registrations per 1,000 people by state in 2014[470]**




*California has the highest PEV penetration of any state, followed by Washington, Oregon, and Georgia. PEV penetrations are generally highest on the West Coast and Northeast, and lower in Central and Southern states.*

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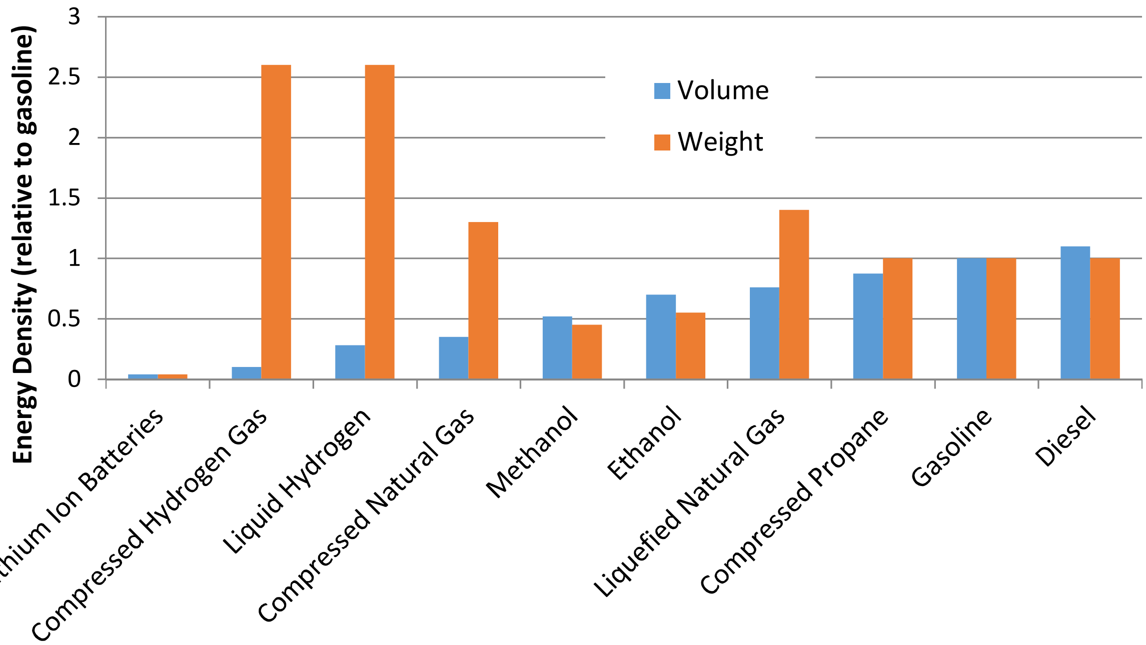
[a] Some states, California most notably, require that a certain fraction of all vehicles sold by all large automakers are zero-emissions vehicles. So-called "compliance vehicles" are primarily introduced to comply with such mandates and are not necessarily intended to be profitable themselves or to gain market share organically. They typically involve the conversion of an existing conventional model by replacing the engine with a battery pack, as opposed to development of a new PEV-specific model such as the Volt or LEAF.

### 5.3.2 Battery Technologies

Figure 5.6 compares energy densities of various transportation fuel types, revealing a primary challenge facing electricity use in vehicles that are not directly linked to the electric grid (all vehicles except electrified rail vehicles and trolleybuses). Lithium-ion (Li-ion) batteries, the most energy-dense, commercially available vehicle batteries, have energy densities that are a small fraction of the most common automotive fuels. Consequently, the electric range of PEVs will be constrained until next-generation battery technologies with increased energy density can be developed and commercialized. This is most constraining for BEVs, most of which have ranges near or below 100 miles. PHEVs avoid this range constraint but must deal with dual drivetrains, which add to cost.

**Figure 5.6. Relative energy densities of various transportation fuels[471]**




*Lithium-ion batteries, which are used in essentially all electric vehicles, have energy storage densities that are roughly 20 times lower than conventional gasoline and diesel fuel. Higher energy densities are more favorable. Increasing the travel range of a BEV requires that its weight be increased significantly as well, thereby reducing its efficiency, all other design features being equal. Data does not consider weight of storage tanks or other equipment that the fuels require.*

Batteries currently account for a quarter or more of the purchase cost of PEVs[a], but battery prices have dropped substantially in recent years. This is particularly the case for larger battery packs. Santini has estimated costs for large battery packs to be about $300/kWh, assuming a 1.5 price/cost factor.[472] McKinsey has estimated that battery pack costs for 2025 will be $160/kWh; the same 1.5 price/cost factor would yield a $240/kWh retail price equivalent for 2025. These projections are relatively close to the cost target that has been established by DOE's Vehicle Technologies Office (VTO)—$125/kW by 2022.[473] As battery costs continue to decrease, PEVs will become increasingly cost-competitive with comparable conventional vehicles.

[a] Batteries make up a greater fraction of total costs in longer-range vehicles, e.g., the batteries in forthcoming 200-mile-range BEVs will likely account for a significantly higher percentage of cost than the current generation of BEVs with roughly 100 miles of range.

### 5.3.3 Charging Infrastructure Technologies

A robust charging infrastructure is also an important enabler of increased market adoption of PEVs, and more specifically, BEVs. While many potential PEV purchasers can have easy access to home recharging through installation of chargers in home garages or garages in multi-family residences, public charging networks will also be necessary to allay range anxiety and to allow longer trips with BEVs. Although multiple organizations are building public chargers, currently there are only 30,000 or so public chargers available, most requiring hours for a single recharge. Even with fast chargers, recharging time is 30[a] minutes or more,[b] and that assumes the charger is not already in use. These issues may limit PEV growth in the near term, but such limitations can be reduced by increased investments in new charging infrastructure and in the development of higher- power batteries that can be charged more quickly.

### 5.3.4 Market Trends

Despite concerns about battery performance and charging infrastructure, other factors might argue for an optimistic future for vehicle electrification. First, despite the range limitations of BEVs, surveys of travel patterns show that even current BEVs can satisfy the great majority of travel requirements. The 2009 National Household Travel Survey showed that the average daily travel of rural and urban cars surveyed was only 34.18 miles and 23.14 miles, respectively.[474] PEVs may be particularly attractive for multi-vehicle households, which could also maintain a conventional vehicle. The PEV could then be used for shorter daily trips, with the conventional vehicle as an option for longer distance travel. With the proliferation of multi-vehicle households (in 2010, about 57% of all households had two or more vehicles)[475] and the availability of car-sharing services (as well as rental cars) that could be used for longer trips, the potential for many households to own at least one PEV is clear. Also, automakers are about to launch mass-market vehicles with 200-mile ranges, which will satisfy a much greater percentage of travel needs. The primary missing enabling factors are an inexpensive energy- (and power-) dense battery and a robust network of fast chargers. However, it is not yet clear whether mainstream consumers will accept 20- or 30-minute charging times, even if fast charging is required only occasionally, nor is it yet clear what portion of multi-vehicle households will accept vehicles that do not have full functionality for longer trips.

## 5.4 Technologies and Strategies

Successful electrification of transportation will require further development of several key technologies and systems, especially the following:

### 5.4.1 Energy Storage Costs

Current-generation Li-ion batteries are too expensive for EVs to be fully cost-competitive with comparable mass-market conventional vehicles. However, the high power capabilities of long-range Li-ion battery packs (e.g., those in the Tesla Model S) have driven success in the luxury/performance market. Accordingly, EVs are holding a sustainable minority share in this market. Major reductions in energy storage costs for Li-ion technology are needed for PEVs to gain substantial mass-market share. Successful development of next-generation battery chemistries, in particular lithium air (see Section 5.4.5), would help more cost-effective PEVs to gain market share, although long recharge times could remain a significant barrier.

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[a] Usually to about 80% state of charge.

[b] As noted previously, charging time can double or triple at extreme temperatures.

### 5.4.2 Vehicle Load Reduction

PEV range, which is crucial to market success, is a function primarily of battery energy capacity and vehicle loads—vehicle weight, aerodynamic and tire losses, and heating and cooling loads (and other accessory losses, e.g., lighting). Minimizing these loads will allow both added range and improved performance. The efficiency of the electric drivetrain is also important to range and performance (e.g., minimization of electric motor losses and transmission losses).

### 5.4.3 Charging Technologies

Development of a robust charging infrastructure is an important component of the development of a successful PEV marketplace. AC Level 1 chargers use normal (120 V) house current; AC Level 2 chargers use higher voltage (240 V), generally used for electric clothes dryers and stoves; and DC Level fast chargers operate at even higher voltage (typically 208/480V AC three-phase input). Multiple manufacturers have developed new charging systems, and prices have dropped dramatically. Efforts are also underway to develop inductive "wireless" charging technologies that would allow PEVs to receive an electric charge while in motion.[476]

### 5.4.4 Standards

Standards must be rigorously implemented and updated for vehicle systems (especially to ensure safety for mechanics and first responders) and charging systems. Interoperability is highly desirable to ensure that vehicles can recharge at any charging station available. Unfortunately, there are three different and incompatible fast-charging technologies currently in use for vehicles.[a] Consolidation of these into one standard will help speed market adoption of PEVs.

### 5.4.5 Batteries

The vehicle battery pack represents the crucial technology for PEVs, currently representing at least 25% of total vehicle cost and largely determining vehicle range. Modern PHEVs and BEVs use Li-ion battery packs. Aside from continuing improvements in manufacturing techniques, pack designs, and supply chain management, and growing economies of scale as battery manufacturing ramps up, there are multiple opportunities to improve Li-ion technology—or to explore other battery chemistries—to reduce costs, increase battery-specific energy (the ability to store electrical energy, measured in kilowatt-hours per kilogram, or kWh/kg) and power (kilowatts per kilogram, or kW/kg), lengthen battery lifetimes, and improve safety. The following are several potential approaches:

- Improving Li-ion batteries, which is the subject of an intensive R&D campaign by private industry and government laboratories. Approaches being pursued by the Center for Electrochemical Energy Science (Northwestern University, University of Illinois at Urbana-Champaign, and Argonne National Laboratory) include:
  - Using silicon anodes protected by graphene[b] to prevent cracking of the anode as it expands and contracts

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[a] The three are: the Japanese CHAdeMO standard; SAE's Combo Charging System (CCS); and the Tesla Supercharger system. China has also proposed its own system (GB). Each has different couplers, so vehicles with one type of coupler cannot use another system without an adapter.

[b] Graphene is a two-dimensional sheet of carbon, one atom thick, in a honeycomb pattern, which has incredible strength.

- Using lithium-manganese-oxide cathodes protected by graphene to prevent the manganese from dissolving
    - Exploring other materials and coatings for the cathode
    - Substituting block copolymers to replace lithium
    - Using waste silicon powder (from chip making) in battery manufacture at lower cost

- Using solid-state batteries to replace the liquid electrolyte with a solid, which would eliminate leakage, greatly reduce fire danger, and reduce temperature sensitivity and cooling requirements.
- Adopting aluminum-ion batteries using an aluminum anode.
- Using lithium-sulfur batteries, which have higher theoretical energy density than Li-ion batteries and should be cheaper. A key research aim is to improve their ability to cycle.
- Reducing battery weight by using metal-air batteries, including lithium air, which have metal anodes and use air as a cathode. Lithium-air batteries offer theoretical energy densities of 5,000 watt-hours per kilogram (Wh/kg), compared to about 100-200 Wh/kg for Li-ion batteries.[477] Gasoline's energy density is about 13,000 Wh/kg.[478] At 5,000 Wh/kg, the Tesla model S 250-mile (85 kWh) battery pack, which weighs 1,200 pounds, would weigh about 37 pounds. However, the achievable energy densities of metal-air batteries will certainly be significantly lower than the theoretical level, probably less than ten times the energy density of Li-ion storage. However, even at an energy density multiple of three or five, these batteries could transform the prospects for EVs if they were affordable and capable of rapid recharge. There remain several major challenges to developing successful lithium air batteries, including preventing blockage of the cathode, damage from water vapor, low electrical efficiency, and long-term stability.

With long time frames for introducing new battery chemistries, improvements in Li-ion batteries may be the crucial determinant of PEV success for the foreseeable future. Multiple research teams sponsored by national governments and private industry are striving to decrease costs, increase safety (Li-ion batteries have fire safety issues[a]), increase longevity, allow more rapid recharging, and maximize specific energy.

The extent to which these technical advances, economies of scale, and "learning through doing" are able to drive down battery prices is a key arbiter of PEV success. The DOE target for battery pack costs is $125/kWh, which is meant to represent the point where plug-in vehicles are competitive with ICE vehicles. However, recent economic evaluations have concluded that pack costs of $250/kWh represent a breakeven point at gasoline prices of $3.00–$4.50/gallon.[479]

Tracking actual costs of battery packs is difficult for a number of reasons, including: (1) the multiple battery chemistries and cell and pack designs being manufactured, (2) industry secrecy, (3) possible direct cost reduction incentives from battery pack and vehicle manufacturers intent on gaining market share, (4) different definitions of battery capacity (both total kWh and "available" kWh[b] are used, but this is not always specified), and (5) different definitions of manufacturer costs, which are not always carefully explained in industry statements and literature. An analysis of more than 80 cost estimates by Nykvist and Nilsson concluded that current battery pack costs are substantially lower than values often cited—for 2014, about $410/kWh on an industry-wide basis and $300/kWh for industry leaders such as Tesla and Nissan.[480] Estimated costs for industry leaders have been declining by about 8% per year since

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[a] It is useful to note that such issues are not unique to batteries; gasoline is also highly flammable and explosive.
[b] PEVs cannot access the full kWh capacity in a battery because deep capacity drawdowns—below 20%—may degrade batteries and reduce their lifetime.

2007 and may well continue to decline at that rate. The key forces behind the decline are reductions in input material costs, greater economies of scale, and learning (as production ramps up) better production techniques. Costs for 2017–2018 are projected at $230/kWh,[481] an estimate compatible with McKinsey's 2012 estimate of $200/kWh by 2020 and $160/kWh by 2025.[482] Costs of PEVs at new large-scale plants (e.g., Tesla's Gigafactory) are projected at about $200/kWh for pack production levels above 100,000 per year.[483]

Santini has produced PEV vehicle and cost estimates for current-generation Li-ion battery manufacturing.[484] Two independent models developed by Argonne National Laboratory and The German Aerospace Center were used to inform these estimates. Cost estimates for PEV batteries with capacities of 15 kWh (the Nissan LEAF battery pack is 24 kWh) or higher were estimated to be about $300/kWh. However, this estimate was made in 2012–2013 for an unspecified future high-volume production level. McKinsey's 2012 estimate for 2020 is consistent with the lower and earlier 2010 estimates of Santini, Gallagher, and Nelson[485]. They estimated that at high volume, for a 33 kWh total (25 kWh useable) battery pack, the average costs at the manufacturer's factory gate could be less than $200/kWh. Note that the Argonne model predicts that per-kWh costs decline with total pack kWh. Most studies cited failed to isolate this effect. Tesla packs have about three times the kWh capacity of Nissan LEAF packs. Santini estimated that the costs of adding power to large Li-ion packs were very low, which is consistent with the current market success and "affordability" (in the high-end luxury/performance market) of the high-power, very-high-performance Tesla EVs.[486]

The results of these studies imply that battery pack costs may well continue to drop, thereby increasing the value proposition of PEVs relative to comparable ICE vehicles.

*Autonomous Vehicles*

In recent years there has been much discussion of, and progress toward, the development of autonomous vehicles, which are able to navigate highways and streets without driver input (aside from initial programming or destination instructions). Autonomous driving could substantially increase vehicle efficiency by reducing acceleration and deceleration events, eliminating congestion slowdowns from accidents, and allowing substantial reductions in vehicle spacing, which in turn would reduce aerodynamic drag. There has been speculation that fully autonomous vehicles could be made much lighter (further reducing energy use) because crash protection could be reduced or even removed. However, such further "lightweighting" would have to wait until all road vehicles are connected and communicating at all times, which is not likely during the next several decades. Whether autonomous vehicles can actually reduce net energy consumption depends on increased vehicle efficiency and rideshare potential on one hand, and increased overall travel demand and addition of "empty trips" with no passengers on the other. Because autonomous vehicles can be sent back to parking areas for charging and/or for dispatch to serve other consumers, they could promote both electrification and vehicle sharing, with strong implications for both energy use and travel. Further analysis and experience is required before reliable predictions of potential energy use impacts can be made.

## 5.5 Interactions with Other Sectors

### 5.5.1 Interaction with Other Market Sectors

Due to the relatively low current penetration rate of PEVs, interactions between electricity consumption in the transportation and residential sectors are currently limited. However, as the penetration of personal PEVs increases, interactions will increase, primarily due to home vehicle charging. The 1.7 kW load of an AC Level 1 charger is less than that of a moderately sized residential central air conditioning system, and therefore could likely be absorbed into the usage profile of a typical home. However, the 7 kW or greater load of an AC Level 2 charger will exceed the current peak consumption rate of many single-family homes, and the simultaneous use of numerous AC Level 2 charging stations in a single neighborhood could pose technical challenges to local substations if charging is not properly managed. This issue could also be addressed by utility upgrades to the substations (similar to upgrades that have been required when smaller homes were initially built and then subsequently replaced by larger homes with dual air-conditioning systems).

In addition to peak effects, home vehicle charging will also increase total residential electricity consumption. A compact PEV that is driven 12,000 electric miles per year will consume approximately 3,600 kWh of energy (assuming 0.30 kWh per mile), which is roughly 33% of the current consumption of a typical residential utility customer.[487] However, this increase in *average* demand does not pose the same technical challenges as potential *peak* demand impacts. The increase in *total* residential electricity consumption will also not be large in aggregate unless PEVs become more widespread.

There will be similar interactions with the commercial sector related to consumers who choose to charge their personal vehicles at businesses or institutions where they work. Such charging will increase total electricity consumption in the commercial sector and contribute to increased peak loads, particularly in warm climates where the summer peak occurs in the middle of the afternoon if the workplace charges are still ongoing during this time period. In addition to providing charging stations for employees' personal vehicles, businesses may choose to use EVs for their own operations—e.g., delivery or service vehicles. These would also typically be charged at night at commercial buildings and therefore would have increased total commercial electricity consumption, but would have minimal peak load impacts.

There are also opportunities for synergies between the transportation and residential or commercial sectors, particularly for consumers who are reliant on distributed energy resources. For example, EVs can be integrated into demand response programs in which utilities provide incentives for consumers who reduce their electricity consumption during periods of high demand. Such programs are currently more common in commercial buildings, but there is potential for more applications in the residential sector in the future.

PEVs can provide a source of backup power in the case of a power outage. A fully charged Nissan LEAF stores 24 kWh of energy, which is sufficient to power a modest home for one or two days, or even longer if power use is restricted to vital services and appliances. Nissan began to implement PEV backup services in Japan in the wake of the 2011 tsunami and associated power outages, and the company is exploring similar possibilities in the United States and other markets.[488] However, technical improvements will be required to ensure that batteries are able to handle such a duty cycle.[a] Such two-

[a] Batteries for automotive use are currently being designed for maximum range. Designing batteries to also handle a duty cycle for distributed generation requires engineering design trade-offs with maximum range, and so is not a priority for commercial EVs.

way vehicle-to-building (V2B) or vehicle-to-home (V2H) interactions can provide short-term energy until power is restored by the utility to cover critical power needs for medical and other purposes. These V2B/V2H interactions can generally be implemented even in the absence of comprehensive smart grid technology, as they potentially involve only two actors (a single vehicle and a single building).

In addition, the storage capacity of PEVs could someday be used to balance the real-time variability of distributed generation resources.[a] For example, buildings that are powered by rooftop solar panels can charge connected vehicles during periods where generation outpaces demand, and withdraw energy from vehicles when demand exceeds generation, just as they would with any storage resource.

### 5.5.2 Grid Impacts

As the market penetration of electrified transportation increases, transportation energy that has traditionally been provided by petroleum-based fossil fuels will increasingly be provided by electricity from the grid. Such electricity can be generated from a variety of primary sources, including fossil fuels and nuclear, hydroelectric, wind, and solar resources. This shift in energy consumption may provide a range of benefits to individual consumers and society as a whole. For consumers, electric fuel sources will likely be cheaper than gasoline from the pump. Furthermore, electricity can be generated from renewable resources, resulting in true zero-emissions transportation. Increased electrification of transportation may also provide the national security benefit of reduced reliance on imported oil products.

Yet there are costs and challenges associated with increased use of electric transportation as well. While energy consumption will shift away from inefficient ICEs and oil-based fuel sources, electricity demand will increase. Depending on its extent, this increased electricity demand may strain the existing electric grid and could possibly require new investments in generation, transmission, and distribution infrastructure. In addition to increasing total electricity demand, electricity consumption patterns may change as well, resulting in new issues that must be considered and addressed. The utility industry is currently undergoing grid modernization actions designed to maintain system reliability as electricity demand profiles continue to evolve. As the modern grid is developed, utility planners will have to consider and account for the additional load that will result from transportation electrification, as well as the reduction in load from increased efficiency (see previous sections in this document) and the increasing generation from renewable sources. Alternatively, a modern grid can also benefit from intelligently managed PEV charging, as is discussed further below. With flat, and in some cases reduced, load growth due to effective energy efficiency technology applications (see prior chapters), the increased load from transportation may prove beneficial, ensuring maximum utility system asset utilization.

Therefore, the economic, societal, and environmental impacts of a shift toward electric transportation will depend on how the electricity is generated, when and where it is consumed, and a number of other factors. The following section focuses primarily on the grid impacts associated with charging battery-powered vehicles while they are not in use—specifically mass-market LDVs. Impacts from increased use of rail and other forms of transportation that are directly powered while in operation are not anticipated to be significant, due to the relatively small projected increase in electricity consumption from these technologies.

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[a] The same concern that is discussed in the previous footnote applies here as well.

### 5.5.3 Impacts Based on Technology Characteristics

The grid impact that results from increased electrification of transportation will depend on both the specific characteristics of the vehicles and charging infrastructure that are interacting with the grid, and the strategies being used to manage those interactions.

As discussed previously, there are three primary classes of vehicle chargers that each draw electricity from the grid at a different rate. AC Level 1 chargers draw approximately 1.7 kW of power; AC Level 2 chargers typically draw approximately 7 kW of power, but can draw as much as 19.2 kW. DC Fast Chargers can charge at a rate of 50 kW or even greater. Tesla Motors is developing a network of public “Superchargers” that can charge at a rate of up to 120 kW. The battery capacity of a vehicle being charged and the state of charge of the battery also directly influence the amount of time required to achieve a full charge, and therefore the period of time over which grid impacts may occur. Larger electrified vehicles, such as freight trucks and buses, are not currently in widespread use but would presumably also be equipped with larger batteries and use AC Level 2 or DC Fast Charging technology.

### 5.5.4 Impacts Based on Consumer Charging Patterns

The most significant impacts to the grid will likely be related to increases in instantaneous power demand (or peak load) as opposed to total energy consumption levels over the course of a year. The extent of these impacts will strongly depend on consumer battery depletion levels, charging patterns, and the automated or controlled charging mechanisms that are implemented.

Absent any external incentives or costs, most consumers will choose to charge their vehicles whenever it is most convenient for them. For many, this will be when they return to their home charger at the end of the day. If a significant number of consumers follow this charging pattern and do not elect to take advantage of time-of-use rates and delayed charging, a rapid increase in instantaneous power demand in the early evening would likely result, particularly if there is widespread use of AC Level 2 charging infrastructure.

One study has suggested that a large PEV fleet using AC Level 1 charging infrastructure would not significantly increase peak power demand, but that similar uncontrolled use of AC Level 2 charging infrastructure would result in increased winter and summer demand peaks.[489] More recent research has shown that home overnight charging takes only about three hours for a typical vehicle and that consumers who utilize time-of-use pricing schemes do shift their vehicle charging to off-peak periods as might be expected.[490] Furthermore, 57% of survey respondents indicated that they changed their utility rate subscription as a result of obtaining a PEV.[491] The use of controlled charging technologies or other techniques to promote off-peak charging can help mitigate or eliminate the need for investments in new peak generation capacity and can even provide additional benefits to the power system, as discussed in more detail below.

### 5.5.5 Charging at Work

Increased penetration of charging infrastructure away from the home—at work or in public places—would spread out load increases throughout the day, thereby reducing this peak load effect and providing other grid benefits. There may also be diminishing marginal returns from investments in workplace charging infrastructure. One study found that 80% of the total potential benefit can be obtained while only providing work charging to 10% of the population.[492]

### 5.5.6 Controlled Charging

Previous discussions have focused on uncontrolled charging when vehicles begin to charge the moment they are plugged in and continue to charge until they are unplugged or the battery is fully charged. However, such instantaneous charging is not typically required by most consumers, who simply require that their vehicle has a full charge by the time their next trip begins. Smart, "controlled charging" techniques may be implemented to reduce the total cost of providing consumers with the service they desire—a fully charged battery when they start a trip.

Such systems are typically based upon the concept of time-varying pricing, whereby consumers are charged a rate for the electricity consumption that varies throughout the day, rather than a single fixed rate, as is more common today. Time-varying pricing enables electric service providers to charge consumers a rate that more closely matches their actual marginal cost of electricity provision. Such rate designs also provide a price signal that encourages consumers to charge their vehicles when the electricity price, and therefore the cost of providing electricity, is low. Such a system could be implemented through prices that are constantly adjusted in real time based on system conditions. Alternatively, a more simplified block-pricing structure with fixed peak periods, fixed prices, or both might be considered. Ideally, charging infrastructure would be developed with the ability to automatically respond to these price signals so that consumers could program their vehicles to only charge when the real-time electricity price is below a certain threshold. Yet, even if chargers do not have automated response capabilities, block-pricing would encourage consumers to manually delay their charging until prices and demand are lower and generation capacity is more readily available. In the absence of time-varying pricing, consumers could also cede some control of their vehicle charging directly to their utility, perhaps in exchange for a lower rate or monthly bill credit. One study has shown that controlled charging may reduce the cost of electricity generation used for charging by 23% to 34%.[493] Controlled charging can be further facilitated through education and outreach programs from the utility to the PEV consumer that provide information on the potential cost-benefits of participating in time-of-use electricity rate programs.

### 5.5.7 Impacts in Systems with High Levels of Renewable Resources

Renewable electricity generation capacity is increasing rapidly in the United States. Much of this new capacity is in the form of variable energy resources (VERs) such as wind and solar, which have variable output profiles that are dependent on environmental conditions. Bursts of wind can increase the amount of energy being supplied to a power system over short timescales, while passing clouds can similarly decrease solar power availability. This variability must be balanced by other resources in the system—both supply and demand resources—to ensure that energy supply is equal to demand in real time.

As previously discussed, one concern related to uncontrolled PEV charging patterns is the potential for an increased evening electricity demand peak. This issue may be further intensified in regions with large penetrations of renewable resources, particularly solar. For example, in California, where renewable resource penetrations are anticipated to grow significantly in coming years, the spring and fall evening demand peak corresponds closely with the natural evening decrease in solar generation as the sun sets. This period also corresponds with the time that many consumers are returning home and turning on air conditioners, doing laundry, cooking, watching television, and charging their vehicles. In the absence of other action, this may necessitate investments in fast-response generation facilities that are capable of rapidly increasing and decreasing their output levels. This technical challenge is by no means a direct consequence of PEV charging alone; it stems primarily from increasing solar generation levels and would be an issue even in the absence of PEV charging. However, large, uncontrolled evening PEV charging loads may contribute to and intensify these concerns.

PEVs also can provide a significant benefit to power systems during this evening ramp period, provided that controlled charging and two-way vehicle-to-grid capabilities (discussed further below) are available. Most PEV owners do not completely deplete their battery during a typical day of driving and instead return home with excess energy stored in their vehicle batteries. The grid could therefore draw upon this capacity to help serve demand during the evening ramp, thereby offsetting the need for more-flexible thermal generation units. This would necessitate the presence of a modernized grid and participation by PEV owners—which could be encouraged either through price signals or some other incentive framework—as well as advanced battery technologies that can support increased duty cycles.

There are also additional opportunities for both power system operators and PEV owners to benefit in systems with high renewable penetration levels. Wind generation tends to peak overnight when electricity demand is low. This can lead to periods of excess power in the system when wind generators are sometimes forced to curtail their generation to maintain a balance between supply and demand. In some cases, wholesale electricity prices may even become negative as wind generators are willing to pay a small amount to avoid curtailment so they are able to claim a federal production tax credit, or alternatively thermal generators may be willing to pay to generate and avoid costly unit shutdowns. Most PEVs will be primarily charged overnight and therefore would have an ideal load profile for taking advantage of these system conditions. In addition to decreasing the cost of charging for consumers, this would help to reduce wind curtailments and support grid stability. In a study of the PJM system, for example, controlled charging resulted in net positive social benefits when wind generation served 20% of total demand, but net negative social benefits under current conditions.[494]

### 5.5.8 Vehicle-to-Grid and System Balancing

In addition to capitalizing on lower overnight electricity prices in regions with large amounts of wind generation, PEVs that are charged intelligently can also support grid reliability over short time horizons. All power systems maintain reserve capacity that is capable of responding to changes in system conditions over various timescales. Regulation and frequency reserves are provided by generation, demand response, or storage resources that are capable of responding to automated signals to either increase or decrease total power in the system in a matter of seconds or faster. Longer-term spinning and non-spinning operating reserves are also maintained that can respond to instructions to change generation levels over a period of roughly 10 to 30 minutes.

In many other applications, demand response programs offer incentives to customers to reduce power consumption over the short term—for example, by temporarily shutting off air conditioners or hot water heaters, or by reducing industrial output. With PEVs, a reduction in charging rate would likely be imperceptible to a consumer who typically only requires that the vehicle receives a full charge over a multi-hour period. Therefore, PEVs potentially have great flexibility in charging schedules and are well-suited to provide short-term demand response, regulation, and frequency control. If managed appropriately, this flexibility could be a valuable resource for power systems, particularly those with high penetration of VERs.

There are two tiers of such interactions between vehicles and the grid that could be implemented to support grid reliability. One-way interactions involve varying charging rates in real time to complement net load variability. For example, if wind generation diminishes suddenly, charging rates could be increased for PEVs that are actively charging to reduce loads and help balance supply with demand. Two-way V2G interaction would additionally enable a transfer of energy from vehicle batteries back to the grid, allowing them to serve as a power supplier during periods of high demand. This would potentially double their beneficial grid impact, allowing vehicles to provide twice as much balancing capacity. There are concerns about the negative effect that the more frequent V2G charge/discharge cycles of two-way V2G life will have on battery life. However, such interactions would also benefit consumers by allowing them to automatically charge the PEVs when electricity prices are low and potentially generate additional revenue by selling stored energy back to the grid. While some research-oriented V2G pilot projects have been implemented across the United States, these services are not yet available to the typical consumer or electric utility.

V2G interactions could be implemented based on short-term price signals, but such interactions could also be facilitated more directly based on automated signals that are already generated by a power system. In the United States, power systems target a grid frequency of 60 hertz (Hz). However, the actual frequency varies naturally around this target as a result of supply and demand imbalances. If frequency drops below 60 Hz, the grid has an undersupply; whereas, if the frequency increases above 60 Hz, there is an oversupply. A PEV charger could automatically detect these changes and adjust its charging rate accordingly, increasing charging when frequency exceeds 60 Hz and decreasing charging when it is below 60 Hz (or some alternative thresholds, such as 60.1 Hz and 59.9 Hz). This approach has a distinct advantage over others, as grid frequency can already be easily detected through a standard connection, and no additional external communication technologies or protocols are needed. Since such frequency response service has value to grid operators, financial incentives could be provided to PEV owners who choose to participate.

One study of the Northwest Power Pool found that if about 13% of all vehicles in the region were electrified and equipped with one-way power flow/control capabilities, these vehicles could provide the 3.7 GW of additional balancing required to support 10 GW of new wind capacity predicted between 2012 and 2019.[495] Two-way V2G would decrease this requirement by about 30% to 35%.[496] It will be important to fully understand both the costs and benefits of utilizing PEVs in this manner, i.e., the value of the balancing versus the increased vehicle complexity and potential negative impacts to battery life.

## 5.6 Markets and Market Actors

### 5.6.1 Light-Duty Consumers

Much of the growth in electrified transportation over the next several decades will likely take place in the LDV market. Growth will be driven primarily by individual consumers who are purchasing vehicles for personal use. Growth may also be driven by use of LDVs by federal, state, and local governments, as well as private corporations both for internal use (e.g., delivery and service vehicles) and customer-facing use (e.g., taxis and ride sharing). PEVs are particularly attractive for such uses, as their relative efficiency gains over traditional ICE vehicles are even greater in urban driving environments. The potential adoption of electrified LDVs will be affected by a variety of factors. While PEV adoption is still in its early stages, a number of studies have attempted to identify the primary factors that influence consumer choice between conventional and electrified LDVs.

Education and awareness campaigns can help consumers to consider the potential for a PEV to meet or exceed their light-duty transportation requirements. The industry has early experience with current PEV customers that has helped to frame the critical questions and concerns that must be answered before a consumer will make the paradigm change from an internal combustion fuel-only vehicle to either one of the PEV models—BEV or PHEV. The challenge will be to use this knowledge to create awareness campaigns that attract the attention of currently non-interested, non-PEV-aware consumers.

Two primary factors must be considered. First, most consumers that would consider purchasing a BEV have some amount of "range anxiety," or the concern that a vehicle will lose its charge before reaching a desired destination. This is not a concern for PHEVs, which can also operate on gasoline when their battery is depleted. This anxiety is closely tied to driving patterns, battery capacity, the availability of public charging infrastructure, and the time required to recharge a battery pack. Since range anxiety is only applicable to BEVs, educating consumers on the benefits of PHEV options that do not have the same range limitations can help speed adoption of PEVs. The second primary factor influencing purchase decisions is the extra up-front cost of a PEV compared to a conventional gasoline-power vehicle. While incentives exist to reduce this cost premium, and PEVs typically have lower fuel and operating costs that allow some or all of the premium to be recovered over the vehicle's lifetime, many consumers are hesitant to make the required larger up-front investment because they have not developed a clear value proposition for PEVs like they have for other high-cost LDV options such as SUVs and pick-up trucks. Some care must be exercised when making vehicle comparisons based purely on cost, as consumers also consider a range of additional factors when purchasing a vehicle, including comfort, size, travel range, refueling/charging time, safety, and overall driving experience. This is clearly shown in the widespread purchase of SUVs, pick-up trucks, and luxury vehicles, despite their high costs of ownership. The general automotive-consuming public has not yet widely accepted the value proposition offered by PEVs; however, there is potential for this to occur.

One study has shown that U.S. consumers prefer low electric range PHEVs with 300-mile overall range, despite greater subsidies for BEVs.[497] Other studies have found that there is typically more support for BEVs from younger, well-educated, environmentally aware consumers[498] and those who are considering a BEV as a potential second vehicle,[499] though these dynamics may change if and when PEVs achieve more mainstream acceptance. Krupa et al. find that those who care about reducing energy consumption and emissions are 71 and 44 times, respectively, more likely to say they are willing to purchase a BEV as opposed to an ICE.[500] However, such consumers still have a willingness-to-pay of no more than several thousand dollars. Higher up-front cost and BEV range anxiety were identified as the biggest concerns and obstacles to greater adoption.

Car purchases are also relatively infrequent for most consumers; therefore, even if consumers are generally interested in obtaining a PEV, it may take several years for them to actually purchase one. Furthermore many purchasers are not interested in a small compact car and are instead interested in a larger car, truck, or SUV, which currently have limited PEV model offerings. As a result, widespread PEV adoption may take time to materialize, particularly if larger PEVs do not become more widely available and consumer preferences do not change. A recent survey found that only 24% of respondents were even considering purchasing a small sedan.[501] Some 68% of respondents indicated that they would consider paying a premium for an EV, but an HEV with a $2,000 premium was preferred to a PHEV with a $4,000 premium. Half of the respondents said that availability of wireless charging would increase their willingness to consider a BEV. This information validates the need for the PEV industry to increase its awareness activities to better inform the consuming public on the value proposition for the family of EVs.

### 5.6.2 Governments

New York City attempted to institute a series of mandates and financial incentives for fuel-efficient, hybrid taxis in the mid-2000s. While these efforts were eventually halted due to a legal challenge, hybrids still make up 60% of the taxi fleet in New York City.[502] A similar push for PEV taxis could help PEV penetration reach the critical mass that is needed to support public charging infrastructure and increased adoption by consumers, provided that PEVs will meet the range and service requirements of an urban taxi fleet. Many cities have also begun to consider electrifying their bus systems. However, the market for these technologies is still immature, and the charging requirements present unique challenges for buses that operate on fixed schedules. In addition to cities that may have an interest in purchasing electrified bus fleets for their transit systems, other government agencies could become consumers of PEVs for their own use (e.g., police, post office, health and environmental inspectors, park rangers).

Non-freight rail in the United States is already largely electrified, and it is unlikely that freight rail will become significantly electrified in the near future. Some efforts are under way to increase electrified passenger rail travel in the United States, most notably in California and to some extent in the Northeast. Intercity rail travel accounted for 6.8 billion p-mi in 2013, roughly 0.1% of total p-mi traveled in the United States, and 2 trillion Btu (586 million kWh) of end use electricity consumption. It has been estimated that by 2040 the proposed California high-speed-rail corridor could have between 17 and 26 million annual VMT.[503] Electricity consumption for rail travel is difficult to predict as it depends on train size, speed, efficiency, and passenger load; however, current data suggest a possible range between 21 and 58 kWh per VMT.[504] Given these assumptions, the resultant annual energy consumption of such a system would fall between 1.2 and 5.0 trillion Btu. Therefore, the new California system alone could potentially increase electricity consumption for passenger rail travel by 50% to 250% nationwide. However, given U.S. consumer preferences for highway and air travel, such growth is still relatively small compared to the potential for increased electricity consumption from electrification of the LDV fleet.

### 5.6.3 Vehicle Manufacturers

EV manufacturers are currently focused primarily on developing PHEVs and BEVs with larger batteries, and therefore a greater travel range, to dispel concerns over range anxiety. They are also aiming to reduce costs to achieve approximate price parity with conventional vehicles. However, much of the cost premium of PEVs is due to battery costs.

There is some division between manufacturers over the development of BEVs as opposed PHEVs. Most notably, Honda has not yet announced plans to develop a BEV that is intended for mass-market consumption,[a] opting instead for PHEVs, and has longer-term plans to introduce fuel-cell vehicles. Chevrolet originally opted to develop a PHEV (the Volt) as their first mass market PEV, though they will also release a BEV (the Bolt) in 2017. Conversely, Nissan chose to develop a BEV (the LEAF) as their first mass market PEV. The Tesla S currently stands apart from the field due to its extended range and its large price tag, but it has proven that BEVs can gain a foothold in the luxury car market.

A number of manufacturers that typically serve the luxury market, including BMW, Porsche, and Audi, are starting to follow suit by introducing their own line of PEVs. Other manufacturers are also beginning

[a] Honda did sell the Fit BEV between 2012 and 2014; however, only 1,100 were manufactured, and they were generally considered to be “compliance vehicles” as they were only sold in a handful states with ZEV mandates.

to announce new models that can compete with the range of the Tesla Model S, including Chevrolet, which has plans to introduce the Bolt in 2016 as a crossover with a 200-mile range. The electric SUV market is still in its infancy, but momentum has grown since Porsche introduced the Cayenne PHEV in late 2014, BMW introduced the X5 PHEV in 2015, and Tesla began taking orders for the Model X also in 2015, and other manufacturers will be joining that market shortly.[a] Increased vehicle choice will likely be a net positive for PEV adoption overall.

A major positive feature of several of the new PEV models is that they are expressly designed as PEVs, rather than being converted conventional vehicles with electric or hybrid electric drivetrains substituted for conventional ICE drivetrains. These new designs indicate their manufacturers' intention to do more than just comply with the Zero Emission Vehicle (ZEV) mandates of California and other states. Automakers clearly are going after a market they believe will grow, with uniquely designed vehicles that take account of both the special requirements and the potential advantages of battery-powered vehicles. PEVs have more to gain from reduced weight than conventional vehicles because of their range issues, and many of the new PEVs use very lightweight materials. For example, the Tesla S uses an all-aluminum body, and both the BMW i3 (BEV) and i8 (PHEV) use large amounts of carbon fiber composite. Furthermore, the purpose-built design allows manufacturers to use the battery as an inherent part of the vehicle structure, saving weight, improving crash protection, and reducing the vehicle's center of gravity by placing the battery very low on the vehicle.

### 5.6.4 Charging Station Providers

The availability of public charging stations can be a major factor in dispelling consumer range anxiety and increasing BEV adoption rates. However, in early stages of BEV adoption, public charging stations will likely be underutilized and therefore may not provide sufficient returns to attract private investments. It is also difficult for developers to properly estimate demand for charging stations in an immature market where costs and consumer perceptions are constantly changing. Yet, a certain level of infrastructure availability may be required by consumers before they are comfortable purchasing enough BEVs to keep charging stations well-utilized. As such, governments, electric utilities, and other public entities (as well as automakers) may consider developing or subsidizing public charging stations as a social service to encourage increased BEV adoption. According to a recent survey, increased availability of public infrastructure makes consumers more likely to consider BEVs, even though most would still charge at home overnight.[505] Even if they overwhelmingly charge at home, consumers are still likely to be worried about the small number of trips where a single charge is not sufficient. The presence of public chargers may be enough to ease range anxiety in these cases, but this assumes that the problem of excessive charging time—even with fast chargers—can be overcome.[b]

However, some maintain that while cities should foster a supportive environment for charging infrastructure—through effective permitting, zoning, and codes—they should only offer direct financial incentives in select circumstances, because fee-based PEV charging is a viable business opportunity.[506] Subscription-based business models (e.g., a yearly fee for unlimited use) also may be more effective than charging per unit of electricity consumed for charging. In addition to public and third-party charging stations, Tesla is developing its own network of Superchargers that are free for all Tesla owners, essentially wrapping the cost of this provision into the price of each new vehicle. Some

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[a] Additional "compliance" SUVs with electric drivetrains added to conventional model vehicles have been also been marketed, e.g., Toyota RAV4 EV.

[b] And as noted above, this problem would be greatly exacerbated under severe hot and cold weather conditions, which both reduce vehicle range and increase charging time.

businesses will view providing charging stations as useful for attracting customers or for retaining employees. DOE's Workplace Charging Challenge had already attracted over 250 business partners as of January 2015, with over 5,000 charging stations installed.[507]

## 5.7 Barriers and the Policies, Regulations, and Programs That Address Them

There are a number of policies, regulations, and incentives to support increased penetration of EVs. Several of these are summarized broadly in Table 5.6, and Table 5.7 details the specific state-level incentives and policies that are active in each state.

Most states offer a range of incentives for PEV purchases and owners. Some of these might be direct financial incentives, augmenting the federal tax credit of up to $7,500 that is provided to purchasers of qualifying PEVs. There are also a variety of other incentives for PEV owners, such as permission to use high-occupancy vehicle (HOV) lanes at all times and reduced electricity rates for vehicle charging. In addition, 10 states[a] have adopted California's ZEV sales mandate, which requires that ZEVs account for a specified share of total vehicle production by large car manufacturers (including a 15% ZEV sales target by 2025). Manufacturers can sell various classes of ZEV credits to others who fall short of prescribed targets, similar to renewable electricity credits in the power sector. The market for such credits can be significant. For example, Tesla Motors generated $76.1 million in revenue from selling ZEV credits in the third quarter of 2014, which amounts to 8.2% of the company's total revenue that quarter.[508] Of course, as more models of PEVs are introduced and sold by more manufacturers, the value of these credits is likely to decrease, unless ZEV targets increase as well. Both the U.S. EPA Light Duty Vehicle Greenhouse Gas Emissions Standards and National Highway Traffic Safety Administration corporate average fuel economy (CAFE) standards provide incentives for the increased deployment of light-duty EVs. The federal emissions and fuel efficiency standards for medium- and heavy-duty vehicles also incentivize increased deployment of EVs.

[a] California, Connecticut, Maine, Maryland, Massachusetts, New Jersey, New York, Oregon, Rhode Island, and Vermont.

**Table 5.6. Policies, Regulations, and Programs in the Transportation Sector**

| | | |
|---|---|---|
| **Codes, Mandates and Target-Setting** | • **The U.S. EPA LDV GHG Emissions Rule provides a credit multiplier for PEVs sold in model years 2017 through 2021. PEVs are currently awarded a zero GHG emissions score by EPA and high fuel economy levels by the National Highway Traffic Safety Administration.**<br>• **The EPA Renewable Fuel Standard and California Low Carbon Fuel Standard both include credits for renewable electricity used to power PEVs.**<br>• **Ten states currently have zero emission vehicle (ZEV) mandates, which require that ZEVs make up a certain fraction of all new vehicle sales.** | ***Non-energy benefits, lack of private incentive for R&D, various others***<br>• **These policies are generally enacted to accelerate technology learning and economies of scale to ultimately reduce costs and promote long-term adoption.**<br>• **Temporary GHG regulatory incentives slightly reduce near-term GHG savings in order to promote PEV technology that could yield large, future GHG savings.[509]** |
| Grants and Rebates | • Payments to consumers who purchase a PEV<br>• The federal program currently offers up to $7,500 for light-duty vehicles (LDVs).<br>• Multiple states have additional programs, typically $2,000 to $3,000 in additional incentives. | *First costs, non-energy benefits, materiality, information/awareness*<br>• Rebates lower the incremental up-front cost of efficient technologies, serving as a proxy for non-priced social benefits of energy efficiency adoption. |
| RD&D for End-Use Technologies | • Major battery RD&D initiatives have been sponsored by DOE to (a) reduce costs of storage and (b) increase storage density.<br>• Initiatives have been implemented to improve charging infrastructure and reduce charging time. | *Lack of private incentive for R&D, consumer risk aversion*<br>• In general, RD&D is undersupplied absent policy intervention because its benefits cannot be fully appropriated by inventors (a "public goods" problem).<br>• Many consumers have "range anxiety," and are thus hesitant to make the shift toward electric vehicles. High first costs are another contributing factor.<br>• Similar issues exist for buses and public transit. |
| Public Infrastructure Investments | • Federal program and multiple states have programs focused on building charging infrastructure.<br>• Federal, state, and local entities invest in rail and other public transporation infrastructure.<br>• Some states have alternatively attempted to recoup infrastructure costs from PEVs that do not pay gasoline taxes through alternative measures (e.g., registration fees). | • Increased PEV penetration is heavily contingent on the availability of charging infrastructure.<br>• More charging stations will help overcome "range anxiety."<br>• High up-front capital investment is required to create supportive environment, tipping point effect.<br>• With more PEVs on the road, per vehicle infrastructure cost will decrease.<br>• High first infrastructure costs exist for light and heavy rail also. |

**Table 5.7. State Incentives for PEV Purchases and Owners**[510]

| Incentives | State |
|---|---|
| PEV Purchase Incentives: Tax Credits and Rebates (Including Low-Interest Loan) | California, Colorado, Connecticut, Delaware, District of Columbia, Kansas, Illinois, Maryland, Massachusetts, Nebraska, Oklahoma, Oregon, Pennsylvania, Rhode Island, South Carolina, Tennessee, Utah, Washington, West Virginia |
| Zero Emission Vehicle (ZEV) Mandates | California, Connecticut, Maine, Maryland, Massachusetts, New Jersey, New York, Oregon, Rhode Island, Vermont |
| High-Occupancy Vehicle Lane Exemption | Arizona, California, Colorado, Florida, Georgia, Hawaii, Maryland, New Jersey, New York, North Carolina, Tennessee, Utah, Virginia |
| Lower Electric Rates for Residents with Separate Meter for PEV Charging | Alabama, Arizona, Georgia, Hawaii, Indiana, Kansas, Kentucky, Maryland, Michigan, Minnesota, Nevada, Virginia |
| Charging Equipment / Installation Incentive | Arizona, California, Colorado, Connecticut, Delaware, Georgia, Illinois, Indiana, Maryland, Massachusetts, Michigan, Missouri, New Hampshire, New Jersey, Oregon |
| Vehicle Inspection / Emission Testing Exemption | Arizona, Connecticut, Idaho, Illinois, Michigan, Missouri, Massachusetts, Nevada, North Carolina, Ohio, Rhode Island, Virginia, Washington |
| Parking Incentives | Arizona, Hawaii, Nevada |
| Sales Tax Exemption | Colorado, New Jersey, Virginia, Washington |
| Fuel Tax Exemption | Idaho, Wisconsin, Utah |
| Reduced License and/or Use Tax | Arizona |
| Reduced Registration Fee | Connecticut, District of Columbia, Illinois |
| Conversion Tax Credit | Montana, Nebraska, Louisiana |
| Vehicle-to-Grid Energy Credit | Delaware |
| Weight Limit Exemption | Colorado |
| Title Tax Exemption | District of Columbia |
| Reduced Toll Road Rates | New Jersey |

As the market for PEVs is still relatively immature and most incentive programs are new, it is difficult to assess how effective programs have been in increasing PEV sales. However, a number of studies have attempted to analyze early results from these programs; selected high-level findings are as follows:

**PEV adoption appears to be greatest when multiple actions are taken in parallel**: PEV incentives have been offered through a variety of different mechanisms, for example, direct cost reductions, infrastructure investments, and non-monetary benefits to vehicle owners (e.g., HOV or parking access). Studies suggest that incentives are most successful at increasing PEV adoption when multiple incentives are offered simultaneously, especially when policies focus on both making vehicles more affordable and attractive and expanding charging infrastructure. Preliminary research indicates that both incentives and charging infrastructure availability are positively correlated with BEV registrations,[511] while other results show that that the top EV adoption cities tended to have some combination of more EV promotion action, greater charging infrastructure per capita, greater consumer incentives, and greater model availability.[512] Sierzchula also notes that both charging infrastructure and financial incentives were important to PEV adoption but neither alone ensured high adoption rates.[513]

**Policies to reduce the high up-front cost of PEVs appear to promote early market growth**: The high up-front purchase cost has long been considered to be a major barrier for market adoption of PEVs. It has been shown that tax rebates to defray the up-front purchase cost are one of the most effective ways of increasing consumer purchases of a PEV.[514] However, one study notes that tax credits are less effective than immediate rebates, as they must be claimed by the purchaser at a later date and are subject to some uncertainty as they depend on the purchasers' tax liability.[515]

**Institutional support factors also appear to be effective in promoting market growth**: Some institutional support factors, such as emissions testing exemptions, low-carbon fuel policies, and outreach actions to support general EV awareness, have also played an important role in PEV market adoption, as recognized by three studies from the International Council on Clean Transportation.[516] [517] [518] One additional study found that PEV Readiness Grants have had a strongly significant positive effect on PEV adoption rates, especially in states without incentives.[519]

**Vehicle charging infrastructure is an important prerequisite for PEV adoption**: Lutsey also identified gaps in promotion actions. First, public charging infrastructure availability has a significant impact on both PHEV and BEV purchases.[520] Even large financial incentives have limited positive effects on PEV adoption if there is a limited charging infrastructure and EV model availability. Such a pattern has also been observed in the European Union. For example, Denmark has large vehicle purchase incentives but limited charging infrastructure and limited PEV success. Similarly, New York City has adopted many vehicle purchase promotion actions and has high EV model availability, but has much less charging infrastructure than the other 24 cities studied. However, lack of state incentives could also contribute to the low market adoption rate in New York City. Future analyses should attempt to isolate the impacts of these possible contributing factors. Note that the quantity of public charging infrastructure may not be as important as ensuring that consumers have ready access to real-time data on the location and availability of charging infrastructure.

**Several studies have reached contradictory conclusions**: Contrary conclusions were reached by some studies even when their analyses were based on the same year of registration data. For example, HOV access was shown to not have a statistically significant effect on BEV purchases in one study using a logit model.[521] Another study that utilized stepwise regression models showed that HOV lane access is one of the most effective promotion actions for BEVs.[522] Two more studies, one using regression analysis[523] and one using surveys,[524] concluded that HOV lane access also encourages PHEV purchases. The contrary conclusions may be associated with the different variables used in each model, in addition to methodological differences.

Contrary conclusions were also found regarding whether purchase rebate or tax credits are a more effective tool for promoting PEV adoption. Coplon-Newfield found that an immediate rebate is more attractive to consumers than a year-end tax credit, based on the experiences in the northeast and mid-Atlantic states.[525] However, Clinton et al. concluded that tax credits are significantly positively correlated with BEV registrations while BEV rebates have a positive but not statistically significant impact.[526] Jin et al. concluded that subsidies (for both vehicles and infrastructure) are one of the most effective incentives based on step-wise regression analysis.[527] However, this study refers to both tax credits and rebates jointly as subsidies.

## 5.8 Outlook through 2040

As noted earlier, the U.S. transportation sector in 2016 uses virtually no electricity. Some 88% of transport electricity use is for transit, commuter, and intercity passenger rail.[528] In addition, there is a small but growing movement toward light personal EVs, including passenger cars, light trucks, motorcycles, and bicycles. Some transportation companies, such as FedEx and UPS, are experimenting with electric delivery vans for their shorter routes, and some bus transit companies, such as Foothill Transit in California, have begun to use electric buses.

Unless a substantial fraction of light personal vehicles (and small delivery vehicles) become electrified, transportation electricity use will likely continue to play a minor role in the U.S. electricity sector. However, there currently is a concerted effort by the federal government, a number of state governments, utilities, and non-governmental organizations to promote the electrification of transportation, especially for LDVs.

The future of electricity use in transportation will depend in large part on the following factors:

- Future growth of personal travel and freight transport, and its characteristics
- The relative costs of electric versus fossil-fuel powered transport, influenced strongly by world petroleum prices and battery costs and performance (and government subsidies for both technologies)
- Consumers' awareness of and reactions to new alternative transportation products and their willingness to pay an up-front premium for electrified vehicles, as well as business decisions about developing and promoting EVs and building a robust charging infrastructure
- State and federal government regulations (see Table 5.6 and Table 5.7) and fleet purchase decisions

### 5.8.1 Growth in Travel

**Table 5.8. Historical Growth Factors in Vehicle Travel and Status Today [529]**

| Growth Factor | Reason for Disruption |
|---|---|
| Increased levels of participation in the labor force by women | Trend now essentially saturated |
| Increased access to vehicles—ratio of vehicles to potential drivers soared and number of zero-vehicle households dropped | Number of vehicles per person ≥ 16 years old is now nearly one, and the percentage of zero-vehicle households has dropped below 10% |
| Sharp drops in average passenger loads in personal vehicles, related to increased vehicle access | Halted and somewhat reversed |
| Increasing speeds on U.S. highways | Highway speeds have stabilized |
| Sharp drops in transit usage, with former users shifting to cars | Halted, with some recent growth in transit usage |
| Substantial migration from the inner core of cities to suburbs, with greater distances to access services | Halted and somewhat reversed |

A recent paper on the prospects for future vehicle travel growth (Table 5.8) in the United States concludes that future growth rates will be well below pre-2007 rates.[530]

The EPSA Side Case projects total light-duty fleet VMT to increase by 1.1% per year from 2015 through 2040 for a 31% total increase, from 2,731 billion VMT in 2015 to 3,565 billion VMT in 2040.[531] Although low energy prices might increase VMT, they would also likely slow the electrification of travel by making conventional vehicles more attractive relative to PEVs. Alternatively, the implementation of new policies and incentives to support PEV adoption could increase electric VMT.

Changes in the distribution of personal vehicle travel (as well as changes in population patterns, especially urban versus suburban versus rural) will also affect prospects for LDV electrification. The rise of services like Uber and ZipCar, as well as shifts to autonomous vehicles, may further affect both travel patterns and volume and provide new markets for EVs. Analysis of such prospects is a topic for further research.

Changes in the magnitude and distribution of freight transport will also affect electrification prospects. In general, long-distance trucking and water shipping are unlikely to be electrified to any extent. Electrification of rail shipping seems unlikely without major public incentives, and air shipping (and air travel) will not be electrified for technical reasons. However, the growth in Internet shopping and the trend toward locating warehouses nearer to markets to facilitate rapid shipping will inevitably lead to growth in shipping via smaller vans and trucks over relatively short distances. This raises the *potential* to electrify a portion of freight transport, depending on the changing economics of electric versus fossil-based vehicles and progress in battery performance. The EPSA Side Case projects commercial light truck travel to grow by 1.7% per year and freight truck travel to grow by 1.5% per year, compared to LDV travel growth of only 1.1% per year.[532] Unfortunately, the EPSA-NEMS dataset does not allow for an analysis of changes in "small truck/short distance" travel.[a]

### 5.8.2 Relative Costs

Rail transit is primarily electric and will remain so. As such, the overall cost of building and maintain rail transit will affect its prospects for expansion, rather than its choice of energy source. The economics of rail transit look poor from a simple comparison of fare revenues and operating and capital costs of the systems. Fare payback is only 38% for the largest systems, generally worse for others.[533] The economics are much better if other savings (e.g., reduced traffic congestion, reduced parking requirements, fewer traffic accidents) are included, but the magnitude of these savings is controversial. A similar case can be made for bus transit, and large investments in both rail and bus systems have been difficult to obtain in recent decades. Major expansion of rail systems and investments in electric buses and charging infrastructure will require a shift in public sentiment as well as a renewed interest by the federal government in building transportation infrastructure.

The costs of plug-in personal vehicles must become more favorable if rapid electrification of the fleet can be realistically expected. This gap can also be overcome by allaying consumer range anxiety and increasing awareness of the value proposition presented by PEVs. As discussed in Section 5.3, battery costs are expected to drop sharply during the next decade through learning and economies of scale, and

[a] Delivery trucks comprise both commercial light trucks and a portion of freight trucks, which are not broken down in the AEO 2015 dataset. AEO data also do not provide information on the changing distribution of freight trip distance.

multiple efforts by governments and industry worldwide seek to reduce costs further as well as achieve major increases in battery performance and lifetime. There appears to be a reasonable chance—but not a certainty—that reductions in battery costs and improvements in performance will be sufficient by 2025 or 2030 to achieve cost parity of shorter-range (~100 miles) BEVs with conventional vehicles, while making both longer-range BEVs and PHEVs more attractive and cost-effective.

### 5.8.3 Business and Consumer Reactions

Although there is a great deal known about how markets respond to changes in the price and performance of conventional vehicles, EVs are a relatively new phenomenon with rapidly changing costs and characteristics, and current data about market response are relevant to "early adopters" rather than to the mainstream public. In general, it is expected that EVs will not take off until consumers become very familiar with the technology, believe that higher vehicle costs will be rapidly paid back by fuel savings within a few years, and perceive that enough public charging infrastructure has been built to allay range anxiety. A reduction in charging time for public chargers may also be necessary for those consumers who frequently rely on public charging infrastructure, and this may be technically challenging. Additional benefits recognized by the current PEV customer base—performance, quiet operation, convenient charging, local procurement, new technology, and environmental friendliness—must be clearly understood by the general buying public. Achieving a good understanding of how market actors behave toward PEVs probably requires several more years of tracking purchase and driving behavior, as well as expansion of the PEV market to mainstream consumers. (See Section 5.6 for a discussion of markets and market actors.)

Business reactions to electric transportation, particularly to light-duty PEVs, appear positive at this early stage of PEV development. Several companies have developed purpose-built BEVs and PHEVs that take account of both the special requirements as well as the potential advantages of battery-powered vehicles. Also, there has been a strong response to calls for building a public charging infrastructure as well as a workplace charging infrastructure, with hundreds of businesses signing on to DOE's Workplace Charging Challenge.

### 5.8.4 Government Regulations and Fleet Purchase Decisions

As noted above (Section 5.7), federal, state, and local governments have taken multiple actions to promote EVs, and their continuance and possible expansion will play an important role in whether or not PEVs gain significant market shares. A key decision point for the future is whether or not to extend federal tax credits for PEVs. Other key factors include:

- Support for expanding public charging infrastructure at all levels of government
- Local building codes, e.g., requirements that new homes either include charging circuits or at least be designed for easy installation of PEV chargers
- Continuation and possible expansion of non-monetary incentives, e.g., access to HOV lanes
    - A crucial factor will be the continued enforcement of ZEV requirements by California and nine other states. As shown later, if these ten states achieve their requirements, it has been estimated that PEVs will account for 6.5% of all LDV sales nationally by 2030. This will presumably help drive vehicle costs down through scale and learning effects.
    - Government fleets will also play a crucial role. According to a recent Executive Order, U.S. government fleets must incorporate 20% PEVs by 2020 and 50% by 2025.[534] Many state

and local fleets have initiated PEV purchases as well, although comprehensive data are not yet available.

### 5.8.5 Projections of Transportation Electricity Use

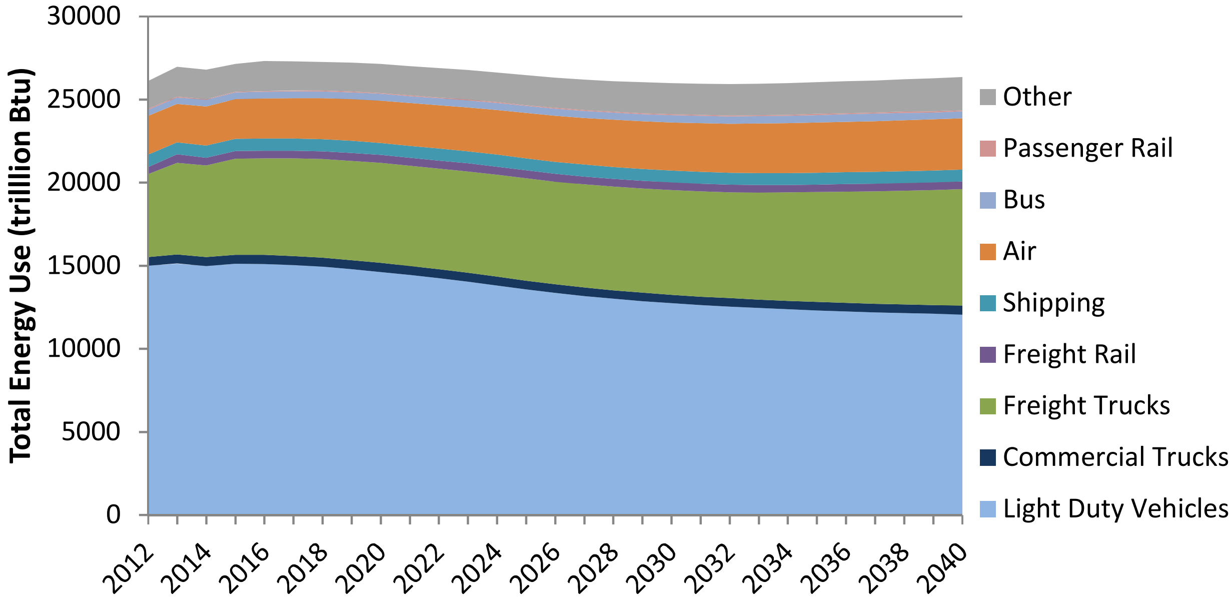
Projections of future sales of EVs vary widely, primarily because there are insufficient data for a robust understanding of the determinants of future sales, and some of the likely driving forces of such sales (e.g., future oil prices, future battery costs and performance, mainstream consumer reactions to the positive values, and the trade-offs associated with plug-in vehicles) are highly uncertain. Also, various projection models have major differences in structure and underlying assumptions, producing very different results even when input assumptions are the same.

*EPSA Side Case*

As of 2013, LDVs accounted for the majority (56%) of all energy consumption in the transportation sector.[535] While the EPSA Side Case projects their total consumption level to be about 20% lower in 2040, LDVs are still projected to account for nearly 46% of all transportation energy consumption.[536] Energy use by freight trucks is projected to grow by 27% between 2013 and 2040[537], with their total share of energy use in the transportation sector increasing from 20% to 27%.[538] Energy use by passenger rail is also expected to grow by about 26% through 2040.[539] However, the overall share of passenger rail in the whole transportation sector is projected to still be small—only 0.2%. Total delivered energy consumption for transportation is projected to decrease by about 2.5% by 2040 relative to 2013 levels, due largely to increasing vehicle efficiency.[540]

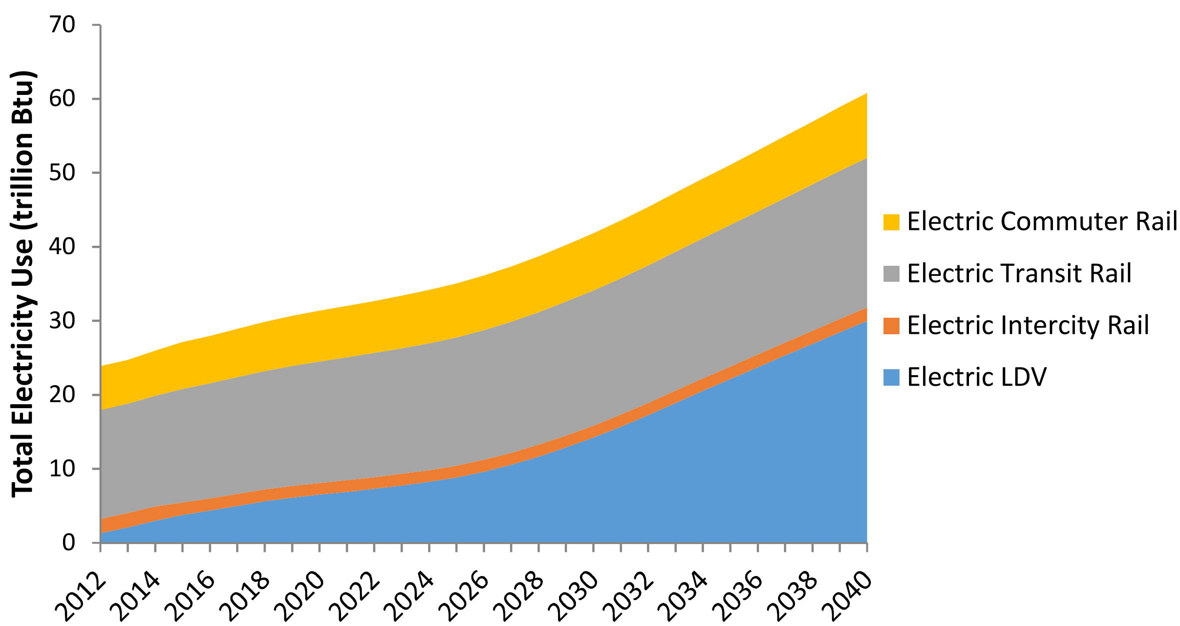
The current share of energy use for transportation that comes from electricity is very small— only 26 trillion Btu out of 26,790 trillion Btu total in 2014. The EPSA Side Case projects electricity use for transportation to increase by a factor of roughly 2.5 to 61 trillion Btu by 2040. However, this is still less than 1% of total projected energy consumption. Almost all of the increased electricity use in the sector is attributed to LDVs, as their electricity use is projected to grow tenfold, from 3 trillion Btu in 2014 to 30 trillion Btu in 2040. This estimate is based on projections of VMT and stock of PHEVs and BEVs. The EPSA Side Case projects that PEVs will account for 1.7% of all LDV sales in 2040 and 1.2% of the total LDV stock. The EPSA Side Case projects only marginal increases in electricity consumption for rail travel, and no electricity consumption from heavy-duty vehicles or buses in 2040. Figure 5.7 shows the EPSA Side Case projection for total transportation energy use by category through 2040 and Figure 5.8 shows the transportation electricity use for the same case. Note that these projections assume that there will no major policy changes to further promote the adoption of PEVs. Before using these projections to inform analysis or decision-makers the foundational assumptions should be reviewed to make sure they still reflect current conditions.

**Figure 5.7. Projection of total primary energy use for transportation in the United States, all fuels**[541]




*Light-duty vehicles (LDVs) are responsible for the largest share of energy consumption in the transportation sector. However, this share is projected to decrease in the future. Freight trucks account for the second greatest share of energy consumption, and this share is projected to increase between 2014 and 2040.*

**Figure 5.8. Projection of total electricity use for transportation in the United States**[542]




*Electricity accounts for only a very small fraction of all energy consumption in the transportation sector. Under EPSA Side Case conditions, electricity use for transportation is projected to grow through 2040, primarily due to increased penetration of light-duty vehicles (LDVs).*

Table 5.9 shows total energy consumption in 2014 and projected for 2040 for each electrified sector, with energy values in trillion Btu. As noted above, the EPSA Side Case projects that electricity will provide a near zero share of transportation energy in 2040, about 0.2%. Even with electrified transport's higher energy efficiency factored in, this case projects that electricity will power less than 1% of U.S. transport in 2040.

**Table 5.9. Electricity Use and Total Energy Consumption in Transport Modes Using Electricity, 2014 and 2040 (in trillion Btu), from the EPSA Side Case[543]**

| Vehicle Type | 2014 Electricity | 2014 Energy | 2040 Electricity | 2040 Energy |
|---|---|---|---|---|
| Light-duty Vehicles | 3 | 14,969 | 30 | 12,061 |
| Intercity Rail | 2 | 19 | 2 | 18 |
| Transit Rail | 15 | 15 | 20 | 20 |
| Commuter Rail | 6 | 17 | 9 | 26 |
| Total Transport Consumption | 26 | 26,790 | 61 | 26,341 |

The EPSA Side Case projects substantial growth in world oil prices, from about $56 per barrel in 2015 to $141 per barrel in 2040 (in real 2013 dollars).[544] Therefore, the projected continued dominance of oil in transportation cannot be explained by low oil prices. Instead, the primary factor holding back electrification of transport appears to be related to projected up-front capital costs for electric transportation, Table 5.10 shows a selected subset of the price projections for new LDVs that projected in the EPSA Side Case.

**Table 5.10. Projected Prices for New Light-Duty Vehicles in 2016 and 2040, from the EPSA Side Case[545]**

| | Compact | | Midsize | |
|---|---|---|---|---|
| Vehicle | 2016 Cost ($) | 2040 Cost ($) | 2016 Cost ($) | 2040 Cost ($) |
| Gasoline Car | 20,753 | 23,395 | 25,270 | 27,638 |
| Hybrid Electric Car | 25,426 | 25,936 | 30,463 | 30,570 |
| PHEV10 Car | 30,693 | 28,985 | 36,613 | 34,383 |
| PHEV40 Car | 39,573 | 34,191 | 46,708 | 40,052 |
| BEV100 Car | 35,540 | 29,943 | 43,241 | 36,431 |
| BEV200 Car | N/A | 40,426 | N/A | 45,698 |

*All prices are in 2013 dollars.*

Based on EPSA Side Case assumptions, the payback periods compared to a 2040 conventional gasoline vehicle for a PHEV10, PHEV40, and BEV100 in 2040 are 27, 46, and 19 years, respectively, at a 0% discount rate. Even an HEV has a 13-year payback. [a] [546] And at the relatively high discount rates that consumers appear to use in their purchases of energy efficient products (20% is not unusual) the payback periods would look much worse to consumers. Aside from high assumed costs for HEVs and PEVs, these long payback periods reflect the EPSA Side Case assumptions (1) that tax credits or other subsidies will no longer be available in 2040, (2) that competing gasoline-powered cars will attain high

[a] Assumptions: gasoline price of $3.90/gallon; 12,000 miles traveled per year; $0.12/kWh electricity price.

fuel economy levels, thus reducing the fuel savings of PEVs, and (3) that there will be no additional policies affecting PEV penetration. All of these assumptions are subject to some debate, and in particular it seems quite likely that there will be a post-2025 extension of federal fuel economy standards, which might stimulate added emphasis by manufacturers on PEVs.

This is a rapidly evolving market and as a result the EPSA Side Case no longer accurately reflects the cost of vehicles that will soon be on the market.[a] For example, the dominant BEV in the current market, the midsize Nissan LEAF, with a 107-mile range, has an average manufacturer's suggested retail price (MSRP) of about $35,500.[b] The EPSA Side Case projects the price of a midsize BEV100 to be $43,241 in 2016. The new model year 2017 compact Chevrolet Volt, a PHEV with a 53-mile electric range to be released in 2016, has an average MSRP of about $35,400. The EPSA Side Case projects the price of a compact PHEV40 to have a higher price tag of $39,573 in 2016 despite its 25% shorter electric range. It is difficult to know for sure whether this superficial comparison is a fair one as there are multiple BEV and PHEV models on the market today (see Appendix Table 7.9), and therefore the comparison with a single model for each vehicle type may be inadequate.

Also, the EPSA Side Case aims to project vehicle prices for the long term, and these must reflect manufacturing costs. Automakers do not demand the same profit margin across their different nameplates,[c] and they may accept lower (or no) margins for models that have been introduced for regulatory reasons or to enhance the company's reputation as a technology leader. It is likely that automakers that are competing in multiple market segments will sell advanced-technology vehicles like PEVs with smaller profit margins factored into their sales price, and at times may accept a (temporary) loss to gain sales share. However, when sales grow, prices will have to reflect reasonable profit margins. This means that current MSRPs for PEVs may not reflect the actual costs of vehicles as accurately as might be hoped for modeling purposes.

The EPSA Side Case also projects that the other transport sectors—shipping, air travel, freight trucks, and buses—will not electrify, at least in any significant way. Some of these modes would be unlikely to electrify under any circumstances, including air travel, most shipping, and long-distance trucking (unless highways were underlain with electric wires, allowing continuous wireless power transmission). Other modes, especially package delivery trucks and transit buses, may become electrified with some combination of high oil prices and greatly reduced battery prices (and higher battery performance), but the Reference case does not make these assumptions.

EIA has presented preliminary Reference case estimates for the AEO 2016 to its Transportation Working Group.[547] These estimates incorporate the potential effects of the ZEV mandates of California and several other states and yield PEV sales estimates for future years that are much higher than those of the EPSA Side Case. In particular, projected BEV sales are about 550,000/year in 2040, compared to about 100,000/year for the AEO 2015, and projected PHEV sales are about 400,000/year versus about 180,000/year for the EPSA Side Case. Total PEV fleet stock in 2040 for the preliminary AEO 2016 projection is over 12 million vehicles compared to about 3.3 million for the AEO 2015; also, the preliminary version of the AEO 2016 projects that over a million fuel cell vehicles will be in the fleet by

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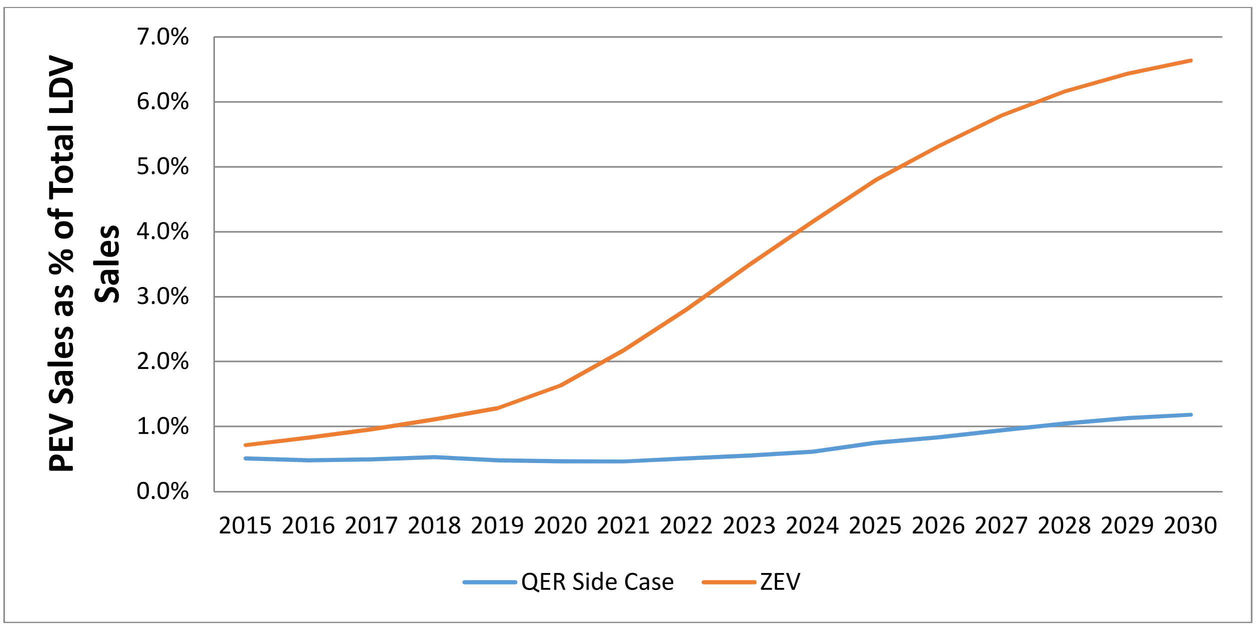
[a] EPSA, like EIA, uses manufacturer's suggested retail prices (MSRPs), without options. The MSRPs are a sales-weighted average of all nameplate models—e.g., Honda Accord, Ford Fusion—in each size class. The historical data that EIA collected uses a simple average MSRP across trim levels for each nameplate.
[b] This reflects the average MSRP for the two trim levels—SV and SL—of the LEAF that attain the 107-mile range; the S trim level attains only 87 miles.
[c] Automakers make more money from their luxury models than from their mainstream entries, for example.

2040, versus about 60,000 in the AEO 2015. It is important to note, however, that even with these higher PEV penetrations, PEVs will remain a small component of the LDV fleet. In 2040, the preliminary AEO 2016 projected LDV fleet stock value at about 270 million vehicles, and therefore PEVs would make up about 4%–5% of the overall LDV fleet in 2040 at these higher estimates of PEV sales.

*Additional PEV Sales Projections*

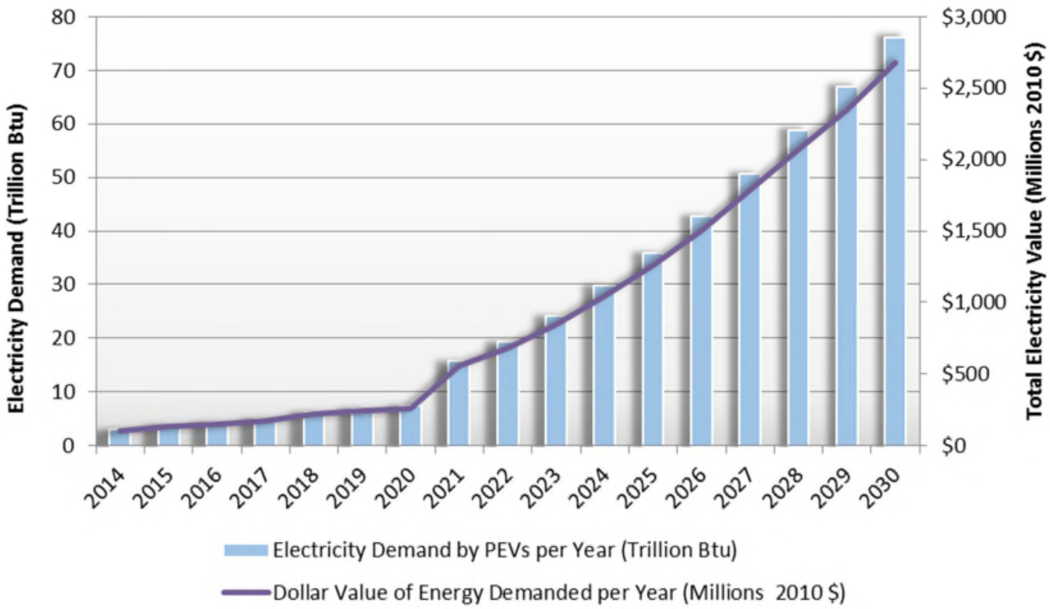
An economic impact analysis of e-mobility by Argonne National Laboratory estimated the electricity consumption of all PEVs on the road by 2030. This analysis assumes that all of the states that have adopted California-style ZEV sales requirements meet their stated goals and account for 70% of all PEV sales in the United States. As indicated in Figure 5.9, such a scenario would result in future PEV sales rates that are more than five times greater than those projected by the EPSA Side Case, reaching roughly 6.5% of all LDV sales in 2030 compared to the roughly 1.2% projected by the Side Case. Similarly, total electricity consumption by PEV is projected to be more than five times greater than EPSA Side Case projections—over 75 trillion Btu compared to roughly 14 trillion Btu (Figure 5.10). This scenario shares the same assumptions with respect to PEV efficiency (i.e., miles per kWh), range, utilization (i.e., miles per vehicle), and charging characteristics (e.g., duration, length, level, location) as the EPSA Side Case.

**Figure 5.9. The U.S. PEV sales rate projected by an Argonne National Laboratory analysis of state Zero Emission Vehicle mandates**[548]




*The analysis projects that PEVs will account for 6.5% of all LDV sales in 2030, whereas the EPSA Side Case projects a PEV sales rate of 1.2%.*

**Figure 5.10. Projected electricity consumption by PEVs based on state ZEV mandates[549]**




*An Argonne National Laboratory analysis of state ZEV mandates projects total electricity consumption by PEVs to reach 75 trillion Btu in 2030. In contrast, the EPSA Side Case projects electricity consumption by PEVs to be roughly 14 trillion Btu in 2030.*

### *Comparison of Five Vehicle Choice Models*

The market for future advanced-technology vehicles is very uncertain and impossible to predict credibly, due to uncertainties in future fuel prices, vehicle characteristics, automakers' marketing strategies, and consumer preferences. A number of projections of future vehicle sales have been made, but it is essential to appreciate that these are not predictions of the future, but only projections that represent possible futures. Large differences in projected outcomes result from differences in assumptions about future vehicle characteristics, consumer preferences, vehicle offerings, and other conditions, as well as differences in modeling methodologies. The usefulness of these projections is not in their predictive accuracy, but in revealing the uncertainty of future vehicle markets and important factors that can influence future market outcomes.

While the EPSA Side Case projects only minimal growth in electrified transportation through 2040, there are a number of vehicle choice models that arrive at dramatically different conclusions for LDVs.[550] These models are $MA^3T$ (Oak Ridge National Laboratory, ORNL), LAVE-Trans (ORNL), LVCFLex (ORNL), ADOPT (National Renewable Energy Laboratory, NREL) and ParaChoice (Sandia National Laboratory, SNL). Figure 5.11 provides a comparison of the results from these five models under a No Program case.[a] The No Program case is a baseline based on simulations of future vehicles, and was developed by assuming that only incremental technology improvements would occur without support from DOE's VTO and Fuel Cell Technology Office (FCTO) programs. Parameters describing vehicle component performance, prices, and other attributes were estimated for 2010, 2015, 2020, 2025, 2030, and 2045 based on input from VTO and FCTO analysts and program managers and Argonne National Laboratory vehicle technology experts.

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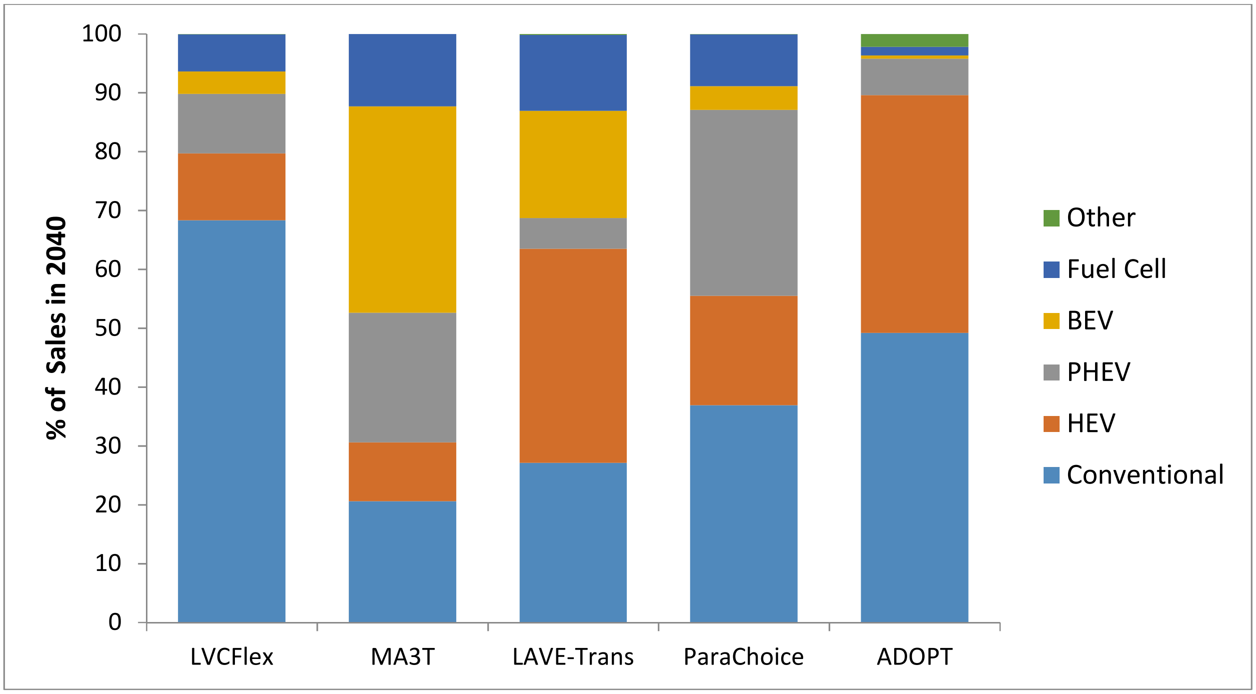
[a] The sets of input assumptions for the five models were designed to replicate the same scenario, so their outputs could be compared on an equal basis. However, the scenario examined was not equivalent to the AEO 2015 Reference case.

The model results show a wide disparity in projected PHEV and BEV sales rates in 2040. On one end of the spectrum, the ADOPT model projects a 6.2% BEV sales rate in 2040, with growth instead primarily occurring for HEVs. On the other end, the MA$^3$T model projects a 57.1% sales rate for PEVs and a further 12.3% sales rate for fuel cell vehicles, with only 20.6% of sales maintained by conventional vehicles. This illustrates the significant level of uncertainty in the potential growth of electrified transportation in the United States over the coming decades. Even the most conservative of these vehicle choice models (ADOPT) predicts PEV sales rates more than five times greater than those projected in the EPSA Side Case, while the most optimistic of these models (MA$^3$T) predicts sales rates almost 50 times greater.

**Figure 5.11. Comparison of projected 2040 vehicle distribution by vehicle type, as determined by five vehicle choice models**[551]




*Vehicle choice models vary significantly in their projections of future alternative vehicle sales rates. The LVCFlex model projects that conventional cars will account for nearly 70% of sales in 2040, while the MA$^3$T model projects that alternative vehicles will account for nearly 70% of LDV sales, including 57% from PEVs.*

Most of the growth potential for electrified transportation in the United States is in the market for LDVs, and to a lesser extent, medium-duty delivery vehicles and transit buses. Growth rates will also depend significantly on the extent of infrastructure investments, cost reductions for batteries and other electric drivetrain components, battery storage densities, and potentially, technology improvements that have not yet been identified. The significant variation in these projections makes it clear that there is far too much uncertainty in this growing and changing market to project transportation electricity use over the next 30 years with any reasonable level of reliability.

### 5.8.6 Outlook Conclusions

LDVs currently account for more than 50% of all U.S. transportation-related energy consumption and represent by far the largest area for potential growth in electrified transportation. It is difficult to project the future market adoption rate of electric LDVs due to uncertainties regarding changing consumer preferences, technological improvements, future technology costs, future oil prices, economic growth, and policy changes.

The EPSA Side Case projects very modest growth in PEVs through 2040. However, this projection appears to be overly pessimistic given the PEV cost assumptions and projections that are used in this analysis. The EPSA Side Case also explicitly does not consider any additional potential policy changes that could support PEV adoption. Specifically, if the 10 states that have adopted voluntary ZEV mandates achieve their goals, PEV sales rates could reach 4.5% by 2030 (not accounting for any growth in the remaining states) or as high as 6.5% (if moderate growth is achieved in the remaining states).[552] These trends are also indicated by the preliminary AEO 2016 results that consider the impacts of ZEV mandates. Alternatively, some vehicle choice models project that cost reductions and technological advancements could lead to PEV sales rates as high as 57% by 2040. Any such projections are dependent on a variety of uncertain parameter assumptions and therefore should be considered in the proper context. Such wide variation in projected PEV sales rates among projections that utilize different methodologies and assumptions underscores the inherent uncertainty in any such projections. It could therefore be concluded that any baseline projection of transport electrification may be only somewhat better than an educated guess.

The transition toward electrified transportation also represents a fundamental shift for consumers who will have to adapt to a new fueling paradigm. It is therefore possible that some sort of tipping point effect will be realized in the event that PEVs reach a particular price point or level of public acceptance. In this case, the steady adoption rates that are currently being experienced could suddenly give way to a period of rapid adoption as consumers make the transition toward the EV paradigm en masse. In this context, it is important to remember that PEVs have only been available to mass market consumers for five years, and it is therefore difficult to establish precedent for the future based upon the limited experiences to date. The relatively modest present share of PEVs, roughly 0.1% of the current LDV stock, by no means restricts potential future adoption.

In other sectors, the negligible growth projections for commercial light trucks and freight trucks in the EPSA Side Case are also likely overly pessimistic due to likely battery improvements, as well as shifts in the delivery model for consumer goods toward online shopping and home delivery (using commercial light trucks and smaller types of freight trucks traveling relatively short distances). The negligible growth projections in the Reference case for electrified passenger rail do not appear to account for potential consumption from the California high-speed rail system that is currently under development. However, unless there is a large paradigm shift in U.S. consumer preference from highway and air travel to rail travel, any growth in electricity consumption from passenger rail will remain relatively small when compared to the potential from electrified LDVs. The projection of essentially zero penetration in bus transit is impossible to assess; although a few transit companies have placed some electric buses in service and longer-range electric buses are now available, it is too early in the development process to make a robust projection. As with passenger rail, any growth in electricity consumption will be small because of bus transit’s small share of passenger transport. The projection of zero progress in electrifying freight rail appears to be in line with the industry's lack of interest and major capital commitments. Similarly, the projection of essentially zero growth in electrification of other modes (e.g., air travel, shipping) appears realistic.

## 5.9 Research Gaps

Following are key research questions and research gaps related to electricity consumption in the transportation sector:

1. What would be the effect of widespread electrification of transportation on the electric grid? How would these effects interact with increased penetration of renewable resources? If electricity use in transportation grows, the magnitude, controllability, and timing of the increased electricity demand will determine its effect on power systems. Geographical concentration of PEVs may strain local transformers, for example. If recharging can be spread over time periods of lower demand, the demand for new electric power production capacity could be minimized and grid economics could be improved. Increased electric transportation loads could also offset projected load reductions from energy efficiency improvements, thereby supporting asset utilization and investments in grid modernization. If PEV batteries can provide storage and balancing services to the grid (vehicle grid integration), variable renewable energy resources such as wind and solar could benefit, and PEV batteries that have been retired from vehicle service might serve as grid storage batteries as a second life. Finally, if electricity use in transportation grows, the achieved emissions reductions will vary regionally based on the current and future fuel mix of electricity generation. Increased analysis and modeling is needed to better understand the net emission impacts, both at a regional and national level.
2. What are the principal determinants of PEV penetration? How can we reliably project PEV penetration? Our current understanding of the factors that will influence future PEV sales is based on our understanding of consumer purchase behavior for conventional vehicles, economic theory, and data from only a few years of actual purchase behavior for PEVs. An important limitation of actual PEV purchase behavior is that it largely reflects the behavior of early adopters, a relatively small portion of potential buyers of new vehicles with a unique set of consumer behaviors and relatively limited market offerings. Continued monitoring and analysis of vehicle sales behavior will be necessary to gain an understanding of mainstream consumers' purchase behavior toward plug-in vehicles, and how they might respond to increasing availability of more affordable PEV models, as well as potential sustained reductions in gasoline prices. We need to understand the value either perceived or real that will cause a willingness to implement a paradigm change from ICE to electricity. We further need to recognize the long time period required to achieve prior significant paradigm changes and manage accordingly.
3. How will changing patterns of personal vehicle travel affect the prospects for PEV penetration? VMT growth is slowing, and there has recently been substantial movement of young professionals to urban areas. Furthermore, fewer young consumers are purchasing personal vehicles. Instead they are using ride sharing and services such as Uber, which could transition toward PEVs themselves. In addition, autonomous vehicles also hold potential to reduce net energy consumption and emissions if certain efficiency improvements, such as trip efficiency (i.e., lower congestion), vehicle "lightweighting," and vehicle-to-vehicle communications are not offset by increases in total travel demand. However, it is unclear if this will be a lasting trend and, if so, the extent to which it may affect prospects for PEV and other new car sales.
4. What business models will work for public charging infrastructure? A substantial public charging infrastructure may have to be in place before large numbers of consumers will purchase BEVs for anything other than purely local service. This implies that public chargers may be underutilized for some time. As batteries improve and vehicle range increases, home recharging will cover an increasing percentage of total trips, but public stations will still be needed for longer trips. Also,

longer trips that require public recharging may have severe peaking issues—e.g., holiday weekends. Further, a combination of heavy traffic and severe heat or cold could greatly exacerbate public charging accessibility issues, since temperature extremes both decrease vehicle range (demanding more frequent recharging) and increase charging time.

5. What policies can be adopted to encourage and shape transport electrification? Evaluating potential electrification policies requires the same kind of knowledge that projecting PEV sales penetration does—a deep understanding of consumer and business behavior. Such evaluation will require nuanced data mining of information from consumer and business behavior regarding other technologies. It will also require careful examination of evolving data from the current generation of EVs and new electrification business ventures and the acknowledgement that business models for vehicle manufacturers and dealerships might evolve to better support PEV adoption; for example, car companies might package charging control and even home charging and public charging services into the sale. Additionally, it will be important to understand how transport electrification may be affected by the adoption of potential new national scale climate policies.
6. What effect will a rising share of PEVs have on the resilience of the transportation system? Although diversifying energy sources in the transport system may superficially appear to increase resilience, electricity has a number of unique characteristics that may complicate this assessment. In particular, in a future where transport has been extensively electrified it may become difficult to move transportation fuel (electricity) into an area where the electric grid has been disrupted. It is, however, also not clear if the impact of such disruptions would be greater or smaller than those from potential similar disruptions of gasoline supply chains and natural gas distribution systems.
7. What is the full value of education and outreach efforts to promote increased consumer awareness of PEVs? How can education and outreach programs be designed to clearly communicate the value proposition of EVs to consumers and their uptake in the market? What are the various programs that have been implemented to date? Which approaches have been successful, and which have not? What lessons can be learned from approaches to increase market adoption of similar products in sectors, e.g., energy efficient appliances?

# 6 Distributed Energy Resources—Distributed Generation, Distributed Energy Storage, and Demand Response

This report focused on the distributed energy resources (DERs) of distributed generation, distributed energy storage, and demand response. Definitions for these resources vary in the literature and for policies and programs. DERs include all demand-side management resources (including energy efficiency), but end-use energy efficiency is often reported separately from other DERs, though it technically constitutes a DER since implementation occurs on the premises of an end-user. *Distributed generation* is sometimes defined as generation that feeds into the distribution grid, rather than the bulk transmission grid, or as smaller capacity power sources.[553] In this work, however, a key attribute for identifying distributed resources is proximity to end users.

For example, the Solar Energy Industries Association (SEIA) states that "distributed generation … refers to electricity that is produced at or near the point where it is used." [a] [554] Thus, a large combined heat and power (CHP) facility at a commercial or industrial consumer's site is considered distributed generation even if it connects to the transmission grid, and large microgrids are viewed as distributed resources if their component resources are largely for local use.[b]

Commercial and industrial distributed generation resources include these non-utility scale resources: [555]

- CHP systems
- Solar photovoltaic (PV) systems
- Wind power systems[c]
- Hydropower systems
- Biomass combustion or co-firing in combustion systems
- Municipal solid waste incineration or waste-to-energy plants
- Fuel cells fired by natural gas, biogas, or biomass
- Reciprocating combustion engines, including backup generators, which are fueled by natural gas or other gaseous fuels (e.g., biogas, landfill gas)

DERs in the residential sector today are predominantly rooftop solar PV systems with anticipated growth in distributed battery storage systems, smart appliances, and demand response. Plug-in electric vehicles (PEVs) may also contribute a new distributed storage resource as costs continue to decline and protocols and policies are developed for their controlled charging as well as discharging to the grid in vehicle-to-grid (V2G) schemes.

This chapter provides an in-depth discussion of CHP, solar PV, distributed wind, distributed energy storage, and demand response, with a briefer discussion of other resources (see Section 6.2.1).[d]

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[a] DOE's SunShot program defines solar PV rooftop systems of any size, and ground-mounted systems up to 5 $MW_{AC}$, as distributed generation, regardless of whether electricity is delivered to the customer side or utility side of the electrical meter. However, these categories consist mostly of systems installed behind the customer meter. See Barbose et al. 2015, p 7.

[b] Chapters 3 and 4 discuss CHP applications in the commercial and industrial sectors.

[c] DOE's 2015 Distributed Wind Market Report breaks down the distributed wind market into three turbine sizes: up through 100 kW (small wind), 101 kW to 1 MW (mid-size), and greater than 1 MW (large-scale).

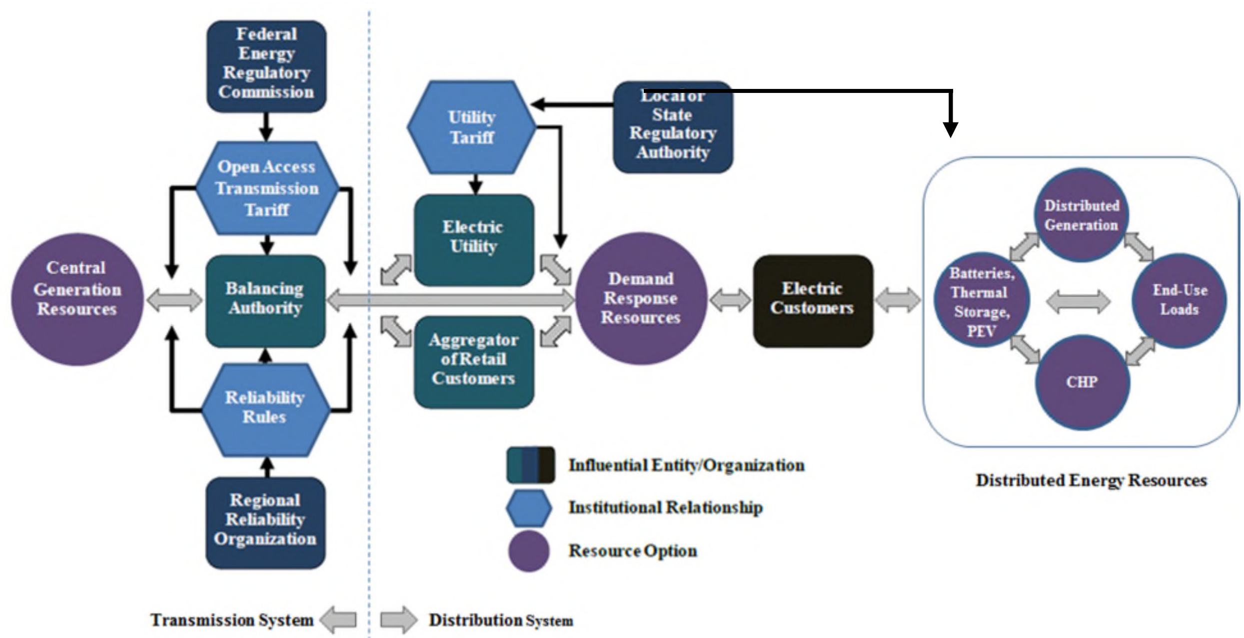
[d] This chapter is not an exhaustive treatment, and not all forms of distributed energy are detailed. For example, solar thermal water heating and thermal storage (e.g., ice storage and firebrick storage) are not discussed.

*Distributed energy storage* refers to storage devices that are connected to the distribution system or storage that is in close proximity to the end user—e.g., a storage system that is installed in a commercial building. Distributed storage includes electric battery storage and thermal energy storage systems (see Section 6.2.2).

*Demand response* includes both incentive-based and time-based programs for electricity consumers that allow them to increase or decrease demand at certain times when such action would be helpful to support the utility grid network (see Section 6.2.4).

Figure 6.1 shows key entities involved in the electricity system (grid) and the interplay of DERs. Moving from left to right along the main axis, central generation resources provide power to the transmission system, and power flows to the local distribution system to serve consumers. The DERs are in proximity to the consumers they serve, and some types of DERs are rapidly expanding (e.g., rooftop solar and battery storage). Distributed generation, including solar PV and CHP, can directly serve end-use loads but also could charge energy storage devices such as electric batteries, thermal storage, and PEV batteries which can subsequently serve end-use loads. Both distributed generation and energy storage devices can also feed electricity back into the grid.

**Figure 6.1. Entities that influence relationships between distributed energy resources and the bulk power system**[556]




*Transmission system entities include central generation resources that supply power via balancing authorities to electric utilities in the distribution system. Demand response resources are supplied by electric consumers and may be aggregated by third-party providers. Behind-the-meter DERs include distributed generation, energy storage, CHP, and end-use loads (demand response). Also shown are the main regulatory bodies and tariff-setting entities: the Federal Energy Regulatory Commission and Regional Reliability Organization for the transmission system and local or state regulatory authorities for the distribution system and DERs.*

Demand response can be thought of as a resource that controls or aggregates a collection of flexible loads that change in response to information communicated through signals from the market, utilities, or regional reliability organizations to ensure system stability and reliability at least cost. These can include, for example, direct control of consumer end-use loads, dispatchable standby generators,[a] and third-party aggregation of a collection of grid-integrated residential water heaters.

Figure 6.1 shows three key regulatory entities: (1) the Federal Energy Regulatory Commission (FERC), which regulates the bulk power market; (2) regional reliability organizations that manage and set guidelines for grid reliability; and (3) the local or state regulatory authority (i.e., the city council, rural co-op board, or state public utility commission) overseeing the utility and setting retail electric prices and other terms and conditions of service.

This chapter assumes that DERs will become increasingly widespread and important for electric system planning and for electricity markets, policies, and programs. All projections are from the EPSA Side Case (see the Introduction to this report), except as noted. Historically, the National Energy Modeling System (NEMS), the model used for the EPSA Side Case, has been very conservative in future projections of energy efficiency and new energy technology adoption,[557] and its projections for renewable DERs are too low to be consistent with recent market adoption trends.[558] Thus, DERs may have a higher rate of adoption than what is depicted in the EPSA Side Case.

## 6.1 Key Findings and Insights

### 6.1.1 DER Trends, Policies, and Programs

*Findings*:

- Distributed solar PV generating capacity grew by about a factor of 80 between 2004 and 2014, while distributed wind increased by about a factor of 14 (Section 6.2.1.3). Combined heat and power (CHP) grew 10.3% over the same period, from a much larger starting base (Section 6.2.1.5).
- The price of installed residential solar PV is projected to fall below \$2/watt ($W_{DC}$) in the next 10 years. [559]
- Distributed solar PV electricity generation is projected to grow by a factor of seven from 2015 to 2040, but it will remain at a low overall percentage of total electricity end use in 2040—about 2.2%.[b]
- Forty-one states have mandatory net metering rules in 2015, but these requirements are highly dynamic with increased pressure from utilities to reduce net metering rates and increase fixed charges for net metering customers. Other rate reform proposals specific to solar PV customers include reduced compensation for grid exports, as well as feed-in tariffs (FITs) and value-of-solar tariffs.[c] [560]
- Most distributed wind is installed at commercial facility sites, including institutional and government facilities. Distributed wind makes up less than 1% of electricity in the commercial sector, with a relative slowing in the last several years (Section 6.2.1.3).

*Insight*: Past growth in distributed generation has been highly policy-dependent, and future growth may be as well. States with longer-term policies (e.g., targets, incentives) have seen more distributed generation adoption.[561] Future growth may continue to be highly dependent on state policies and thus concentrated geographically. In particular, supportive policy incentives for rooftop solar, coupled with

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[a] A dispatchable standby generator is both an example of distributed generation and a resource for demand response.
[b] This is much lower than DOE solar projections, underscoring the uncertainty in future projected deployment, which depends on factors such as continuing reductions in technology and soft costs, rates for solar PV energy and capacity, and the level of retail electric rates.
[c] A FIT offers a guarantee of payments to renewable energy developers for the electricity they produce typically based on project costs, while value-of-solar tariffs provide credit for the electricity generated by a solar PV system, incorporating factors such as energy, capacity, and environmental benefits to the utility system.

dramatic reductions in installed costs, have led to rapid growth in the past few years. Continued cost reductions and new product offerings, such as solar PV bundled with battery storage and utility tariffs that reflect the grid or societal value of these resources, are drivers for greater consumer adoption of DERs, while a reduction in net energy metering policy support will act as a counterforce (Section 6.5.1.1).

*Findings:*

- CHP at industrial facilities represents about 86% of overall CHP capacity in 2015 (Section 6.2.1.5).
- There has been a considerable slowdown in the rate of new CHP additions since the early 2000s (Section 6.2.1.5).
- The highest number of CHP installations in 2013 and 2014 occurred in states with multiyear CHP-incentive programs (New York and California, Section 6.5.1.3).
- CHP generating capacity is equivalent to about 8% of U.S. generating capacity from utility-scale power plants in 2015. CHP systems use 25% to 35% less primary energy than grid electricity plus conventional heating end-uses (e.g., water heaters, boilers), with a typical 75% overall efficiency versus 50% with conventional generation (Section 6.2.1.5).
- CHP is projected to increase to 10% of total electricity end use by 2040 from about 8% in 2015 (Section 6.3.1).
- The technical potential[a] for additional CHP applications in the United States is significant, at 134 GW, with the most potential in the chemicals sector in industry.

*Insight*: CHP growth has slowed but has a large untapped potential. The share of CHP-generated electricity in the United States is expected to grow moderately by 2040.

*Findings:*

- Distributed battery storage is projected to grow rapidly over the next decade.

*Insight:* Declining costs for storage technology (e.g., due to greater production of batteries for PEVs) and state policies such as storage mandates will drive greater adoption of distributed energy storage. Systems that combine distributed generation and battery storage offer the prospect of greater grid flexibility through aggregation of DERs for load balancing, but the regulatory environment to support such services is still taking shape.

### 6.1.2 Barriers to Distributed Generation Deployment

*Findings:*

- Recently the competitiveness of distributed wind has declined with the low relative price of electricity (10% lower price of electricity in the commercial sector from 2007 to 2012), as well as continuing declines in solar PV costs (Section 6.2.1). Other barriers include project financing, lack of a robust vendor supply chain during market downturns, high soft costs (e.g., permitting and insurance costs), and concerns about turbine performance (Section 6.5.1.2).
- Uncertainty in the duration of federal incentives—the investment tax credit (ITC) and production tax credit (PTC)—can drive boom and bust cycles in renewable energy installations. Lack of certainty in

[a] *Technical potential* refers to the amount that is technically possible, not all of which is cost-effective.

federal policy can make it hard for renewable energy companies and suppliers to adequately plan for the future.[a]

- Barriers to distributed solar include the lack of suitable rooftop space for a large fraction of residents, the complexity of PV system purchases (multiple options for payment/ ownership, equipment, system sizes, etc.), and the reluctance to make a long-term energy investment (Section 6.5.1.1).
- Multiple review bodies address permitting and siting of CHP facilities (air and water quality, fire prevention, fuel storage, hazardous waste disposal, worker safety and building construction standards), adding to project delays and costs.

*Insight*: Sustained policy support is needed for the continued growth of distributed solar, wind, and CHP resources.

### 6.1.3 Policies and Programs Enabling Demand Response for Grid Support

*Findings:*

- Long-standing incentive-based demand response programs include direct load control, interruptible load, demand bidding/buyback, and emergency demand response. Recent additions include demand response participating in capacity markets and ancillary service markets. Demand response programs also include time-based retail rates, which are gaining ground where advanced metering infrastructure (AMI) has been installed (Section 6.2.4.2).
- Overall, the market size for demand response in the United States is estimated at $1.4 billion in 2015.[562] Load as a Capacity Resource (LCR) and Direct Control Load Management (DCLM) are the largest ISO/RTO (Independent System Operator / Regional Transmission Organization) demand response program types, with about 75% of overall capacity (Section 6.2.4.2).
- The largest demand response market is in the PJM RTO, which includes day-ahead or real-time "economic demand response" that provides participants with an opportunity to reduce electricity consumption and receive a payment when locational marginal prices are high in PJM's Energy Market. Estimated revenue in PJM for demand response is $300 million to $500 million per year from 2010–2012. Demand resources can also be bid into several ancillary services markets in PJM, including Synchronized Reserve, Regulation, and Day-Ahead Scheduling Reserves Markets (but the portion of demand response in the ancillary services market is very small).[563]
- Behind-the-meter generation (primarily diesel generators) makes up about 35% of demand response capacity[b] in the Midcontinent Independent System Operator (MISO) RTO and about 15% in PJM (Section 6.2.4.2).
- Some state energy efficiency resource standards set targets for peak demand reduction, encouraging demand response programs, as well as energy efficiency that reduces peak loads (Section 6.5.4).
- The regulatory environment for demand response programs is dynamic and evolving. State-level regulatory actions in support of demand response include such activities as testing new approaches through pilot programs, approving investments in enabling technologies such as AMI, and implementing time-varying pricing (Section 6.5.4).

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[a] For example, expiration of the federal PTC in 2013 led to a large drop in central wind and a reduction in distributed wind installations. In December 2015, the ITC for solar was extended in full for an additional three years. See Section 5.5.1.1 for more details.

[b] *Demand response capacity* is measured by the total megawatts (MW) registered by program participants available for grid operators to call upon during a demand response event.

*Insight*: Higher penetration of variable renewable energy resources, both on the distribution system and at the bulk power level, requires greater grid flexibility. More responsive loads through demand response can support grid operations. The ancillary services market is currently relatively small but is expected to grow with higher penetration of wind and solar PV. Third-party aggregators and emerging business models will facilitate demand response, but the regulatory environment is still evolving. Environmental impacts of changes in power plant dispatch and use of on-site backup power generation are important to consider when planning demand response programs.

## 6.2 Characterization

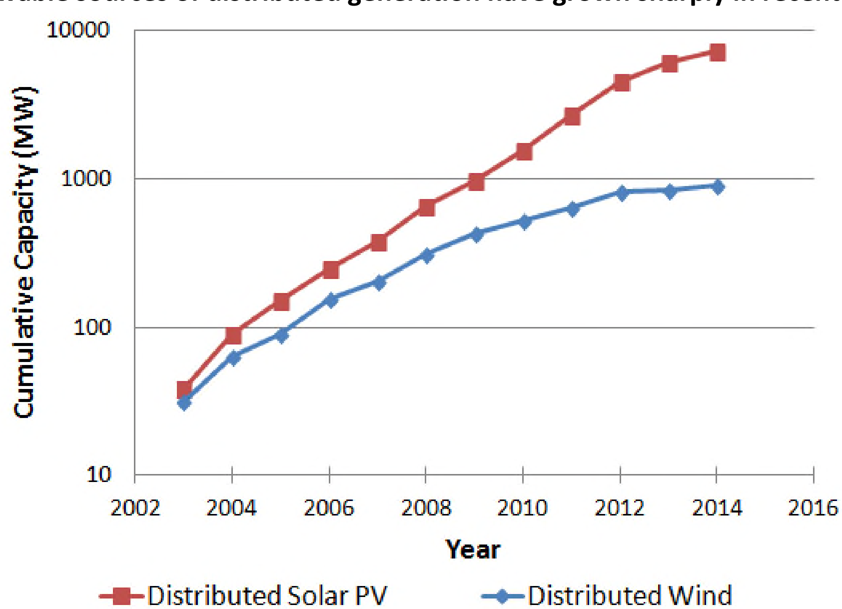
### 6.2.1 Distributed Generation

The United States has more than 12 million distributed electric generation units, equivalent in capacity to 18% of the nation's utility-scale capacity.[564] Much of the distributed generation capacity is for back-up power, used primarily by end-use customers to provide emergency power during grid outages. This report focuses on distributed generation for primary, nonemergency power—specifically, distributed solar PV, distributed wind, and CHP. Total distributed generation capacity, including CHP (83 GW),[565] distributed PV, and distributed wind (but not including emergency power) was estimated at 91 GW in 2014.[566]

#### 6.2.1.1 *Distributed Solar PV and Wind*

Distributed solar PV and wind refer to solar PV and wind turbines that are located near the point where the generated electricity is used, rather than being defined by project size.[567] Distributed solar PV and wind generating capacity grew sharply over the past decade, as Figure 6.2 shows. Distributed solar PV generating capacity grew by about a factor of 80 between 2004 and 2014, while distributed wind increased by about a factor of 14.

**Figure 6.2. Renewable sources of distributed generation have grown sharply in recent years[568]**



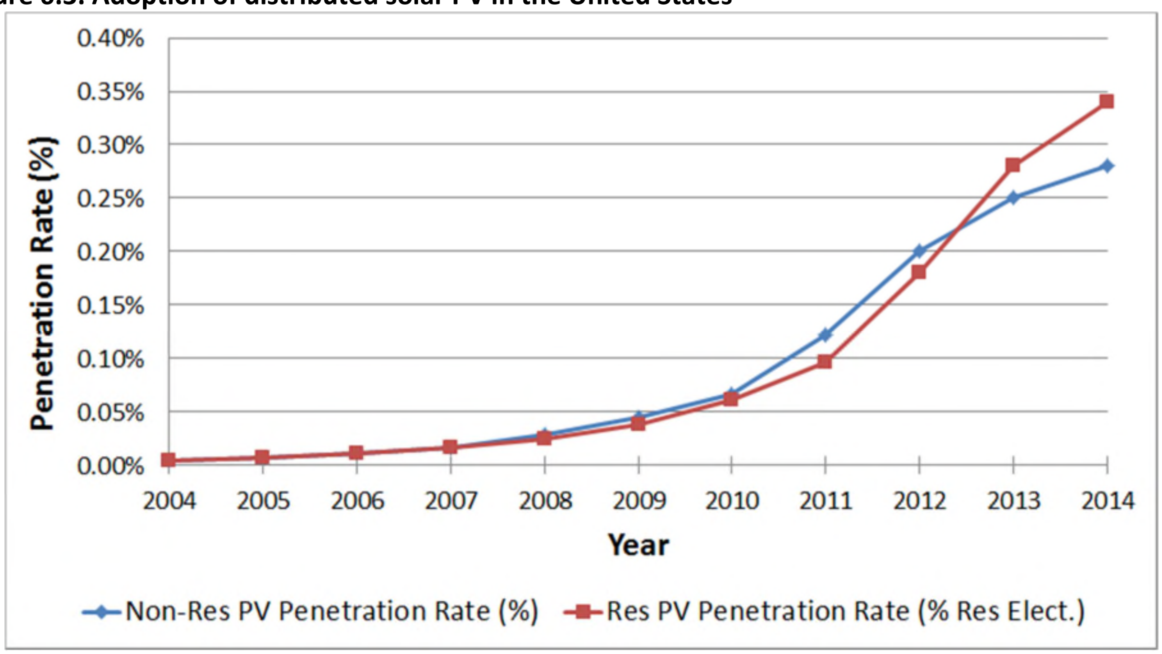

*Distributed solar capacity increased by over 8,000% between 2004 and 2014; distributed wind grew by over 1,300%.*

Distributed solar PV growth has been driven by a dramatic drop in the total installed cost of solar PV and has been further encouraged by reduced up-front consumer costs due to the greater availability and market adoption of third-party ownership and leasing options.

Despite the rapid growth of distributed PV and wind generating capacity, these resources contribute a very small portion of overall U.S. electricity supply. Figure 6.3 and 6.4 depict recent adoption trends for distributed PV and wind power. The penetration rate of distributed solar PV is expressed as PV electricity generation as a percentage of the total electricity load of each sector (residential and nonresidential). Similarly, the penetration rate of distributed wind is expressed as distributed wind generation as a percentage of total U.S. electricity load in the commercial sector.

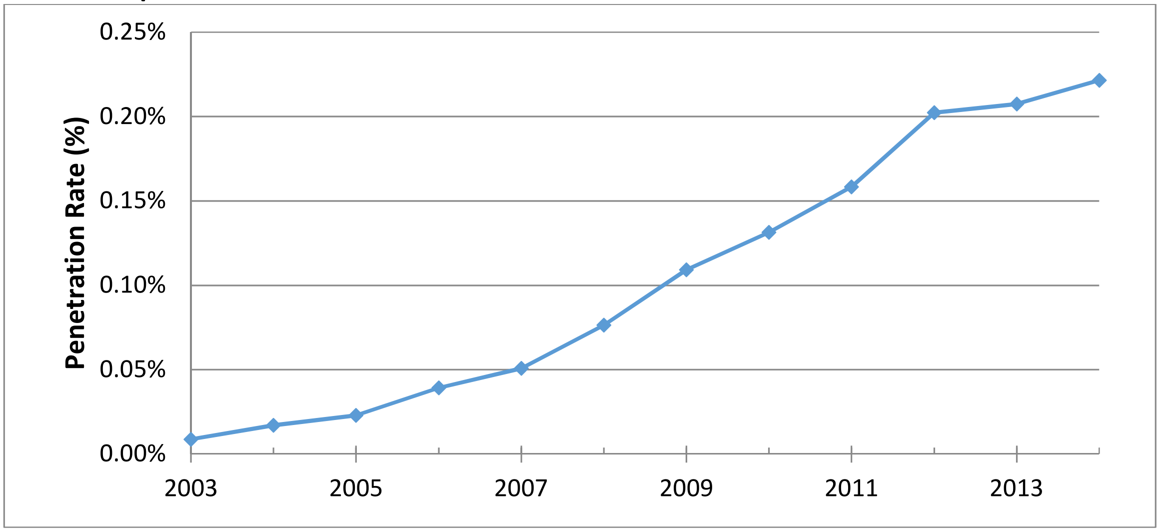
The penetration of distributed solar PV in 2014 was about 0.35% and 0.28% in the residential sector and nonresidential sectors, respectively, with the former overtaking the latter for the first time in 2013. In the United States, California dominates rooftop solar PV, with about 40% of the nation's installed capacity, due in large part to legacy statewide incentive programs such as the California Solar Initiative as well as having retail electricity rates that are among the highest in the nation. New Jersey, Arizona, and Massachusetts follow California, with about 10%, 8%, and 7% of the nation's total installed capacity, respectively (Figure 6.5). Distributed wind penetration is just under 0.25% in the commercial sector, with a leveling off of penetration in the last three years.

**Figure 6.3. Adoption of distributed solar PV in the United States[569]**



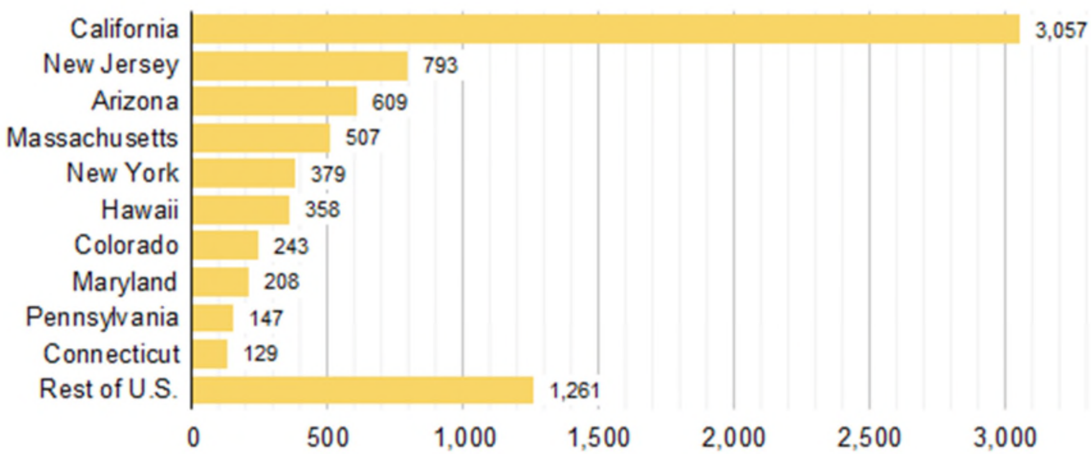

*Penetration rates are expressed as PV electricity generation as a percentage of the total electricity load of each sector—residential or nonresidential (commercial plus industrial sectors)—in gigawatt-hours (GWh), assuming a solar PV capacity factor of 20.3%. Distributed solar PV is growing faster in the residential sector, with growth in the nonresidential sector tapering off in recent years.*

**Figure 6.4. Adoption of distributed wind in the United States[570]**




*The penetration rate is expressed as wind electricity generated as a percentage of total electricity load in the commercial sector, assuming a wind capacity factor of 36.8%. Distributed wind makes up less than 1% of electricity in the commercial sector, with a relative slowing in the last several years. Most distributed wind is installed at commercial facility sites, including institutional and government facilities.*

**Figure 6.5. Distributed solar PV installed capacity in $MW_{AC}$[571]**




*The figure ranks the top 10 states in terms of distributed solar PV capacity as of September 2015.*

"Smart inverter" technologies[a] [572] for solar PV systems can help provide voltage regulation and reactive power support to address voltage and frequency fluctuations, and may help to increase the amount of solar PV that can be connected to the distribution grid. For example, Hawaiian Electric Company is developing and enabling smart inverter functionality at consumer-owned sites that could allow a doubling of the amount of PV installed on heavily utilized circuits.[573] It investigated the impact of high concentrations of solar PV on distribution circuit voltage disruptions and found the primary issues for solar-heavy circuits are the age and quality of power-conducting cable and transformers on each circuit.

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[a] In addition to basic DC-to-AC power conversion functionality, smart inverters also offer: (1) reactive power control, with the ability to supply or absorb reactive power in the desired quantity, to operate distribution systems more efficiently and improve power quality and (2) voltage and frequency ride-through responses, to correct fluctuations in distribution system voltage or frequency by modulating reactive or active power, respectively. In many cases, this can allow distributed generation to continue operation through a fault.

Recently the competitiveness of distributed wind has declined with the low relative cost of electricity. Other barriers for distributed wind are project financing, lack of a robust vendor supply chain during market downturns, high soft costs (e.g., permitting and insurance costs), regulatory and planning uncertainty (discussed in Section 6.5.1), and concerns about turbine performance.[574]

#### 6.2.1.2 *Fuel Cell Systems*

Fuel cells are electrochemical energy conversion devices that react hydrogen and oxygen to produce electricity and heat, with water as a by-product. Fuel cells can accept a variety of fuel types (typically natural gas), depending on the type of fuel cell technology, and have very low criteria emissions (e.g., oxides of nitrogen and sulfur oxides).

Several fuel cell technologies are either on the market for distributed generation applications (e.g., molten carbonate fuel cells, phosphoric acid fuel cells, solid oxide fuel cells, low-temperature proton exchange membrane fuel cells) or in development (e.g., low- temperature solid oxide fuel cells, high-temperature proton exchange membrane fuel cells). Fuel cell vehicles are starting to appear on the market as well, although the need for hydrogen fueling stations is a major infrastructure challenge. With potential high penetration of wind and solar resources in the future, large-scale electrolyzers (essentially fuel cells operated in reverse to produce hydrogen and oxygen from water) may enable renewably produced hydrogen[a] that can be stored for future use, used as a transportation fuel, or provide on-site power and heating.

While fuel cells are a small market share of distributed generation today, they are an intensive area of research, development, and deployment (RD&D) in the United States and globally. High system cost is still a major barrier for greater market adoption. Fuel cell systems can be used for distributed generation—e.g. power-only systems or CHP systems.

#### 6.2.1.3 *Small-Scale Hydropower*

While there is no consensus on the definition of small-scale hydropower,[b] a value of up to 10 megawatt (MW) capacity is generally accepted.[575] A recent Oak Ridge National Laboratory (ORNL) study estimated 12 GW of potential hydro capacity in the United States, based on a survey of nonpowered dams. Most of the potential capacity is on waterways with locks and dams for river transportation.[576] [c] Some 90% of the total capacity is on large dams (597 sites with an average of 18 MW per site). The remaining 53,794 sites total 1.26 GW of potential capacity and an average size of 23.4 kilowatts (kW) per site.

#### 6.2.1.4 *Waste-to-Energy Plants*

As of 2014, 84 waste-to-energy plants were in place in the United States, accounting for 2,554 MW of total U.S. capacity, or about 0.3% of power generation.[577] Most of these facilities produce electricity for sale to the grid, but about a quarter of them are cogeneration facilities or steam generators. This distributed subset represents under 0.1% of power generation in the United States. Waste-to-energy facilities face barriers of high capital cost and "not in my backyard" concerns of social equity due to airborne emissions.[578] A recent study by the U.S. Environmental Protection Agency (EPA) and North

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[a] Today, hydrogen is commonly produced by steam methane reforming with natural gas as an input fuel. This process still produces carbon dioxide ($CO_2$) emissions. In contrast, hydrogen produced by the electrolysis of water would create no $CO_2$ emissions if produced by electricity from non-polluting renewable energy sources.

[b] EPSA Side Case does not break out small-scale hydro capacity in future electricity projections for renewable power.

[c] This study does not discuss economic viability or the locations of smaller-sized non-powered dams.

Carolina State University found that incinerating garbage is more environmentally friendly than land-filling garbage. Waste-to-energy potential is dependent in part on municipal solid waste diversion rates, as some states and localities have goals for achieving reductions in municipal solid waste sources as well as high diversion rates for recycling and composting.

#### 6.2.1.5 *CHP Systems*

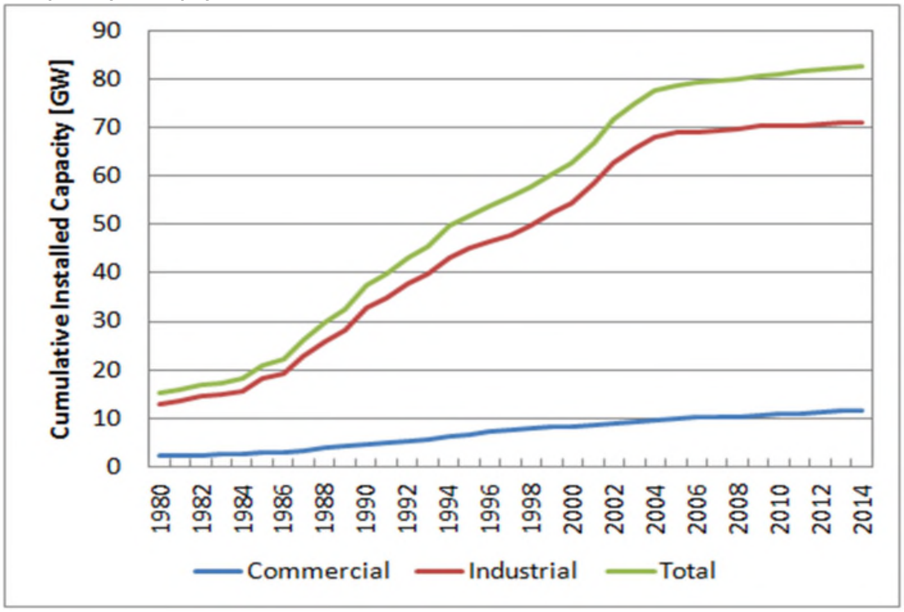
Combined CHP generates useful hot water or steam and electricity from a single system at or near the point of use. CHP systems use 25% to 35% less primary energy than using grid electricity plus conventional heating end-uses (e.g., water heaters, boilers), with typical 75% overall efficiency versus 50% with conventional generation.

CHP capacity is equivalent to about 8% of U.S. utility-scale generating capacity[579]—nearly 83 GW at more than 4,300 industrial, institutional, and commercial facilities,[580] most commonly in industrial applications with continuous processing and high steam requirements. After a period of sustained growth from the mid-1980s to the early 2000s, recent growth in CHP capacity has slowed to less than 1% annual growth since 2006. Market penetration is much lower in commercial buildings, but CHP can be well suited to facilities such as hospitals, hotels, laundries, nursing homes, educational institutions, prisons, and recreational facilities.[581]

Direct benefits of CHP to end-use consumers include reduced energy consumption and lower energy costs. CHP can offer additional benefits of increased reliability, decreased risk of power outages with additional power supply, enhanced economic competitiveness, reduction in air pollutants, and lower demand on transmission and distribution systems.

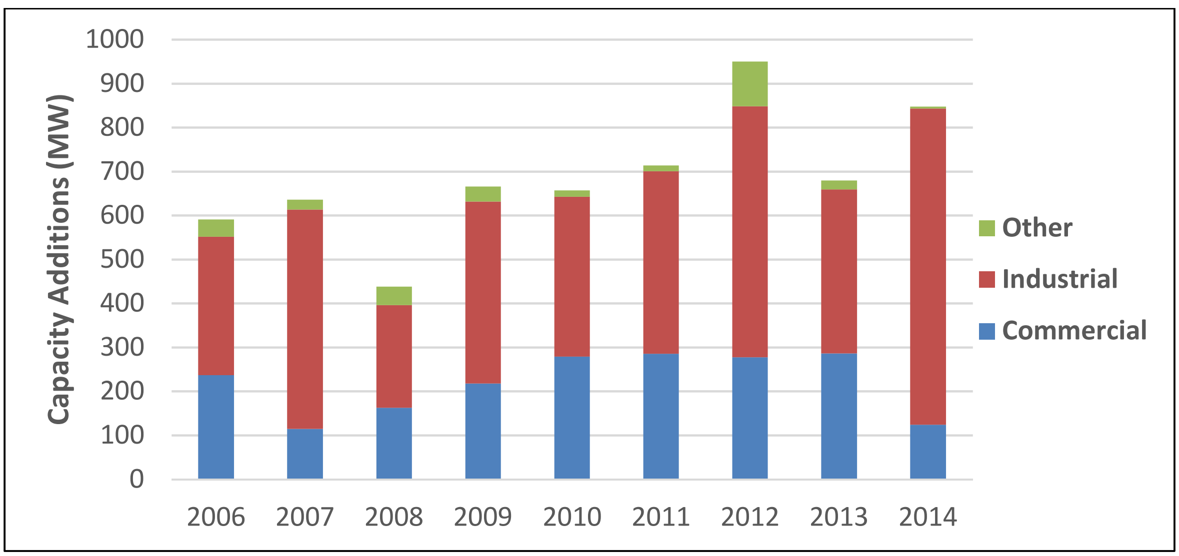
Figure 6.6 shows the increases in CHP capacity over time. Most CHP capacity is at industrial sites that have high energy demands and a generally steady demand for manufacturing process heating. Capacity additions slowed in the early to mid-2000s. Other prime mover types include combustion turbines, reciprocal engines, waste-heat-to-power, fuel cells, and microturbines. Figure 6.7 shows annual CHP capacity additions over time. The market is dominated by industrial applications, with the chemicals, refining, paper, and food subsectors making up 61% of installed CHP capacity.[582]

**Figure 6.6. CHP capacity sharply increased in the late 1980s and 1990s[583]**




*CHP facilities at industrial sites represented about 86% of overall CHP capacity in 2014. There has been a considerable slow down in the rate of new CHP additions since the early- to mid-2000s due to changes in policy.*

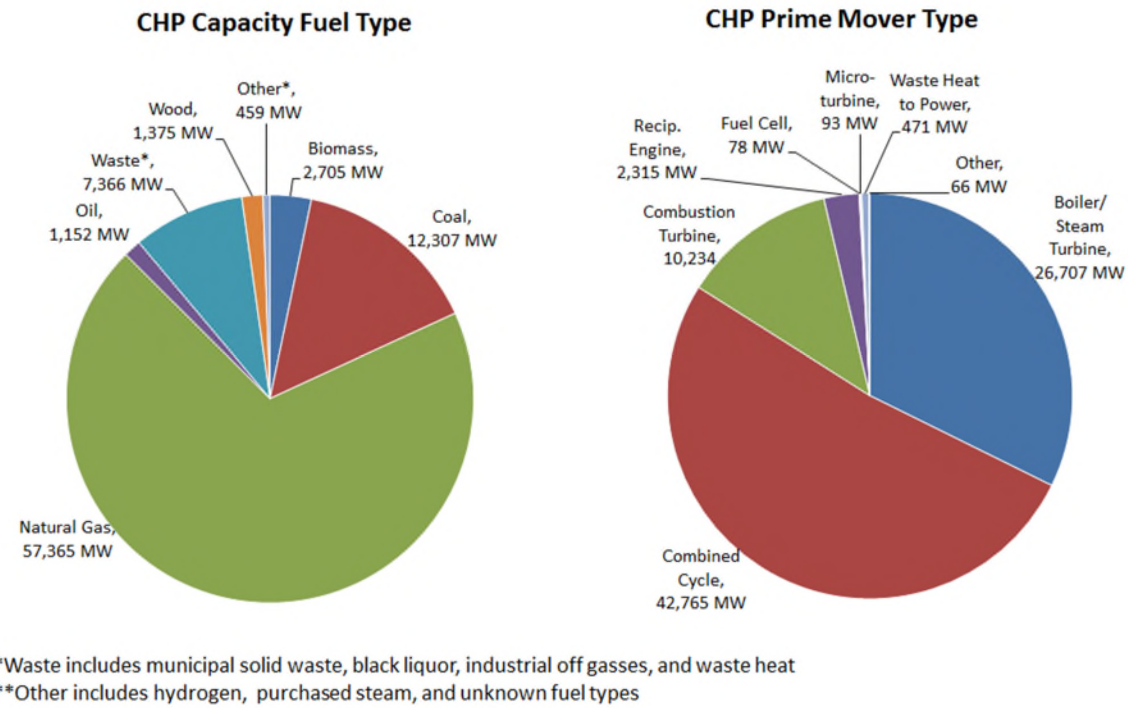
**Figure 6.7. CHP capacity additions in the United States from 2006–2014[584]**




*Capacity additions varied from 430 MW to 940 MW annually during the period of 2006 to 2014, with most of the additions in the industrial and commercial sectors. This is down from peak annual installation of 5,000 MW to 6,000 MW earlier in the 2000s.*

Figure 6.8 shows that 69% of CHP is fueled by natural gas, with combined-cycle comprising 57% and boiler/steam turbines making up 32%.

**Figure 6.8. CHP capacity fuel mix and prime mover type, 2015**[585]



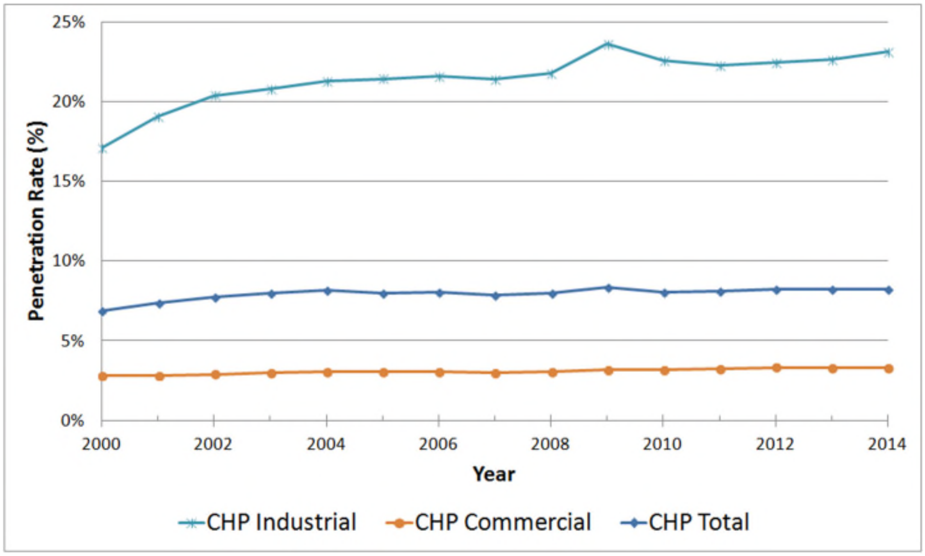

*Natural gas dominates the fuel mix while combined-cycle and boiler/steam turbines make up the bulk of the capacity.*

CHP is found in every state, but with uneven distribution of capacity among states. Texas and California have the most CHP installed capacity at 21.3% and 10.6% of national CHP capacity, respectively (see Distributed Energy Resources Appendix, Figure 7.33 and Figure 7.34). Some 70% of total CHP capacity is in 10 states (Texas, California, Louisiana, New York, Florida, Pennsylvania, Alabama, Michigan, New Jersey, and Oregon), while 32 states have less than 1 GW each comprising 12.4% of total U.S. CHP capacity.

CHP cost-effectiveness depends on many factors, such as equipment cost, the matching of CHP system output with facility load profiles, overall system efficiency and availability, the price of electricity and fuel, and the price of any excess electricity sold back to the grid. The large drop-off in CHP installations in the mid-2000s was due in large part to a change in Public Utility Regulatory Policies Act (PURPA) regulations reducing the reimbursement rate for power sold back to the grid (from the “avoided cost” of new utility generation to prevailing wholesale market rates for energy and capacity). (See Section 6.5 for a discussion of CHP barriers and policies.)

In Figure 6.9, adoption of CHP is expressed as CHP electricity generation for a particular sector as a percentage of the total electricity load of the sector. The CHP share of total electricity load has been steady at about 8% since 2002.

**Figure 6.9 CHP in the industrial and commercial sectors[a] [586]**




*CHP steadily supplied an estimated 22%–23% of electricity for the industrial sector over the last decade. This penetration rate represents the estimated CHP electricity output divided by the total electricity load of that sector, expressed as a percentage. CHP total penetration is the sum of CHP generation in the commercial and industrial sectors divided by the total electricity load in the United States for all sectors.*

### 6.2.2 Distributed Energy Storage

Energy storage can contribute to energy security, balancing electricity loads and integrating variable energy resources (VERs, e.g., wind and solar). The U.S. Department of Energy (DOE) has recognized several grid-scale energy storage issues that also are relevant to distributed energy storage: "The future for energy storage in the U.S. should address the following issues: energy storage technologies should be cost competitive (unsubsidized) with other technologies providing similar services; energy storage should be recognized for its value in providing multiple benefits simultaneously; and ultimately, storage technology should seamlessly integrate with existing systems and sub-systems leading to its ubiquitous deployment." [587]

DOE's strategic goals for meeting this vision are: (1) energy storage should be a broadly deployable asset, to enable higher penetration levels of renewable resources; (2) energy storage should be available to industry and regulators as an effective option to resolve issues of grid resiliency and reliability; and (3) energy storage should be a well-accepted contributor to realization of smart-grid benefits—specifically, enabling confident deployment of electric transportation and optimal utilization of demand-side assets.

DOE outlined four key challenges that must be addressed to meet these goals:[588]

- Cost-competitive energy storage technology – Overcoming this challenge requires cost reduction, improvement of performance factors (e.g., round-trip efficiency, energy density, cycle life, capacity fade), and the capacity to realize revenue for all the grid services that storage provides.
- Validated reliability and safety – Validation of the safety, reliability, and performance of energy storage is essential for greater consumer adoption.

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[a] Residential CHP is a very small fraction (0.2%) of total CHP in the United States and is not included.

- Equitable regulatory environment – Achieving value streams from energy storage depends on reducing institutional and regulatory hurdles to levels comparable with those of other grid resources.
- Industry acceptance – Greater adoption by industry requires confidence that energy storage will deploy as expected and deliver as predicted and promised.

DOE's Electricity Advisory Committee (EAC) recently highlighted that the "most recent and potentially significant trend is in the identification of emerging applications for distributed energy storage … and the committee recommends that applications for storage interconnecting at the distribution level should be an area of increased focus."[589]

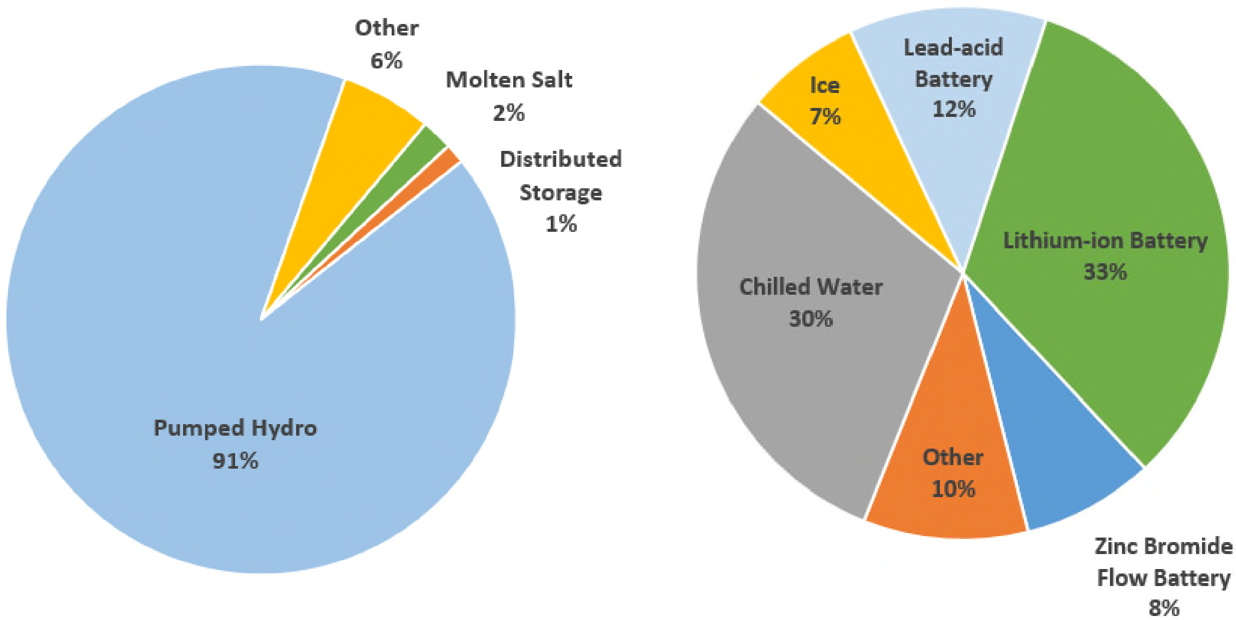
Distributed storage at the facility or campus level can improve power quality, provide bridging power in an emergency outage, and facilitate responsiveness to utility demand programs and time-varying rates to cut peak demand costs.[590] At the residential level, storage can provide greater on-site use of electricity produced by distributed generation systems and enable optimization of energy usage as time-varying pricing becomes more widespread.

Distributed energy storage technology options include the following:

- Batteries are electrochemical devices that can store electricity. Batteries are the most mature and available option for small- to medium-sized electric storage, but their relatively high cost has limited their wider deployment. Battery technologies must also ensure that any risks to human health and safety are carefully managed. Batteries contain toxic chemicals in their components and have the potential, however slight, to overheat, ignite, and explode. These issues can be mitigated through appropriate designs, proper installation procedures and fire protection. Demonstrations of safe operation in the field in pilot studies can also help to assuage concerns about battery safety.
    - *Lithium-ion (Li-ion) batteries* are a leading battery technology with much higher power density than the common lead-acid battery. Many other electrochemical battery types are in the research and development (R&D) phase.
    - *Sodium sulfur batteries* tend to be larger battery installations and can be used for transmission grid support, as well as on the distribution system. Size ranges from 1 MW to tens of MWs.
- Plug-in hybrid electric vehicles (PHEVs) and battery electric vehicles (BEVs) have onboard electric batteries, which can store electricity and release electricity at a later time.
- Hydrogen can be produced by electrolyzing water. Hydrogen can be stored in gas, liquid, or metal hydride form. Energy can be released in a fuel cell as electricity for powering hydrogen fuel-cell vehicles or for stationary power or CHP applications.
- Thermal energy storage includes generating ice or chilled water during hours when electricity rates are low. The stored energy can meet cooling demand during hours of peak electricity use. Electric water heaters equipped with advanced controls and two-way communication devices can act as an excellent storage medium by heating water during times of low electricity demand. Appropriate design and use of thermal mass in buildings can also improve comfort and save on energy bills.
- Supercapacitors use electric charge storage on parallel plates and offer high power density and efficiency, but have high costs and low energy density. Supercapacitors have been proposed for home use in conjunction with DC buses and microgrids.[591]

**Figure 6.10. Total storage capacity (a) and distributed storage capacity (b), as of September 2015[592]**

(a) Total Energy Storage Capacity (b) Distributed Energy Storage Capacity




*Total storage capacity of 29.6 GW is 91% pumped hydro. About 1%, or 364 MW, of total storage capacity is distributed, of which thermal storage (both ice and chilled water) makes up the largest share at 37%, followed by lithium-ion batteries at 33%.*

Energy storage in the United States is dominated by grid-scale pumped hydro (91% of capacity) and relatively little is distributed storage (7% of capacity) (See Figure 6.10a).[a] Distributed storage capacity in the United States as of September 2015 is 364 MW with median storage system capacity of 152 kW.[593] Figure 6.10b shows the allocation of distributed storage by technology. Thermal storage (both ice and chilled water) and Li-ion batteries each account for about one-third of distributed storage in the United States. Currently the demand for storage is largely driven by a mandate in California to add 1.3 GW of storage (both distributed and transmission grid–connected) by 2020.[594]

Energy storage on the grid can mitigate peak load problems, improve electrical stability, and eliminate power quality disturbances.[595] Standardized control strategies are needed to better facilitate interoperability and aggregation of resources. Distributed generation deployed with energy storage can help optimize use of distributed generation, improve electric system flexibility, and increase energy security during grid outages.

Today, a primary source of value of storage systems for large utility customers is to reduce utility demand charges. These charges, tied to the customer's peak electricity demand (in kW) in the billing period, comprise up to 30% of a commercial customer's electricity bill. Recently, partnerships of solar PV and storage companies have been formed to develop market offerings combining PV and battery storage, including Stem and SunPower, Green Charge and SunEdison, and Tesla and SolarCity.

[a] This "Other" category in the DOE database is made up of 18% capacity with reported distribution interconnection, 45% with reported transmission interconnection, and 37% with no reported interconnection.

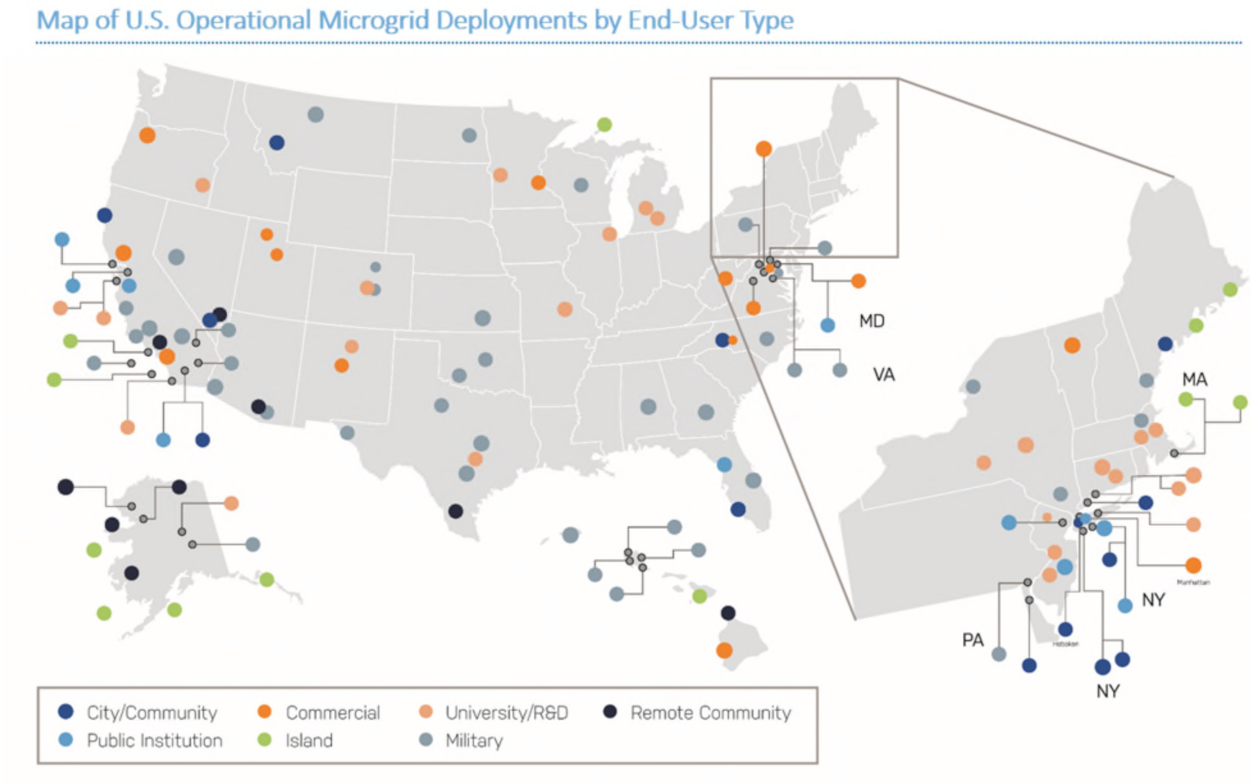
*Community energy storage* refers to the deployment of modular distributed energy storage at points in the utility distribution system close to residential and commercial customers. These installations can help manage the effects of distributed generation and PEVs by protecting power quality and ensuring grid stability. Community energy storage offers better economies of scale compared to individual consumer installations and where on-site consumer site storage is not practical. Community energy storage is still in the early stage of demonstration and deployment. Two early demonstration projects are (1) American Electric Power investigations that started in 2005 with a 2 MW sodium sulfur battery connected to a substation and later added many smaller units (25 kW) located near end-user sites, and (2) Detroit Edison's community storage project with units just under 1 MW, coupled with utility-scale solar PVs—a $10.9 million project with support from the 2009 federal stimulus.

### 6.2.3 Microgrids

A *microgrid* is a group of interconnected loads and DERs within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid. Microgrids can connect and disconnect (or "island") from the grid. Configurations are flexible and varied, including various DER types and microgrid sizes. Microgrids can include CHP, solar PV systems, wind turbines, thermal storage, battery storage, and fleets of PEVs. Such a collection of resources can provide a wide range of energy system design and operating practices with potential greater power quality, flexibility, and reliability for economic or emissions optimization. Microgrids can offer energy security for grid outages and natural disasters.

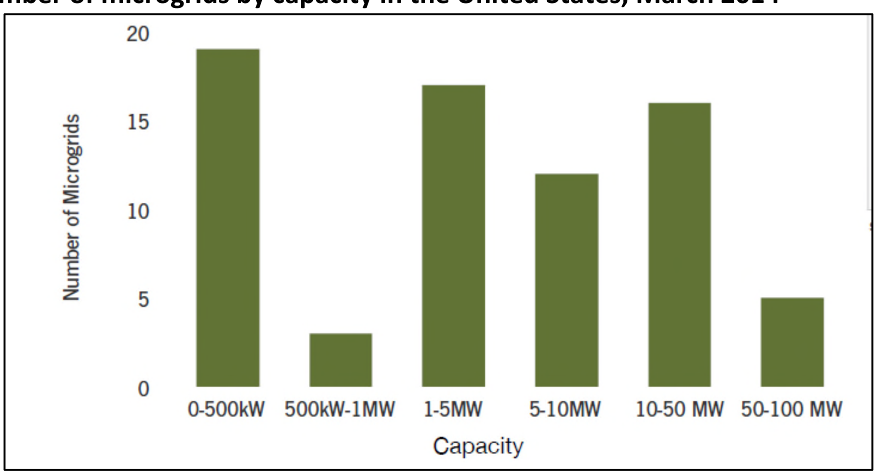
As of August 2015, the operational microgrid power capacity in the United States is 1.2 GW, with approximately 50% of the capacity commissioned after January 2013.[596] United States microgrids are dispersed around the country, with hotspots in California, Hawaii, and the Northeast (Figure 6.11). Figure 6.12 shows the distribution of microgrids by capacity, with sizes ranging from 100 kW to 100 MW. Military installations and university/research facilities currently make up the majority of current operational microgrid capacity (Figure 6.13). However, a growing share of planned microgrid installations are for commercial and public institution settings. Microgrids for commercial applications and third party-owned microgrids also are entering the market, subject to the regulatory constraints discussed in Section 6.5.3. Microgrids also have important off-grid applications in remote rural areas.[597]

**Figure 6.11. Microgrids in the United States as of Q3, 2016**[598]



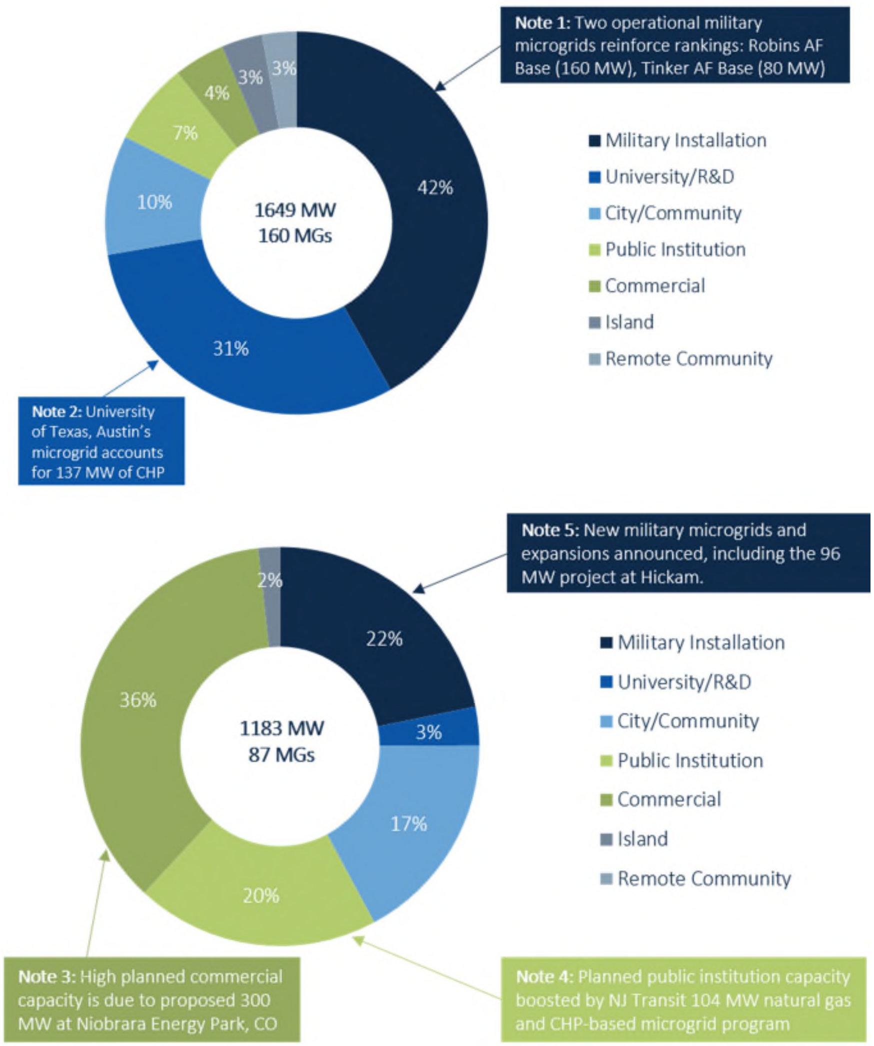

*Microgrids are distributed around the country with hotspots in California, Hawaii, and the Northeast.*

**Figure 6.12. Number of microgrids by capacity in the United States, March 2014**[599]




*Most microgrids are either less than 500 kW or between 1 MW and 50 MW.*

**Figure 6.13. Known (top) and Announced (below) Microgrids in the United States by End User, as of Q3, 2016**[600]




*Some 160 microgrids were in operation (left), with 87 planned (right). Among the key trends is third-party ownership.*

### 6.2.4 Demand Response

Demand response programs have been under way for several decades, traditionally administered and managed by utilities to manage peak load. FERC defines *demand response* as "changes in electric usage by demand-side resources from their normal consumption patterns in response to changes in the price of electricity over time, or to incentivize payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized."[601] These changes in consumption of grid-produced electricity can be done in three ways: (1) reducing electricity usage at peak demand times or times of high electricity rates; (2) shifting energy use consumption in response to price signals or demand response program incentives; and (3) using on-site back-up or emergency generation.

Historically, demand response has had two primary purposes: (1) for emergency response (a few times a year) to ensure system stability and (2) to reduce consumption during times of high prices (50–100 hours a year). Demand response is beginning to play a greater role in facilitating integration of VERs (e.g., wind and solar), which could occur on a year-round, more automated basis at varying times of day. Demand response services in support of renewable energy integration could include increasing end-use demand—for example, during periods of high renewable energy ramp rates, not just the traditional reduction during hours of peak demand.

The benefits of demand response include improved system reliability, reduced need for capital investments to serve peak demand, reduced electricity market prices, and better utilization and integration of renewable energy.

The continuum from demand response to energy efficiency has been discussed in other reports.[a] For example, an energy efficiency program may reduce energy consumption throughout the year, while a demand response program may be invoked only a few days a year to reduce peak demand and have a far smaller impact on overall energy consumption. "Coordinating energy efficiency and demand response could provide customers with better tools to understand, manage, and reduce their electricity use,"[602] and greater coordination of energy efficiency and demand response is occurring in state programs and plans as described in Section 6.5.4.

Today, the confluence of AMI, greater capabilities in building and end-use equipment sensors and controls, and advances in IT (e.g., big data, advanced data analytics, and cloud computing) has facilitated increased demand response capabilities. More automated demand response capabilities will enable greater flexibility of demand-side resources, improved integration of variable renewable energy resources, and improved opportunities for system optimization.

#### 6.2.4.1 *AMI and Smart Devices That Enable Demand Response*

Advanced metering infrastructure (AMI) provides two-way communication between the utility and the end-use customer and, with a customer's permission, access to end-use equipment and appliances for direct load control by the utility, or a customer's preprogrammed, automated responses to time-varying electric prices. AMI enables time-based rates and facilitates the integration of distributed generation systems, among other capabilities.

More than 50 million smart meters have been deployed in the United States, covering 43% of U.S. homes (See Figure 7.32). Utilities have installed about 70% of their target number of meters (Table 6.1). Figure 6.14 shows the distribution of installations by state.

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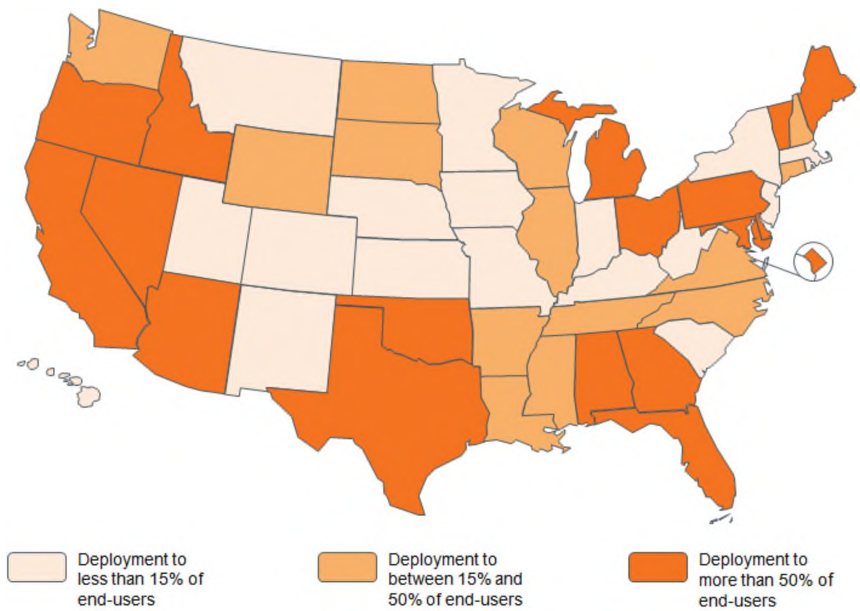
[a] See, for example C. Goldman, M. Reid, R. Levy, and A. Silverstein, *Coordination of Energy Efficiency and Demand Response,* Berkeley, CA: LBNL (Lawrence Berkeley National Laboratory), 2010, LBNL-3044E.

**Figure 6.14. Smart meter deployments by state for investor-owned utilities, large public power utilities, and some cooperatives: Completed, under way, or planned as of 2014**[603]




*Deployment in 17 states exceeds 50% of end users.*

**Table 6.1. Smart Meters Installed by Utility Type, 2014** [a] [604]

| Utility Type | Meters Installed | Target Number of Meters | % Installed vs. Target | Target Number as a Percentage of Total Customers |
|---|---|---|---|---|
| Investor-Owned Utilities | 43,115,000 | 60,126,000 | 72% | 59% |
| Municipal and Cooperative Utilities | 6,963,000 | 9,874,000 | 71% | 24% |
| Total as of July 2014 | 50,078,000 | 70,000,000 | 72% | 49% |

*As of July 2014, utilities were about 70% of the way to their goal of 70 million smart meters. Note that data on Smart Meter installation for municipal and cooperative utilities can be limited so these values may under-represent actual deployment values.*

Table 6.2 indicates that smart meter penetration is fairly evenly spread between the residential, commercial, and industrial sectors. (See Figure 6.15 for a map of North American Electricity Reliability Council [NERC] regions.) Penetration has already exceeded 50% in Texas, Florida, and the Western United States. The 2009 American Recovery and Reinvestment Act (ARRA, federal stimulus bill) provided significant funding to assist utilities with deployment of AMI assets (Table 6.3). Some 63% of AMI expenditures funded under the ARRA went toward smart meters, with 37% of overall cost supporting other AMI assets such as IT hardware, systems, and applications. Smart meters help facilitate the integration of DERs and new customer services such as more frequent notifications of energy use. In addition, AMI systems help to provide enhanced outage management and restoration and improved distribution system monitoring and utility operational savings.[605]

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[a] The target number of meters will continue to evolve as more regulatory proceedings are announced for future AMI deployments. The smaller target for municipal and cooperative utilities is partly due to the cited report's focus on larger utilities.

**Table 6.2. Estimated Penetration of Smart Meters by North American Electricity Reliability Council (NERC) Region and Customer Class in 2013**[606]

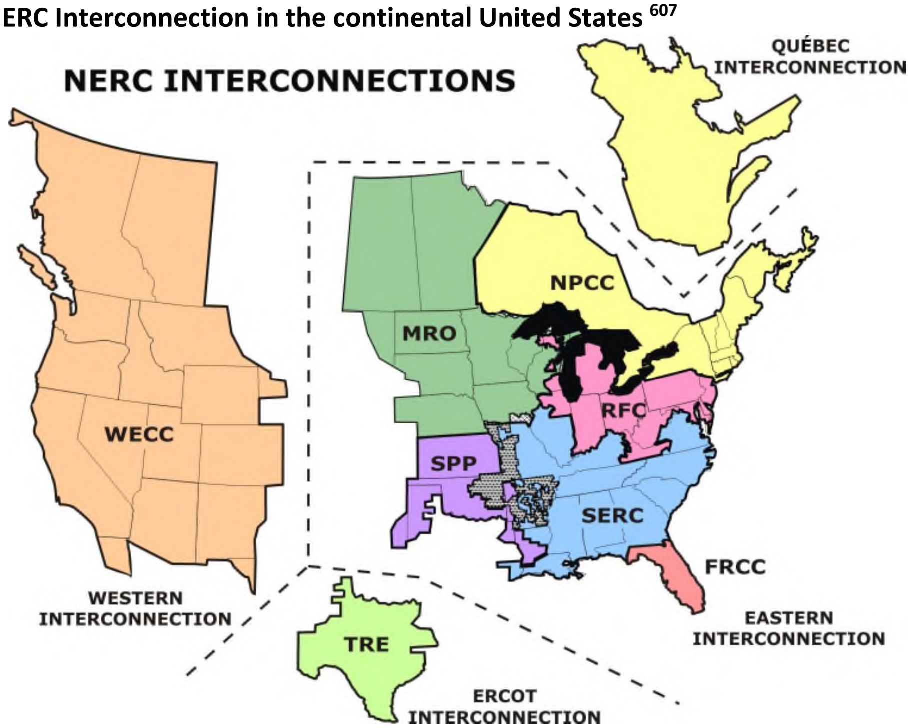
| NERC Region | Customer Class | | | |
|---|---|---|---|---|
| | Residential | Commercial | Industrial | All Classes |
| AK | 5.2% | 2.3% | 0.0% | 4.8% |
| FRCC | 59.3% | 63.2% | 80.2% | 59.6% |
| HI | 22.5% | 28.7% | 57.5% | 23.3% |
| MRO | 18.0% | 14.7% | 19.9% | 17.7% |
| NPCC | 10.8% | 13.7% | 23.2% | 11.1% |
| RFC | 24.8% | 18.0% | 16.1% | 24.0% |
| SERC | 26.9% | 24.0% | 20.7% | 26.5% |
| SPP | 34.8% | 35.8% | 41.4% | 35.1% |
| TRE | 79.0% | 81.4% | 48.1% | 79.1% |
| WECC | 61.7% | 60.4% | 52.0% | 61.5% |
| Unspecified | 15.7% | 17.5% | 70.2% | 17.0% |
| **All Regions** | **37.8%** | **36.1%** | **35.2%** | **37.6%** |

*Sources*: EIA, 2013 Form EIA-861 Advanced_Meters_2013 data file.

*Note*: Although some entities may operate in more than one NERC Region, EIA data have only one NERC region designation per entity. The "unspecified" category represents respondents to the EIA-861 short form, which were not required to report a NERC region. Commission staff has not independently verified the accuracy of EIA data.

*Penetration varies widely by region, with overall penetration highest in Texas, Florida, and Western states.*

**Figure 6.15. NERC Interconnection in the continental United States** [607]




*The eight regions are Western Electricity Coordinating Council (WECC), Midwest Reliability Organization (MRO), Southwest Power Pool (SPP), Texas Reliability Entity (TRE), Southeast Electric Reliability Council (SERC), ReliabilityFirst Corporation (RFC), Florida Reliability Coordinating Council (FRCC), and Northeast Power Coordinating Council (NPCC). AK (Alaska) and HI (Hawaii) are two additional regions not shown.*

**Table 6.3. Smart Grid Investment Grant (SGIG) Program Expenditures for Advanced Metering Infrastructure (AMI) Deployments, as of December 31, 2014** [608]

| AMI Assets | Quantity* | Incurred Cost** | Number of Entities Reporting*** | Cost per Unit | % of Overall Cost |
|---|---|---|---|---|---|
| AMI smart meters**** | 16,322,970 | $2,744,872,492 | 81 | $168 | 63.0% |
| Communications networks and hardware that enable two way communications | | $585,918,713 | 78 | | 13.4% |
| IT hardware, systems, and applications that enable AMI features and functionalities | | $666,314,859 | 75 | | 15.3% |
| Other AMI-related costs | | $362,052,698 | 105 | | 8.3% |
| Total AMI cost | | $4,359,158,762 | 105 | | 100.0% |

*Notes:*
**In some circumstances, costs are incurred before devices are installed resulting in a reported cost where the quantity is zero. Projects only report data on devices they plan to install. Each project installs equipment that best supports their individual goals. Therefore, the number of projects reporting is expected to vary by equipment category. The individual project reporting pages show what equipment that project is installing.*
***All dollar figures are the total cost, which is the sum of the federal investment and cost share of the recipient (the recipient cost share must be at least 50% of the total overall project cost).*
****In some cases the number of entities reporting is greater than the total number of projects funded by the Recovery Act because some projects have multiple subprojects that report data.*
*****SGIG recipients are also required to submit monthly reports to DOE through SIPRIS (the SGIG project reporting system) that include the number of smart meters they have installed. DOE reports both numbers. The count provided here includes meters that are installed AND functioning (i.e., they are transmitting information to the utility in support of their primary function). The SIPRIS numbers report the number of meters installed.*

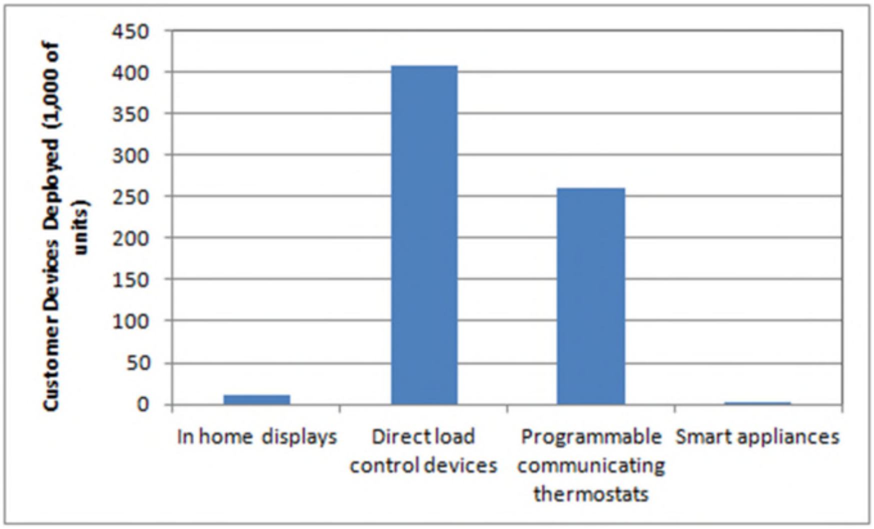
DOE's Smart Grid Investment Grant (SGIG) program also provided incentives for deployment of smart devices at customer premises (Figure 6.16).[a] Customer devices can be used with smart meters to provide information that enables customers and utilities to better manage electricity use. Devices include: [b]

- In-home displays—Small devices that provide consumers with real-time information on their energy use.
- Energy management devices—A device in the customer's premise, including hardware and software, designed to control the operation of energy-consuming devices according to customer preferences and objectives, such as reducing energy costs or maintaining comfort. Examples of controlled devices are thermostats, lighting, and smart appliances. Energy management devices can accept energy pricing signals from a utility or third-party energy services provider.
- Direct load control devices—A remotely controllable switch that can turn power to a load or appliance on or off or can be used to regulate the amount of power that a load can consume.
- Programmable communicating thermostats—Thermostats with communications capabilities can modify set temperature start-up points and load consumption based on signals from the utility or another provider.

[a] National sales data for these devices are not readily available.
[b] These definitions are largely drawn from OpenEI Wiki, accessed on November 20, 2015, http://en.openei.org/wiki/Main_Page.

- Smart appliances—Appliances that include the intelligence and communications to enable automatic or remote control based on user preferences or external signals from a utility or other provider. A smart appliance may communicate with other devices in the customer's premise or use other channels to communicate with utility systems. For example, a smart refrigeration or air conditioning system could communicate automatically with the utility to stay within a narrow band of slightly higher temperatures that are acceptable to the customer during periods of peak demand.

**Figure 6.16. Customer devices installed and operational through the Smart Grid Investment Grant program as of March 2015** [609]




### 6.2.4.2 *Types of Demand Response Programs*

Demand response programs can be classified in various ways. EIA identifies two major classes:[610]

- Incentive-based demand response programs ("dispatchable") include direct load control, interruptible load, demand bidding/buyback, emergency demand response, and demand response participating in capacity markets and ancillary service markets.
- Time-based rate programs ("non-dispatchable") include real-time pricing (RTP), critical peak pricing (CPP), variable peak pricing, and time-of-use (TOU) rates administered through a tariff.

As described in NERC, "controllable and dispatchable demand response requires the system operator to have physical command of the resources (controllable) or be able to activate it based on instruction from a control center. Controllable and dispatchable Demand Response includes four categories: Critical Peak Pricing (CPP) with Load Control; DCLM; LCR; and Interruptible Load (IL)."[611]

*Dispatchable* refers to demand response capacity as a resource that is called upon only when needed and by a prescribed amount. Non-dispatchable programs curtail load solely according to a retail tariff structure, not in response to instructions from a responsible entity.[612] Demand response programs include the following,[613] as depicted in Figure 6.17:

- Capacity products
    - Direct control load management (DCLM) –The utility directly controls customer end use to use a lower consumption setting or turn off appliances and equipment during pricing or system reliability events (mostly residential).
    - Interruptible tariffs or interruptible load – Consumers receive an incentive payment for agreeing to reduce consumption, by a prespecified amount or to a prespecified setting, during system reliability events (mostly large industrial).
    - Critical peak pricing (CPP) – The utility sets a prespecified high price during designated critical peak periods triggered by system contingencies or high wholesale market prices (residential and commercial).
    - Load as a capacity resource (LCR) – The consumer commits to making prespecified load reductions when system contingencies arise (industrial and commercial).
    - Voluntary energy products, such as “emergency” demand response – These programs provide incentive payments to consumers for load reductions achieved during an emergency event (industrial and commercial).

- Ancillary services
    - Spinning reserves – Operating reserves from resources that are synchronized to the grid and can respond to instructions from the system operator (commercial and industrial).
    - Nonspinning reserves – Operating reserves that can be started, synchronized, and loaded within a specified time period in response to instructions from the system operator (mostly industrial).
    - Frequency regulation – Incremental load that ideally needs to respond within seconds to balance out the frequency on the grid (residential, commercial, and industrial).

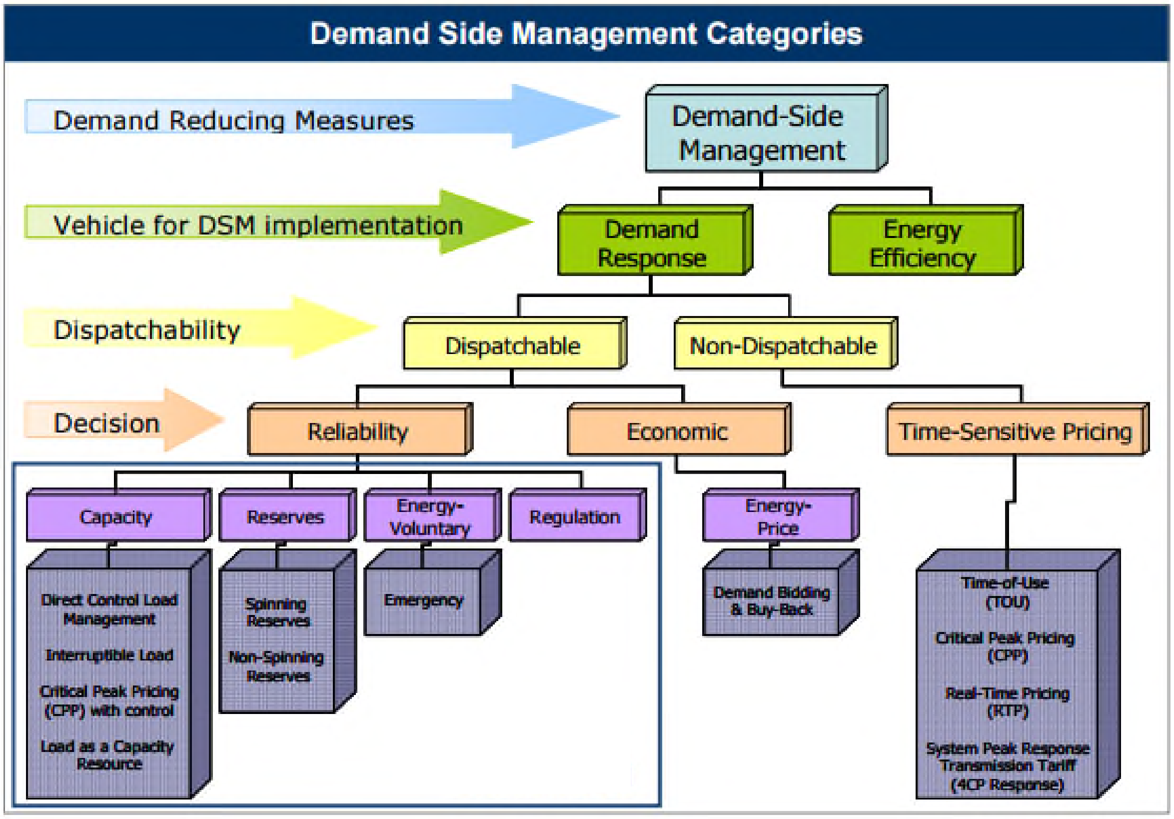
- Economic demand response – Demand bidding (e.g., day-ahead market) and buy-back allow consumers to offer load reductions in retail and wholesale markets at a bid price or at a price established by the utility or system operator.

- Time-sensitive (also called time-varying or time-based) pricing – Includes TOU pricing, CPP, RTP, and variable peak pricing.[614] [615]

    - Time of Use (TOU) rates – Electricity unit prices vary by more than one time period within a 24-hour day. Daily pricing blocks may include, but are not limited to, on-peak (highest price), mid-peak, and off-peak prices (lowest price) for nonholiday weekdays.
    - Critical Peak Pricing (CPP) – Price structure is designed to encourage reduced consumption during periods of high wholesale market prices or system contingencies by imposing a pre-specified high rate for a limited number of hours and days, typically in a defined season (e.g., summer).
    - Real Time Pricing (RTP) – A rate in which the price for electricity fluctuates frequently (e.g., every hour) to reflect changes in market prices.
    - Variable Peak Pricing – Variable peak pricing is a hybrid of TOU and RTP. The peak period is defined in the tariff, but the price established for the on-peak period varies by system or market conditions.

Utilities and grid system operators offer demand response programs to reduce peak load constraints, improve reliability of the electricity grid, or reduce price spikes.[616] Utility programs are referred to as “retail” programs and programs administered by ISO/RTO regions as “wholesale” programs, though in practice, both utilities and ISO/RTO regions can administer products that address similar issues. For example, some utilities may offer programs that address bulk power reliability, which is the primary charter for ISO/RTO programs, and programs that use LCR are offered in both the retail and wholesale markets, albeit with different participation rules and compensation schemes.

**Figure 6.17. Demand-side management categories**[617]



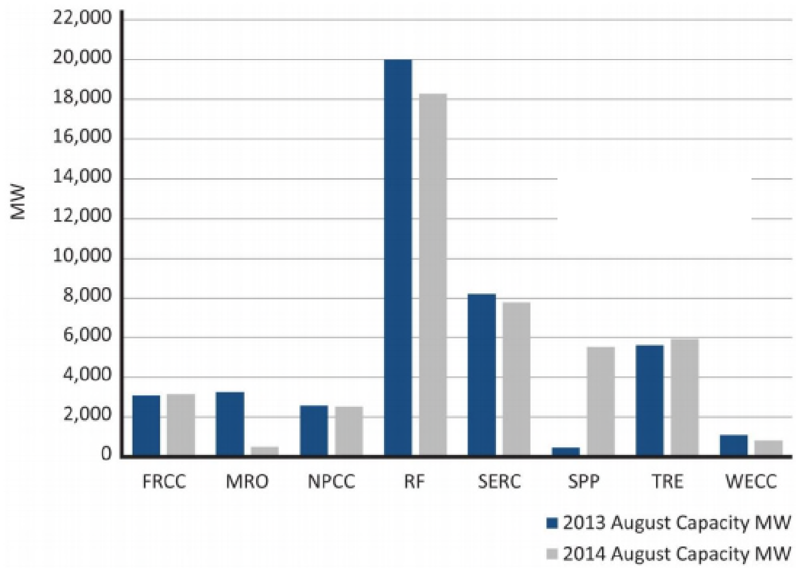

*Demand response categories can be classed into dispatchable and non-dispatchable resources, and further into programs based on reliability provisions, economic considerations, and time-sensitive pricing. See text for definitions and further details.*

In the following subsections, demand response capacity is presented according to three reporting frameworks: (1) by NERC region for both retail and wholesale programs, (2) by NERC region for utility retail programs only, and (3) by ISO/RTO region for wholesale programs. For each case, the types of demand response programs included in the quoted demand response capacity are specified.

### *Overall Demand Response Capacity*[618]

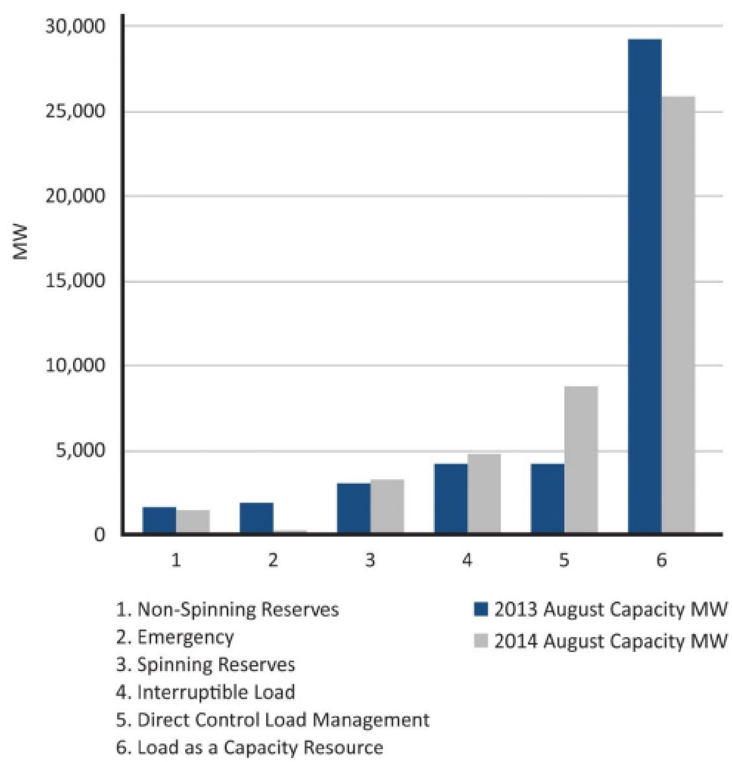
Total capacity in NERC regions for retail and wholesale programs was about 44 GW in both 2013 and 2014[619] (Figure 6.18), with the largest capacity in the ReliabilityFirst Corporation (RFC), Southeast Electric Reliability Council (SERC), and Texas Reliability Entity (TRE) regions. Figure 6.19 shows that LCR and DCLM are the two program types with the largest capacity.

**Figure 6.18. Registered demand response capacity (in MW) for all product service types by NERC region**[620]




*Demand response capacity is measured by the total MW registered by program participants available for grid operators to call upon during a demand response event. In August 2013 and 2014, demand response capacity in all NERC regions was 44,285 MW and 44,583 MW, respectively, including both retail and wholesale programs.*

**Figure 6.19. Registered capacity in MW for all NERC regions by service type in August 2013 and 2014**[621]




*Load as a Capacity Resource and Direct Control Load Management made up about 75% of overall capacity, including both retail and wholesale programs.*

*Demand Response Capacity (MW) by NERC Region*

Table 6.4 shows potential peak reduction from incentive-based demand response programs by NERC region in 2012 and 2013. Four regions accounted for about 80% of demand response in 2012: the SERC, RFC, Midwest Reliability Organization (MRO), and Western Electricity Coordinating Council (WECC). The table also illustrates annual changes in demand response capacity. Demand response decreased by 4.9% between 2012 and 2013, with large drops in the Florida Reliability Coordinating Council (FRCC) and MRO offset in part by a large increase in the SERC region, due to a large increase in reported savings from industrial programs operated by the Tennessee Valley Authority.

The FRCC and MRO saw significantly lower potential peak savings in both magnitude and percentage from much lower reported savings from Florida Power & Light's demand response programs, and from programs operated by Nebraska Public Power District and Northern States Power Company (Minnesota), respectively.

**Table 6.4. Potential Peak Reduction Capacity from Retail Demand Response Programs by NERC Region in 2012 and 2013[622]**

| NERC Region[a] | Annual Potential Peak Reduction (MW) | | % of Overall Potential for All Regions | Year-on-Year Change | |
|---|---|---|---|---|---|
| | 2012 | 2013 | 2013 | MW | % |
| AK | 27 | 27 | 0.10 | 0 | 0.0 |
| FRCC | 3,306 | 1,924 | 7.10 | -1383 | -41.8 |
| HI | 42 | 35 | 0.13 | -7 | -16.8 |
| MRO | 5,567 | 4,264 | 15.74 | -1303 | -23.4 |
| NPCC | 606 | 467 | 1.72 | -139 | -23.0 |
| RFC | 5,836 | 5,362 | 19.79 | -475 | -8.1 |
| SERC | 6,046 | 8,254 | 30.46 | 2209 | 36.5 |
| SPP | 1,323 | 1,594 | 5.88 | 271 | 20.5 |
| TRE | 480 | 459 | 1.69 | -21 | -4.3 |
| WECC | 5,269 | 4,681 | 17.28 | -588 | -11.2 |
| Unspecified | 0 | 28 | 0.10 | 28 | -- |
| Total | 28,503 | 27,095 | 100 | -1,408 | -4.9 |

*Demand response programs include direct load control, contractually interruptible (curtailable load), and Load as a Capacity Resource. SERC, RFC, MRO, and WECC each account for about 20% of the overall demand response potential for all regions, with about a 5% decrease in potential peak demand reduction from 2012 to 2013. Note: Figures from source data are rounded to the nearest MW. The percentage change is calculated based on the unrounded figures. Although some entities may operate in more than one NERC region, EIA data use only one NERC region designation per entity.*

[a] **Acronyms**: **AK**—Alaska; **FRCC**—Florida Reliability Coordinating Council; **HI**—Hawaii; **MRO**—Midwest Reliability Organization; **NPCC**—Northeast Power Coordinating Council; **RFC**—ReliabilityFirst Corporation; **SERC**—Southeast Electric Reliability Council; **SPP**—Southwest Power Pool; **TRE**—Texas Reliability Entity; **WECC**—Western Electricity Coordinating Council.

**Table 6.5. Potential Peak Capacity Reduction (in MW) from Retail Demand Response Programs, by NERC Region and Customer Sector in 2013[623] [a]**

| | Customer Sector (MW) | | | | |
|---|---|---|---|---|---|
| NERC Region | Residential | Commercial | Industrial | Transportation | All Classes |
| AK | 5 | 13 | 9 | 0 | 27 |
| FRCC | 817 | 750 | 357 | 0 | 1,924 |
| HI | 20 | 15 | 0 | 0 | 35 |
| MRO | 1,865 | 801 | 1,598 | 0 | 4,264 |
| NPCC | 38 | 256 | 160 | 13 | 467 |
| RFC | 1,545 | 684 | 3,133 | 0 | 5,362 |
| SERC | 1,348 | 810 | 6,095 | 1 | 8,254 |
| SPP | 213 | 324 | 1,057 | 0 | 1,594 |
| TRE | 88 | 341 | 31 | 0 | 459 |
| WECC | 1,037 | 1,130 | 2,361 | 154 | 4,681 |
| Unspecified | 28 | 0 | 0 | 0 | 28 |
| All Regions | 7,003 | 5,124 | 14,800 | 168 | 27,095 |
| NERC Region | By Percentage of Total DR Capacity (%) | | | | |
| AK | 19 | 48 | 33 | 0 | 100 |
| FRCC | 42 | 39 | 19 | 0 | 100 |
| HI | 57 | 43 | 0 | 0 | 100 |
| MRO | 44 | 19 | 37 | 0 | 100 |
| NPCC | 8 | 55 | 34 | 3 | 100 |
| RFC | 29 | 13 | 58 | 0 | 100 |
| SERC | 16 | 10 | 74 | 0 | 100 |
| SPP | 13 | 20 | 66 | 0 | 100 |
| TRE | 19 | 74 | 7 | 0 | 100 |
| WECC | 22 | 24 | 50 | 3 | 100 |
| Unspecified | 100 | 0 | 0 | 0 | 100 |
| % of total | 25.8 | 18.9 | 54.6 | 0.62 | 100 |

*Demand response programs include direct load control, contractually interruptible (curtailable load), and Load as a Capacity Resource. Industrial demand response makes up over half of the overall demand response capacity.*

[a] Note: Demand response capacity is measured by the total MW registered by program participants available for grid operators to call upon during a demand response event. Figures from source data are rounded to the nearest MW. The percentage change is calculated based on the unrounded figures. Although some entities may operate in more than one NERC region, EIA data use only one NERC region designation per entity.

Table 6.5 shows potential peak reduction from retail (typically utility-administered) incentive-based demand response programs.[a] The residential, commercial, and industrial sectors account for 30%, 23%, and 47% of total demand response potential, respectively. There is considerable variation in sector distribution by NERC region. The commercial sector accounts for most of the demand response in Alaska (AK), Hawaii (HI), Northeast Power Coordinating Council (NPCC), and TRE. Industrial demand response is the largest sector in MRO, RFC, SERC, Southwest Power Pool (SPP), and WECC, and overall accounts for the largest amount of demand response capacity. FRCC is the only region where residential demand response is the largest sector, with 53% of the demand response potential.

Total enrollment in incentive-based programs grew rapidly from 2011 to 2013, with 9.18 million customers (Table 6.6), or about 6.2% of total electric industry customers.[624] Part of this increase in demand response deployment is attributed to utility investments supported by SGIGs under ARRA for the deployment of advanced meters and associated infrastructure. The 240% increase in enrollments in WECC from 2012 to 2013 occurred for several utilities in California, Arizona, and New Mexico.
New devices and device capabilities such as smart thermostats have enabled innovative new demand response programs. One such set of programs are known as "Bring Your Own Thermostat," which first appeared in 2012. Instead of direct installation of control hardware by the sponsoring utility, these programs allow consumers to purchase their own devices and participate in utility-managed demand response programs. There are an estimated 50,000 customers in Bring Your Own Thermostat programs in the United States, and this market is expected to grow rapidly in the future.[625]

**Table 6.6. Enrollment in Incentive-Based Demand Response Programs by NERC Region, 2011-2013[626]**

| NERC Region | Enrollment in Incentive-Based Programs | | | 2011 to 2013 Change | |
|---|---|---|---|---|---|
| | 2011 | 2012 | 2013 | Customers | % |
| AK | 2,460 | 2,432 | 2,468 | 8 | 0.3% |
| FRCC | 1,283,904 | 1,328,487 | 1,554,830 | 270,926 | 21.1% |
| HI | 37,304 | 36,703 | 36,332 | -972 | -2.6% |
| MRO | 714,669 | 795,345 | 1,248,723 | 534,054 | 74.7% |
| NPCC | 46,368 | 54,413 | 62,631 | 16,263 | 35.1% |
| RFC | 1,546,608 | 1,398,341 | 1,852,985 | 306,377 | 19.8% |
| SERC | 652,940 | 715,225 | 1,084,449 | 431,509 | 66.1% |
| SPP | 112,041 | 91,585 | 193,507 | 81,466 | 72.7% |
| TRE | 67,113 | 109,875 | 138,613 | 71,500 | 106.5% |
| WECC | 903,063 | 884,299 | 3,002,607 | 2,099,544 | 232.5% |
| Unspecified | 0 | 15,004 | 10,205 | 10,205 | - |
| Total | 5,366,470 | 5,431,709 | 9,187,350 | 3,820,880 | 71.2% |

*Incentive-based demand response programs include direct load control, interruptible load, emergency demand response, and Load as a Capacity Resource. Note: Although some entities may operate in more than one NERC Region, EIA data have only one NERC region designation per entity. FERC staff have not independently verified the accuracy of EIA data.*
*Sources: EIA, EIA-861 dsm_2012, utility_data_2012, and Demand_Response_2013 data files.*

[a] Potential peak reduction (or potential peak demand savings) refers to "the total demand savings that could occur at the time of the system peak hour assuming all demand response is called." EIA (U.S. Energy Information Administration). *Form EIA-861 Annual Electric Power Industry Report Instructions.* Washington, D.C., 2016, 15. https://www.eia.gov/survey/form/eia_861/instructions.pdf.

The 5.98 million customers enrolled in time-based programs in 2013 (Table 6.7) represent about 4% of total electricity industry customers, with the largest increases compared to 2012 in RFC and SPP. RFC saw large increases in residential program enrollment for several utility service territories, while SPP saw program enrollment increases across all customer classes.

**Table 6.7. Customer Enrollment in Time-Based Demand Response Programs by NERC Region in 2012 and 2013[627]**

| NERC Region | Enrollment in Time-based Programs | | Year-on-Year Change | |
|---|---|---|---|---|
| | 2012 | 2013 | Customers | % |
| AK | 38 | 43 | 5 | 13% |
| FRCC | 27,089 | 16,203 | -10,886 | -40% |
| HI | 323 | 365 | 42 | 13% |
| MRO | 82,310 | 108,527 | 26,217 | 32% |
| NPCC | 293,721 | 258,426 | -35,295 | -12% |
| RFC | 433,879 | 1,977,536 | 1,543,657 | 356% |
| SERC | 180,619 | 236,662 | 56,043 | 31% |
| SPP | 61,618 | 1,143,774 | 1,082,156 | 1,756% |
| TRE | 604 | 968 | 364 | 60% |
| WECC | 2,601,112 | 2,146,548 | -454,564 | -17% |
| Unspecified | 57,435 | 88,229 | 30,794 | 54% |
| **Total** | **3,738,748** | **5,977,281** | **2,238,533** | **60%** |

*Sources*: EIA, EIA-861 dsm_2012,utility_data_2012, and Dynamic_Pricing_2013 data files.
*Note*: Although some entities may operate in more than one NERC Region, EIA data have only one NERC region designation per entity. Commission staff has not independently verified the accuracy of EIA data.

*Time-based programs include time-of-use rates, critical peak pricing, real-time pricing, and variable peak pricing.*

### *Demand Response Capacity (MW) by ISO/RTO Region*

Demand response potential for ISO- and RTO-administered programs remained flat overall from 2013 to 2014, with a large increase in ISO New England, Inc. (ISO-NE) but decreases in New York ISO (NYISO) and SPP (Table 6.8).[a] The increase in ISO-NE is attributed in part to greater spending on demand-side management programs by utilities in New England states. The sharp drop in the SPP region is due to reclassification of certain behind-the-meter resources, cogeneration facilities, and industrial loads as special case generation resources. Overall the FERC 2015 report observes little net change in the contribution of demand response to meeting peak demand since 2009. For reference, Figure 6.20 is a map of ISO/RTO regions.

Several ISOs/RTOs allow demand response resources to participate in the markets they administer.[b] For example, PJM has created three demand response products for capacity, based on availability of the resource: Limited Demand Response (10 days for six hours per day during the summer peak period), Extended Summer Demand Response (unlimited days during the summer peak period for 10 hours per

[a] Note that the sum of demand response capacity in Table 6.5 and Table 6.8 for 2013 is 56 GW, which is larger than the 44 GW shown in Figure 6.18. This is attributed to sampling issues. For example, Table 6.8 includes some utility programs (in MISO, for example), and thus there is some double-counting with the NERC data in Table 6.5.
[b] Note that most markets require a certain size resource to participate (e.g., 150 kW minimum bid for a capacity market), which means that some potential resources are not able to participate unless they can be aggregated into a larger resource.

day), and Annual Demand Response (unlimited number of days for 10 hours per day, any time of the year).

The largest demand response market is in PJM, followed by MISO. Of the 9,901 MW of capacity in 2013, 2,660 MW was day-ahead or real-time economic demand response that provided participants with an opportunity to reduce electricity consumption and receive a payment when locational marginal prices were high in PJM's Energy Market. The remainder of the capacity was emergency demand response, where program participants received two streams of revenue: capacity payments for contributing to reserve capacity and an energy payment to compensate for the hours during which they reduced their consumption. About 1,550 MW of emergency demand response was provided by diesel-powered, behind-the-meter generation. Demand resources can also bid into ancillary services markets in PJM, including reserve and regulation markets. Capacity payments dominated the revenues in the demand response market.[628]

MISO is the second-largest ISO/RTO demand response market. Behind-the-meter generation (e.g., backup diesel generators) makes up 35% of demand response capacity in MISO. Of the remaining capacity, 78% is interruptible load under regulated utility programs and 14% is emergency demand response.[629] In the California ISO (CAISO), about one-half of the demand response capacity in Table 6.8 is made up of reliability-based programs such as interruptible tariffs, and about one-half is price-responsive economic demand response programs, including day-ahead customer alerts and same-day demand response through air-conditioning cycling programs and curtailment service providers.

**Table 6.8. Peak Reduction (in MW) from ISO/RTO (Wholesale) Demand Response Programs in 2013 and 2014[630]**

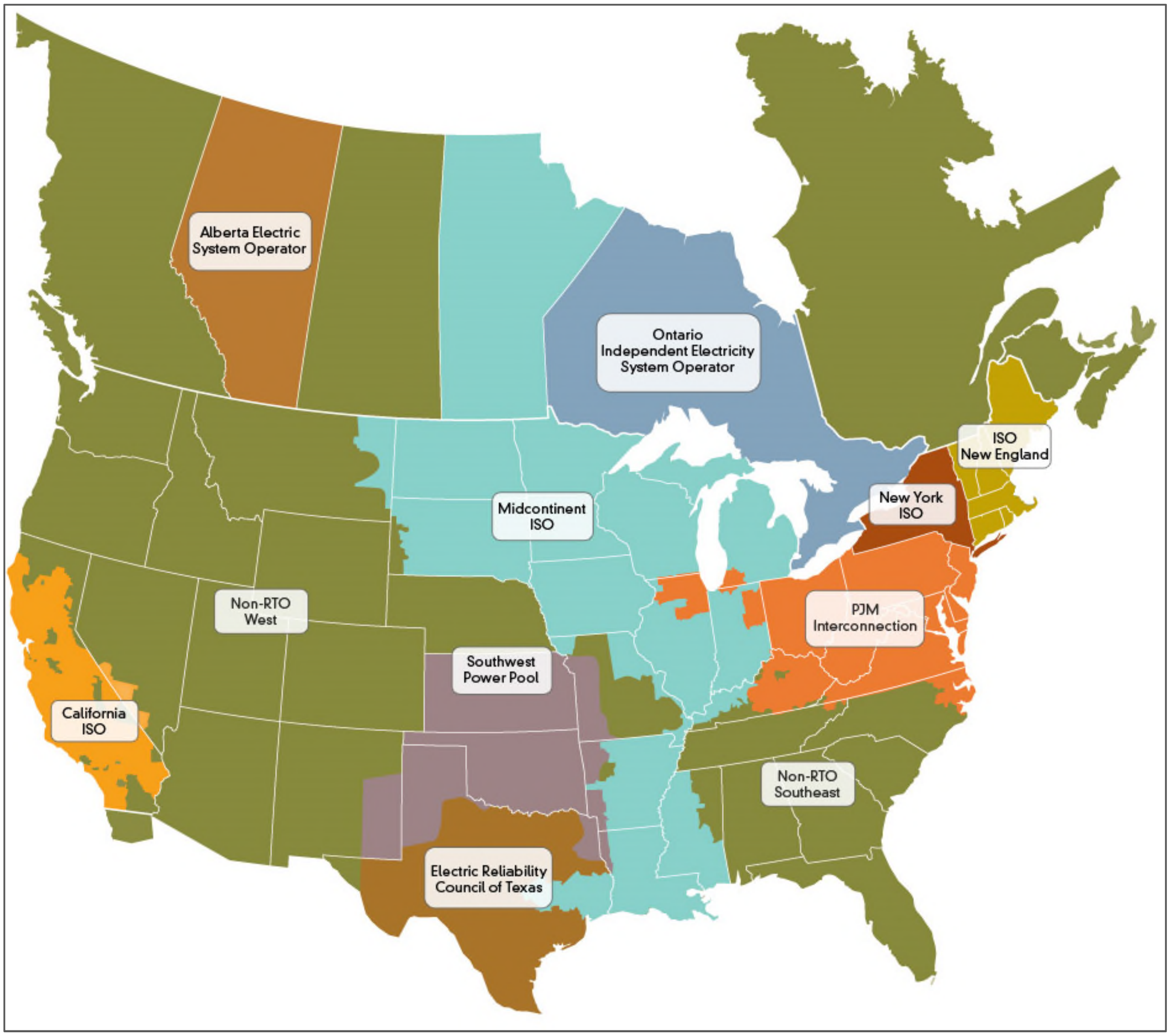
| RTO/ISO | 2013 | | 2014 | | 2013 to 2014 | |
|---|---|---|---|---|---|---|
| | Potential Peak Reduction (MW) | Percent of Peak Demand (%) | Potential Peak Reduction (MW) | Percent of Peak Demand (%) | MW | % |
| California ISO (CAISO) | 2,180 | 4.8 | 2,316 | 5.1 | 136 | 6.2 |
| Electric Reliability Council of Texas (ERCOT) | 1,950 | 2.9 | 2,100 | 3.2 | 150 | 7.7 |
| ISO New England, Inc. (ISO-NE) | 2,100 | 7.7 | 2,487 | 7.7 | 387 | 18.4 |
| Midcontinent Independent System Operator (MISO) | 9,797 | 10.2 | 10,356 | 10.2 | 559 | 5.7 |
| New York Independent System Operator (NYISO) | 1,307 | 3.8 | 1,211 | 9.0 | -96 | -7.3 |
| PJM Interconnection, LLC (PJM) | 9,901 | 6.3 | 10,401 | 7.4 | 500 | 5.0 |
| Southwest Power Pool, Inc. (SPP) | 1,563 | 3.5 | 48 | 0.1 | -1,515 | -96.9 |
| Total ISO/RTO | 28,798 | 6.1 | 28,934 | 6.2 | 136 | 0.5 |

*Demand response programs include emergency demand response, day-ahead and real-time economic demand response, Load as a Capacity Resource, and, in some regions (e.g., MISO), behind-the-meter generation.*

Significant growth in demand response resources has recently occurred for the Electric Reliability Council of Texas (ERCOT) Emergency Response Service. This program includes 10- and 30-minute demand response resources (as well as distributed generation service) and is designed to be deployed in the late stages of a grid emergency, prior to shedding involuntary firm load. Procurement of Emergency

Response Service during the summer peak-time period grew from 422 MW in 2013 to 626 MW in 2014, nearly a 50% increase. LCRs[a] providing ancillary services are also expected to increase due to new rules enabling controllable load resources to bid into the real-time market for nonspinning reserves. [631] CAISO is actively engaged with stakeholders to develop demand response products capable of directly participating in wholesale markets.[632]

**Figure 6.20. RTO/ISO regions of the United States and Canada[633]**




*There are seven ISO/RTO regions in the continental United States (California ISO, Midcontinent ISO, Southwest Power Pool, Electricity Reliability Council of Texas, ISO New England, New York ISO, and PJM Interconnection) and two non-RTO regions (West and Southeast).*

## 6.3 Metrics and Trends

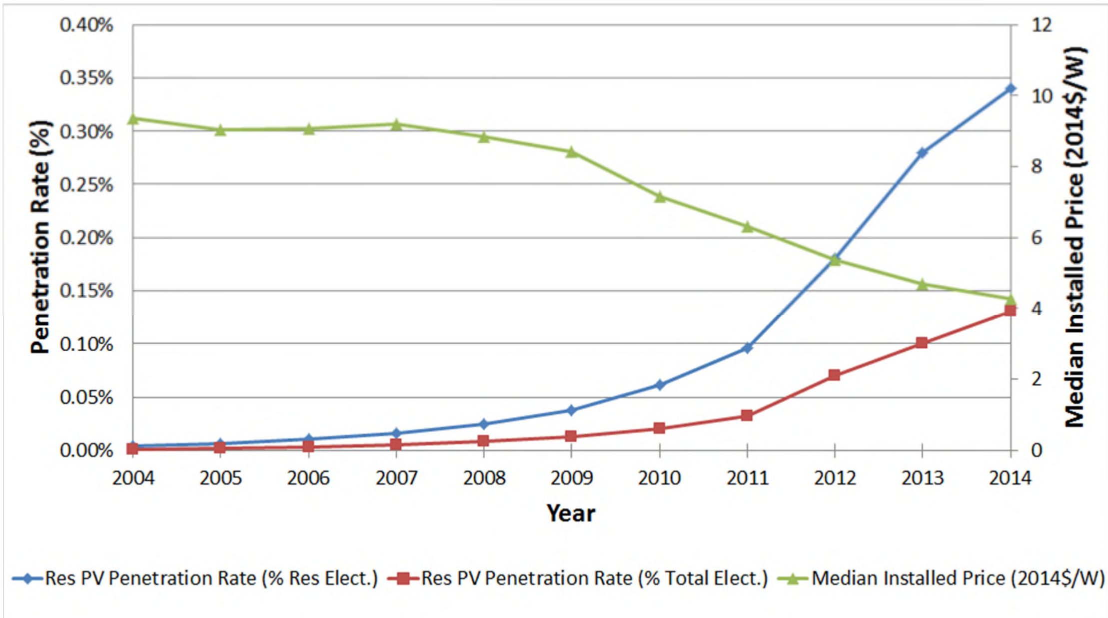
### 6.3.1 Solar PV and CHP Projections

The median installed price of solar PV declined dramatically over the last decade, with the greatest rate of reduction occurring from 2009-2014.[634] Factors driving price reductions include the drop in polysilicon

[a] A Load as Capacity Resource (LCR) commits to making pre-specified load reductions when system contingencies arise.

feedstock material as well as high-volume, low-cost manufacturers, and incentives and policies encouraging greater adoption (see Section 6.5.1 for further discussion of policies). Figure 6.21 shows a sharp increase in the rate of adoption, coinciding with the rapid decline in median installed price.

**Figure 6.21. Penetration rate (%) and median installed price ($/$W_{DC}$) of U.S. residential solar PV systems**[635]




*Median installed prices have dropped significantly over the last three years, and the penetration rate in the residential sector has risen sharply but from a low base. Residential solar PV penetration rate is the annual GWh from PV over total residential demand (% residential electricity) or over total electricity demand (% total electricity).*

Steep reductions in module prices were the primary driver for installed price reductions from 2008 to 2012, accounting for about 80% of the decline in total installed price. Since 2012, however, module prices have remained relatively flat, and installed price declines have been driven primarily by reductions in nonmodule costs.[636]

Hardware component prices (inverters and racking)[a] have fallen significantly,[637] though they comprise only about 10% to 20% of the total drop in nonmodule costs from 2013 to 2014. However, recent nonmodule cost reductions are associated primarily with declining soft costs. Soft cost reductions stem partly from increasing system size and module efficiency,[b] a maturing industry with consolidation of market share, and widespread policy and industry efforts.[638] The price of solar PV is expected to further decline in the future. Figure 6.22 depicts the projected median installed price of residential solar PV, with the minimum price of $1.63/$W_{DC}$ for residential PV achieved in 2020 per the SunShot Initiative target.[c 639]

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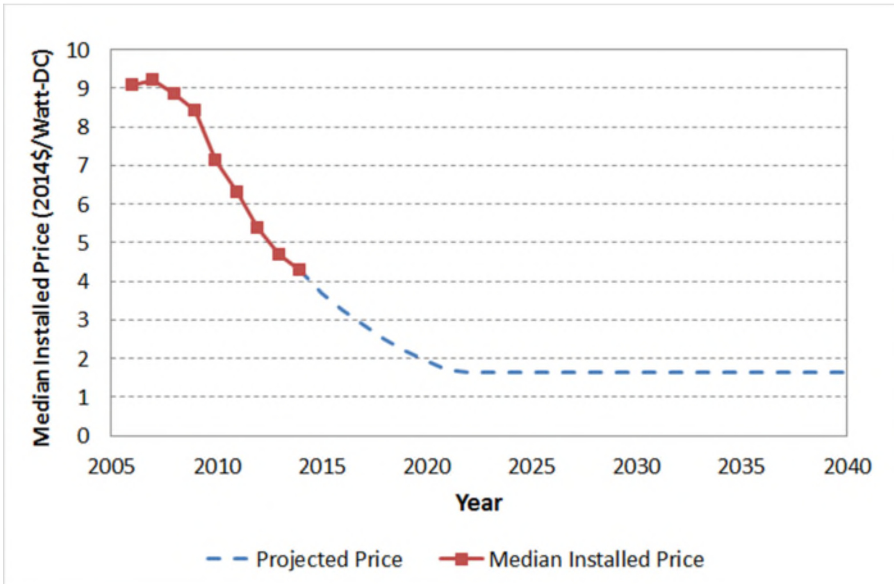
[a] PV racking refers to the mounting systems that are used to attach solar panels to surfaces such as rooftops or building facades.
[b] Increased module efficiency can reduce the footprint of PV systems, thus helping to contribute to lower soft costs.
[c] DOE's SunShot Initiative is a national collaborative effort to make solar energy cost-competitive with other forms of electricity by the end of the decade. See http://energy.gov/eere/sunshot/sunshot-initiative

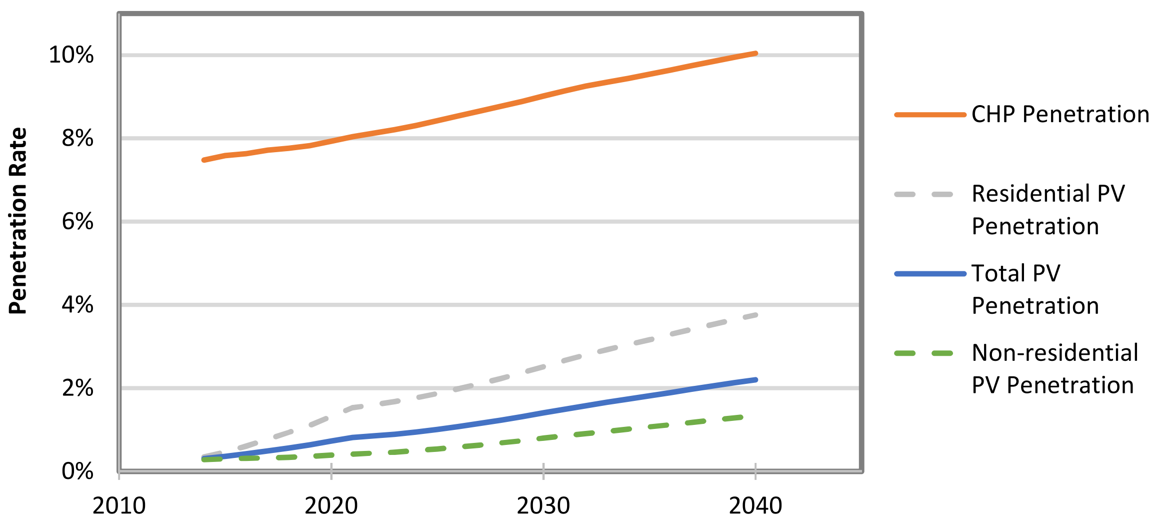
**Figure 6.22. Projection of the median installed price ($\$/W_{DC}$) of U.S. residential PV systems[640]**




*The price after 2020 is assumed to be the SunShot target price for 2020.*

Figure 6.23 shows the projected penetration rate of distributed solar PV and CHP from 2015 to 2040. Solar PV is expected to account for about 3.8% and 1.34% of electricity end use in the residential and nonresidential sectors, respectively, and grow to 2.2% of overall sales by 2040. CHP is projected to grow more slowly for the next decade, increasing to almost 12% of total electricity end use by 2040.[641]

**Figure 6.23. Projected penetration rates (%) of CHP and distributed solar PV[642]**




*Distributed PV generation is projected to grow from 0.36% in 2015 of total residential and commercial sector electricity end use to 2.2% in 2040. CHP is projected to grow from 7.6% in 2015 to 10% of total retail electricity sales by 2040.[a]*

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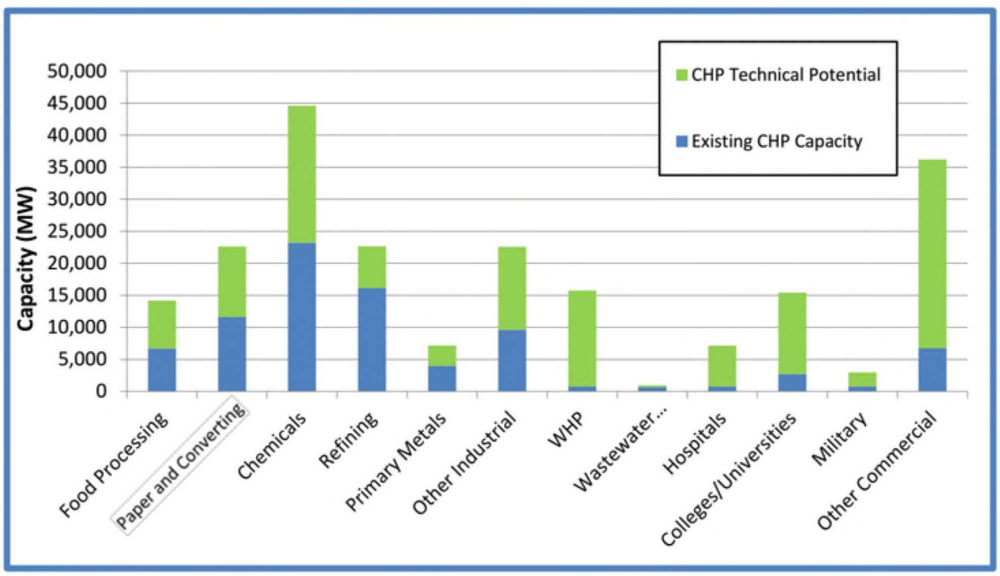
[a] Residential PV penetration is the projected GWh from residential solar PV over total residential demand; non-residential solar PV penetration is the projected GWh from commercial PV divided by commercial demand; total PV penetration is the total projected GWh from solar PV over total demand; CHP penetration is the projected GWh from CHP over total demand.

Time-varying pricing (e.g., TOU pricing) generally increases bill savings for consumers with distributed solar PV, but the degree of savings depends on wholesale electricity market dynamics, surplus generation capacity, and the level of solar energy penetration.[643] The future trajectory of distributed generation installations is highly policy-dependent, and thus any projections are quite uncertain.

The technical potential[a] for additional CHP applications in the United States is significant, at 134 GW (Figure 6.24 and 6.25). About one-third of that potential has an estimated payback time of 10 years or less. The chemicals sector in industry and colleges/universities in the commercial sector have the most technical potential.[644] However, CHP adoption is highly dependent on government policies, incentives, and tariff structures, and significant barriers exist (see Sections 6.5 and 6.5.1.3).

Combined heat and power (CHP) may have a greater role to play in the future if water consumption at utility-scale power plants becomes a critical constraint. Several CHP technologies use negligible amounts of water (reciprocating engines, combustion turbines, microturbines, and fuel cells).

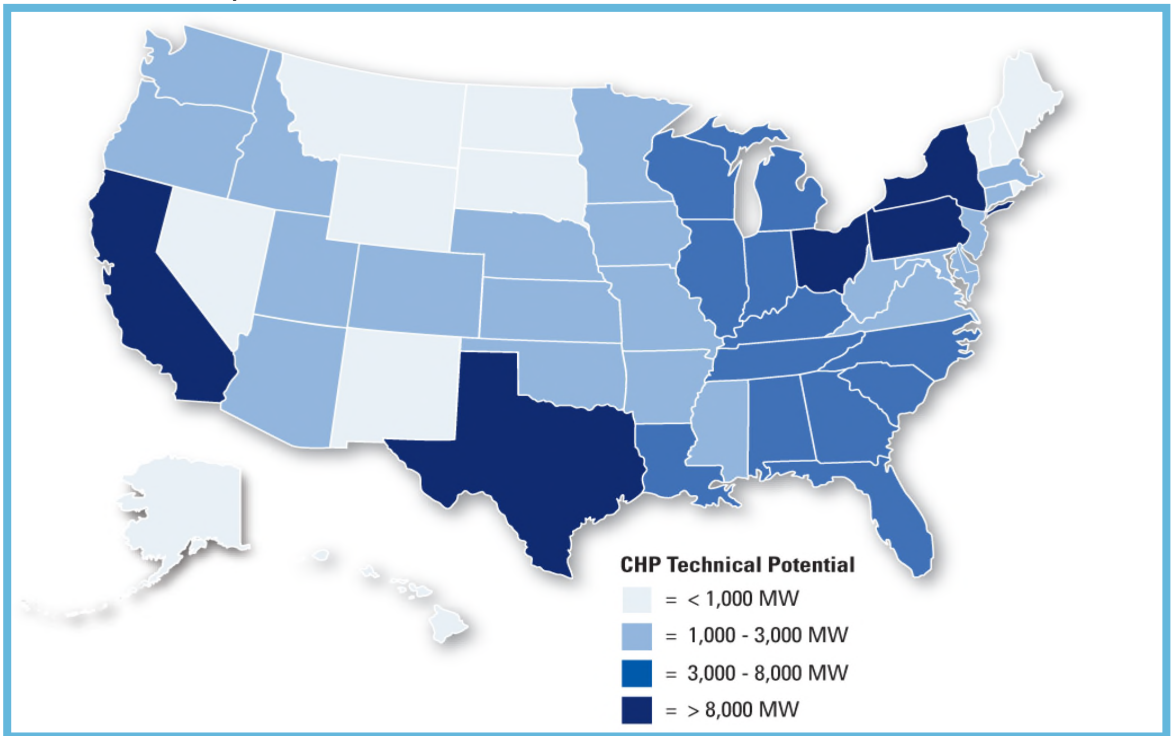
**Figure 6.24. Existing CHP capacity and CHP technical potential, by sector[645]**




*Existing capacity is 83 MW, and technical potential is 134 MW.*

[a] *Technical potential* refers the amount that is technically possible, not all of which is cost-effective.

**Figure 6.25. Technical potential of CHP[646]**

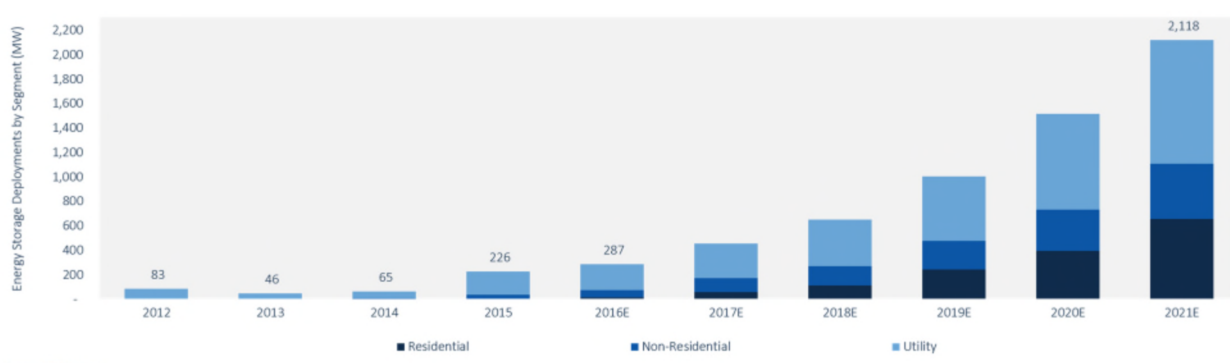



*Technical potential for additional CHP applications at existing industrial, commercial, and institutional facilities is 134 GW. Systems smaller than 100 MW comprise nearly all this amount. By sector, some 56 GW of technical potential is projected for industrial CHP applications and 68 GW for commercial or institutional CHP. About 40 GW of the estimated technical potential have estimated paybacks less than 10 years.*

### 6.3.2 Energy Storage Projections

Annual non-utility storage deployment is projected to grow to 700 MW in 2020 from 38 MW in 2015, with an annual growth rate of 80%. Distributed storage is projected to capture over half of the storage market by 2020 (Figure 6.26). Table 6.9 shows storage targets in California, which are driving much of the projected deployment.

**Figure 6.26. Projection of energy storage deployment capacity by sector[647]**




*Some 728 MW of distributed energy storage is projected by 2020.*

**Table 6.9. California's Energy Storage Targets by Point of Interconnection (or Grid Domain)** [a] [648]

| STORAGE GRID DOMAIN POINT OF INTERCONNECTION | 2014 | 2016 | 2018 | 2020 | TOTAL | 2014 | 2016 | 2018 | 2020 | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|
| Units | MW | MW | MW | MW | | % | % | % | % | % |
| Transmission | 110 | 145 | 192 | 253 | 700 | 55 | 54 | 53 | 52 | 53 |
| Distribution | 67 | 90 | 115 | 153 | 425 | 34 | 33 | 32 | 31 | 32 |
| Customer | 23 | 35 | 58 | 84 | 200 | 12 | 13 | 16 | 17 | 15 |
| TOTAL | 200 | 270 | 365 | 490 | 1,325 | 100 | 100 | 100 | 100 | 100 |

*California's storage target for 2020 is 1,325 MW. About 47% of the target is at the distribution or consumer level.*

Other potential studies include longer-term projections. A study for the Eastern Interconnection projects 2 GW of distributed storage by 2030.[649] Another study, focused on ERCOT, estimates that up to 5 GW of grid-integrated, distributed storage would be cost-effective in the region by 2020.[650]

A recent report shows that the cost of Li-ion battery packs declined from more than $1,000/kilowatt-hours (kWh) in 2007 to about $410/kWh in 2014, or a 14% annual historical decline.[651] The learning rate[b] (LR) was found to be an estimated 6% to 9%, and if the authors' estimated annual cost reduction of 8% is assumed in the future, costs will reach $150/kWh in 2025. The levelized cost of electricity[c] (LCOE) from battery storage will depend on several factors in addition to the capital cost, such as efficiency, maintenance costs, and battery lifetime. For a set of nominal assumptions,[d] the LCOE is estimated to be in the range of $0.19–0.20/kWh for a $410/kWh battery pack, and in the range of $0.12–0.13/kWh for a $150/kWh battery pack.

LR for Li-ion batteries is lower than the LR for other DER technologies such as solar PV (20% LR from 1970–2006) and onshore wind (15% LR from 1990–2004). The LR is a critical parameter in future cost-effectiveness calculations that inform market adoption projections. Several recent works have highlighted the correlation of deployment programs and LRs.[652]

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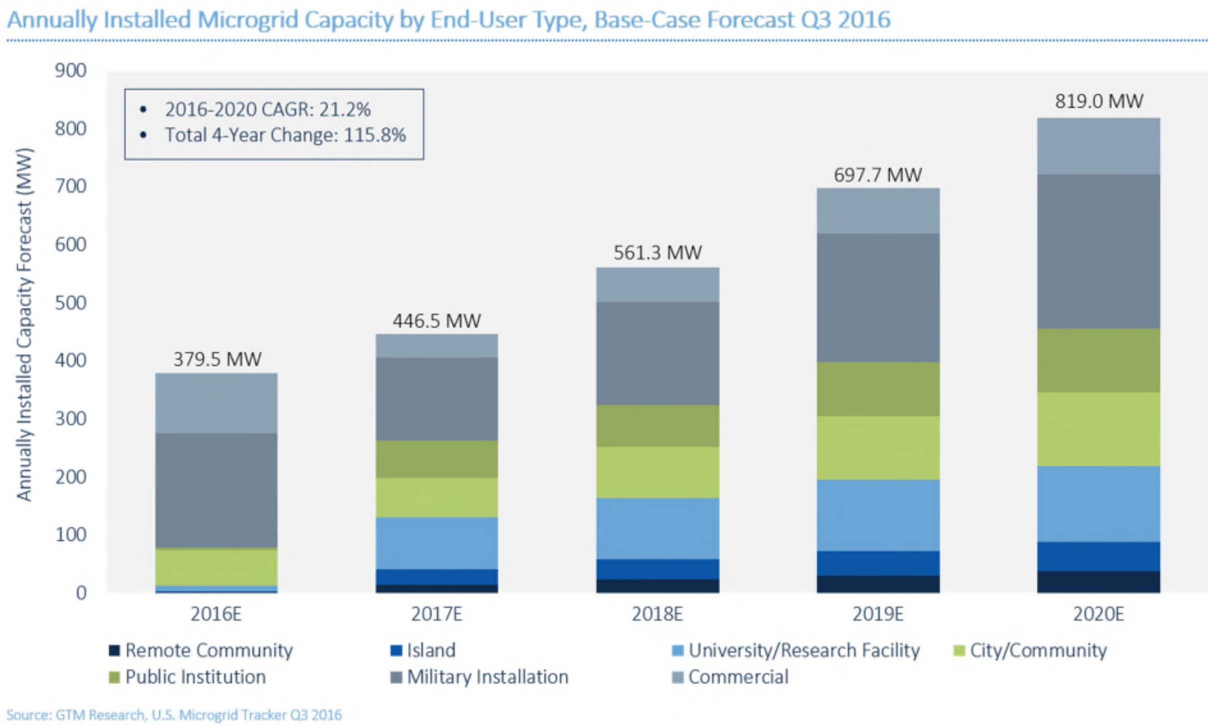
[a] Set by California PUC Decision 13-10-040 for Pacific Gas & Electric, Southern California Edison, and San Diego Gas & Electric.
[b] The *learning rate* (LR) is a figure of merit for the rate of cost reduction of a given technology as a function of its cumulative production. The LR is the cost reduction (typically in percent) for every doubling in cumulative production volume.
[c] "Levelized cost of electricity (LCOE) is often cited as a convenient summary measure of the overall competiveness of different generating technologies. It represents the per-kilowatt-hour cost (in real dollars) of building and operating a generating plant over an assumed financial life and duty cycle. Key inputs to calculating LCOE include capital costs, fuel costs, fixed and variable operations and maintenance (O&M) costs, financing costs, and an assumed utilization rate for each plant type." EIA (U.S. Energy Information Administration), *Levelized Cost and Levelized Avoided Cost of New Generation Resources in the Annual Energy Outlook 2015*, last modified June 3, 2015, https://www.eia.gov/forecasts/aeo/electricity_generation.cfm.
[d] Assumptions include: capital costs of $410 or $150/KWh for 6 hours of storage capacity, $.050/kWh cost to charge, one full cycle per day (full charge and discharge), efficiency of 75%–85%, and fixed O&M costs of $22.00 to $27.50 per KWh installed per year. See for example, *Lazard's Levelized Cost of Energy Analysis*, Lazard, September 2014, https://www.lazard.com/media/1777/levelized_cost_of_energy_-_version_80.pdf.

### 6.3.3 Microgrid Projections

Microgrid capacity is projected to grow from 1.2 GW in 2014 to 2.9 GW by 2020, with the most capacity in military installations and university/research facilities (Figure 6.27). In some cases, future development may be in concert with utility modernization efforts. Several larger projects of 30 MW to 200 MW are planned in New York.[653]

**Figure 6.27. Projected growth in microgrids, 2014 to 2020[654]**




*Overall capacity is projected to reach 2.85 GW in 2020, with the largest capacity in university/research facilities, followed by military installations.*

### 6.3.4 Demand Response Projections

Greater adoption of variable renewable energy resources is placing greater demands on the electricity system, particularly in some regions (e.g., Texas, California). For example, in the West, renewable resources, including small hydro, are expected to make up nearly 17% of generating resources and almost 20% of capacity by 2024.[655] Increased penetration of VERs will lead to a more dynamically changing grid, and thus require a more frequent and broader array of grid support services—e.g., to address frequency imbalances, supply shortfalls, and over-supply conditions that may be hard to predict.[656] Demand response can facilitate greater amounts of penetration of VERs.

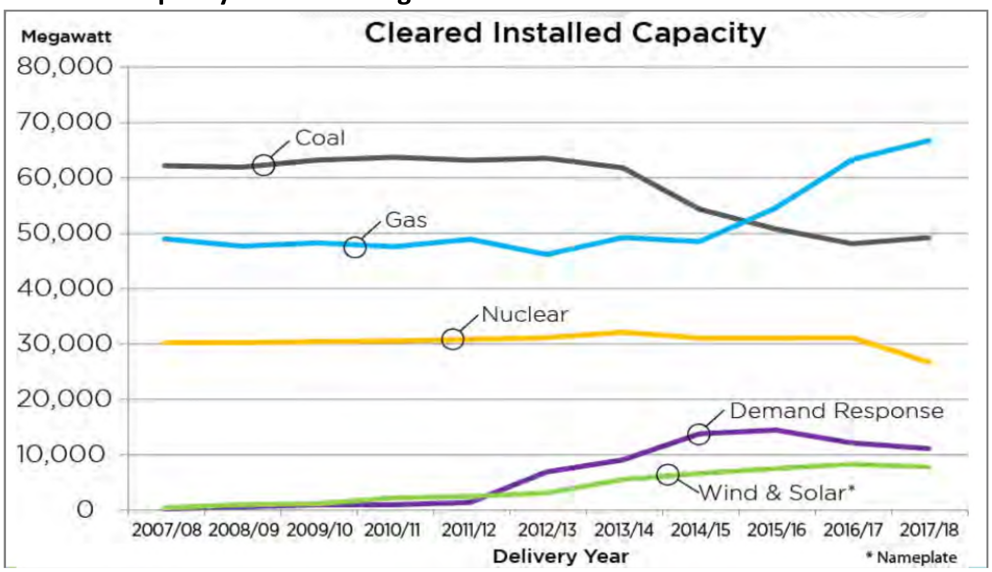
The development of more powerful IT capabilities, communication protocols, smart metering infrastructure, and grid-enabled end-use equipment, and the emergence of more affordable distributed storage[a] provides additional flexibility for demand response and the potential for new business models and new market entrants. Today, demand response programs are typically offered to customers to reduce their load in peak demand situations in exchange for capacity or energy payments.

[a] Distributed storage can be utilized for demand response applications such ancillary services.

In the future, a new class of demand response applications may have wider availability, with faster, more automated response and capability of moving customer loads in both directions. Advanced demand response resources are customer loads equipped with automation equipment that can increase and decrease while being available throughout the year and frequently measured (FERC 2014). Ancillary services typically include three types of products (spinning, nonspinning, and regulation), but high VER penetration is anticipated to add additional flexible capacity products such as maximum continuous ramping and load following products.

Figure 6.28 shows the cleared installed capacity[a] for the next three years in the PJM ISO region as an example of typical capacity changes observed and expected over time for generation: (1) a reduction in coal and nuclear capacity, (2) a sharp increase in natural gas to replace coal, and (3) an increase in wind and solar resources. Demand response capacity is projected to drop over the next several years, after a period of sharp growth.

**Figure 6.28. Installed capacity in the PJM region[657]**




*PJM's relative mix of electricity resources through 2017/2018 is illustrative of trends in the relative mix of generation fuels and demand response for a large ISO region. Coal capacity is reduced by 20% from its peak and replaced largely by natural gas, with levels of wind and solar increasing. Demand response is projected to drop slightly from 2015/2016 to 2017/2018.*

Figure 6.29 and Figure 6.30 show demand response projections[b] for NERC regions. Demand response for all regions is projected to account for less than 5% of overall demand to 2024. Overall, demand response is projected to increase only 1.7%, from 39.4 GW to 40.1 GW. Over the same period, total peak demand is projected to increase by 10%, from 864.3 GW to 950.2 GW. Thus, the percentage of demand response would drop from 4.6% to 4.2%. A breakout by individual NERC regions shows similar trends. Demand

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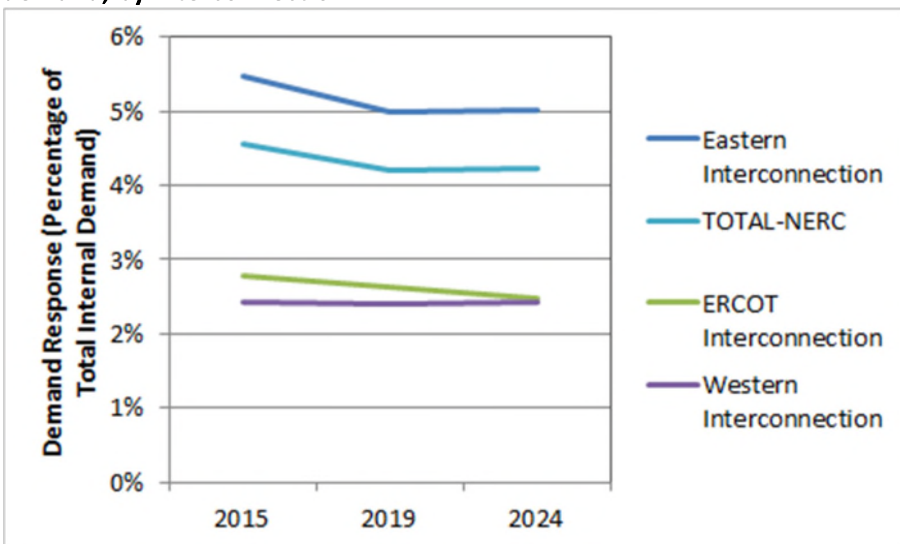
[a] *Cleared installed capacity* refers to the bid-in capacity that was accepted in the PJM capacity auction for delivery in the year as shown on the x-axis of Figure 6.28.

[b] *Demand response* here is defined as "Total Internal Demand in MW - Net Internal Demand in MW," where this difference is the amount of controllable and dispatchable demand response projected to be available during the peak hour. Total Internal Demand includes considerations for reduction in electricity use due to projected impacts of energy efficiency and conservation programs and normal weather.

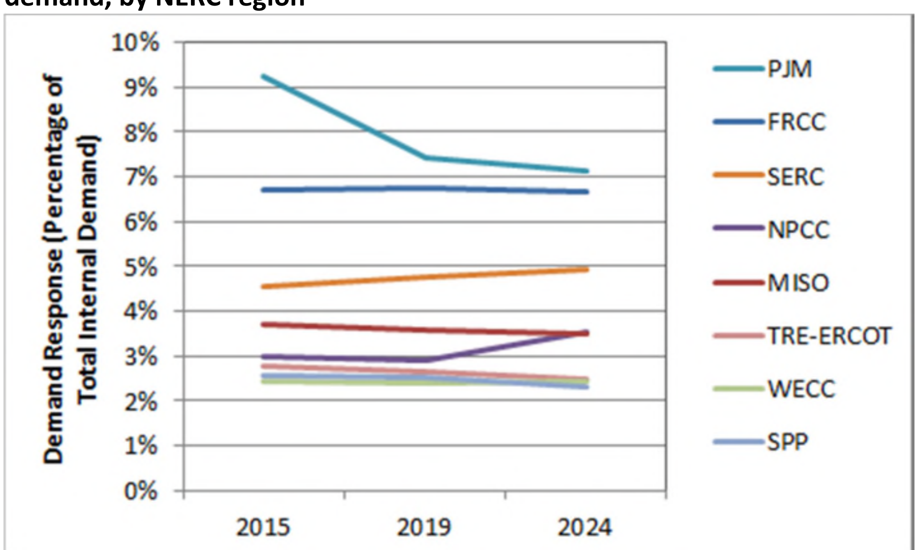
response is projected to increase from 3% to 3.6% of demand in NPCC and from 4.6% to 4.9% in SERC, but it is projected to drop or stay flat in other regions.

**Figure 6.29. Total controllable and dispatchable demand response as a percentage of total summer peak internal demand, by interconnection**




*Overall, demand response is projected to drop slightly in the next 10 years, with a downward trend projected in the Eastern Interconnection and ERCOT and demand response virtually flat in the Western Interconnection.*[658]

**Figure 6.30. Total controllable and dispatchable demand response as a percentage of total summer peak internal demand, by NERC region**[659]




*Demand response is projected to decrease in PJM from about 9% in 2015 to 7% in 2024, increase somewhat in SERC and NPCC, and remain flat or trend downward in the five other regions. All regions in the continental United States are summer-peaking except for the WECC-Northwest Power Pool subregion of WECC, which is winter-peaking.*

The following factors contribute to projections that overall demand response will decrease or remain flat over the next decade:

- Recent greater deployment of energy efficiency, conservation, TOU rates, and distributed generation have contributed to the lowest annual growth rate on record for NERC-wide summer and winter peak demand. Thus, demand response's contribution to demand reduction has flattened and is projected to remain fairly flat for the next decade, with minimal projected growth in the reference case.[660] NERC-wide controllable and dispatchable demand response is projected to grow by 1.7 GW (increasing from 38.9 GW in 2015 to 40.6 GW in 2024).
- In some regions such as FRCC, a decrease in the cost-effectiveness of demand response programs has reduced its rate of adoption. Projected benefits are lower relative to 2009 levels due to a number of factors, including lower fuel price projections and lower projected costs for environmental compliance, especially for carbon dioxide ($CO_2$) emissions.[661]

In some subregions, demand response capacity may be higher in the next decade than described above in order to meet reliability requirements for reserve margin at least cost.[a] In particular, five of the 15 NERC subregions in the United States are projected to fall below their reserve margin target with anticipated capacity[b] in the next five years. These five NERC subregions are projected to have less than 5% demand response capacity in 2024, at levels that are flat to 12% down from 2015 levels.

- Midcontinent ISO (MISO)
- Northeast Power Coordinating Council–New York (NPCC-NY)
- Reliability Entity, Inc. – Electric Reliability Council of Texas (TRE-ERCOT)
- Mid-Continent Area Power Pool (MRO-MAPP)
- Southeastern Electric Reliability Council – East (SERC-E)

Among the remaining regions, seven of the 15 NERC subregions are projected to meet their reserve margins through 2024:

- Florida Reliability Coordinating Council (FRCC)
- Northeast Power Coordinating Council – New England (NPCC-NE)
- Pennsylvania-New Jersey-Maryland Interconnection (PJM)
- Southeastern Electric Reliability Council – Southeast (SERC-SE)
- Southwest Power Pool (SPP)
- Western Electricity Coordinating Council – Northwest Power Pool (WECC-NWPP)
- Western Electricity Coordinating Council – Rocky Mountain Reserve Group (WECC-RMRG)

The remaining three subregions are close (within 2%) to meeting their reserve margin target for 2024:

- Western Electricity Coordinating Council – California-Mexico Power (WECC-CA-MX)
- Western Electricity Coordinating Council – Southwest Reserve Sharing Group (WECC-SRSG)
- Southeastern Electric Reliability Council – North (SERC-N)

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[a] *Reserve margin* is the primary metric used to measure resource adequacy and is defined as the difference in peak load resources and net demand (both in units of GW), divided by net demand.
[b] Capacity that is under construction or approved.

Thus, the demand response projections for 10 of the 15 NERC subregions are reasonably consistent with meeting system reserve margin requirements from 2015 to 2024, under all of the other assumptions of this NERC study.

Another important consideration is market and regulatory uncertainty for demand response programs. This includes issues of regulatory authority and the treatment of aggregated resources for market participation. On January 25, 2016, the U.S. Supreme Court upheld FERC's authority to regulate demand response programs in wholesale electricity markets (FERC Order 745). This ended a period of multiple years of uncertainty for demand response compensation in energy markets, the impact of which is not captured in the above projections. (See Section 6.5.4 for more discussion.)

Overall these projections indicate that without further regulatory or policy changes, demand response programs are unlikely to grow significantly in the next decade. At the same time, demand response product offerings may broaden as technology and software for the control and aggregation of end-use equipment and DERs improve, DER market adoption increases, new sources of electricity demand are brought online (e.g., PEVs), and more variable energy renewable sources need to be integrated into the grid. The demand response sector, including third parties that aggregate demand response from residential and commercial consumers, may thus have greater opportunities for growth as new demand response resources are identified by utilities and regulators, and these resources participate in retail and wholesale markets.

The following subsections discuss several region-specific demand response forecasts beyond 2024:

#### *ERCOT to 2032*[662]

An ERCOT study to 2032 projects a 2.7% to 3.5% demand response load reduction in reference-case scenarios (2.7 to 3.5 GW out of 100.7 GW peak demand). The highest demand response capacity is achieved in the "Environmental EE & DR" scenario with a 10 GW demand response mandate, or 13% of a projected 76.9 GW peak demand. This scenario assumes more aggressive energy efficiency programs, emissions cost adders, continuation of the federal PTC for renewable resources until 2032, and high natural gas prices relative to business-as-usual cases.

#### *Eastern Interconnection to 2030*

Table 6.10 provides estimates for peak load reduction resources from a recent demand response study for the Eastern Interconnection.[663] Demand response from conventional demand response programs and smart grid-enabled programs is projected to total 5.4% of peak demand in 2025 and 2030, similar to NERC's estimates cited above. Together with demand response, energy efficiency programs, distributed generation, and energy storage are projected to increase to 19.6% of peak load by 2030.

**Table 6.10. Peak Load Impact Projections in the Eastern Interconnection**[664]

| Resource Category | | Projected Total Demand-Side Resource Capacity (MW) | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 2012 | 2013 | 2014 | 2015 | 2020 | 2025 | 2030 |
| Energy Efficiency | | 3,016 | 5,650 | 8,567 | 11,542 | 25,956 | 40,106 | 53,369 |
| Demand Response | *Conventional Programs* | 23,514 | 26,451 | 31,245 | 32,005 | 31,614 | 32,412 | 33,415 |
| | *Smart Grid-Enabled** | 929 | 1,032 | 1,184 | 1,322 | 3,230 | 4,451 | 5,639 |
| Energy Storage | | 64 | 68 | 76 | 79 | 629 | 1,253 | 2,040 |
| DG-Fossil | | 15,740 | 15,666 | 15,663 | 15,625 | 16,031 | 16,695 | 17,671 |
| DG-Renewables | | 4,198 | 4,713 | 5,289 | 5,972 | 10,745 | 17,007 | 24,516 |
| Smart Grid (CVR) | | 353 | 557 | 612 | 1,124 | 1,481 | 3,276 | 4,075 |
| **TOTAL** | | **48,103** | **54,424** | **62,918** | **67,948** | **89,950** | **115,454** | **140,972** |
| *Total Annual Peak Load* | | *577,087* | *585,752* | *596,594* | *604,471* | *640,249* | *677,684* | *718,217* |
| % of Peak Load Supported by Demand-Side Resources | | 8.3% | 9.3% | 10.5% | 11.2% | 14.0% | 17.0% | 19.6% |

** Includes time-based rate programs that require AMI meters with two-way communication capability.*

*Demand response programs are projected to contribute 5.4% of peak load support in 2030, up from 4.2% in 2012.*

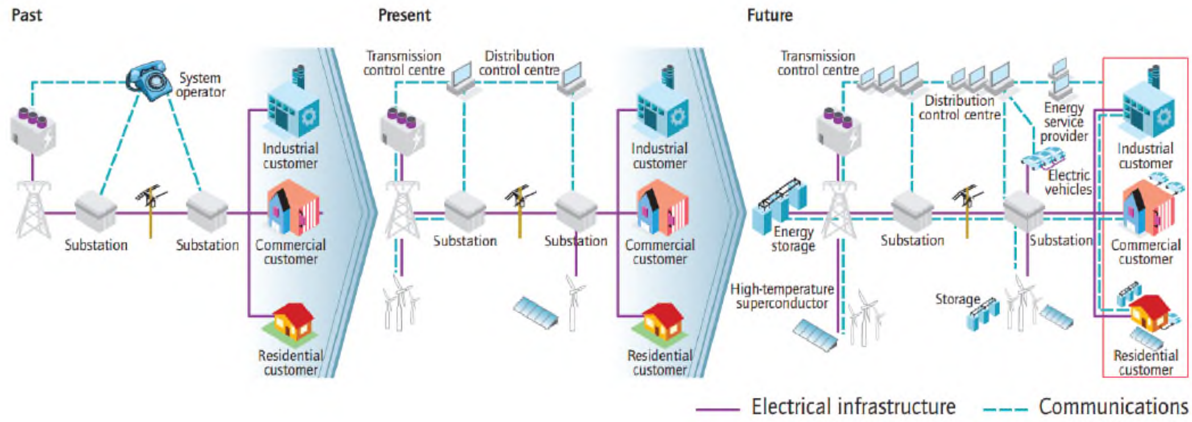
*WECC to 2022*

A recent Lawrence Berkeley National Laboratory (LBNL) study presents potential estimates for the 11 states and two provinces in the Western Interconnection.[665] The potential estimate is for "traditional" demand response with well-established programs. The "High DSM" case in the study estimates 14.39 GW of potential demand response resource capacity in 2022, or about 8.3% of peak demand. Interruptible programs accounted for the largest demand response capacity at ~5,028 MW (~35%). Pricing programs accounted for ~4,266 MW (~30%) of demand response capacity. The reference case estimated 7.96 GW of potential demand response, or about 4.6% of peak demand—~3,615 MW (~45%) direct load control programs and ~2,714 MW (~35%) interruptible programs.

## 6.4 Markets and Market Actors

The electricity grid today consists of utility-scale generation, transmission and distribution systems and control centers, relatively low levels of DERs, and end users (See Figure 6.32). Generation, transmission, and distribution are also linked via communications, and recent implementation of AMI allows end-use customers to directly communicate with their utility. Figure 6.31 conceptualizes the electricity system and key market actors and roles. (Modeling is subsumed within the planning layer, and R&D occurs across all areas.) Table 6.11 adapts Figure 6.31 to conceptualize the future grid in a similar manner.

**Figure 6.31. Evolution of the electricity grid[666]**




*The electricity grid is evolving to accommodate more DERs, more extensive flows of information and communication, and new market participants.*

The electricity grid of the future is likely to have higher levels of DERs, including two-way power flows between the distribution system and end-use consumers, and new market participants, such as DER aggregators. It is likely that the grid of the future will need to accommodate new or evolving roles for consumers, utilities, grid operators, and regulators, as well as potential new entities. For example, consumers that both produce and consume power through advanced distribution infrastructure will become "prosumers." This denotes a change in the customer-utility relationship from a consumer who only pays for electricity services to a consumer who also sells electricity services to the grid. Another example of change is the greater potential role energy service providers can play in offering DER equipment and integration for customers, as well as aggregating customer-sited DERs to provide energy, capacity, and other grid services.

One emerging business model is partnerships of rooftop solar PV and on-site battery storage vendors. Examples include Solar City and Tesla, Sungevity and Sonnenbatterie, SunPower and Sunverge, Sunrun and Outback Power, and Enphase and Eliiy. Solar PV combined with storage can provide customers with emergency backup power and peak demand reduction.

Another example of new business models is the aggregation of customer-sited storage systems for participation in the wholesale power market, recently demonstrated in CAISO.[667] Storage was installed on commercial building sites (hotels, software companies, and nursing homes). Other key participants in the demonstration include the utility (Pacific Gas and Electric), regulators (California Public Utilities Commission [CPUC]), a network platform provider (Olivine), a start-up company providing real-time analytics and storage dispatch and optimization (Stem), and legislators who enacted the state's storage mandate.

**Table 6.11. Market Actors in the Electric Grid of the Future**

| LAYER | AREA | LEAD MARKET ACTORS | KEY ROLES |
|---|---|---|---|
| CUSTOMER | RESIDENTIAL SECTOR | RATE PAYERS | **CONSUMERS TO PROSUMERS** |
| | COMMERCIAL SECTOR | BUSINESS OWNERS | **CONSUMERS TO PROSUMERS** |
| | INDUSTRIAL SECTOR | BUSINESS OWNERS | **CONSUMERS TO PROSUMERS** |
| DISTRIBUTED ENERGY RESOURCES | RES/ COMM/ IND SECTORS | CHP, SOLAR PV, **DR, STORAGE PROVIDERS** | EQUIPMENT INSTALLATION / SERVICE |
| **ENERGY SERVICE PROVIDER** | RES/ COMM/ IND SECTORS | **CUSTOMER DER AGGREGATORS** | **CUSTOMER SERVICE AND GRID SUPPORT INTERFACE** |
| COMMUNICATION AND SOFTWARE | **SPANNING THE GRID FROM GENERATORS TO CUSTOMERS** | **DISTRIBUTION UTILITY, ENERGY SERVICE PROVIDERS** | **ENERGY SERVICE OPTIMIZATION** |
| UTILITY | UTILITY | UTILITY | SETS TARIFFS, PROVIDE ENERGY SERVICE AND EE/DR PROGRAMS |
| DISTRIBUTION | SUBSTATION STEP DOWN TRANSFORMER | DISTRIBUTION CONTROL CENTER **TO DISTRIBUTION SYSTEM OPERATOR?** | SUBSTATION CONTROL, DISTRIBUTION SYSTEM OPERATIONS |
| GRID SUPPORT | ENERGY MARKETS | REGION-DEPENDENT ISO/RTOs, BALANCING AUTHORITIES | BALANCE SUPPLY AND DEMAND, ENSURE RESOURCE ADEQUACY, **INTEGRATE VARIABLE RENEWABLE SUPPLIES** |
| | CAPACITY MARKETS | | |
| | **ANCILLARY SERVICES MARKETS** | | |
| TRANSMISSION | BALANCING AUTHORITIES | ISO/RTOs, **BULK STORAGE PROVIDERS** | INTEGRATES RESOURCE PLANS, MAINTAINS SUPPLY/DEMAND BALANCE, SUPPORTS INTERCONNECTION FREQUENCY IN REAL TIME |
| GENERATION | MERCHANT POWER PLANT, VERTICALLY-INTEG. UTILITY | POWER PLANT OWNERS | PROVIDE BASELOAD AND FLEXIBLE POWER, **MEET RPS OR EMISSIONS TARGETS** |
| PLANNING | STATES, FEDERAL GOV'T, ISO/RTOs | STATE PUCS, EPA, ISO/RTOs | RESOURCE AND EMISSIONS TARGETS AND POLICIES; **PLANNING FOR HIGHER DER PENETRATION** |
| REGULATORY | TRANSMISSION | FERC | BULK ELECTRIC SYSTEM, WHOLESALE MARKETS AND TRANSMISSION, SETS OPEN ACCESS TRANSMISSION TARIFFS; **NEW PLANNING TOOLS AND PROCEDURES** |
| | RELIABILITY | NERC | ESTABLISHES RELIABILITY RULES; **NEW PLANNING TOOLS AND PROCEDURES** |
| | NATIONAL, REGIONAL, LOCAL | SPECIFIED JURISICTIONS | NATIONAL, STATE, AND LOCAL POLICIES AND INCENTIVES; **INCORPORATING HIGHER DER PENETRATION** |

*This table adapts Figure 6.31 to conceptualize the future grid to 10 layers. Some layers are cross-cutting, such as communication and software. These layers span generation, transmission, and distribution layers. Distributed generation and storage can provide more flexibility to both distribution and transmission systems. Energy service providers can use advanced modeling and data analytics to aggregate consumer-hosted DERs for grid support. Consumers can both consume and produce power ("prosumers"). Blue text indicates changes due to greater DER adoption; red text indicates changes due to greater levels of utility-scale renewable generation.*

### 6.4.1 Sources of DER Value

Table 6.12 defines and maps DER value components by beneficiary: utility customers, society, electric utility distribution system, and wholesale electricity markets. For utility customers, potential benefits can accrue from greater market choices, lower electricity bills, improved energy security (backup power in grid outage or emergency), and enhanced property value.

**Table 6.12. DER Value Components and Definitions[668]**

| | Value Component | Definition |
|---|---|---|
| Wholesale | WECC Bulk Power System Benefits | Regional BPS benefits not reflected in System Energy Price or LMP |
| | System Energy Price | Estimate of CA marginal wholesale system-wide value of energy |
| | Wholesale Energy | Reduced quantity of energy produced based on net load |
| | Resource Adequacy | Reduction in capacity required to meet Local RA and/or System RA |
| | Flexible Capacity | Reduced need for resources for system balancing |
| | Wholesale Ancillary Services | Reduced system operational requirements for electricity grid reliability |
| | RPS Generation & Interconnection Costs | Reduced RPS energy prices, integration costs, quantities of energy & capacity |
| | Transmission Capacity | Reduced need for system & local area transmission capacity |
| | Transmission Congestion + Losses | Avoided locational transmission losses and congestion |
| | Wholesale Market Charges | LSE specific reduced wholesale market & transmission access charges |
| Distribution | Subtransmission, Substation & Feeder Capacity | Reduced need for local distribution upgrades |
| | Distribution Losses | Value of energy due to losses bet. BPS and distribution points of delivery |
| | Distribution Power Quality + Reactive Power | Improved transient & steady-state voltage, harmonics & reactive power |
| | Distribution Reliability + Resiliency | Reduced frequency and duration of outages & ability to withstand and recover from external threats |
| | Distribution Safety | Improved public safety and reduced potential for property damage |
| Customer & Societal | Customer Choice | Customer & societal value from robust market for customer alternatives |
| | Emissions (CO2, Criteria Pollutants & Health Impacts) | Reduction in state and local emissions and public and private health costs |
| | Energy Security | Reduced risks derived from greater supply diversity |
| | Water & Land Use | Synergies with water management, environmental benefits & property value |
| | Economic Impact | State or local net economic impact (e.g., jobs, investment, GDP, tax income) |

*This list includes potential DER value components for utility consumers, society, the distribution system, and wholesale electricity markets. BPS = bulk power system; LMP = locational marginal pricing; RPS = Renewable Portfolio Standard; LSE = load serving entity.*

DERs can provide services to utilities in supporting distribution system operation and can defer or avoid costly distribution system upgrades. Utilities could play a larger role in both DER deployment and DER integration, management, and optimization. This will depend on several factors, including the rate of technology innovation, market evolution, and firm cost structure.[669] For example, San Diego Gas and Electric (SDG&E) recently proposed a storage tariff that would reward consumers who are willing to allow utility control of batteries at their premises.[670] This type of program could help defer distribution grid investments with assets owned by utility customers. Integration and management of DERs represent a potential role for the utility or an independent entity serving as the Distribution System Operator (DSO). DSOs are responsible for planning and operational functions associated with a distribution system that is modernized for high levels of DERs.[671]

Three California utilities recently submitted DER Plans to the CPUC as mandated by state statute (AB 327).[672] The utilities are proposing several hundreds of millions of dollars each over the next several years to integrate DERs (including rooftop PV, behind-the meter storage, and PEVs) in distribution planning and operation. Funding would cover distribution grid and substation automation, communication systems, technology platforms and applications, and grid reinforcement (e.g., upgrading conductors to a larger size and increasing circuit voltage to support increased DER penetration). Proposed automation systems include data collection and management systems.

## 6.5 Barriers and the Policies, Regulations, and Programs That Address Them

Barriers to DER adoption are listed below. Most of these barriers are applicable for all types of DERs, and many are interrelated. Contracting with a third party (e.g., demand response aggregators, solar leasing entities, energy services companies) can address many of these barriers.

- First costs (including transaction costs) and short payback times—Market actors typically require short payback periods. High capital, installation, and transaction costs can pose barriers to DER investments.
- Information/awareness—Market actors may have imperfect information about the cost, performance, and benefits of DERs and may lack awareness of new technology developments, incentive programs, or third-party service providers.
- Risk aversion/performance concerns—Market actors may be risk averse to new or unfamiliar DER technologies and new operating and maintenance procedures or business practices, and may be concerned about DER performance relative to the status quo.
- Technical staffing and capability—For example, potential CHP customers may lack technical know-how or capability to install and maintain an on-site energy generation system.
- Materiality—When energy costs are small, relative to other costs, it is hard to get building owners to pay attention to energy efficiency and DERs.
- Limited access to capital—Households and companies have limited spending or capital investment budgets, and DERs may not be considered for renovations.
- Lack of monetization of non-energy benefits and price signals—DER prices are set to recover service provider and equipment supplier costs and do not capture the true social costs and benefits of DER adoption (e.g., environmental and health benefits). In addition, tariff structures may discourage consumer investments in DERs.
- Lack of private incentive for R&D—In general, RD&D is undersupplied absent policy intervention because its benefits cannot be fully appropriated by inventors (a "public goods" problem).
- Uncertainty in market and regulatory and nonmarket factors—The uncertainty associated with long-term investment outcomes, future fuel and electricity prices, and utility tariff structures can hamper DER adoption. For example, the price at which commercial and industrial consumers can sell back excess electricity production from CHP systems is a critical factor in the cost-effectiveness of these systems, but this is an uncertain parameter when planning for a 15- to 25-year investment horizon.
- Utility interactions—Utility tariff structures, and in particular standby rates,[a] [673]impact the economics of on-site generation, including CHP. For example, many water and wastewater utilities have reported long, difficult, and expensive processes related to interconnection agreements for distributed generation from a variety of on-site renewable sources, including biogas. Interconnection processes can delay the project development schedule and add expenses by requiring extensive studies and technical requirements.[674] Multiple review bodies and local permitting and siting issues (air and water quality, fire prevention, fuel storage, hazardous waste

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[a] *Standby* (or partial requirements) *service* is the set of retail electric products for utility customers who operate on-site, non-emergency generation. Utility standby rates cover some or all of the following services: backup power during an unplanned generator outage; maintenance power during scheduled generator service for routine maintenance and repairs; supplemental power for customers whose on-site generation under normal operation does not meet all of their energy needs, typically provided under the full requirements tariff for the customer's rate class; economic replacement power when it costs less than on-site generation; and delivery associated with these energy services.

disposal, worker safety, and building construction standards) can add delays due to the review body's unfamiliarity with the technology, as well as transaction and legal costs.

- Limited CHP supply infrastructure—The downturn in CHP investment since 2005 has reduced the size and focus of the industry's sales and service infrastructure.

Barriers specifically to greater adoption of demand response include the following (directly quoted from *A National Assessment of Demand Response Potential*, Federal Regulatory Energy Commission, 2009)[675]:

- Regulatory barrier—Some regulatory barriers stem from existing policies and practices that fail to facilitate the use of demand response as a resource. Regulatory barriers exist in both wholesale and retail markets.
    - Lack of a direct connection between wholesale and retail prices
    - Measurement and verification challenges
    - Lack of real-time information sharing
    - Ineffective demand response program design
    - Disagreement on cost-effectiveness analysis of demand response
    - In the traditional utility business model, the opportunity for vertically integrated, investor-owned utilities to earn a return on capital investments, but not expenses. Thus, utilities may view demand response as less preferred to capital-intensive investments in generating plants.
- Technological barriers
    - Lack of AMI
    - High cost of some enabling technologies
    - Lack of interoperability and open standards
- Other barriers
    - Lack of consumer awareness and education
    - Lack of enabling infrastructure investment
    - Revenue availability and revenue capture. [a] [676]
    - Concern over environmental impacts; for example, the use of diesel generators for peak generation reduction

The following table and technology-specific sections describe additional barriers and existing policies and programs that are currently being implemented to address them.

[a] For some markets, "DR [demand response] program providers and the participating customers must assess and decide whether the available revenues from participating in various AS [Ancillary Services] markets are sufficient (*Revenue Availability*) and can be captured with enough certainty (*Revenue Capture*)."

**Table 6.13. Major Policies, Regulations, and Programs to Address Barriers to Cost-Effective DERs**

| Policy, Regulation, or Program | Description and Implemented Examples | Principal Barriers Addressed |
|---|---|---|
| Codes and Standards | • Mandatory prescriptive or performance-based energy standards that regulate end-use equipment, controls, or distributed generation, such as provisions for demand response capability (e.g., smart thermostats) or distributed generation equipment<br>• Zero net energy building (ZNEB) codes that mandate on-site distributed generation | *Information/awareness, materiality, split incentives*<br>• Codes and standards set a minimum level of performance, guarding against uninformed or inattentive purchase of lower performance or lower efficiency devices or buildings and limiting the impact of split incentives. |
| Clean Energy Mandates and Target-Setting | • Renewable portfolio standard (RPS) carve-outs<br>• Public Utility Regulatory Policies Act (PURPA), feed-in tariffs and net metering<br>• Cap-and-trade emission reduction programs<br>• State targets for storage, solar PV, and CHP | *Non-energy benefits, lack of private incentive for R&D, various others*<br>• These policies are enacted for a variety of reasons, including resource diversification, using local resources, reducing carbon and other air pollutant emissions, and other non-energy benefits. |
| Grants and Rebates | • Payments to consumers or third parties that reduce or offset the incremental cost of DERs | *First costs, short payback requirements, non-energy benefits, materiality, information/awareness*<br>• Grants and rebates lower the incremental up-front cost of efficient technologies, serving as a proxy for nonpriced social benefits of energy efficiency adoption. |
| Resource Planning | • Utility integrated resource planning (IRP) to ensure system reliability that appropriately factors in distributed energy resources | *Price signals, non-energy benefits*<br>• IRPs can ensure that DERs are valued appropriately in utility planning for energy and capacity. |
| State Regulations Including Rate Design | • State regulations on peak demand reduction, time-varying pricing, demand response incentive programs, service providers, integrated resource planning, PURPA implementation, standby rates, interconnection, and utility ownership of DERs | *Price signals, non-energy benefits*<br>• These interventions modify costs and returns on DER investments. |
| RD&D for end-use technologies | • Direct federal support for RD&D<br>• Manufacturer incentives<br>• DOE SunShot program | *Lack of private incentive for R&D*<br>In general, and particularly in the energy industry, RD&D is undersupplied absent policy intervention. |

| | | |
|---|---|---|
| Financing | • Property-assessed clean energy (PACE) programs<br>• PV leasing programs<br>• State financing programs<br>• Green banks | *Lack of capital, first costs, transaction costs, performance risk*<br>Financing programs extend capital and often eliminate up-front cost entirely. Financing is often packaged with other programmatic offerings and potentially removes the need to seek out a source of capital, which can otherwise be a barrier to program participation. Performance contracting transfers energy performance risk to the energy services company. Performance contracting also provides technical expertise and lowers transaction costs. |
| Tax incentives | • Federal investment tax credits for CHP, fuel cell systems, solar PV, and small wind on-site generation | Tax incentives |

### 6.5.1 Distributed Generation Barriers in Existing Policies

Policy and regulatory drivers that affect the penetration of distributed generation include the following:

- National and state incentive policies—The deployment of renewable energy resources, both utility-scale and distributed, has been highly dependent on availability of financial incentives. However, declining cost and increasing performance have enabled a reduction in incentive levels.
- State renewable portfolio standards with carve-outs for distributed generation—State-level mandates provide certainty to the market and have been a significant driver of solar PV in particular.
- Policies and regulations affecting electricity tariffs, such as net metering, FITs, and retail rate design—Retail electricity rate structures significantly affect net benefits for customers considering installation of distributed generation or storage systems or participation in demand response programs.
- Zero net energy building (ZNEB) policies—Policies requiring on-site generation (or that count participation in offsite generation projects) as part of ZNEBs, which also incorporate deep energy efficiency measures, may serve as an additional driver for distributed generation adoption.

Corporate policies also can contribute to greater demand for distributed generation. Energy efficiency, renewable energy, and sustainability more broadly are a renewed focus that is exemplified in "RE100" initiative.[677] RE100 is a global collaborative of companies committed to 100% renewable electricity in the near term (2015 to 2020) to long term (2050). Participating companies have varying renewable energy goals as a percentage of their overall energy consumption. Microsoft reported 100% renewable electricity in 2014; Goldman Sachs set a 100% target for 2020, and Johnson and Johnson set a 100% target for 2050. The companies meet their renewable electricity with a mix of on-site generation, power purchase agreements, and renewable energy certificates.

#### 6.5.1.1 *Solar PV*

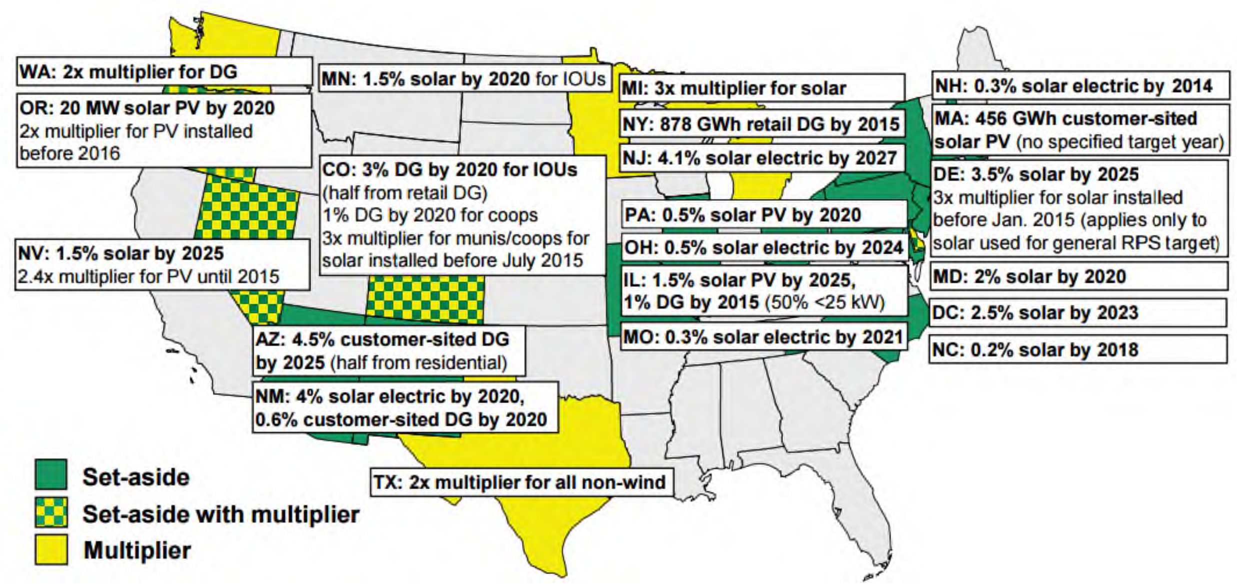
In the past, adoption of distributed solar PV routinely required an up-front investment in hardware and installation costs. This "first-cost" barrier has been the focus of federal and state incentive policies and spurred the growth of third-party leasing providers. Other barriers to distributed solar include the lack of suitable rooftop space for a large fraction of buildings; the complexity of PV system purchases, which include multiple options for payment and ownership, equipment, and system sizes;[678] and the reluctance of consumers to make a long-term energy investment.

The relatively high levels of growth achieved in the U.S. solar PV market in recent years have been aided by financial incentives and other supportive policies. At the federal level, incentives have been provided primarily through the U.S. tax code, in the form of a 30% ITC. In December 2015, the ITC for solar was extended in full for an additional three years. It will now ramp down incrementally through 2021 and remain at 10% beginning in 2022 for businesses and commercial installations and drop to zero for residential owners.[679] Businesses also can use an accelerated, 5-year tax depreciation schedule for solar installation.

State renewable portfolio standards (RPSs) are a major driver of renewable energy deployment. An RPS requires utilities and other electricity suppliers to purchase or generate a targeted amount of qualifying renewable energy or capacity by specified dates. While design details vary considerably, RPS policies typically enforce compliance through penalties, and many include the trading of renewable energy certificates (each representing 1 megawatt-hour [MWh] of qualifying energy). Many states and

Washington, D.C., have RPS policies with specific solar provisions.[680] Figure 6.32 shows states that include such distributed generation "set-asides," multipliers that assign qualifying distributed generation with higher levels of qualifying renewable energy credits, or both.

**Figure 6.32. State renewable portfolio standards with distributed generation set-asides and multipliers[681]**




*Many states support deployment of solar PV and other distributed generation resources through specific energy or capacity targets or additional credits toward compliance with the standards.*

The growth in U.S. distributed generation, and in particular residential solar PV, has been facilitated in large part through policies, regulations, and programs that enable third-party ownership.[682] Under this structure, a party other than the consumer or utility invests in, owns, and operates the distributed generation system at a consumer's site. The customer signs a long-term contract to lease the system or purchase the electricity generated by the system. The consumer avoids the up-front investment cost, and the third party takes care of operation and maintenance. In 2013, third-party ownership represented approximately two-thirds of the U.S. residential solar market and a considerable portion of the commercial market.[683] The success of this model is partially due to its economic proposition, where consumers access PV-generated electricity at a price that is competitive with utility retail rates.[684]

The value proposition of rooftop PV is further tied to utility tariff structures, including the level of monthly fixed customer charges (charges that the customer cannot reduce—e.g., through reducing or shifting electricity consumption or demand),[a] net metering policies,[685] and time-varying rates.[686] When setting solar PV-related tariffs, utility regulators balance a host of interests, including ratemaking principles such as economic efficiency and fairness/equity. Such equity issues may arise if solar PV owners are not contributing their fair apportionment of system capacity costs. But similar issues arise absent solar PV. For example, "peaky" customers—those who use more electricity when it is most expensive, relative to the average customer—are subsidized by customers with flatter loads.

[a] Recovery of utility fixed costs through fixed charges and other means is the subject of a forthcoming report in the Future Electric Utility Regulation series: https://emp.lbl.gov/future-electric-utility-regulation-series.

*Net Metering Policies* [687]

Net metering policies provide a billing mechanism that allows consumers to generate electricity at their homes or businesses using eligible technologies (e.g., solar, wind, hydro, fuel cells, geothermal, biomass), reduce purchases from the utility, and receive a credit on their utility bills for net excess energy. This credit offsets the customer's electricity consumption during other times, typically rolling forward over the course of a year. Net metering has served as a principal policy for increasing market adoption of distributed generation.

State-developed mandatory net metering rules apply to utilities in most of the United States (41 states, Washington, D.C., and three territories[688] (see Appendix Figure 7.35 and Figure 7.36). Due to rapidly falling costs for rooftop solar PV, utilities in several states are approaching or have already hit their previously established net metering caps.[689] Utilities argue that increasing capacity of distributed generation with existing compensation and tariff structures shifts costs unfairly to non-solar customers, and that solar PV owners should pay more for transmission and distribution charges. Distributed solar also represents a potential threat to utilities' existing business model.[690]

Recently, utilities throughout the country have proposed changes in net metering rules, as well as fundamental rate design changes such as increasing fixed charges or adding demand charges—for all customers or just solar PV customers. At the end of last year, Hawaii ended its solar net metering program, and Nevada recently announced sharply increased monthly fixed charges and much lower net metering rates to be phased in over the next four years.[691] In January 2016, the California PUC updated its net metering regulations. The decision upheld compensation at retail rates for net excess generation but also imposed an "aggressive" move to time-of-use electricity consumption rates for net metering customers.[692] The decision will be revisited in 2019, with major efforts ongoing at the CPUC and the state's three largest utilities to better determine the proper valuation and appropriate compensation mechanisms for rooftop solar and other DERs.[693]

*Community* or *shared* solar[694] is an emerging model where, instead of being installed at a consumer's site, a solar PV system is installed in a nearby location (e.g., a parking lot or empty lot) to serve multiple consumers. Consumers can buy or lease a portion of the community project, or participate in a utility program where they contribute toward the project through charges on their utility bills (and receive the renewable energy credits and other benefits of the project). Community solar projects provide greater project economies of scale compared to small systems at individual properties, as well as provide an option where roof- or ground-mounted systems are not feasible. While designs vary, typically utility customers are credited with the amount of solar production associated with their share of the PV capacity. Some states have enacted policies to support community solar projects. For example, California SB 43 calls for 600 MW of community solar to be installed in the state by 2019. A barrier that is specific to this business model is the ability of project hosts and participants to benefit from federal or state incentives.[695] Utilities or project developers can overcome this barrier by taking advantage of such incentives. Many utilities, local governments, and others are sponsoring community solar projects.[696]

### 6.5.1.2 *Distributed Wind*

The wind industry and utility customers have benefited from federal incentives for wind projects, such as ITC. Most distributed wind projects do not use the PTC and therefore have not been as affected by the expiration of the PTC.[a] Figure 6.33 shows the trend for distributed wind in the United States.

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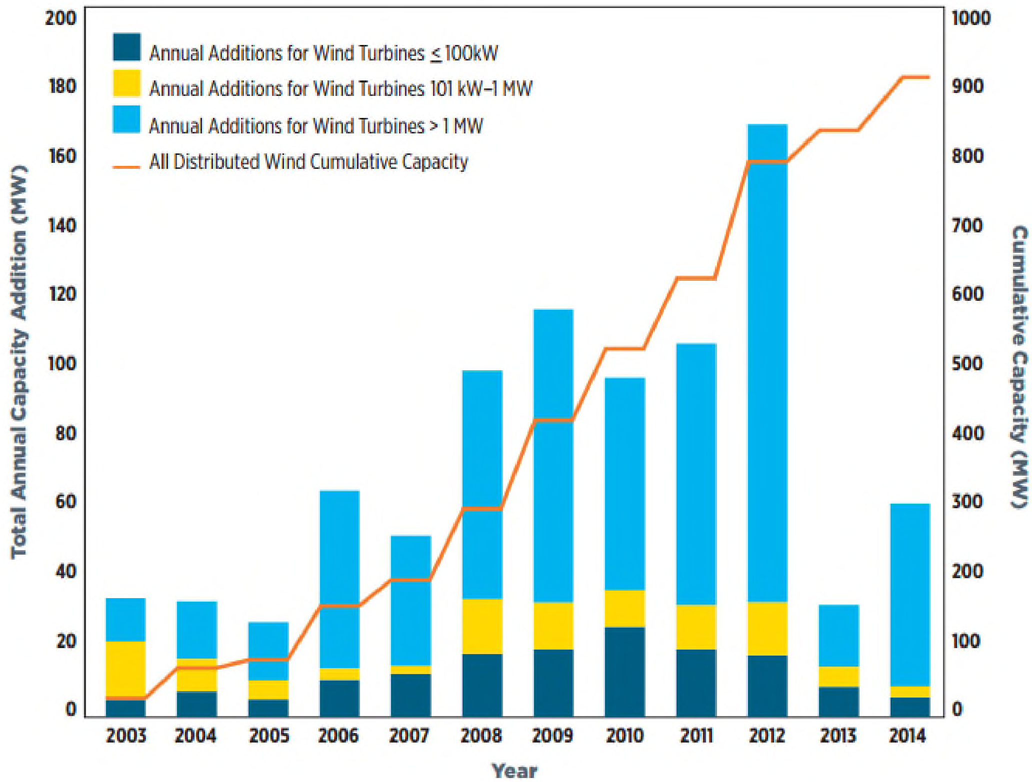
[a] The expiration of the PTC has a larger impact for wind installations greater than 1 MW.

**Figure 6.33. U.S. distributed wind capacity, 2003–2014** [697]




*Annual installations of distributed wind capacity has fallen sharply from its peak in 2012.*

The U.S. Department of Agriculture (USDA) provides agricultural producers and rural small businesses grant funding as well as loan financing to purchase or install renewable energy systems.[698] However, wind projects constitute a small and declining amount of funding ($0.4 million in 2014). In addition, several states provide incentives for distributed wind (e.g., Alaska, Iowa, New Mexico, and Oregon).

An important innovation for distributed wind is the third-party leasing model. Leasing and other third-party ownership models for distributed wind are similar to those for solar PV. The model allows a customer to host a wind turbine installed and owned by a third party on the customer's property. The customer then makes monthly payments for wind electricity produced that displaces the customer's electricity consumption. The leasing arrangement can include guaranteed performance, warranties, maintenance, and insurance. Third-party leasing models help transfer key economic and risk barriers from the customer to the lessor, including resource uncertainty, site assessment, performance uncertainty, maintenance and reliability, and avoidance of high initial cost.[699]

#### 6.5.1.3 *CHP*

Many states have targeted CHP deployment using a range of programs and policies that include: [a]

- Setting goals for developing new CHP capacity through legislation or executive order (Figure 7.36)
- Allowing efficient CHP systems to qualify under energy efficiency resource standards or renewable portfolio standards
- Providing allowance set-asides for CHP in emissions trading programs
- Recognizing CHP's emissions reductions in state air permitting policies by using output-based emissions limits
- Recognizing CHP's emissions reductions in state air quality planning
- Providing incentives for CHP through grants, loans, or tax policies

Currently, 25 states include CHP in their state energy plans, and more than 10 states offer some type of financial incentive for CHP or waste heat and power systems.[700] As of 2014, New York and California added the most new CHP sites (see Figure 7.37). Both states have had multiyear incentive programs for CHP installations.[701]

To address barriers to CHP in utility regulation, state utility commissions can:

- Establish uniform technical standards, processes, applications, and agreements based on model protocols for interconnecting CHP systems to the electric grid
- Review the electric rates that utility customers with CHP systems pay to stay connected to the grid and receive backup and supplemental power to ensure that all utility charges are based on the utility's actual costs of providing service, to evaluate fixed charges that adversely affect the economics of installing CHP capacity, and to provide incentives for customers to reliably operate and maintain CHP systems.
- Recognize CHP as a solution to needed investments in new generation and distribution system infrastructure
- Consider strategies that enable utilities to invest in CHP facilities at customers' sites while mitigating risk to other ratepayers
- Provide standard offer rates—uniform prices that all CHP systems up to a certain size will be paid for power they sell to the utility, based on actual avoided costs to the utility, recognizing that those costs vary by location, time of day, and other factors—or issue competitive solicitations to determine prices

In particular, state utility commissions can help address barriers to CHP in utility regulation by: (1) establishing uniform technical standards, processes, applications, and agreements for interconnecting CHP systems to the electric grid; (2) by reviewing the electric rates that utility customers with CHP systems pay to stay connected to the grid and receive backup and supplemental power to ensure that all utility charges are based on the utility's actual costs of providing service; and (3) providing standard offer rates—uniform prices that all CHP systems up to a certain size will be paid for power they sell to the utility, based on actual avoided costs to the utility.

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[a] SEE Action Network 2013 describes these policies and programs; also see "Policies and Resources for CHP Deployment," ACEEE, http://aceee.org/sector/state-policy/toolkit/chp, accessed November 10, 2015.

### 6.5.2 Distributed Storage

As an emerging technology, building owners and operators generally have a poor understanding of energy storage systems, how they operate, and their potential value streams.[702] In addition, storage-related policies are nascent.

High costs and the lack of clearly defined value streams are the most important barriers to the wider-scale deployment of battery storage. Rebates, tax credits, and favorable depreciation treatment can improve the economic viability of storage projects. Demand management programs that provide greater incentives for peak shaving and load shifting can encourage more investment in storage systems.

Permitting and siting barriers are an issue for larger distributed storage applications due to the size and weight of many battery types. In addition, DOE's EAC noted a lack of validated reliability and safety codes and standards.[703] States can adopt best practices from early-adoption jurisdictions—for example, New York's building fire code for Li-ion batteries.

### 6.5.3 Microgrids

Beyond those barriers that apply to the DER technologies described above, barriers to greater deployment of microgrids are primarily regulatory,[704] as existing regulatory frameworks were set up with the traditional electricity system model of centralized generation, transmission, and distribution.

For a developer, several unique barriers related to microgrids increase project risk and can make the process time-consuming, complex, and expensive:

- Utility franchise rights can lead to litigation.
- The project could be subject to public utility regulation.
- Interconnection procedures and rules governing microgrids' grid-support functions (e.g., volt/volt-ampere reactive [VAR] support) may not be well defined.

Some states are advancing microgrids by providing financial support. Connecticut issued a Microgrid Grant and Loan Program in 2013 and another solicitation in 2014 (allotting $23 million to 11 projects). California, Massachusetts, New Jersey, and New York have microgrid programs and solicitations under way.[705] For example, the New York State Energy Research and Development Authority (NYSERDA) recently funded feasibility studies for 83 microgrid proposals as part of the "NY Prize" ($8.3 million).[706] The next phase will include state assistance in engineering for selected projects, and the final phase will include state funding for construction. The total announced budget for completion is $40 million.

### 6.5.4 Demand Response

Five policy principles are contained within the QER's "Policy Framework for the Grid of the Future." One of those states that "the future grid should encourage and enable energy efficiency and demand response to cost effectively displace new and existing electric supply infrastructure, whether centralized or distributed."[707]

An *energy efficiency resource standard* (EERS) is a quantitative, long-term energy savings target for utilities that can include targets for peak load demand reduction as well as energy efficiency (see Chapter 1). In addition, state legislation or PUC regulations can establish discrete demand response goals. For example, in Arizona demand response programs are eligible for cumulative electricity sales reduction goals through 2020; California sets goals for peak demand reduction through 2020; and Ohio set peak demand reduction targets through 2018. Delaware, Maryland, Pennsylvania, Texas, and Wisconsin have all set peak demand reduction targets.[708] While interruptible load that participates in real-time energy markets cannot be counted toward these targets, the peak demand requirements in a state's energy efficiency resource standard, or the greater value of energy efficiency at peak times as demonstrated in a utility's integrated resource plan or energy efficiency plan, could provide additional incentives for efficiency measures that reduce load at peak times.

The legal and regulatory environment for demand response is highly dynamic and evolving at both the national and state levels. For example, on January 25, 2016, the U.S. Supreme Court upheld FERC's authority to regulate demand response programs in wholesale electricity markets (FERC Order 745).[709] In May 2014, the FERC order had been vacated by the U.S. Court of Appeals on the basis that the agency was encroaching on the state's exclusive legal right to regulate electricity markets. The FERC order aims to ensure that demand response providers are compensated at the same rates as generation owners. This ruling is also expected to provide a more favorable environment for demand response market growth by facilitating the participation of third parties to aggregate demand response resources.

The following are state and federal activities that are currently being implemented to help overcome barriers to demand response, described at the beginning of Section 6.5:

- Deployment of common information models and protocols such as OpenADR, Smart Energy Profile 2.0, and Green Button
- Continuing evaluation of new demand response programs and rate structures
- Making time-varying pricing more widely available, especially as the default rate design
- Customer education and engagement, such as behavior-based programs for utility customers that combine time-varying pricing with communication strategies designed to engage customers—for example, personalized energy-saving tips, immediate feedback on results, and comparisons with similar households
- Deployment of enabling technologies such as AMI
- Broadening the demand response market beyond existing programs
- New program administration and enrollment models that incorporate third-party (non-utility) aggregators

The following are recent examples of state regulatory actions that have impacted demand response:[710]

- The CPUC will require default TOU rates for residential customers in 2019 and is working with CAISO and the California Energy Commission to create a market for demand response and energy efficiency resources.[711]
- In 2014, Massachusetts ordered its electricity distribution companies to file TOU rates with CPP as the default rate design for residential customers once utility grid modernization investments are in place.[712]
- In 2015, the Michigan Public Service Commission directed DTE Electric to make TOU and dynamic peak pricing available on an opt-in basis to all customers with AMI by January 1, 2016. Similarly, Consumers Energy must make TOU available on an opt-in basis by January 1, 2017.
- Also in 2015, the New York Public Service Commission released a regulatory framework and implementation plan (Reforming the Energy Vision) to align electric utility practices and the state's regulatory framework with technologies in information management, power generation,

and distribution. A related measure in 2014 approved a $200 million Brooklyn-Queens demand management program which includes 41 MW of customer-side measures, including demand response, distributed generation, distributed energy storage, and energy efficiency, to defer cost-effectively approximately $1 billion in transmission and distribution investment.

- In June 2015, the Pennsylvania PUC set a total peak demand reduction of 425 MW for electric distribution companies by 2021, against a 2010 baseline.
- In Rhode Island, demand response is continuing to be tested in pilot programs by National Grid and will be incorporated in analysis for "non-wires alternatives"[a] to traditional utility infrastructure planning.

At higher penetration levels of wind and solar (variable) energy resources, policies and regulations that enable greater penetration of demand response in grid services markets are likely to become increasingly important:[713]

- Allowing demand response providers to participate in energy markets—In many markets, demand response aggregation for participation in energy markets is not allowed.
- Modifying telemetry and metering requirements—Telemetry and metering requirements have been set up historically for generation-side resources and may be too onerous for demand response participation in grid markets.
- Adoption of capacity markets that provide up-front payment to capacity additions that could include demand response resources—Year-ahead capacity markets with up-front payment exist in some ISO/RTO markets such as PJM, but not all markets.

Recent proposals from CAISO are highlighted here to illustrate each of these points. It recently announced plans to create a new class of grid market players, known as *distributed energy resource providers,* to serve grid markets. These could be energy service companies that aggregate many discrete DERs to bid into CAISO energy markets. CAISO has imposed constraints on the size required for bids (>500 kW to participate) as well as proposed modifications to telemetry and metering requirements that would make it easier for energy service aggregators to participate. Specifically, a DER provider participating in the ISO's wholesale energy markets will not be required to provide telemetry if they are under 10 MW in size. However, real-time visibility is required in the case of ancillary market participation.[714]

In terms of metering requirements, instead of requiring each subresource that is aggregated to have a direct metering feed to the ISO, CAISO is allowing a delegation of meter and meter data arrangements to the scheduling coordinator.[715]

Another CAISO proposal would create a demand response auction market. Under the proposal, demand response providers would receive an up-front payment for electricity reductions they promise to deliver in the coming year, providing an attractive incentive for new market entrants. Similar capacity auctions have expanded demand response markets in other parts of the country, including the large-scale capacity auction in PJM, which has supported the nation's largest demand response market. One key difference from the PJM capacity market is that the CAISO proposal would seek to enable flexible capacity—in other words, the ability to shift customer loads in time to provide better matching of load to generation supply, as well as future peak load reductions.[716]

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[a] Non-wires alternatives to distribution and transmission investments include demand response, energy efficiency, distributed generation, energy storage, volt VAR optimization, and dynamic pricing.

## 6.6 Interactions with Other Sectors

The DER sector is interconnected with all of the electricity market sectors described in this report: residential, commercial, industrial, and transportation. Distributed generation continues to grow for both residential and nonresidential buildings, and more on-site energy storage is projected in the future for all market sectors. ZNEB targets may become a greater driver for distributed generation, and providers of solar PV and storage are emphasizing the greater energy security that integrated generation and storage systems can provide. CHP is already widely deployed in the industrial sector and is a growing presence in the commercial sector as a good fit for campuses, hotels, and hospitals, among other applications.

Demand response programs are active in the residential, commercial, and industrial sectors, and time-varying pricing tariffs for electric vehicle charging are beginning to be developed. Aggregation of demand response for residential consumers is an emerging area with significant potential.

Storage is inherently crosscutting (Table 6.14). For example, in the transportation sector, growing PEV adoption increases the volume of batteries produced, contributing to cost reduction in batteries for stationary applications in the residential and commercial sectors. Further, used PEV batteries could contribute to the supply of batteries for stationary storage applications. In addition, PEV fleets enable aggregation of a collection of batteries as a storage and demand response resource.

**Table 6.14. Crosscutting Nature of Energy Storage**[717]

| Crosscutting theme description | Crosscutting technology | Sectors affected |
|---|---|---|
| **Energy storage** is important to a modernized electric grid, and also for electric vehicles, albeit with vastly different requirements. Flexible, low-cost, high round-trip-efficiency storage technologies can provide short term (frequency support) and long-term (firming, arbitrage) services to the electricity system. Alternatives to hydrocarbon fuels such as hydrogen and batteries are under investigation for electric vehicles. Fundamental research on development and manufacturing of efficient, durable, low-cost, high energy-density storage could enable transformational change across multiple sectors. | Batteries | **Transportation**, Grid, Manufacturing |
| | Hydrogen | **Fuels**, Transportation, Manufacturing, Power, Grid |
| | Thermal storage | **Power**, Grid, Buildings |
| | Flywheels | **Grid**, Transportation |
| | Pumped hydro, compressed air energy storage | **Grid**, Power |

*Storage affects all electricity market sectors (residential, commercial, industrial, and transportation) as well the electricity grid itself.*

Energy efficiency and DERs have many existing and several emerging interactions. CHP systems can offer much higher system-wide energy efficiency than grid-supplied electricity and conventional heating or steam systems. In the context of ZNEBs, building envelope construction, heating, ventilation, and air conditioning (HVAC) equipment selection, and on-site distributed generation can be optimized for least cost and design objectives. Finally, greater penetration of variable renewable sources of electricity is anticipated to drive the need for more flexible capacity on the supply side and more flexible loads on the demand side.[718] Energy efficiency will continue to be a key focus area in all sectors, and demand response programs that can provide either flexible capacity or flexible loads are expected to grow. In some cases there may be a balancing or trade-off of higher energy losses versus increased flexibility (e.g., pre-cooling a building or pre-heating water can increase energy consumption but reduce peak load and improve system flexibility). To ensure a robust and cost-effective future electricity system operation meeting all service and environmental requirements will require dynamic controls, advanced sensors, and communication systems with sophisticated control software.

## 6.7 Research Gaps

Fundamental research questions for demand response, distributed generation and distributed storage include the following:

- What changes in policies and regulations, and what types of market designs, are needed to integrate and optimize the use of these DERs in the electric system?
- What frameworks, methods, processes, and tools are needed?
- What are these resources worth, and how should valuation be determined?

Another policy question is how to ensure access to DERs in low-income communities, including programs that provide enabling technology and financial incentives for demand response.

Three other key research themes are described below.

### 6.7.1 Modeling and Simulation

DOE's 2015 Quadrennial Technology Review (QTR 2015) highlights the need to develop high-fidelity planning models, tools, simulators, and a common framework for modeling, especially based on probabilistic models that can account for uncertainties in demand-side and supply-side resources, technology, markets, and policies. QTR 2015 further points toward the need to perform scenario analysis on potential future energy systems that are radically different from today's systems due to significant uptake of architecture-altering technologies—for example, decentralized electricity systems with high adoption of distributed generation and storage. This may include more detailed and integrated modeling of the distribution system and addressing the following questions:

- What is the optimal locational placement of DERs within the distribution system?
- What are the limits and limitations of DER penetration on the existing distribution system?
- What are the benefits of community solar and storage systems?
- What strategies and approaches lead to least-cost implementation for distribution upgrades and replacements for conventional utility investments?

In addition, climate change is widening the temperature probability distribution toward more frequent and intense heat events, as well as increasing the mean temperature.[719] This could translate into some regions having a higher summer peak load than what is currently modeled in existing projections for peak load. That raises additional research questions. For example, how should predictions for climate change be taken into account in projecting future electricity demand and the potential role of demand response, distributed generation, and distributed storage in meeting those changing demands cost-effectively?

### 6.7.2 Impacts of Higher DER Adoption on the Electric System and Stakeholders

Developments in DER technology and IT are enabling electricity service with much greater degrees of freedom for both supply and demand. This offers multiple value streams (e.g., energy, capacity, reactive power, frequency support, deferred utility capital expenditures, energy security, and avoided emissions). At the same time, regulators must ensure the safety and reliability of the electricity system and balance the interests of regulated electric utilities, competitive markets, customers, and the public interest.

Key research questions in this area include the following:

- What are the implications of various regulatory mechanisms for DERs on safety and reliability of the electric system?
- What are the financial impacts of high levels of DERs on electric utilities and utility customers? What data, methods, and tools are needed to characterize costs and benefits and optimize deployment strategies, and what changes in ratemaking and regulation are needed to mitigate financial impacts on utility shareholders and customers?
- What tariff designs can appropriately compensate DERs for multiple value streams while maintaining principles of rate design (e.g., economic efficiency, equity/fairness, and customer satisfaction)? What tariff designs appropriately charge DER customers for the services they need from the electric grid?
- Who controls the various streams of (big) data and manages data-sharing among third parties?

### 6.7.3 Policies and Regulations for Distributed Storage

Distributed storage, including adoption of PEVs with battery storage, could be a transformative technology.[720] Key policy questions include:

- What policies and regulations would facilitate pairing distributed storage with distributed generation or demand response to provide value to utility customers, utility systems, and society?
- What policies, regulations, and protocols would best help to integrate mobile distributed storage (i.e., PEVs) into the distribution system to facilitate electrification of the transportation sector?
- Beyond mandatory energy storage requirements, what policies, regulations, and programs would remove barriers to deployment of cost-effective energy storage?

# 7 Appendices

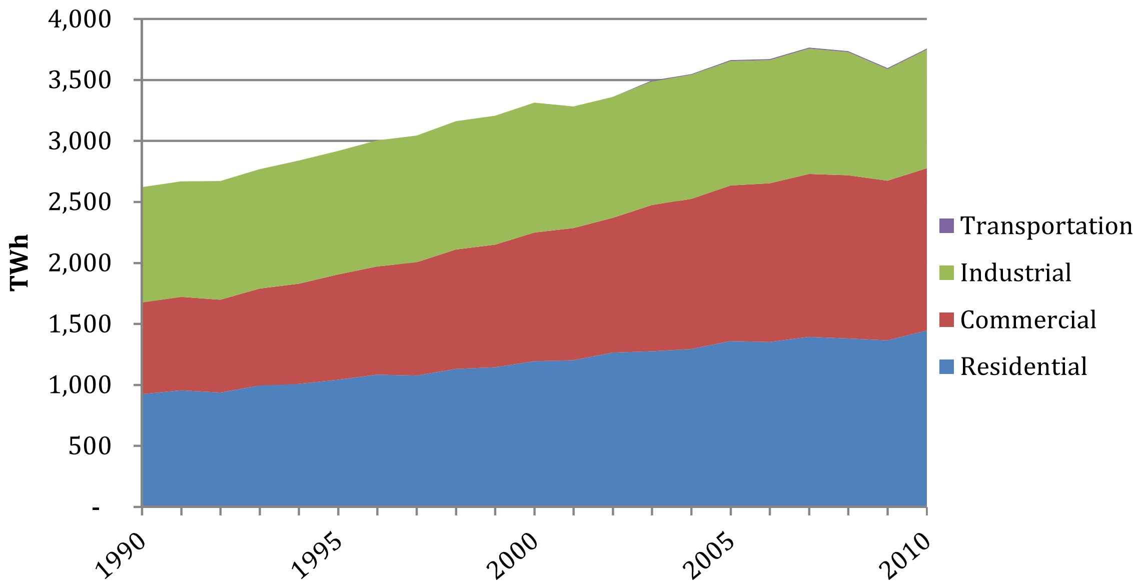
## 7.1 Summary of Electric Use and Trends Appendix

*Historical consumption and electricity prices*

From 1990 to 2010, national electricity consumption (sales) grew 38%, led by an increase in commercial sector sales, which increased by 77% during this period (from 751 TWh to 1,330 TWh, increasing the sector's share of electricity sales from 28% to 35%).

Residential sector sales also grew significantly, by 56% during this period (from 924 TWh in 1990 to 1,446 TWh in 2010), increasing the sector's share of the total from 35% to 39%. The industrial sector tempered overall growth in electricity sales, increasing by just 3% (from 946 TWh to 971 TWh), representing a decrease in its share of overall sales from 36% to 26%. See Figure 7.1.

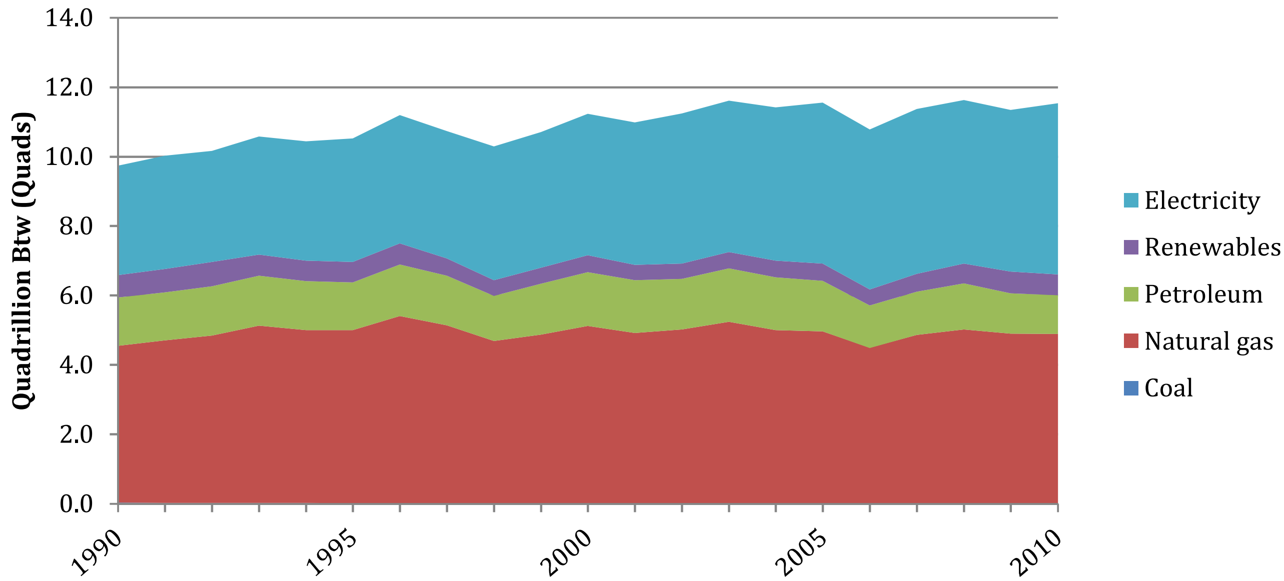
**Figure 7.1. Historical electricity consumption (sales) by market sector, 1990 to 2010**[721]




*Total electricity sales in all sectors grew 38% from 1990 to 2010 (from 2,712 TWh to 3,754 TWh). The transportation sector used a tiny fraction of the electricity consumed throughout the period (purple line at top of graph). Natural gas and petroleum utilized for feedstocks are included in totals. Note: the data set includes an 'Other' category from 1990 to 2002. In 2003, the sales for the 'Other' category were incorporated into the categories listed above. 'Other' is not included in Figure 7.1 but total numbers reported do include the 'Other' category.*

Electricity use in the residential sector grew by 56% from 1990 to 2010, from 3.2 quads (32% of total residential energy consumption) to 4.9 quads (43% of total residential energy consumption), respectively. See Figure 7.2.

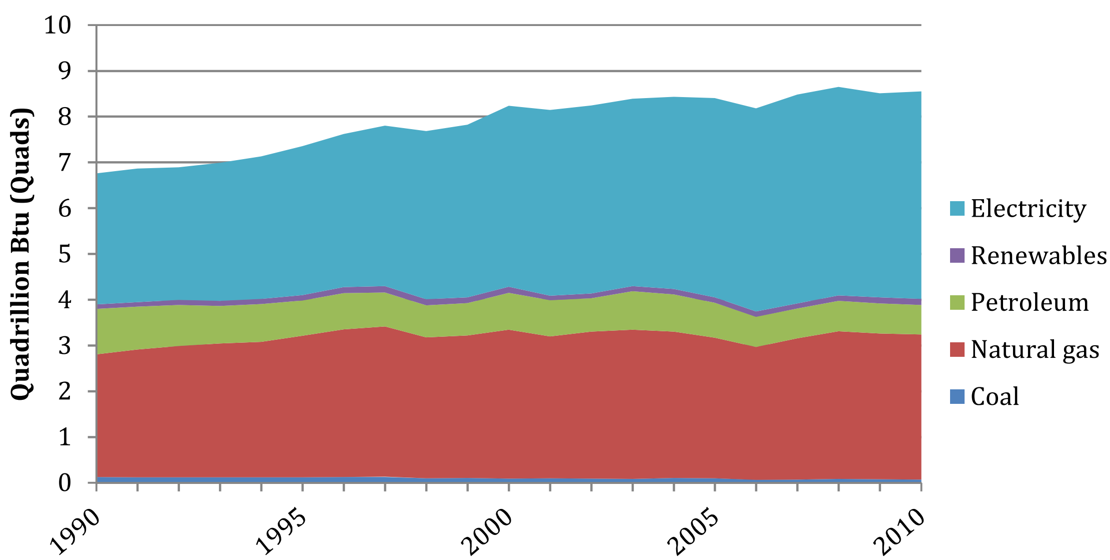
**Figure 7.2. Residential energy consumption by energy source, 1990 to 2010**[722]




*Use of electricity in the residential sector increased by 56% between 1990 and 2010, from 3.2 quads to 4.9 quads. Electricity's share of residential energy consumption increased from 32% in 1990 to 43% in 2010. Electricity line losses are not included.*

From 1990 to 2010, electricity use in the commercial sector grew 59%, from 2.9 quads to 4.5 quads. In 1990, electricity accounted for 42% of commercial energy consumption; in 2010, it accounted for 53%. See Figure 7.3.

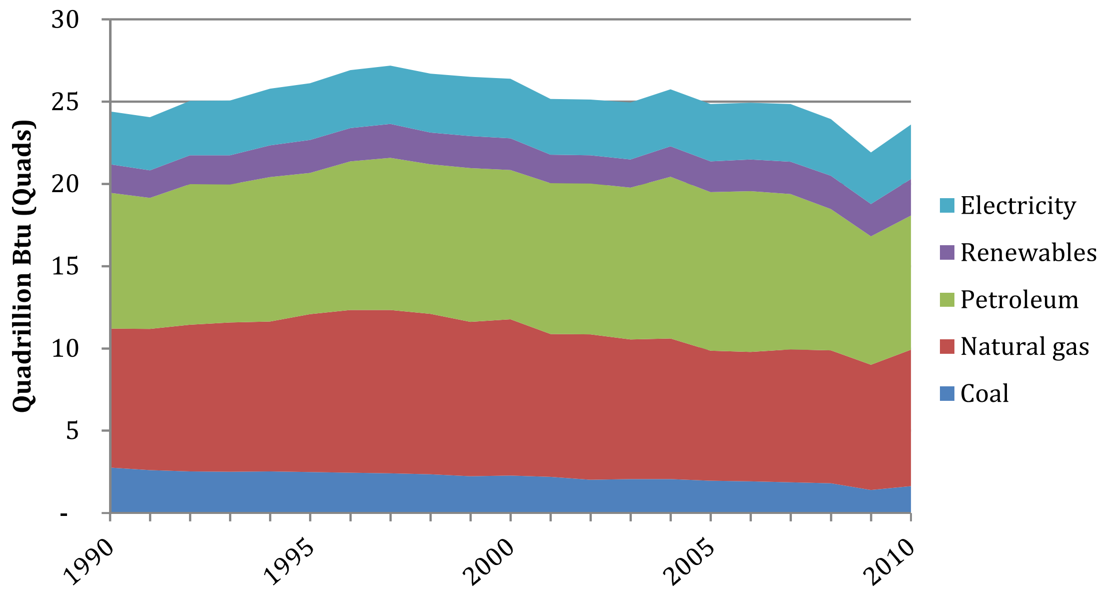
**Figure 7.3. Commercial sector energy consumption by energy source, 1990 to 2010**[723]




*Electricity use in the commercial sector increased by 59% from 1990 to 2010, from 2.9 quads to 4.5 quads. During this period, electricity increased its relative share of use compared to other fuels from 42% to 53%. Electricity line losses are not included.*

Between 1990 and 2010, retail electricity purchases in the industrial sector increased by 3% (from 3.2 to 3.3 quads), although retail electricity's share of industrial sector energy consumption rose slightly from 13% to 14%. See Figure 7.4.

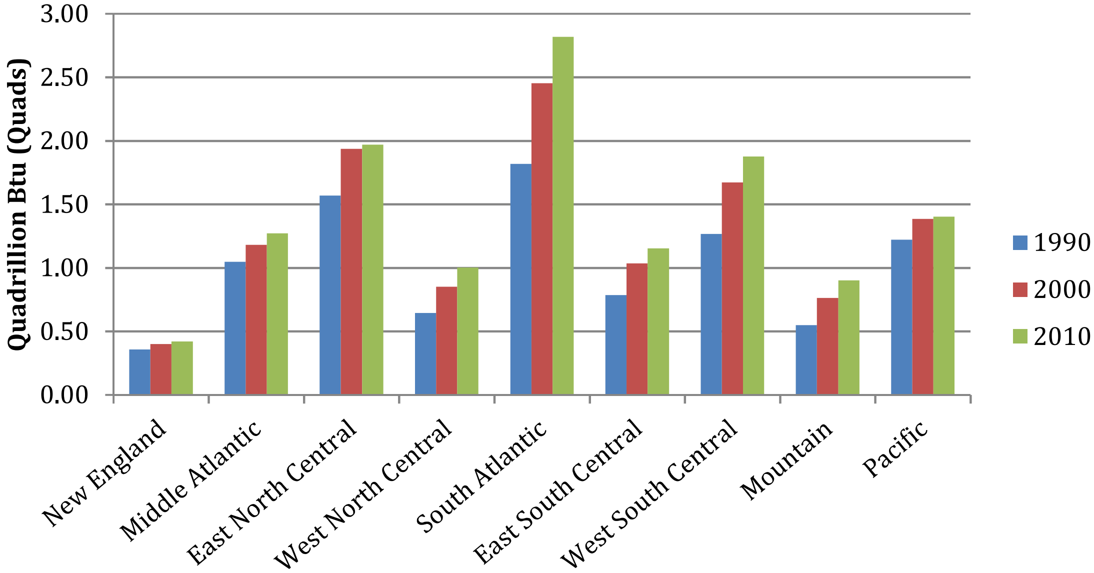
**Figure 7.4. Industrial sector energy consumption by energy source, 1990 to 2010**[724]




*Use of electricity in the industrial sector increased by 3% between 1990 and 2010, from 3.2 quads to 3.3 quads. Its share of industrial energy consumption, however, rose slightly, from 13% to 14%. Electricity line losses are not included. Data do not include on-site electricity generation, except for CHP fuels. Natural gas and petroleum used for feedstocks are included.*

Between 1990 and 2010, the South Atlantic Census division consumed the most electricity, using 1.8 quads in 1990. The New England Census division was the lowest-consuming division, using just 0.36 quads in 1990. In 2010, these two were again the highest and lowest electricity-consuming Census divisions, respectively, with the South Atlantic Census division using 2.8 quads and New England Census division using 0.42 quads. The Census division with the fastest growth in usage was the Mountain Census division, increasing consumption by 64%, from 0.6 quads in 1990 to 0.9 quads in 2010. The slowest Census division for growth in electricity consumption was the Pacific Census division, increasing consumption by 15% over the period, from 1.2 quads in 1990 to 1.4 quads in 2010. See Figure 7.5.

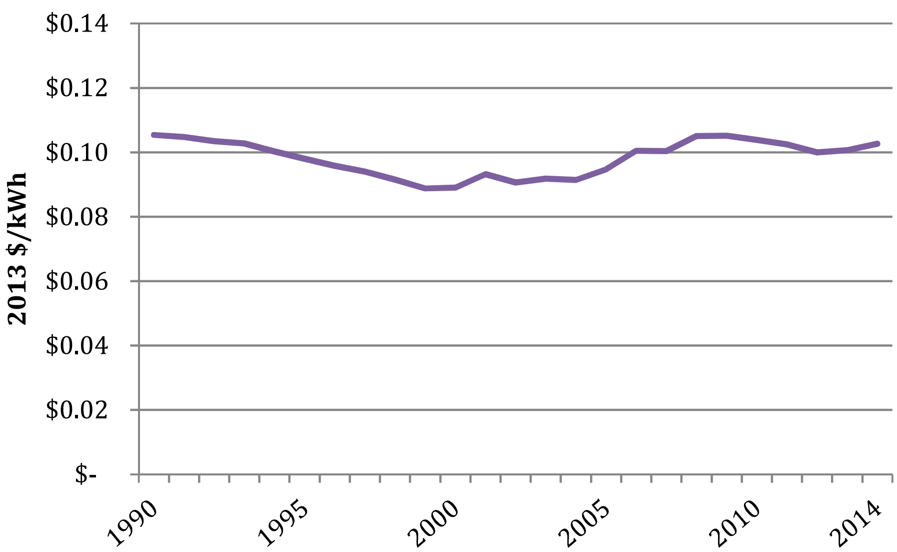
**Figure 7.5. Delivered electricity consumption by region, 1990 to 2010**[725]




*Between 1990 and 2010, electricity consumption grew in every region. The fastest growth took place in the Mountain region (growing 64% from 0.6 quads in 1990 to 0.9 quads in 2010), and the slowest growth took place in the Pacific region (growing 15%, from 1.2 quads in 1990 to 1.4 quads in 2010). New England had the lowest consumption overall (just 0.36 quads in 1990 and 0.42 quads in 2010), and the South Atlantic had the highest overall consumption in both 1990 and 2010 (1.8 quads and 2.8 quads, respectively).*

Between 1990 and 2014, average electricity prices in the United States decreased 2.5% in real terms (constant 2013 dollars), from 10.5 cents/kilowatt-hour (kWh) to 10.3 cents/kWh. Prices fell from 1990 to 2000, and then began to rise moderately from 2001. See Figure 7.6.

**Figure 7.6. Average U.S. electricity prices, 1990 to 2014**[726]




*The average electricity price in the United States decreased 2.5% in real terms (constant 2013 dollars) during this period, from 10.5 cents/kWh to 10.3 cents/kWh. Average electricity prices include the transportation sector.*

## 7.2 Summary of Policies, Regulations, and Programs Appendix

This section summarizes crosscutting policies, regulations, and programs put in place by federal, state, and local governments and private sector activities that provide support for energy efficiency and distributed energy resources (DERs) as well as transportation electrification initiatives. Policies, regulations, and programs constitute pathways made up of interdependent actions in the public and private sectors that are intended to result in measurable electricity savings streams and other benefits, such as avoided air emissions, over time. The policies, regulations, and programs that make up a pathway are overseen by one or more responsible entities, such as a federal, state (e.g., state energy office or public utility commission), or local (e.g., municipal utility board) entity, occur in a specific timing sequence, and can be supported for success through infrastructure elements such as marketing strategies and workforce development.[a]

Policies, regulations, and programs alone do not necessarily result in the intended benefits. It is the resulting projects (activities involving one or more measures or actions implemented at a single facility or site), and their ongoing maintenance and operation, that result in energy and demand savings and other benefits. Savings and benefits are thus typically quantified at the project and program levels (see Appendix for EM&V).

Policies, regulations, and programs can focus on one strategy (e.g., energy efficiency or demand response), one technology (e.g., motors or rooftop solar), or one market sector (e.g., residential or commercial). More often, they cross over strategies, technologies, and sectors. This chapter organizes policies, regulations, and programs into 10 crosscutting categories for energy efficiency, transportation electrification, and DERs. In addition to these crosscutting categories, Chapters 2 through 6 describe policies, regulations, and programs that apply exclusively or primarily to the residential, commercial, industrial, or transportation sector, or to DERs.[b]

### 7.2.1 Resource Standards

State renewable portfolio standards (RPSs) are a major driver of renewable energy deployment. An RPS requires utilities and other electricity suppliers to purchase or generate a targeted amount of qualifying renewable energy or capacity by specified dates. States have been active in adopting or increasing RPSs, and 29 states now have them.[727] The requirement may apply only to investor-owned utilities, but many states also include municipalities and electric cooperatives, though their requirements may be set lower. Some state RPS policies include “set-asides” or “carve-outs” for particular types of distributed generation, addressing all or a subset of technologies such as solar photovoltaic (PV) and combined heat and power (CHP) systems. Figure 7.7 shows states whose RPS policies include distributed generation “set-asides,” multipliers that assign qualifying distributed generation with higher levels of renewable energy credits, or both. Figure 7.8 shows states that set goals for developing new CHP capacity through

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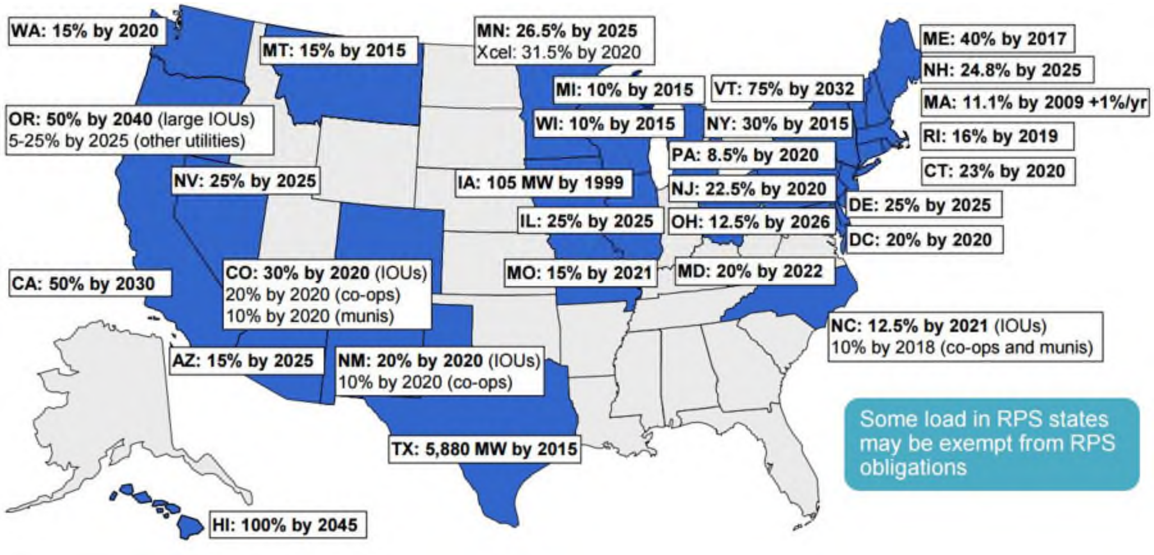
[a] For more information about states’ best practices in the design and implementation of policies, see EPA’s *Energy-Environment Guide to Action: State Policies and Best Practices for Advancing Energy Efficiency, Renewable Energy, and Combined Heat and Power*, 2015, at https://www.epa.gov/statelocalclimate/energy-and-environment-guide-action. Also see L. Schwartz, G. Leventis, S. R. Schiller, and E. Fadrhonc, *State and Local Energy Efficiency Action Network (SEE Action) Guide for States: Energy Efficiency as a Least-Cost Strategy to Reduce Greenhouse Gases and Air Pollution and Meet Energy Needs in the Power Sector,* U.S. Department of Energy, February 2016, DOE/EERE 1335, https://www4.eere.energy.gov/seeaction/EEpathways.

[b] For example, a financial incentive for rooftop solar or a mandate for energy storage will encourage just those specific technologies and thus are not particularly crosscutting.

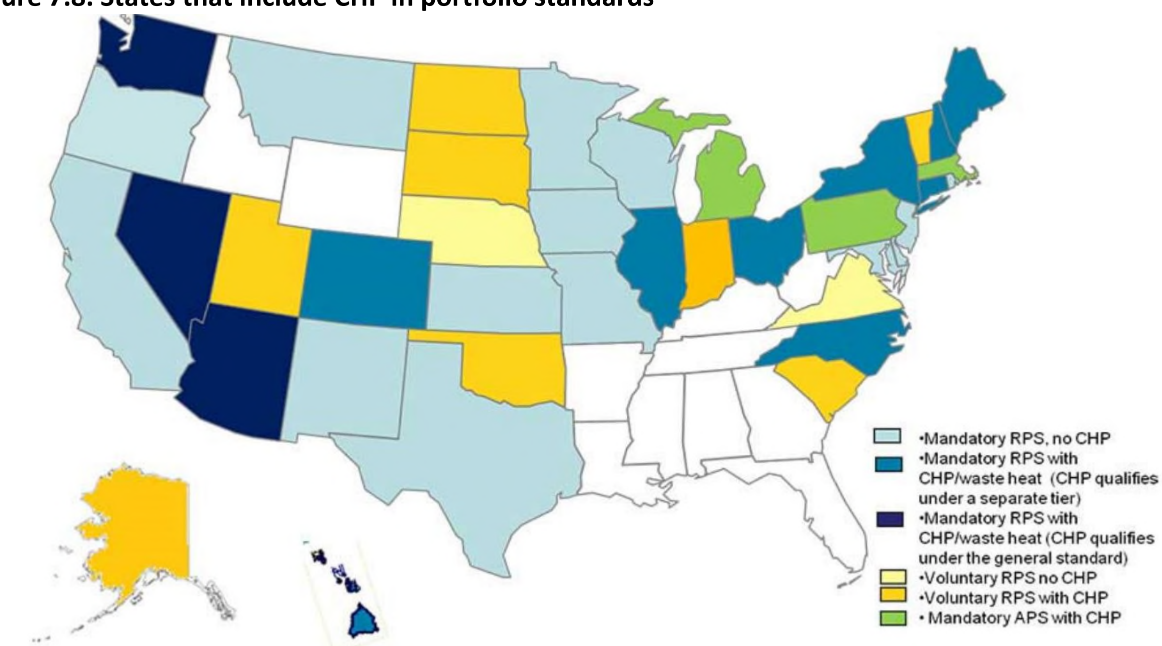
legislation or executive order. Furthermore, 25 states include CHP in their state energy plans. Many states offer financial incentives for CHP systems.

**Figure 7.7. State RPSs[728] [a]**




*RPSs apply to over half of retail electricity sales and are in force in 29 states plus Washington, D.C.*

**Figure 7.8. States that include CHP in portfolio standards[729]**

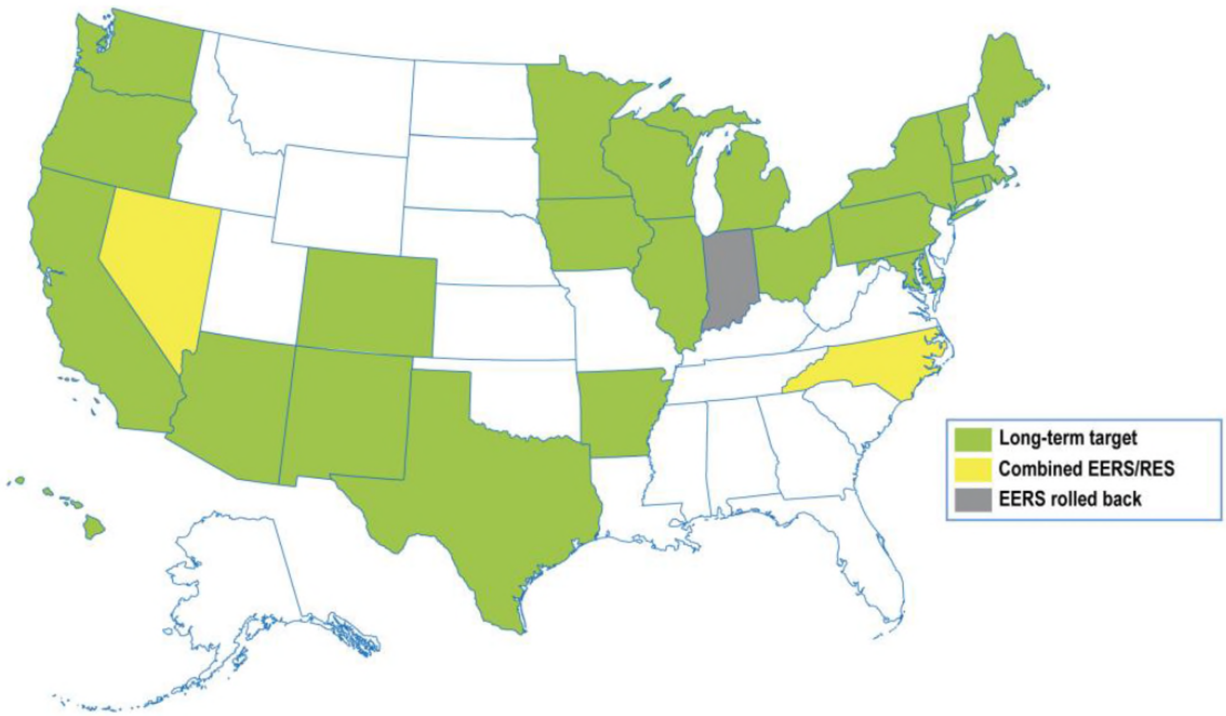



*Twenty states specifically include CHP as an eligible resource in their RPSs.*

[a] Notes: Estimated retail sales subject to RPS obligations account for any applicable exemptions. In addition to the RPS policies shown on this map, voluntary renewable energy goals exist in a number of U.S. states, and both mandatory RPS policies and non-binding goals exist among U.S. territories (American Samoa, Guam, Puerto Rico, U.S. Virgin Islands).

The primary type of resource standard for energy efficiency is what is generically referred to as an *energy efficiency resource standard* (EERS). About half of U.S. states have some form of an EERS with binding annual energy savings targets, typically specified as a set percentage of electricity sales, percentage of projected growth of electricity sales, or in energy (kWh) or capacity (kilowatt [kW]) units.[730] States have taken a variety of approaches to setting targets, including enacting legislation to enact formal standards, public utility commissions setting long-term energy savings targets that are tailored to each utility, or incorporating energy efficiency as an eligible resource in a clean energy standard[731] or an RPS. Figure 7.9 shows which states have adopted various forms of an EERS.

**Figure 7.9. States with an EERS[732]**



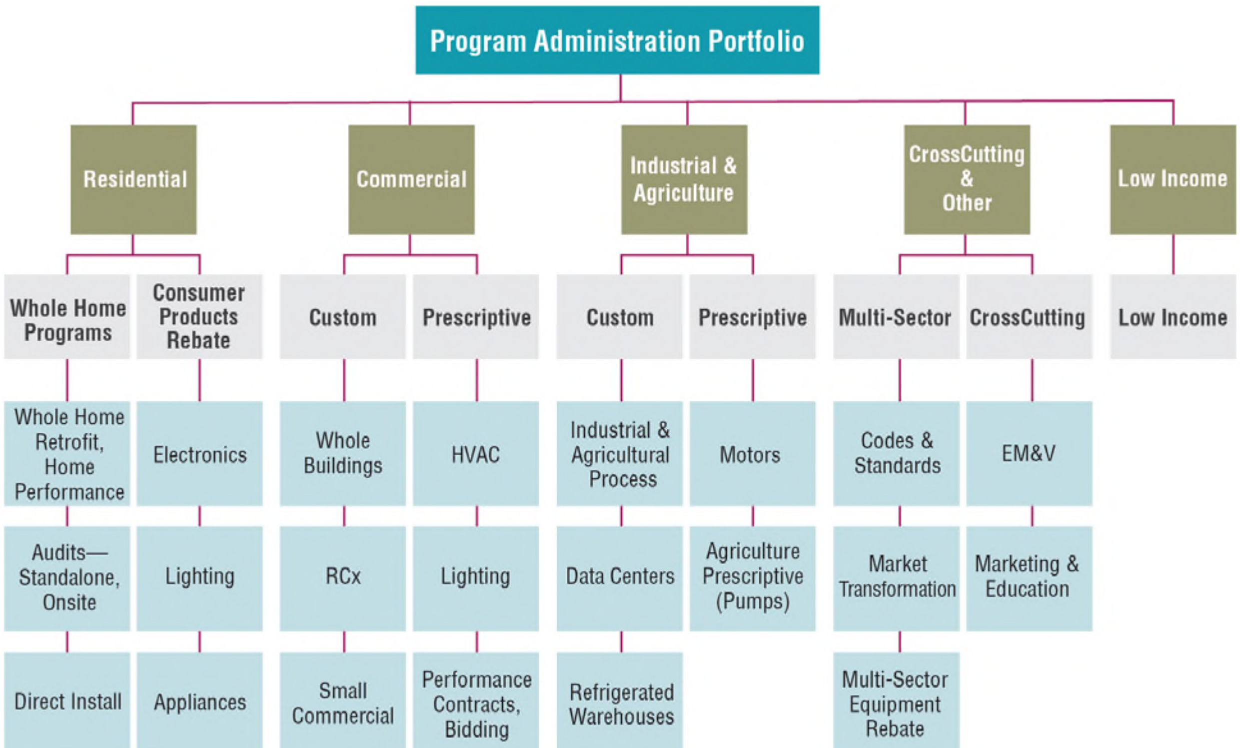

*Nearly half of all states have adopted various forms of an EERS.*

Another type of standard that affects energy efficiency and distributed energy resources (DERs), as well as transportation electrification, is air pollution regulation. Energy efficiency and renewable energy projects have the advantage of reducing all types of power plant–related emissions simultaneously by avoiding the need to generate electricity in the first place. Under the federal Clean Air Act, criteria pollutants are regulated through the development of National Ambient Air Quality Standards (NAAQS), which set permissible ambient air concentrations on a pollutant-by-pollutant basis. States develop pollutant-specific State Implementation Plans showing how they will meet these standards. The U.S. Environmental Protection Agency (EPA) encourages state and local governments to use energy efficiency and renewable resources as a way to help meet the NAAQS. In 2012, EPA released a roadmap for incorporating efficiency and renewable energy programs and policies in State Implementation Plans.[733] In addition, EPA's Clean Power Plan provides for demand-side energy efficiency and renewable resources as a carbon dioxide ($CO_2$) emissions mitigation strategy for electricity generating units.[734] Another version of the generic category of resource standards could also be *outcome-based performance standards*—such as those being considered in New York as part of their Reforming the Energy Vision Initiative.[735]

### 7.2.2 Utility Ratepayer-Funded Programs

Utility ratepayer-funded programs promote or directly support the uptake of cost-effective energy efficiency, demand response, distributed generation (e.g., rooftop solar and CHP), and electricity storage. Financial incentives to consumers or third parties to reduce or offset the incremental cost of energy efficiency and DERs are a common mechanism used in these programs, with energy efficiency the most common application for programs funded by utility customers. Figure 7.10 is a simplified categorization of common types of energy efficiency programs funded by utility customers. Informational intervention programs, direct installation, workforce education and training, emerging technology support, and market transformation[a] are other strategies used, primarily for energy efficiency investments.

**Figure 7.10. Selected program types in the LBNL program typology[736]**




*Numerous types of programs serve the residential, commercial, and industrial sectors and offer a wide variety of measures. Programs typically generate a significant portion of a state's electricity savings. Net savings from these programs corresponded to 0.69% of U.S. retail electricity sales in 2014, with some states achieving savings over 2%.*[b] [737]

However, some states also provide incentives for distributed generation through their utility ratepayer-funded programs—particularly PV systems and other forms of self-generation, as well as (in a few states) energy storage. For example, the California Self-Generation Incentive Program provides incentives to support existing, new, and emerging DERs. The program provides rebates for qualifying distributed energy systems installed on the customer's side of the utility meter. Qualifying technologies

[a] See discussion of market transformation in Chapter 1.

[b] These are new electricity savings with free rider and spillover effects taken into account. The median savings value for states was 0.56% of retail electricity sales.

include wind turbines, waste heat-to-power technologies, pressure reduction turbines, internal combustion engines, microturbines, gas turbines, fuel cells, and advanced energy storage systems.738 About 40 states739 also support research, development, and demonstration (RD&D) activities for energy efficiency and DERs, coordinated by state agencies, public-private partnerships, and universities, often using utility ratepayer funds.

### 7.2.3 Building Energy Codes

State and local building energy codes reduce electricity use and demand in new buildings and buildings undergoing major renovations by establishing minimum energy efficiency standards for building design, construction, and remodeling. Building energy codes cover commercial and residential buildings; some types of industrial and agricultural buildings are captured under commercial building codes. While the primary focus for most energy codes is efficiency, recent versions of the energy code in California require that certain new and retrofitted equipment and systems be ready for two-way, automated utility-to-customer energy management—e.g., ready for use with demand response programs.[740] [741] Policy and regulatory efforts involve code development adoption, updating (if a jurisdiction chooses to do so), and compliance. In addition, to support code compliance, some states offer education and technical assistance programs for local building officials who enforce codes, as well as building owners, architects, and engineers. See Chapters 2 and 3 in this report for more information.

### 7.2.4 Appliance and Equipment Standards

Appliance and equipment standards specify the minimum efficiency levels of specific products. National standards apply to more than 60 categories of appliances and equipment sold in the United States.[742] For products that are not subject to existing national standards and DOE regulation,[a] states may adopt their own product standards for sales within their borders. Within the last decade, states have set standards for products such as televisions, battery chargers, and vending machines, often taking into consideration product efficiency criteria established by the federal ENERGY STAR program. Historically, California has taken the lead in setting state standards, with several other states following suit. Since 2001, Arizona, Connecticut, Maryland, Massachusetts, New York, Oregon, Rhode Island, and Washington have each passed several rounds of state standards.[743] [744]

### 7.2.5 Financial Incentives and Tax Policies

Many federal, state, and local policies, regulations, and programs provide for financial incentives for energy efficiency and DERs, such as tax credits, rebates, grants, and low-cost financing. Federal tax incentives include:[745]

- Residential Renewable Energy Tax Credit (Personal Tax Credit)
- Residential Energy Efficiency Tax Credit (Personal Tax Credit)
- Energy-Efficient New Homes Tax Credit for Home Builders (Corporate Tax Credit)
- Energy Efficient New and Existing Commercial Buildings Tax Deduction
- Business Energy Investment Tax Credit (ITC[b]; Corporate Tax Credit)
- Renewable Electricity Production Tax Credit (PTC; Corporate Tax Credit)

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[a] Federal regulation becomes the law and supersedes any state regulation. Once the federal government establishes an energy efficiency standard, no state may have a regulation different from the federal standard.

[b] Eligible technologies: solar water heat, solar space heat, geothermal electric, solar thermal electric, solar thermal process heat, solar PV, wind (all), geothermal heat pumps, municipal solid waste, CHP, fuel cells using non-renewable fuels, tidal, wind (small), geothermal direct-use, fuel cells using renewable fuels, and microturbines.

In addition, a number of states offer tax credits for energy efficiency, renewable resources, and transportation electrification (Table 7.1).

**Table 7.1. Energy Tax Policies by State**[746]

| | Personal Tax Credit | Personal Tax Deduction | Property Tax Incentive | Sales Tax Incentive | Corporate Tax Credit | Corporate Tax Deduction | Corporate Tax Exemption |
|---|---|---|---|---|---|---|---|
| AK | | | X | | | | |
| AL | | X | | | | | |
| AR | | | | | | | |
| AZ | X | X | X | X | X | | |
| CA | | | X | X | | | |
| CO | | | X | X | X | | |
| CT | | | X | X | | | |
| DC | | | X | | | | |
| DE | | | | | | | |
| FL | | | X | X | X | | |
| GA | | | | X | | | |
| HI | X | | X | | X | | |
| IA | X | | X | X | X | | X |
| ID | | X | X | | | | |
| IL | | | X | X | | | |
| IN | | X | X | X | | | |
| KS | | | X | | | | |
| KY | X | | | X | X | | |
| LA | X | | X | | X | | |
| MA | X | | X | X | | X | X |
| MD | X | | X | X | X | | |
| ME | | | | | | | |
| MI | | | X | | | | |
| MN | | | X | X | | | |
| MO | X | X | X | X | X | | |
| MS | | | | | | | |
| MT | X | | X | | X | X | |
| NC | X | | X | | X | | |
| ND | X | | X | X | X | | |
| NE | X | | X | X | X | | |
| NH | | | X | | | | |
| NJ | | | X | X | | | |
| NM | X | | X | X | X | | |
| NV | | | X | X | | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| NY | X | | X | X | X | | |
| OH | | | X | X | | | |
| OK | X | | X | | X | | |
| OR | X | | X | | X | | |
| PA | | | X | | | | |
| RI | | | X | X | | | |
| SC | X | | | X | X | | |
| SD | | | X | X | | | |
| TN | | | X | X | X | | |
| TX | | | X | X | | X | |
| UT | X | | | X | X | | |
| VA | | X | X | X | | | |
| VT | X | | X | X | | | |
| WA | | | | X | | | |
| WI | X | | X | X | X | | |
| WV | | | X | | | | X |
| WY | | | | | | | |

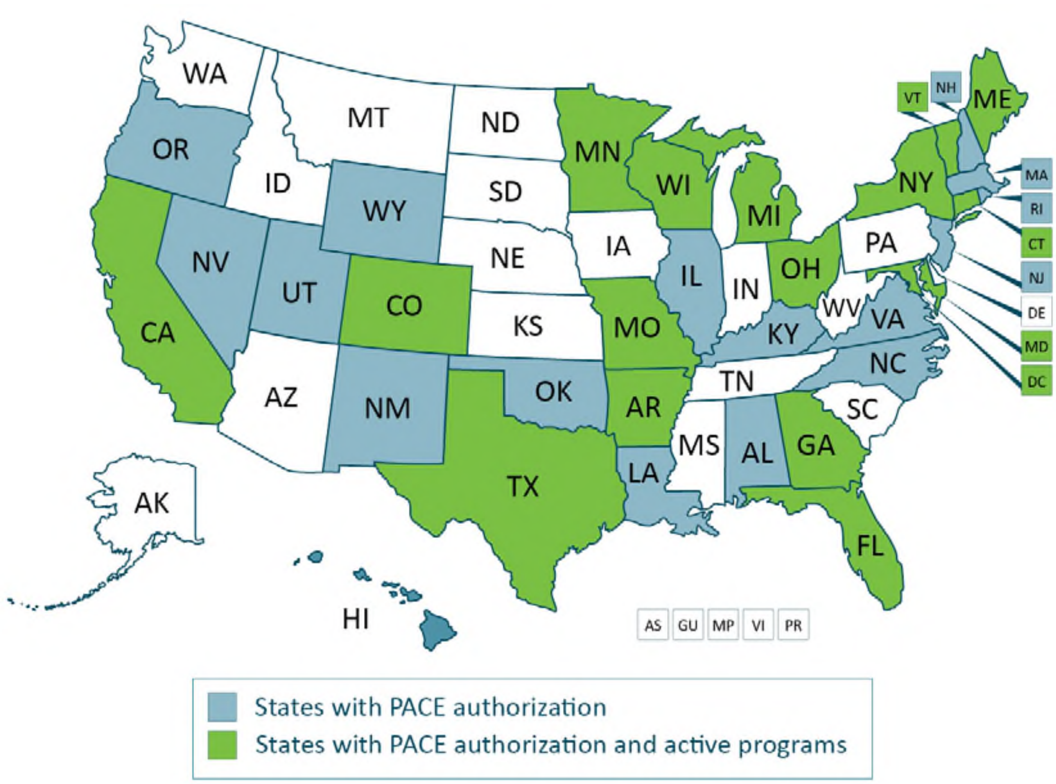
*Blue: State policies apply to energy efficiency only.*
*Yellow: State policies apply to renewable energy only.*
*Green: State policies apply to both energy efficiency and renewable energy, or the state has policies that apply to energy efficiency and, separately, renewable energy.*

Access to low-cost financing can support energy efficiency and DERs in all market segments. Financing options facilitated by the public sector include using state or local bond funds to finance energy efficiency, DER, and transportation electrification projects in both the public and private sectors. Both Connecticut and New York have established Green Banks—stand-alone, quasi-public entities that attract private capital for energy efficiency and renewable energy projects. Green Banks typically are capitalized initially with state capital funds, general obligation bonds, or utility ratepayer funds and seek to attract large amounts of private capital with that seed funding.

In addition, property-assessed clean energy (PACE) programs can finance energy efficiency improvements and distributed generation in the residential and commercial sectors with financing that property owners pay off over time through their property tax bill or possibly another form of assessment. This is made possible through an assessment on the property that can remain with the property if sold. Typically, PACE is state-authorized, and implementation and administration is left to local jurisdictions that wish to implement a program. In the 31 states or districts where PACE-enabling legislation is in place, municipalities may use special assessments to finance energy efficiency, renewable energy, and other improvements on private property. Multiple municipalities have completed PACE projects, including Toledo, Ohio; several cities in Connecticut; several cities in Michigan; several jurisdictions in California, including the Western Riverside Council of Governments; several cities in Florida; several cities in Utah; several cities in New York; several cities in Missouri; and Milwaukee, Wisconsin.[747]

Figure 7.11 indicates states with PACE-enabling legislation. The Federal Housing Finance Agency[a] has raised issues concerning possible residential PACE-related risks to lenders and secondary market entities. In response, in August 2015[748], the Federal Housing Agency (FHA) announced anticipated guidelines that will support borrowers seeking to make energy-efficient improvements to their homes, including guidance that will allow borrowers to use single family FHA financing for properties with existing PACE loans that meet certain conditions. As of April 2016, those FHA guidelines have not been released. Table 7.2. shows the broad variety of financing programs each state offers.

**Figure 7.11. States with PACE-enabling legislation[749]**




*More than half of states have passed legislation to facilitate the implementation of PACE loan programs; nearly half of those have active PACE programs.*

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[a] An independent, federal regulatory agency that oversees vital components of the secondary mortgage market, including Fannie Mae, Freddie Mac, and the Federal Home Loan Banks. See "Federal Housing Finance Agency," FHFA (Federal Housing Finance Agency), accessed March 21, 2016, http://www.fhfa.gov.

**Table 7.2. Financing Programs by State**[750]

| | Residential PACE | Commercial PACE | Utility Financing Program | On-Bill Program | State Energy Office Revolving Loan Fund |
|---|---|---|---|---|---|
| AL | | | X | X | X |
| AK | | | | | X |
| AZ | | | X | | |
| AR | | X | X | X | X |
| CA | X | X | X | X | X |
| CO | | X | X | X | X |
| CT | | X | X | X | X |
| DE | | | | | X |
| DC | | X | | | |
| FL | X | X | X | X | X |
| GA | | X | X | X | X |
| HI | | | | X | X |
| ID | | | X | | X |
| IL | | X | | X | X |
| | | | | | |
| IN | | | | | |
| IA | | | X | X | X |
| KS | | | | X | X |
| KY | | X | X | X | X |
| LA | | X | | | X |
| ME | | | | X | X |
| MD | | X | | X | X |
| MA | | | X | X | X |
| MI | | X | | X | X |
| MN | | X | X | | X |
| MS | | | X | X | |
| MO | X | X | X | | X |
| MT | | | | | X |
| NV | | | | | X |
| NH | | X | X | X | X |
| NJ | X | X | | X | X |
| NM | | X | | X | X |
| NY | | X | | X | X |
| NC | | | X | X | X |
| ND | | | X | | |
| OH | | X | | X | X |
| OK | | | X | X | X |

| | | | | | |
|---|---|---|---|---|---|
| OR | | X | X | X | X |
| PA | | | X | | X |
| RI | | | X | X | |
| SC | | | X | X | X |
| SD | | | X | | X |
| TN | | | | X | X |
| TX | | X | X | X | X |
| UT | | X | | | X |
| VT | X | | X | | X |
| VA | | X | | X | X |
| WA | | | X | X | X |
| WV | | | | | |
| WI | | X | X | X | X |
| WY | | | | | |

*Definitions used in this table:*

- *Residential and commercial Property Assessed Clean Energy (PACE) financing typically involves a transaction in which a municipality adds an assessment or charge to a property owner's property tax bill as a means to pay back an energy efficiency loan that was made to the property owner.*
- *Utility financing programs include programs administered by a utility (or a third-party administrator) that use funds provided by utility customers (or other sources) either to capitalize loans, provide credit enhancements, or buy down interest rates to customers, and which are repaid off the utility bill.*
- *On-bill programs refer to any offerings in which financing for energy efficiency is paid back on the borrower's utility bill.*
- *State Energy Office Revolving Loan Funds (RLF) include programs in which loans are made to end users for eligible efficiency measures and the capital of the RLF is replenished through repayments of those loans by borrowers.*

### 7.2.6 Federal and State Lead-by-Example Programs

The federal government and states have established a wide range of policies, regulations, and programs that affect private and public sector adoption of energy efficiency, DERs, and transportation electrification. With respect to their own facilities, government entities can implement improvements that reduce electricity consumption and demand, and thus lead by example. These improvements directly contribute to energy and cost savings, as well as other benefits, and demonstrate successful policies and programs for others to consider. An example federal program is the Federal Energy Management

*Federal Policies, Regulations, and Programs*

The federal government implements a wide range of activities to support energy efficiency and DERs. Examples include research programs (e.g., ARPA-E), appliance and equipment standards, model building energy codes, demonstration programs (e.g., fuels cells, energy storage), financial incentives (e.g., tax credits), and programs for federal facilities (e.g., FEMP).

Program (FEMP).[a] This program supports energy efficiency and DERs in federal facilities, including backing implementation of Executive Order 13693: Planning for Federal Sustainability in the Next Decade.[751] This executive order, released on March 19, 2015, declared that 30% of electricity consumed by the federal government is to come from renewable energy sources by 2025. It established a hierarchy of practices for federal agencies to achieve the 30% target by 2025.

State lead-by-example programs include establishing infrastructure and regulations that encourage energy savings performance contracting (described later in this chapter) as well as building energy performance requirements, energy-efficient product procurement standards, and public financing access via bond pools. States can also adopt complementary policies and programs that support and enable these strategies, such as setting overarching energy savings goals for state facilities, establishing energy-efficient design and retrofit standards, and training and certifying state building operators and designers.

### 7.2.7 Local Government-Led Efforts

Cities and other local government jurisdictions, including school districts, have set energy efficiency and renewable energy goals, and have tested and refined policies, regulations, and programs that later may be adopted statewide or nationally. For example, local governments have adopted sustainable procurement policies and periodic energy assessments for their own operations, as well as design and retrofit standards for their facilities, including energy efficiency and onsite generation. Another example for many local governments is outdoor lighting, a leading expenditure in municipal energy budgets. Using high-performance or LED street lighting systems and controls can improve light quality, reduce energy costs, and mitigate greenhouse gas emissions. These types of policies, regulations, and programs, which focus on saving energy and costs in local government–controlled assets, also provide models for private sector actions. Voluntary programs operated by local governments include energy project financing and challenges for businesses to achieve a targeted level of energy savings.[752] Other types of public policies at the local level are building performance requirements for large commercial buildings, benchmarking and disclosure initiatives, and requirements for energy efficiency upgrades on sale of the property (see Section 3.6).

Local governments also share resources and experiences on a wide range of energy topics. For example, the Energy Standing Committee of The United States Conference of Mayors focuses on bringing energy efficiency to America's cities and energy independence to the United States,[753] and the National League of Cities' Sustainable Cities Institute provides cities with information on building energy efficiency and clean energy resources.[754] Also, ICLEI – Local Governments for Sustainability provides information on energy efficiency and DERs for member cities, towns, and counties.[755]

### 7.2.8 Performance Contracting

Energy service companies (ESCOs)[b 756] contract primarily with public and institutional sector entities (Figure 7.12) to achieve significant energy savings and other operation and maintenance savings. Typical projects involve energy efficiency and distributed generation, such as rooftop PV and CHP projects.

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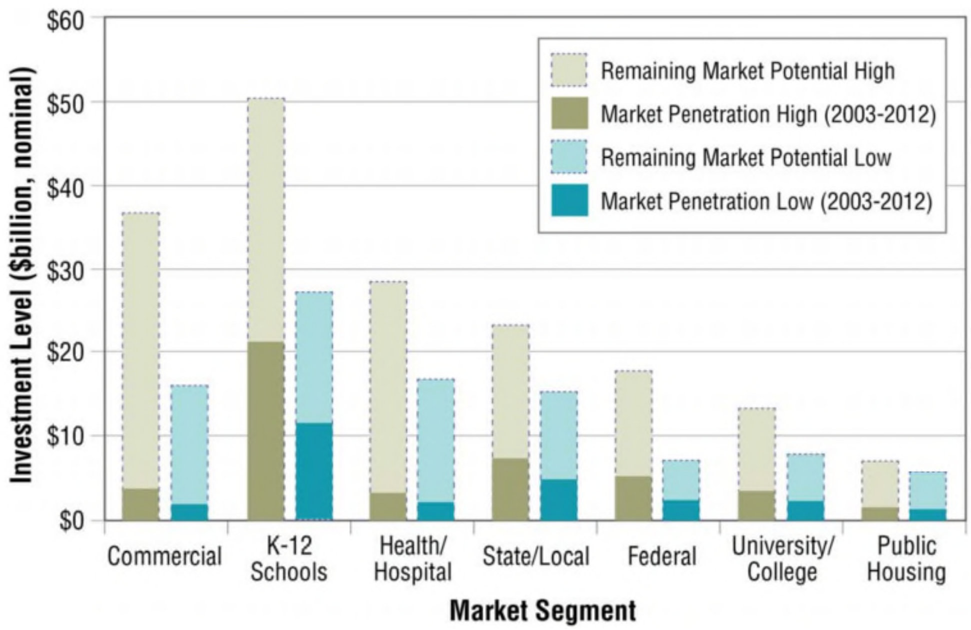
[a] FEMP provides agencies with the information, tools, and assistance they need to meet and track their energy-related requirements and goals. "Federal Energy Management Program," DOE EERE, http://energy.gov/eere/femp/federal-energy-management-program, accessed February 26, 2016.

[b] ESCOs act as project developers as they integrate a project's design, installation, and operational elements. The main difference between ESCOs and other contractors is the guarantee of energy savings specified in an energy savings performance contract.

ESCOs typically use performance-based contracting, guaranteeing annual energy savings levels (see Section 3.5). Some energy savings performance contracting structures allow government agencies and businesses to procure cost-saving facility improvements with no up-front capital costs through a turnkey contracting process using private capital. In addition to FEMP's energy savings performance contracting initiative,[757] nearly all states have enacted legislation or an executive order that facilitates the use of performance-based contracting with ESCOs for energy projects in the public and institutional sectors.[758] State policies can cover local government facilities and schools, as well as state facilities. Many state programs ease the procurement process for performance contracting through such features as a pre-certified process for qualified ESCOs, standard procurement processes, and technical assistance services for government agencies.[759]

**Figure 7.12. Range of estimated existing ESCO market penetration (2003–2012) and remaining ESCO market potential by customer market segment[760]**




*ESCOs contract mainly with public and institutional sector entities.*

### 7.2.9 Voluntary Efforts of Businesses and Consumers

Commercial and residential electricity consumers can undertake a variety of voluntary initiatives to use electricity efficiently and install DERs, driven by the business case—lower operating costs, increased competitiveness, and improved reliability—as well as corporate or personal goals such as sustainability and comfort. Businesses can adopt strategic energy management strategies that systematically and continually improve energy performance of facilities and energy-consuming systems, integrated within normal business practice. For example, the U.S. Department of Energy's (DOE's) Superior Energy Performance program supports reducing energy consumption at individual industrial facilities and provides a platform to continually improve energy performance. The program certifies facilities through third-party verification bodies, including verification of energy performance improvement, to implement an energy management system that conforms to the ISO 50001 global energy management system standard.[761]

Another program that supports such voluntary actions is ENERGY STAR—an EPA program that helps businesses and individuals save money and energy through superior energy efficiency. Working with product manufacturers, the ENERGY STAR program has spearheaded the adoption of higher efficiency products, practices, and services through partnerships, objective measurement tools, and education that informs consumers about the energy use of products and homes.[762]

### 7.2.10 Power Sector Regulations

Federal and state electricity and environmental regulatory agencies influence energy efficiency, DERs, and transportation electrification through regulation of wholesale and retail electricity generation, transmission, and distribution activities and the associated environmental impacts.[a] Examples of such regulations include:

- Utility resource-planning requirements[763] (Figure 7.12)
- Retail tariff structures[b]
- Ratemaking tools such as decoupling of utility profits from retail sales volumes[764] (Figure 7.13)
- Performance incentives for utilities[765] (Figure 7.14)
- Support for non-discriminatory prices and access to the grid for independent power producers (e.g., Public Utility Regulatory Policies Act [PURPA][c] implementation)
- Enabling participation of energy efficiency, demand response, and distributed generation in wholesale markets, such as capacity markets implemented by regional transmission organizations [766]
- Uniform interconnection technical standards, processes, and agreements for distributed generation[767]
- Utility ownership of distributed generation[768]
- Development of electricity tariffs targeted at distributed generation, both CHP and renewable resources; standard offer programs for energy efficiency; and retail incentive programs for demand response resources.[d]

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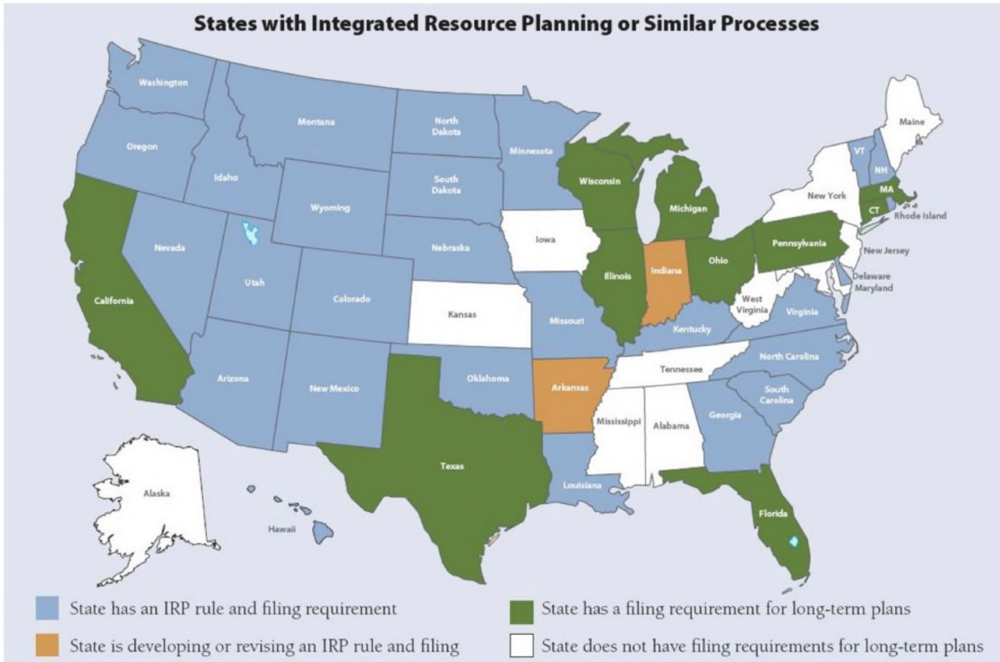
[a] State electricity regulators (public utility commissions) regulate investor-owned utilities. In most states, rural electric co-operatives and municipal utilities are governed by local boards.

[b] Retail tariffs specify the rates and other terms for the specified electricity service and customer class, as approved by the state regulator.

[c] The federal Public Utility Regulatory Policies Act (PURPA, Pub.L. 95–617, 92 Stat. 3117, enacted November 9, 1978) and associated Federal Energy Regulatory Commission (FERC) regulations encourage the development of efficient CHP and small renewable energy facilities by independent power producers. PURPA requires electric utilities to purchase all energy and capacity from qualifying facilities at the utility's "avoided cost." Regulations also require non-discriminatory interconnection and backup power policies and pricing.

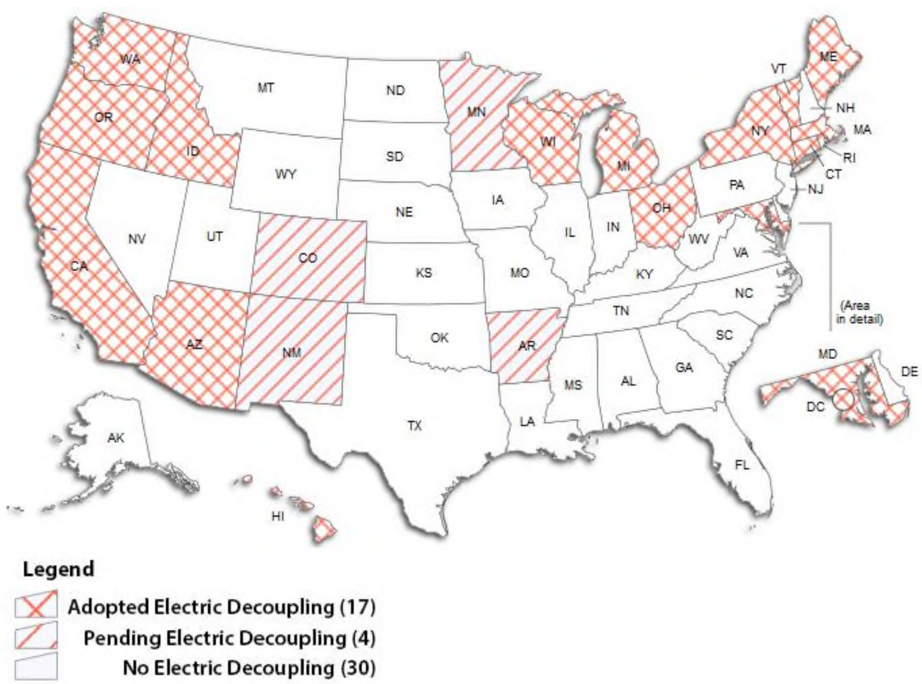
[d] These mechanisms provide contracts for purchase of renewable electricity, savings (from efficiency), or capacity (from demand response), often with long terms.

**Figure 7.13. States with integrated resource planning or similar processes[769]**



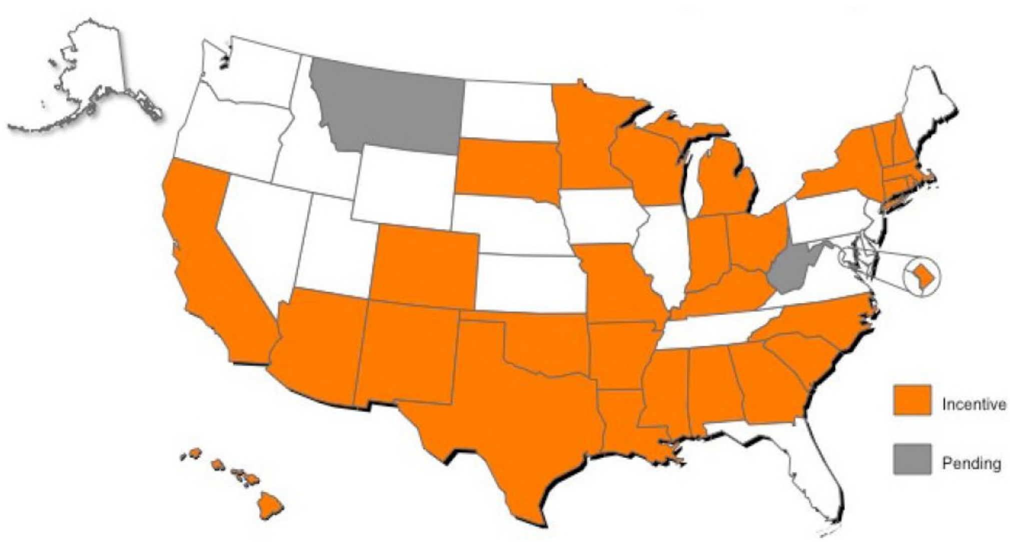

*Most states have some type of utility resource planning requirement or are developing such rules.*

**Figure 7.14. Electric utility decoupling status by state[770]**




*Twenty states and the District of Columbia have implemented decoupling of utility profits from retail sales volume.*

**Figure 7.15. Energy efficiency performance incentives for electric efficiency providers by state**[771]




*Thirty states and the District of Columbia offer performance incentives to utilities for achieving energy efficiency goals.*

Retail electricity pricing and rate (tariff) design is particularly important because it affects the cost-effectiveness of consumer investments in energy efficiency, DERs, and electric transportation. Certain retail rate designs, such as high fixed charges or rates that decrease with increased consumption (declining block rates), can discourage consumer investments in energy efficiency and distributed generation. Designing tariffs involves consideration of a wide range of factors. It begins with the utility's revenue requirements and allocation of costs to each customer class. The process results in the rates that consumers pay as well as the retail rate structure—for example, the level of volumetric charges ($/kWh, $/kW) versus fixed charges, whether volumetric rates are flat or vary by time of use or amount of electricity used in the billing period (e.g., inclining block rates, where the highest level of usage is charged a higher rate).[772]

In addition to retail rates for standard service, several types of supplemental rates affect deployment of distributed generation, including net metering and standby rates (see Section 6.6 of this report), as well as rate designs for purchase of energy and capacity from distributed generation, such as feed-in tariffs (FITs). A FIT is an energy supply policy focused on supporting the development of new renewable energy projects by offering long-term purchase agreements.

## 7.3 Residential Appendix

Air conditioning (AC) efficiency is measured by energy efficiency ratio (EER), which measures cooling output per electric energy input, and by two variants: seasonal energy efficiency ratio (SEER) for central air conditioners and heat pumps,[a] and combined energy efficiency ratio (CEER) for room air conditioners. Air source heat pump heating efficiency is measured by heating season performance factor (HSPF), which is conceptually analogous to SEER. Ground source heat pump heating efficiency is measured by coefficient of performance (COP), which is the ratio of the heating energy produced to the work required to produce it. As Table 7.3 shows, while current technology can attain much higher levels of performance than the installed stock (except in the case of room AC), typical installed units are expected to improve only marginally from those available today. A larger gap exists between today's performance levels and those of the installed stock, so equipment turnover will improve performance in the short run.

**Table 7.3. Current and Projected Efficiency of Selected Electric Space-Conditioning Units[773]**

| Residential AC Type | 2009 Installed | 2013 | | 2020 | | 2030 | | 2040 | |
|---|---|---|---|---|---|---|---|---|---|
| | | Typical | High | Typical | High | Typical | High | Typical | High |
| Room AC (CEER) | 9.3 | 10.9 | 11.6 | 11 | 12 | 11 | 13 | 11.2 | 13 |
| Central AC (SEER) | 11.4 | 13/13.5 * | 24 | 14/14.5 * | 24 | 14.5 | 24 | 14.5 | 24 |
| Air Source Heat Pump Cooling (SEER) | 12 | 14 | 22 | 14.5 | 23 | 15.5 | 24 | 16 | 25 |
| Air Source Heat Pump Heating (HSPF) | 7 | 8.3 | 9 | 8.4 | 10.8 | 8.6 | 10.9 | 8.7 | 11 |
| Ground Source Heat Pump Cooling (EER) | 12.3 | 14.2 | 28 | 17.1 | 36 | 21 | 42 | 24 | 46 |
| Ground Source Heat Pump Heating (COP) | 3 | 3.2 | 4.5 | 3.6 | 4.9 | 3.8 | 5.2 | 4 | 5.4 |

*Typical installed unit efficiency is projected to improve only slightly, though much higher performance levels are technologically possible. Asterisked values characterize typical efficiencies in the South, where high cooling loads and humidity place a premium on air conditioning performance relative to the rest of the United States. Note that CEER, SEER, EER, COP, and HSPF factors are not directly comparable to one another.*

[a] Air-source heat pumps extract heat from the air, and ground-source heat pumps extract heat from the ground. A variety of air-source heat pump technologies are available, including ductless and ducted models and both single-room and multi-zone models. The vast majority of installed units are air source. Some rural electric cooperatives promote ground source heat pumps and give incentives for their installation. (Air-source heat pumps are also promoted, much more widely and especially in the South.)

**Table 7.4. Status of Consumer Product and Lighting Standards that Impact Residential Electricity Use[774]**

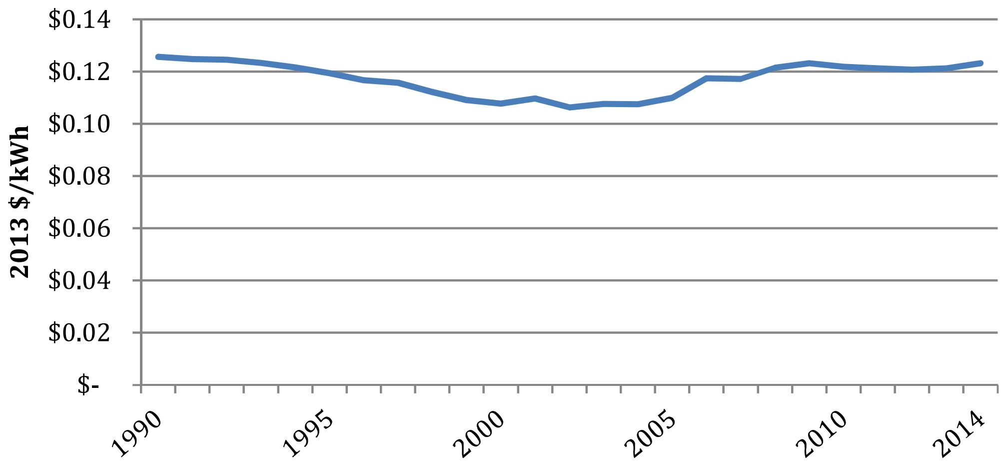
| Product Covered | Last Standard Issued | Effective Date | Updated Standard Expected | Potential Effective Date | States with Standard |
|---|---|---|---|---|---|
| Consumer Products | | | | | |
| Battery Chargers | None | None | 2016 | 2017 | CA, OR |
| Boilers | 2015 | 2021 | 2022 | 2027 | |
| Ceiling Fans | 2005 | 2007 | 2016 | 2019 | |
| Central Air Conditioners and Heat Pumps | 2011 | 2015 | 2016 | 2021 | |
| Clothes Dryers | 2011 | 2015 | 2017 | 2021 | |
| Clothes Washers | 2012 | 2015 | 2018 | 2021 | |
| Compact Audio Equipment | | | | | CA, OR, CT |
| Dehumidifiers | 2007 | 2012 | 2016 | 2019 | |
| Dishwashers | 2012 | 2013 | 2016 | 2019 | |
| DVD Players and Recorders | | | | | CA, OR, CT |
| External Power Supplies | 2014 | 2016 | 2016 | 2018 | CA |
| Furnace Fans | 2014 | 2019 | 2020 | 2025 | |
| Microwave Ovens | 2013 | 2016 | 2019 | 2022 | |
| Miscellaneous Refrigeration Products | | | 2016 | 2019 | CA |
| Pool Heaters | 2010 | 2013 | 2016 | 2021 | |
| Pool Pumps | | | 2016 | 2021 | AZ, WA, CA, CT |
| Portable Air Conditioners | None | None | 2016 | 2019 | |
| Portable Electric Spas | | | | | AZ, OR, WA, CA, CT |
| Refrigerators and Freezers | 2011 | 2014 | 2018 | 2021 | |
| Room Air Conditioners | 2011 | 2014 | 2017 | 2020 | |
| Televisions | None | None | None | None | CA, CT, OR |
| Water Heaters | 2010 | 2015 | 2016 | 2021 | |
| Lighting | | | | | |
| Candelabra & Intermediate Base Incandescent Lamps | 2007 | 2012 | 2016 | 2019 | |
| Ceiling Fan Light Kits | 2015 | 2016 | None | None | |
| Compact Fluorescent Lamps | 2005 | 2006 | 2017 | 2020 | |
| General Service Lamps | 2007 | 2012 | 2017 | 2020 | |
| Incandescent Reflector Lamps | 2015 | None* | 2023 | 2026 | D.C., OR |
| Incandescent Reflector Lamps (includes certain BR and Other Exempted IRLs) | None | None | 2016 | 2019 | |
| Luminaires | None | None | None | None | CA |
| Torchiere Lighting Fixtures | 2005 | 2006 | None | None | |

*New federal standards for a number of significant products—AC, heat pumps, washers and dryers, refrigerators and freezers, and ceiling fan light kits—went into effect in 2014 and 2015. In addition, many states set standards for appliances and equipment that are not covered by federal standards.*

** There is no effective date for this standard because the 2015 rule found that "amending energy conservation standards for incandescent reflector lamps (IRLs) would not be economically justified.[775]*

Between 1990 and 2014, electricity prices in the residential sector decreased by about 2% in real terms (constant 2013 dollars), from 12.6 cents/kWh to 12.3 cents/kWh. Residential electricity prices are higher than any other market sector (Figure 7.16).

**Figure 7.16. Electricity prices for the residential sector, 1990 to 2014[776]**




*Electricity prices in the residential sector decreased by about 2% in real terms (constant 2013 dollars) between 1990 and 2014.*

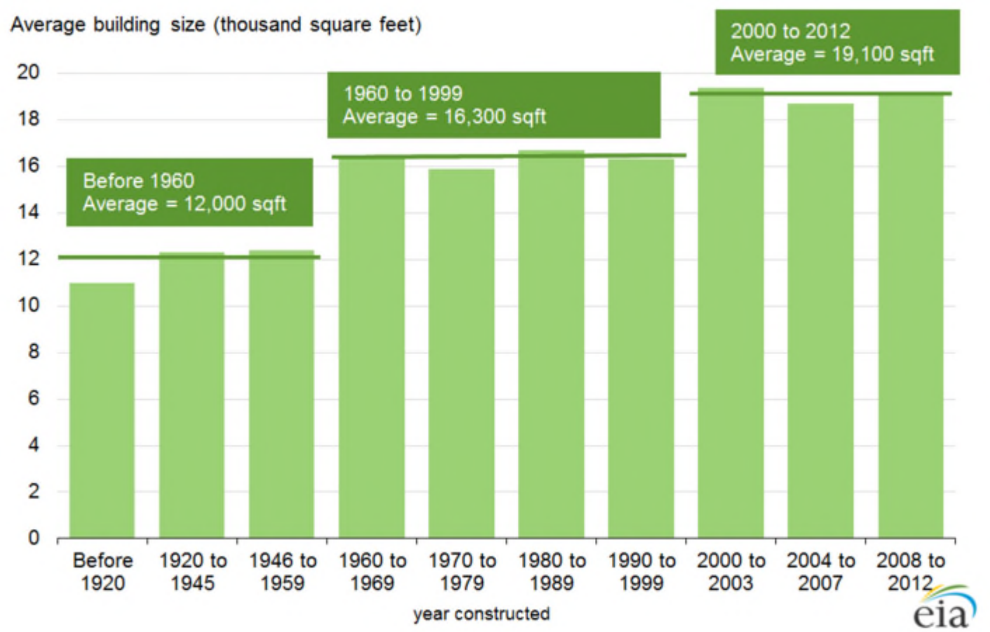
**Table 7.5 Example Residential and Commercial Sector Miscellaneous Electric Loads[777]**

| Example Residential MELs | Example Commercial MELs |
|---|---|
| Audio Equipment | Distribution Transformers |
| Ceiling Fans | Data Center Servers |
| Dehumidifiers | IT Equipment (non-data center) |
| DVD/Media Players | Video Displays |
| External Power Supplies | Large-Format Video Boards |
| Modems & Routers | Water Treatment/Distribution |
| Monitors (i.e. desktop PC monitors) | Monitors (i.e. desktop PC monitors) |
| Non-Computer Rechargeable Electronics | Kitchen Ventilation (Exhaust Hoods) |
| Pools/Pool Pumps | Lab Refrigerators/Freezers |
| Portable Electric Spas | Security Systems, Commercial |
| Security Systems, Home | Medical Imaging Equipment |
| Set-top Boxes, All | |
| Televisions | |

## 7.4 Commercial Appendix

Figure 7.17 shows that office buildings' share of electricity consumption has been falling since 1992, with a growing share from mercantile and service, education, and food sales. Figure 7.18 shows electricity intensity by building category in units of kilowatt-hours per square foot (kWh/ft$^2$). Total electricity intensity is highest in the food sales, food service, health care, and other[a] building categories. Mercantile and service, education, and assembly building intensity has increased by about 40%, 30%, and 20%, respectively, from 1995 to 2003. These results should be viewed as intermediate results since building-level consumption data have not yet been released from the 2012 Commercial Buildings Energy Consumption Survey (CBECS). The combination of building-level consumption data and floor space data from 2012 will provide better insight into recent consumption and electricity intensity trends by building category.

**Figure 7.17. New commercial buildings are larger, on average, than older buildings[778]**




*Buildings constructed from 1960 to 1999 are 36% larger than buildings built before 1960, and buildings constructed from 2000 to 2012 are 59% larger than pre-1960 buildings.*

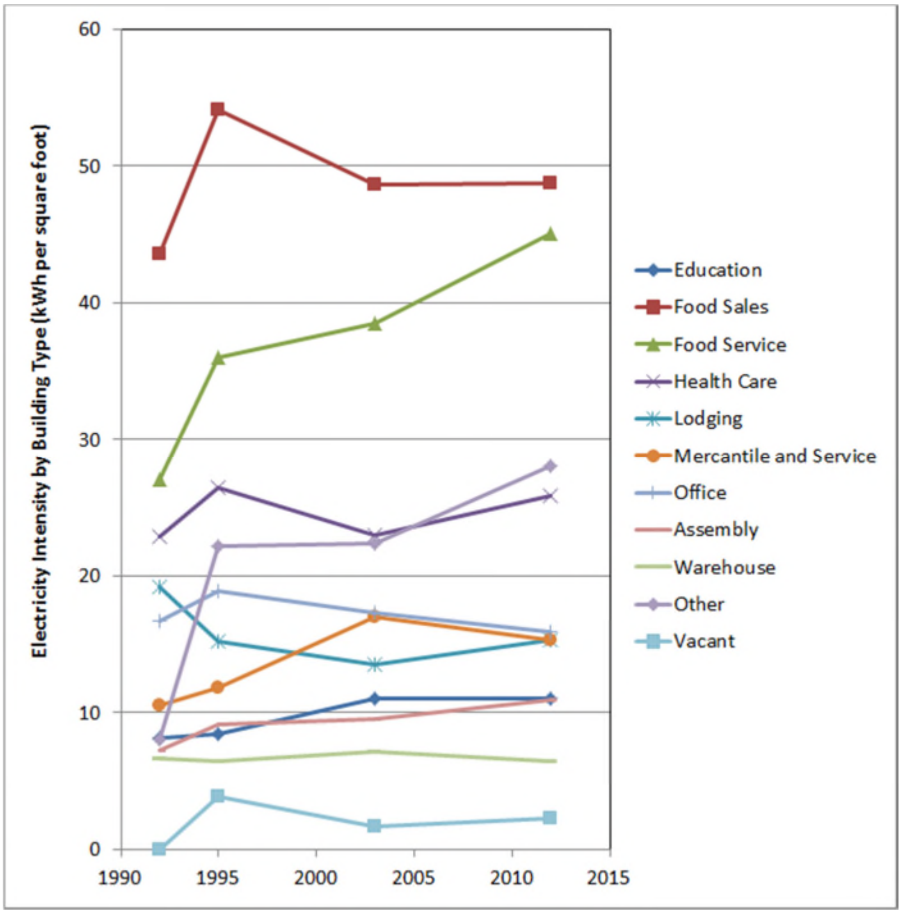
[a] "Other" buildings include data centers and server farms, airplane hangars, crematoriums, laboratories, telephone switching centers, agricultural facilities with some retail space, and manufacturing or industrial facilities with some retail space. The classification of data centers depends on the source of data: CBECs includes them in its inventory of buildings. The Annual Energy Outlook (AEO) includes data centers in the sector where their energy supplier classifies them. Thus, they could be classified in the industrial sector. Joelle Michaels, CBECS Survey Manager, personal communication, November 2, 2015.

**Table 7.6. Summary of Electricity Consumption by Building Category from CBECS 2003 and 2012 [779]**

| Principal building activity | Building Floorspace (Billion sq. ft.) | | % change 2003 to 2012 | Building Electricity Intensity (kWh per sq. ft.) | | % change 2003 to 2012 | Electricity (TWh) | | % change 2003 to 2012 | % of End-Use Electricity by Building Type | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2003 | 2012 | | 2003 | 2012 | | 2003 | 2012 | | 2003 | 2012 |
| Food sales | 1.26 | 1.25 | 0% | 49.4 | 48.7 | -1% | 61.0 | 61.0 | 0% | 5.8% | 4.9% |
| Food service | 1.65 | 1.82 | 10% | 38.4 | 45.0 | 17% | 63.6 | 81.8 | 29% | 6.0% | 6.6% |
| Other | 1.74 | 2.00 | 15% | 22.5 | 28.0 | 24% | 39.0 | 56.0 | 44% | 3.7% | 4.5% |
| Vacant | 2.57 | 3.26 | 27% | 2.4 | 2.3 | -4% | 4.4 | 7.6 | 73% | 0.6% | 0.6% |
| Health care | 3.16 | 4.16 | 31% | 22.9 | 25.8 | 12% | 72.7 | 107.0 | 47% | 6.8% | 8.6% |
| Lodging | 5.10 | 5.83 | 14% | 13.5 | 15.3 | 13% | 68.9 | 89.1 | 29% | 6.5% | 7.2% |
| Education | 9.87 | 12.24 | 24% | 11.0 | 11.0 | 0% | 108.7 | 134.2 | 23% | 10.2% | 10.8% |
| Warehouse | 10.08 | 13.03 | 29% | 7.6 | 6.4 | -16% | 71.5 | 83.2 | 16% | 7.2% | 6.7% |
| Mercantile/ Service | 15.24 | 15.96 | 5% | 19.2 | 15.3 | -20% | 258.5 | 243.8 | -6% | 20.2% | 16.6% |
| Office | 12.21 | 15.95 | 31% | 17.3 | 15.9 | -8% | 210.7 | 253.5 | 20% | 19.8% | 20.4% |
| Assembly | 8.78 | 11.60 | 32% | 10.9 | 10.1 | -8% | 83.8 | 125.7 | 50% | 13.2% | 13.1% |
| Total | 71.65 | 87.09 | 22% | 14.6 | 14.3 | -2% | 1042.8 | 1242.9 | 19% | 100% | 100% |

*Overall building electricity intensity is down slightly (-2%) with fairly stable fractions of end-use electricity by building type*.

**Figure 7.18. Trend in electricity intensity in kWh/ft² by building category from 1992 to 2012**[780]

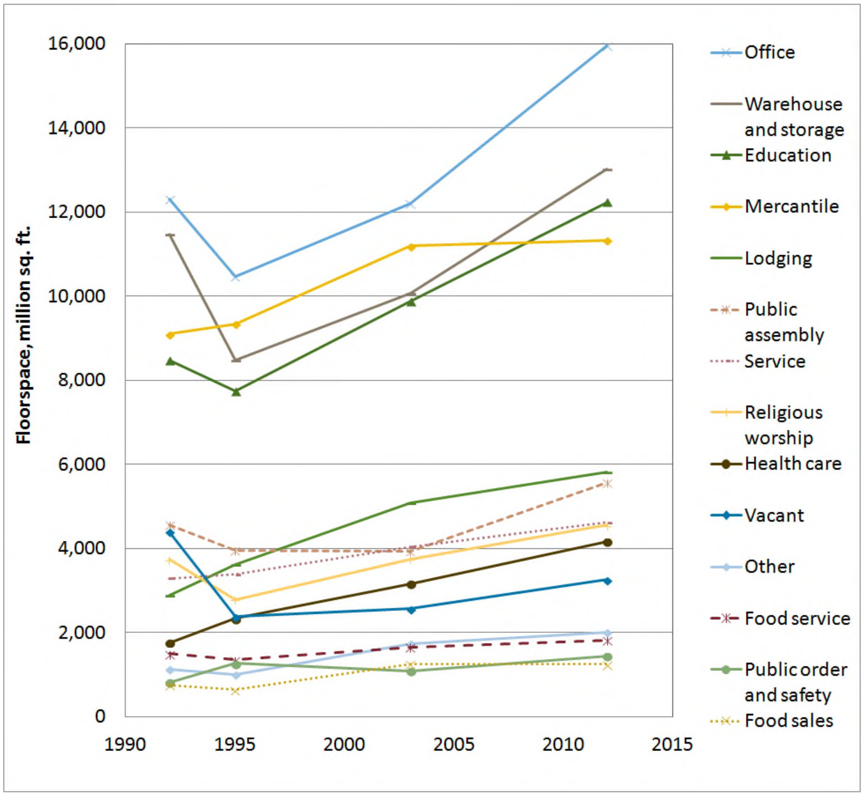



*Total electricity intensity is highest in the food sales, food service, other, and health care building categories.*[a]

[a] For comparison with 1992 and 1995 CBECS data, which had fewer building categories, 2003 data for some building categories are combined. Mercantile and service includes mercantile (mall), mercantile (non-mall), and services; health care includes inpatient and outpatient healthcare; assembly includes public assembly, public order, and safety and religious worship.

Figure 7.19 shows the trend in building floor space since 1992. Floor space has increased the most in public assembly, health care, office buildings, warehouses and education, with total mercantile floor space holding steady from 2003 to 2012.

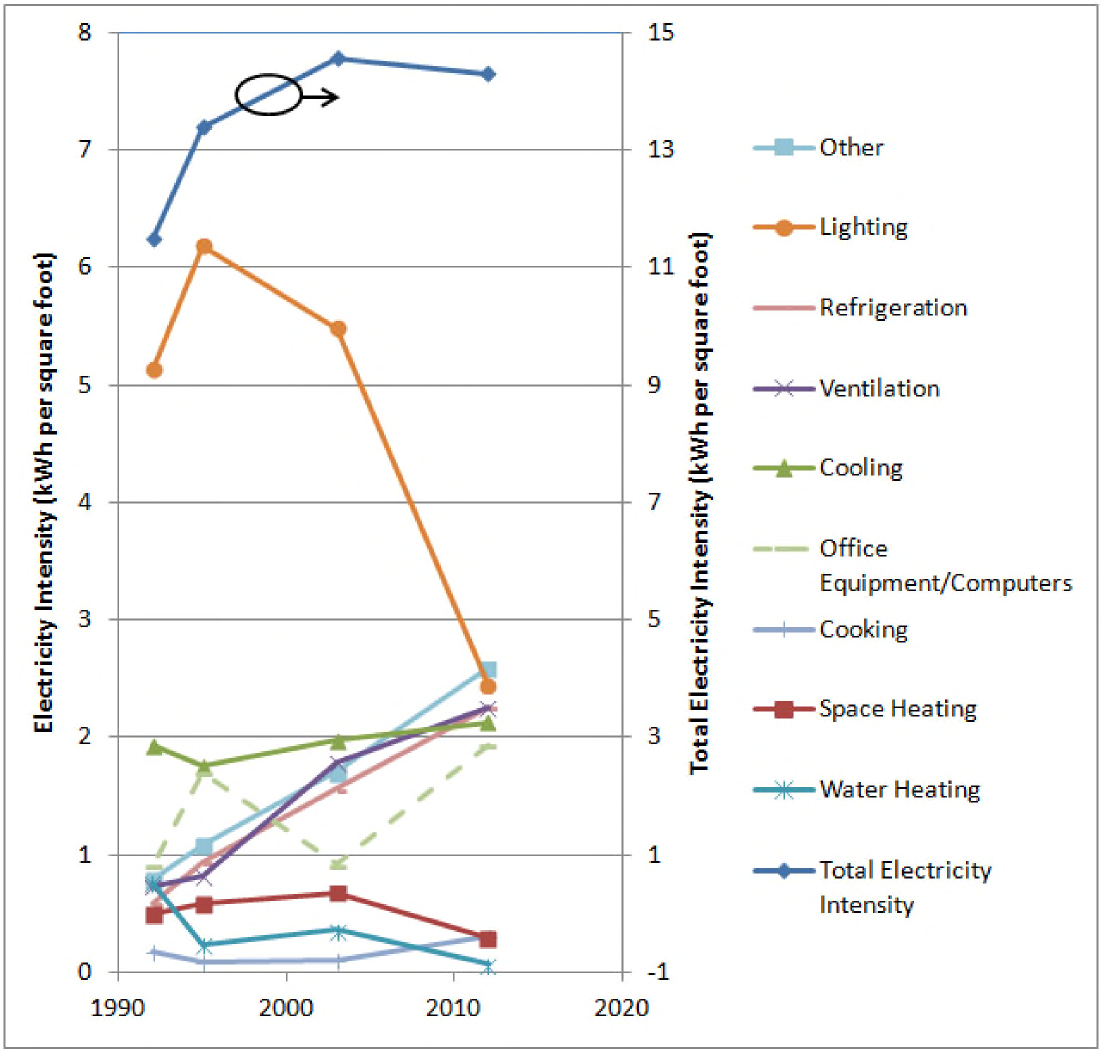
**Figure 7.19. Building floor space trend from 1992 to 2012[781]**




*Floor space increased most rapidly in public assembly, health care (both inpatient and outpatient), office buildings, and warehouse and storage buildings from 2003 to 2012. Overall, annual growth in floor space was 2.2% over this period.*

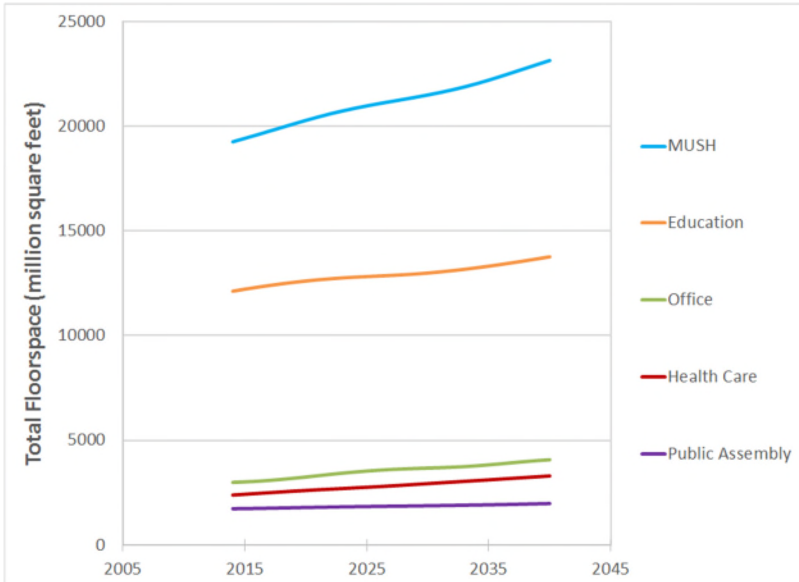
Figure 7.20 shows that total electricity intensity (kWh/ft$^2$) increased by 11% from 1995 to 2003 (right axis) as the demand for more services that use electricity increased. The most electricity-intensive end uses are lighting, cooling, ventilation, and other, together making up 75% of overall sector electricity intensity. Lighting intensity has been falling due to more efficient lighting and controls, but this is more than offset by increases in ventilation, refrigeration, cooling, and other end uses.

**Figure 7.20. Trend in electricity intensity in kWh/ft$^2$ by end use from 1992 to 2012[782]**




*Total electricity intensity decreased slightly by 1.8% from 2003 to 2012 (right axis), led by a sharp drop in lighting intensity. Six end uses contribute between 14% and 18% of overall sector electricity intensity (other, lighting, refrigeration, ventilation, cooling, and office equipment/computers). Note: The circled data series (Total Electricity Intensity) uses the right axis.*

**Figure 7.21. Floor space projection in Municipal, University, School, and Hospital (MUSH) buildings for 2014 to 2040**[783]




*Overall, floor space in the MUSH subsector is projected to increase by 0.7% per year. Health care is growing fastest at 1.2% per year.*

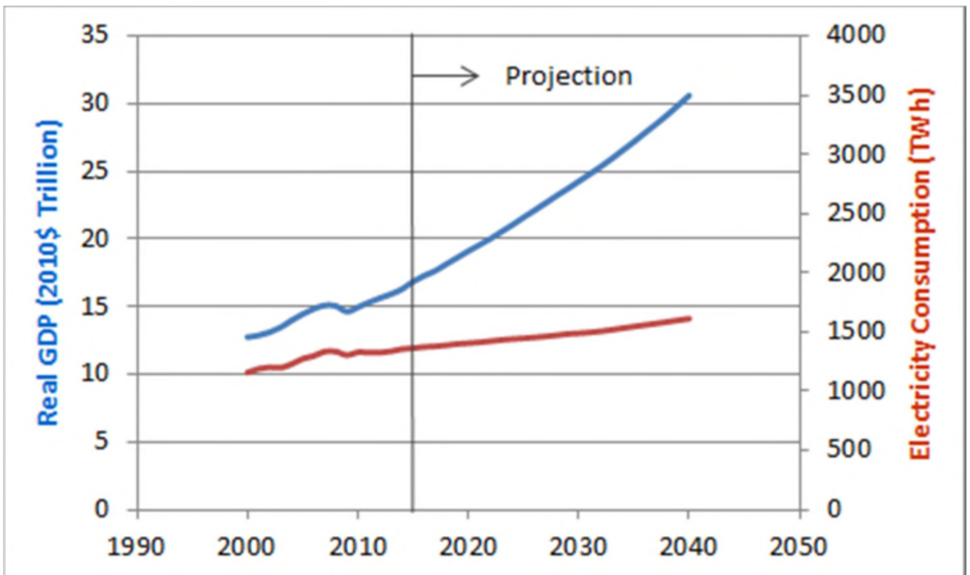
**Table 7.7. Federal Appliance Standards for Commercial Products**[784 785]

| Product Covered | Initial Legislation | Last Standard Issued | Effective Date | Issued By | Updated DOE Standard Expected |
|---|---|---|---|---|---|
| Commercial Water Heaters | EPACT 1992 | 2001 | 2003 | DOE | 2016 |
| Warm Air Furnaces, Commercial | EPACT 1992 | 2016 | 2018 | DOE | 2024 |
| Water-Source Heat Pumps (HP) | EPACT 1992 | 2001 | 2003 | DOE | 2016 |
| Commercial Central Air Conditioning (CAC) and HP (65,000 Btu/hr to 760,000 Btu/hr) | EPACT 1992 | 2015 | 2018/2023 | DOE | 2025 |
| Commercial CAC and HP (<65,000 Btu/hr) | EPACT 1992 | 2015 | 2017 | DOE | 2023 |
| Packaged Terminal AC and HP | EPACT 1992 | 2015 | 2018 | DOE | 2023 |
| Single Package Vertical AC and HP | EPACT 1992 | 2015 | 2018 | DOE | 2023 |
| Boilers, Commercial | EPACT 1992 | 2009 | 2012 | DOE | 2016 |
| Vending Machines | EPACT 2005 | 2016 | 2019 | DOE | 2024 |
| Commercial CAC and HP (Water- and Evaporatively Cooled) | EPACT 1992 | 2012 | 2013 | DOE | 2018 |
| Clothes Washers, Commercial | EPACT 2005 | 2014 | 2018 | DOE | 2021 |
| Commercial Refrigeration Equipment | EPACT 2005 | 2014 | 2017 | DOE | 2022 |
| Walk-in Coolers and Freezers | EISA 2007 | 2014 | 2017 | DOE | 2016 |
| Automatic Commercial Ice Makers | EPACT 2005 | 2015 | 2018 | DOE | 2023 |
| Pumps | EPCA | 2015 | 2020 | DOE | 2024 |

*Of the 14 standards, 11 are for electricity-powered appliances. Updated standards for all products are expected by 2023.*

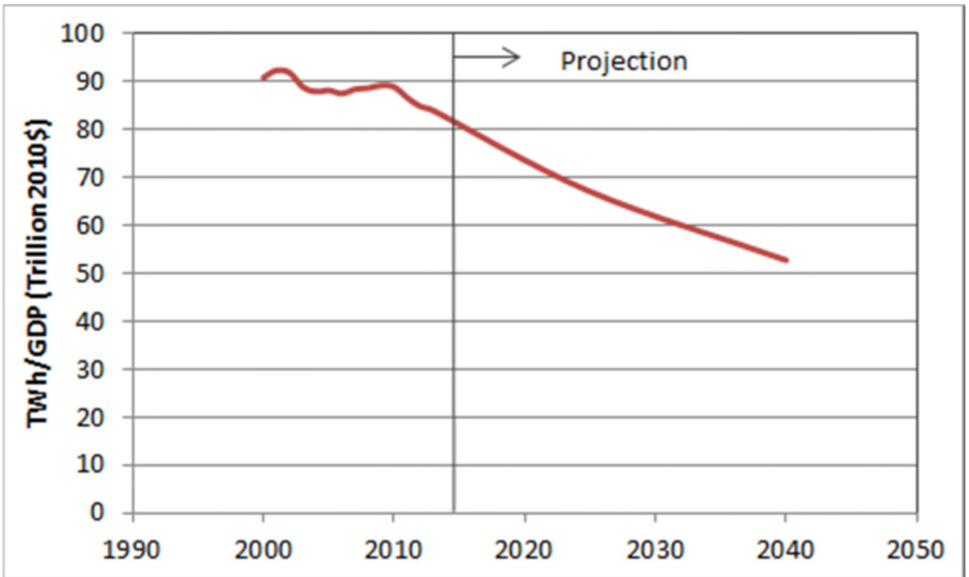
Figure 7.22 and Figure 7.23 show commercial electricity use relative to economy-wide gross domestic product (GDP). Gross domestic product is projected to grow 2.4% annually from 2012 to 2040, but commercial electricity consumption is projected to grow at a much lower rate (0.7% per year). This represents a 26% higher GDP growth rate than in the past 15 years (1.9% annual growth), but closer to the 50-year historical average of 2.8%. Conversely, projected growth in commercial-sector electricity use to 2040 is about 40% lower than the 1.1% annual growth rate since 2000. The net result is a projected 1.7% annual reduction in the ratio of electricity consumption to GDP through 2040 (Figure 7.23).

**Figure 7.22. Trend of real GDP and commercial electricity sector consumption[786]**




*Real GDP is projected to grow at about three times the rate of electricity consumption (2.4% per year vs. 0.8% per year, respectively).*

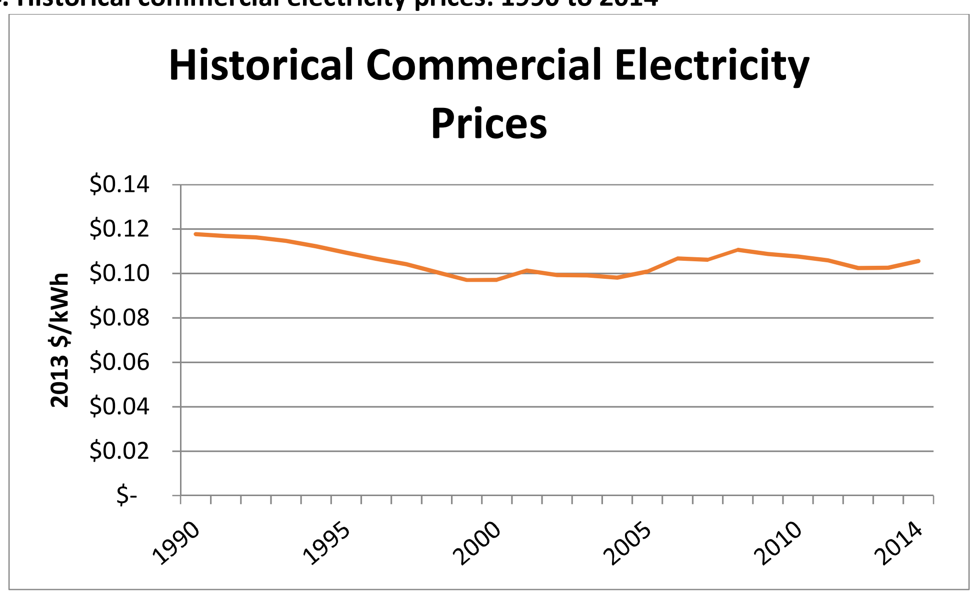
**Figure 7.23. Commercial electricity end-use energy per unit of GDP (GDP units in US$ trillion (2010), $CO_2$ in million metric tons, and electricity in terawatt-hours [TWh])** [787]




*The ratio of TWh per unit of GDP is projected to drop by 35% from 2013 to 2040, and commercial $CO_2$ per unit of GDP to drop by 42%.*

As Figure 7.24 shows, between 1990 and 2014, commercial sector electricity prices decreased 10% in real terms (constant 2013 dollars), from 11.8 cents/kWh to 10.6 cents/kWh. Electricity prices for the commercial sector are higher than industrial sector prices but lower than residential sector prices.

**Figure 7.24. Historical commercial electricity prices: 1990 to 2014**[788]




*Electricity prices in the commercial sector decreased by 10% in real terms (constant 2013 dollars) between 1990 and 2014.*

### 7.4.1 Characterization of "Other Uses"

As characterized by NEMS in the EPSA Side Case, the "Other uses" category includes an adjustment to relieve discrepancies between supply- and consumption-side data sources. Figures 7.25 and 7.26 below present an alternative characterization of commercial end-use consumption in 2014 and 2040. These figures re-allocate this adjustment proportionally to the other end uses, rather than including it together with the "Other uses" category. "Other uses" remain the largest end use in 2014 and 2040.

**Figure 7.25. Commercial electricity consumption by end use, with adjustment re-allocation, 2014**

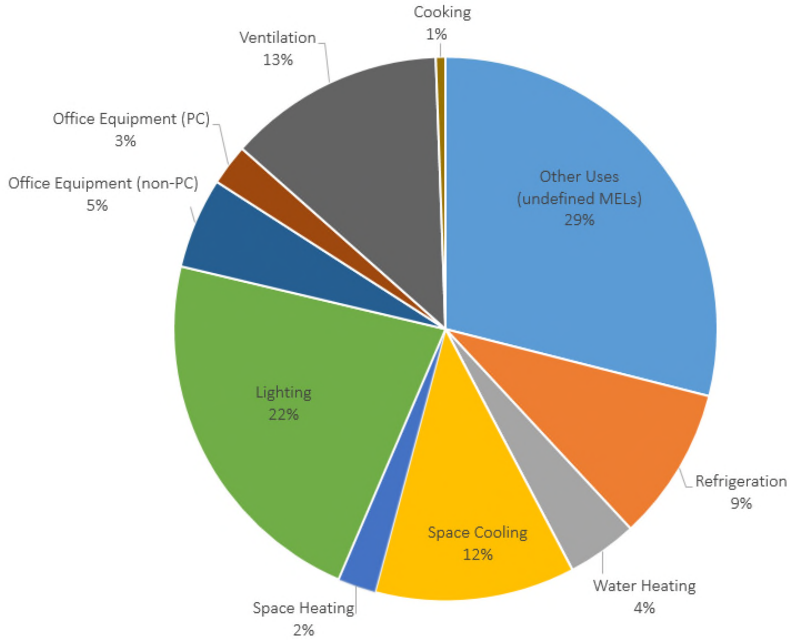
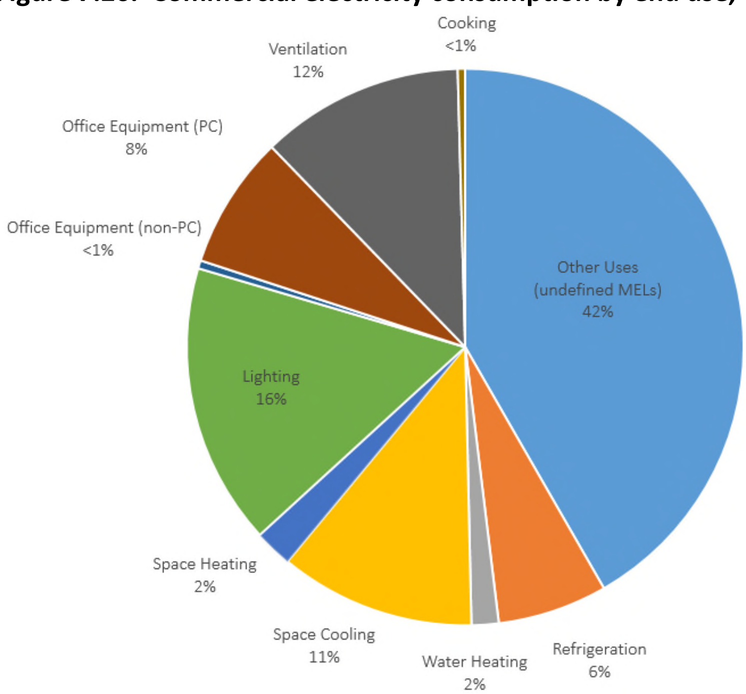



**Figure 7.26. Commercial electricity consumption by end use, with adjustment re-allocation, 2040**



## 7.5 Industrial Appendix

### 7.5.1 Grid Purchases and CHP Scaling

For both grid-purchased electricity and CHP-generated electricity, the National Energy Modeling System (NEMS) reports two industrial sector forecasts: (1) total aggregated industrial sector—benchmarked to historical trends (reported in Table 6) and (2) individual industrial subsectors modeled individually within NEMS (reported in Tables 35–43, 139–140). The sum of the individual industrial subsectors does not equal the total aggregated forecast.[a] Table 7.8 shows the NEMS variable names and the associated NEMS tables that report their forecasts.

**Table 7.8. NEMS Variables and Tables for Industrial Purchased Electricity as Reported in the Annual Energy Outlook (AEO) 2014 and AEO 2015**

| NEMS Variable Name | NEMS Table |
|---|---|
| Industrial : Total Industrial Sector Use : Purchased Electricity (quad Btu) | 6 |
| Refining Industry : Total Energy Use : Purchased Electricity (TBtu) | 35 |
| Food Industry : Energy Use : Purchased Electricity (TBtu) | 36 |
| Paper Industry : Energy Use : Purchased Electricity (TBtu) | 37 |
| Bulk Chemical : Energy Use : Heat and Power : Purchased Electricity (TBtu) | 38 |
| Glass Industry : Energy Use : Purchased Electricity (TBtu) | 39 |
| Cement Industry : Energy Use : Purchased Electricity (TBtu) | 40 |
| Iron and Steel : Energy Use : Purchased Electricity (TBtu) | 41 |
| Aluminum Industry : Energy Use : Purchased Electricity (TBtu) | 42 |
| Metal Based Durables : Fabricated Metal Products : Use : Purchased Electricity (TBtu) | 139 |
| Metal Based Durables : Machinery : Use : Purchased Electricity (TBtu) | 139 |
| Metal Based Durables : Computers : Use : Purchased Electricity (TBtu) | 139 |
| Metal Based Durables : Electrical Equipment : Use : Purchased Electricity (TBtu) | 139 |
| Metal Based Durables : Transportation Equipment : Use : Purchased Electricity (TBtu) | 139 |
| Other Manufacturing : Wood Products : Use : Purchased Electricity (TBtu) | 140 |
| Other Manufacturing : Plastics : Use : Purchased Electricity (TBtu) | 140 |
| Other Manufacturing : Balance of Manufacturing : Use : Purchased Electricity (TBtu) | 140 |
| Nonmanufacturing : Energy Use : Agriculture : Purchased Electricity (TBtu) | 43 |
| Nonmanufacturing : Energy Use : Construction : Purchased Electricity (TBtu) | 43 |
| Nonmanufacturing : Energy Use : Mining : Purchased Electricity excluding Oil Shale (TBtu) | 43 |
| Nonmanufacturing : Energy Use : Mining : Purchased Electricity for Oil Shale (TBtu) | 43 |

***Acronym**: TBtu: trillion British thermal unit*

Throughout this report, all NEMS subsector-specific electric grid–purchased electricity is scaled by the ratio of the total aggregated grid-purchased electricity to the sum of the subsectors' grid-purchased electricity. Similarly, all NEMS subsector-specific CHP own-use electricity is scaled by the ratio of the total aggregated CHP own-use electricity to the sum of the subsectors' CHP own-use electricity. The year-to-year values and scaling ratios for purchased electricity are shown in Figure 7.27, and for CHP, they are shown in Figure 7.28.

[a] The U.S. Energy Information Administration (EIA) is in the process of reconciling differences between the two forecasts; however, as of AEO 2015, this has not been reconciled.

**Figure 7.27. Grid purchased electricity: Total aggregated industrial sector reported in Table 6, sum of individual industrial subsectors, and the ratio between the two**[789]

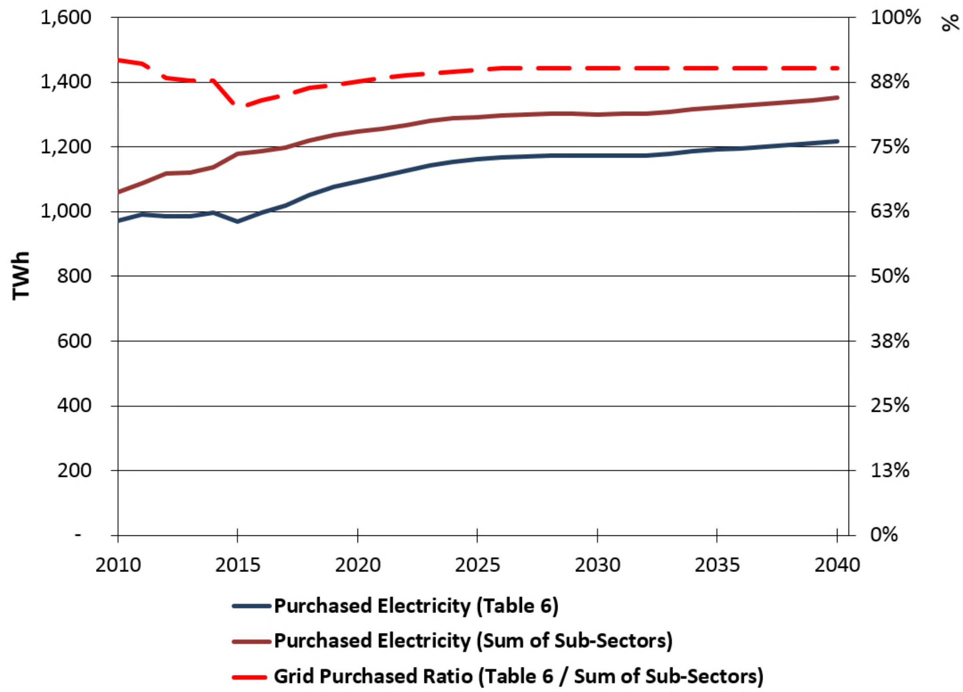
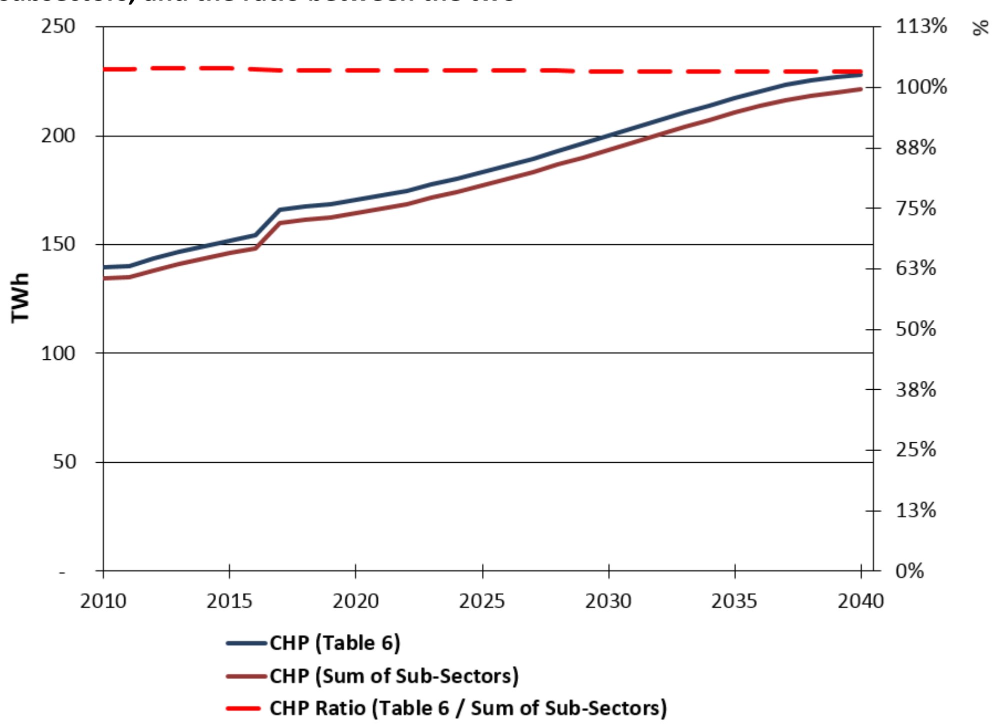
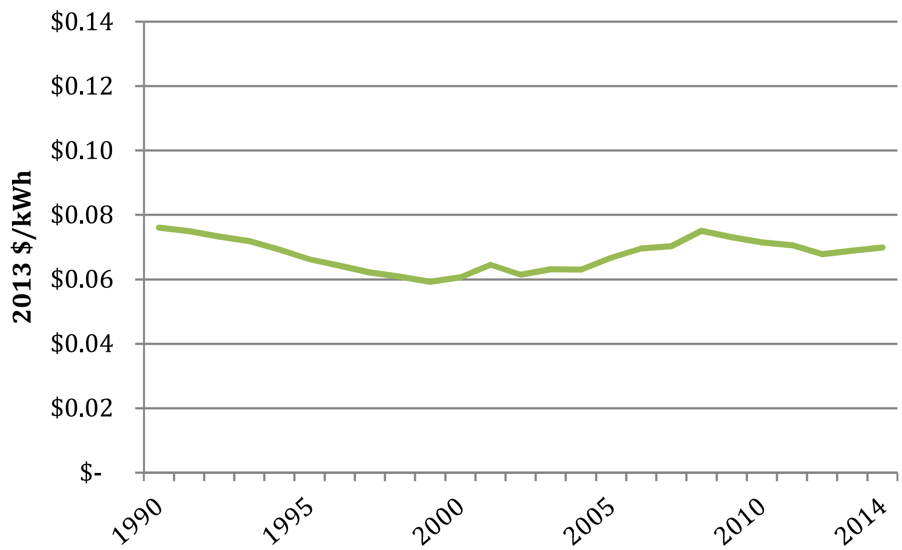



**Figure 7.28. Own-use CHP: Total aggregated industrial sector reported in Table 6, sum of individual industrial subsectors, and the ratio between the two**[790]



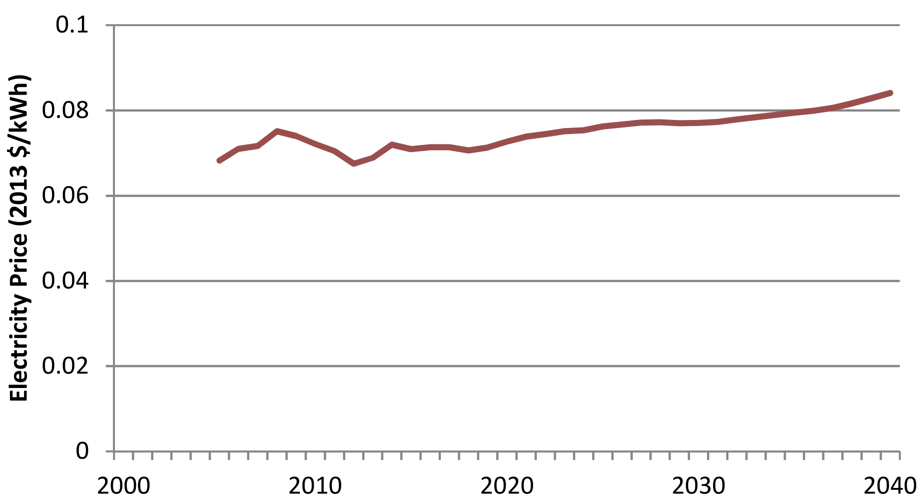
Between 1990 and 2014, electricity prices for the industrial sector fell 8% in real terms (constant 2013 dollars), from $0.076/kWh to $0.070/kWh (Figure 7.29). Industrial electricity prices have stayed much lower than prices for other market sectors. As Figure 7.30 shows, electricity prices in the industrial sector are projected to increase modestly to 2040 in real terms.

**Figure 7.29. Electricity prices for the industrial sector, 1990 to 2014[791]**




*Electricity prices for the industrial sector decreased by 8% between 1990 and 2014 in real terms (constant 2013 dollars).*

**Figure 7.30. Electricity prices for the industrial sector to 2040[792]**



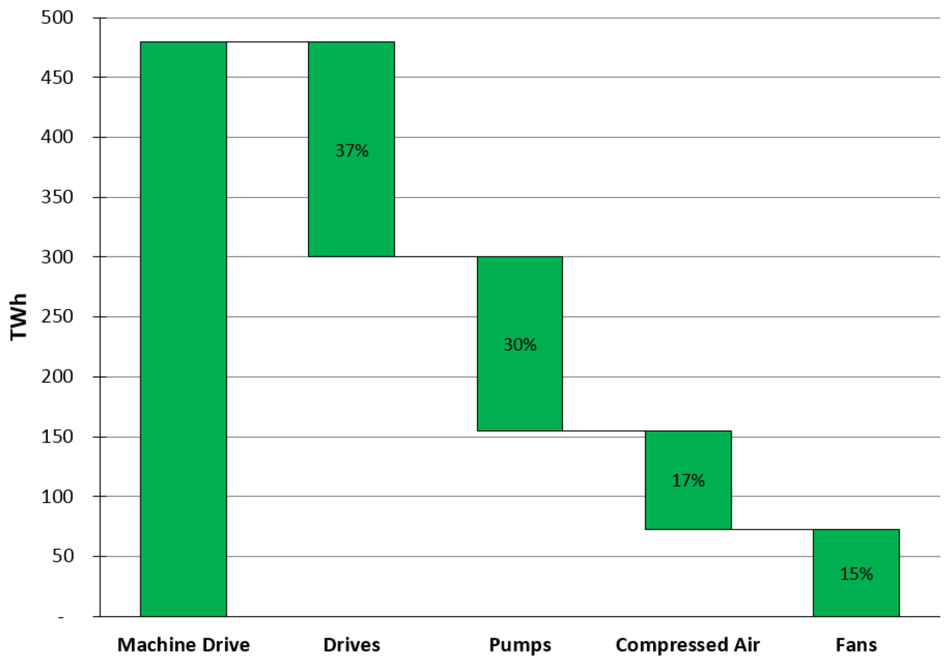

*Electricity prices for the industrial sector are projected to grow modestly, at 0.6% per year.*

### 7.5.2 Manufacturing Energy Consumption Survey (MECS) Definitions[a] [793]

*Machine Drives*

Machine drives convert electric energy into mechanical energy and are found in almost every process in manufacturing. MECS categorizes process-related machine drives by several subcategories. Figure 7.31 shows total end-use electricity consumption in the manufacturing sector in 2010 for process-related motor end uses. Motors are also included in other MECS end uses (e.g., facility HVAC, process cooling and refrigeration). However, their electricity consumption is accounted for by those MECS end-use categories. In this respect, motors consume more electricity than indicated in MECS for process-related motor end uses.

**Figure 7.31. Machine drive electricity end uses in the U.S. manufacturing sector in 2014, based on MECS percentages and the EPSA Side Case[794]**




*The machine drive category consists of drives for mechanical systems (drives), pumps, compressed air, and fans. Drives and pumps are the largest machine-drive end uses in the manufacturing sector.*

*Process Heating*

According to MECS, process heating raises "the temperature of substances involved in the manufacturing process. Examples include using heat to melt scrap for electric-arc furnaces in steelmaking, to separate components of crude oil in petroleum refining, to dry paint in automobile manufacturing," and to use microwave heating in food processing.

*Electrochemical Processes*

Electrochemical processes are the end uses "in which electricity is used to cause a chemical transformation. Major uses of electrochemical processes occur in the aluminum industry…and in the alkalis and chlorine industry."

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[a] Note: All definitions in this appendix originate from Manufacturing Energy Consumption Survey (MECS), Terminology see: http://www.eia.gov/consumption/manufacturing/terms.cfm.

*Direct Non-Process End Uses*

Direct non-process end uses in manufacturing "include heating, ventilation, and air conditioning (HVAC), facility lighting, facility support, onsite transportation, conventional electricity generation, and other nonprocess uses. 'Direct' denotes that only the quantities of electricity or fossil fuels used in their original state (i.e., not transformed) are included in the estimates."

*Process Cooling and Refrigeration*

Process cooling and refrigeration lowers "the temperature of substances involved in the manufacturing process. Examples include freezing processed meats for later sale in the food industry and lowering the temperature of chemical feedstocks below ambient temperature for use in the chemical industries. Not included are uses such as air-conditioning for personal comfort and cafeteria refrigeration."

*End Use Not Reported*

This composes all electricity consumption that does not fall into one of the other MECS end-use categories.

*Indirect Uses: Boiler Fuel*

MECS uses the Indirect Uses category for boiler fuel: "Fuel in boilers is transformed into another useful energy source, steam, or hot water, which is in turn used in end uses, such as process or space heating or electricity generation." It is difficult to measure quantities of steam as it passes through various end uses as "variations in both temperature and pressure affect energy content. Thus, MECS "does not present end-use estimates of steam or hot water and shows only the amount of fuel used in the boiler"—which includes a small amount of electricity—"to produce secondary energy sources."

## 7.6 Transportation Appendix

**Table 7.9. Efficiency Data for the Most Recent Models of Mass-Market PEVs[795]**

| Manufacturer | Model | Type | All-Electric Range (miles) | Combined Fuel Economy—Charge Depleting[a] ($MPG_{ge}$) | Combined Fuel Economy—Charge Sustaining (MPG) |
|---|---|---|---|---|---|
| BMW | Active E | BEV | 94 | 102 | |
| BMW | i3 | BEV | 81 | 124 | |
| | | PHEV | 72 | 117 | 39 |
| BMW | i8 | PHEV | 15 | 76 | 28 |
| Smart USA | Smart ED | BEV | 68 | 107 | |
| Chevrolet | Volt | PHEV | 38 | 98 | 37 |
| Chevrolet | Spark | BEV | 82 | 119 | |
| Ford | Focus | BEV | 76 | 105 | |
| Ford | C-Max Energi | PHEV | 21 | 88 | 38 |
| Ford | Fusion Energi | PHEV | 21 | 88 | 38 |
| Honda | Accord | PHEV | 13 | 115 | 46 |
| Honda | Fit EV | BEV | 82 | 118 | |
| Mitsubishi | I EV | BEV | 62 | 112 | |
| Mercedes | B-Class | BEV | 87 | 84 | |
| Nissan | LEAF | BEV | 75 | 114 | |
| Toyota | Prius PHEV | PHEV | 11 | 95 | 50 |
| Toyota | RAV4 EV | BEV | 103 | 76 | |
| Tesla | Model S (60 kWh battery) | BEV | 208 | 95 | |
| Tesla | Model S (90 kWh battery) | BEV | 265 | 89 | |
| Fiat | 500E | BEV | 87 | 116 | |
| Porsche | Panamera S E-Hybrid | PHEV | 16 | 50 | 22 |
| Cadillac | ELR | PHEV | 37 | 82 | 33 |
| Volkswagen | e-Golf | BEV | 83 | 116 | |
| Kia | Soul EV | BEV | 93 | 105 | |

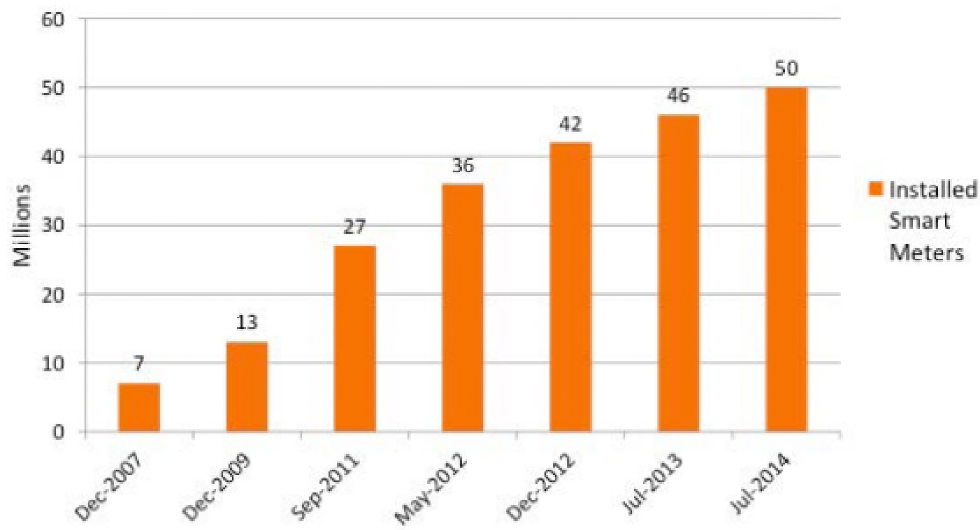
*MPG: miles per gallon, $MPG_{ge}$: miles per gallon of gasoline equivalent.*[b]

[a] *Charge depleting* means that the battery is providing most or all of the energy, and thus is being depleted; *charge sustaining* means that the PHEV is operating more like an HEV, with battery charge varying over a narrow range and most vehicle energy being provided by gasoline (or other conventional fuel).

[b] $MPG_{ge}$ is a metric used by EPA to compare the fuel efficiency of conventional and alternative vehicles. The calculation assumes 33.7 kWh of electricity is equal to one gallon of gasoline.

## 7.7 Distributed Energy Resources Appendix

**Figure 7.32. Smart meter deployment[796]**




*As of July 2014, 50 million smart meters were deployed in the United States, covering 43% of U.S. homes.*

**Figure 7.33. CHP is located in every state[797]**

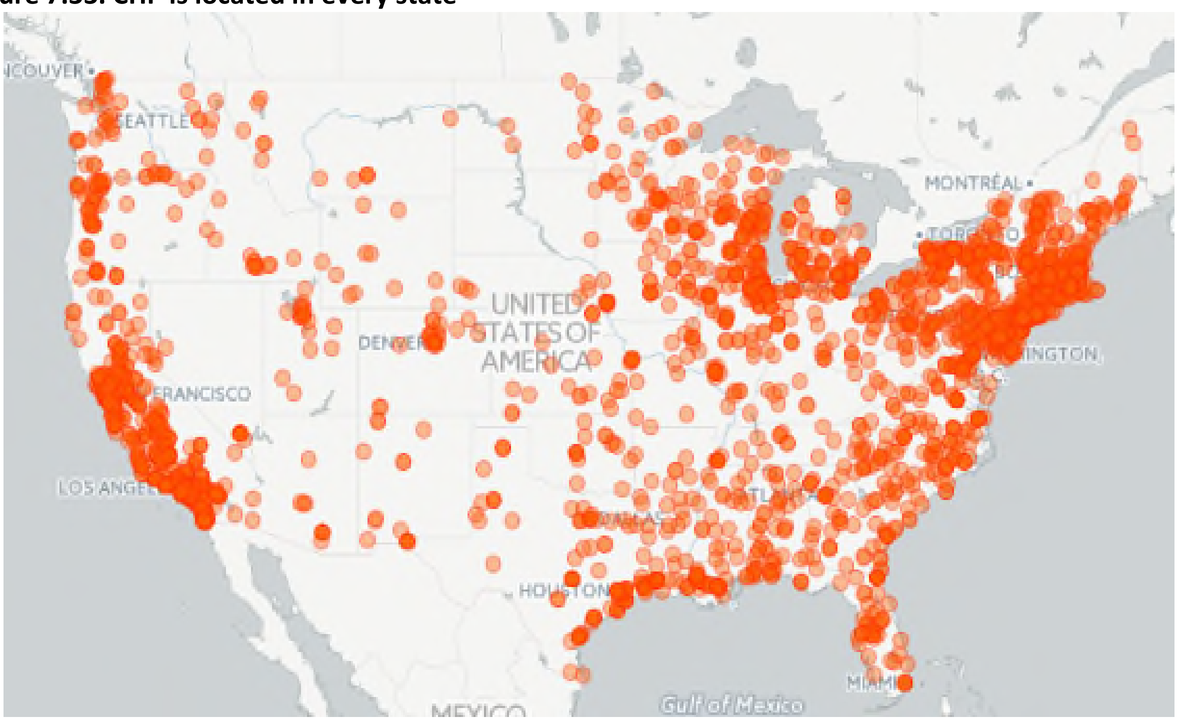
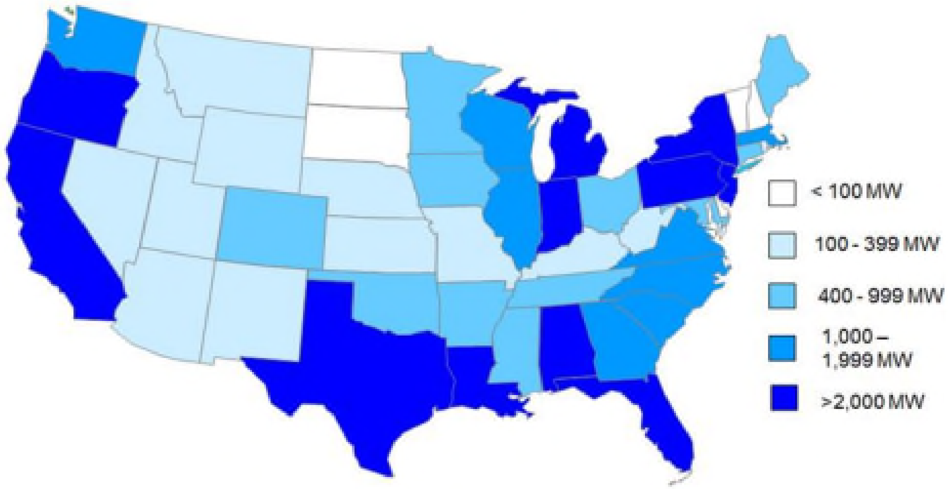
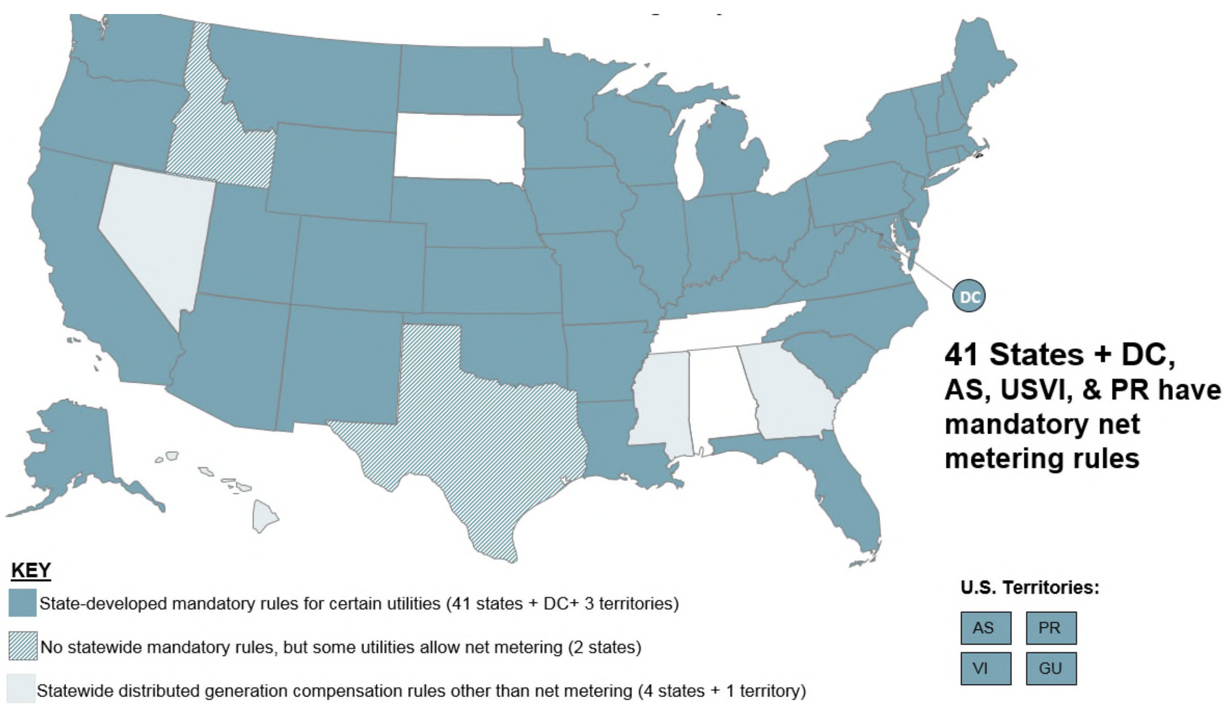


**Figure 7.34. Existing CHP capacity by state in 2012**[798]




*Alaska and Hawaii had 479 megawatts (MW) and 434 MW of CHP capacity in 2012, respectively*.

**Figure 7.35. States with net metering rules, as of July 2016**[799]




*Note: states without color do not have net metering rules.*

**Figure 7.36. Customer credits for monthly net excess generation (NEG) under net metering[800]**

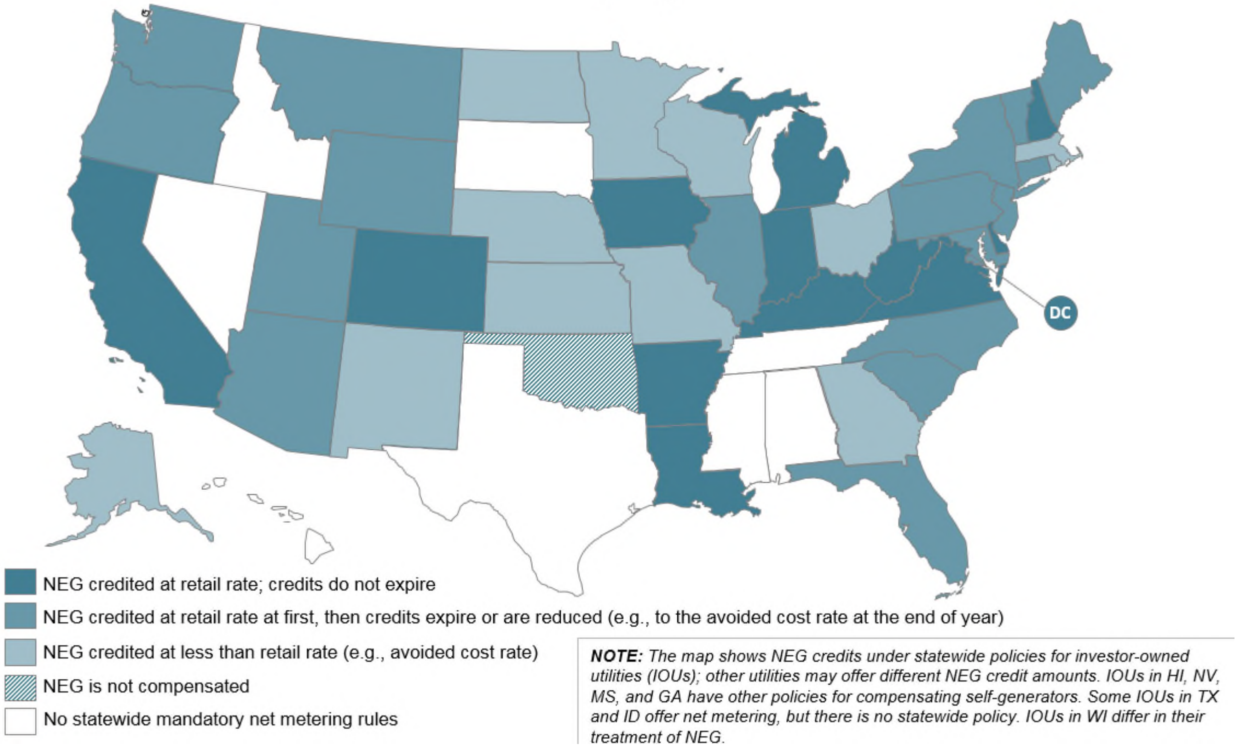
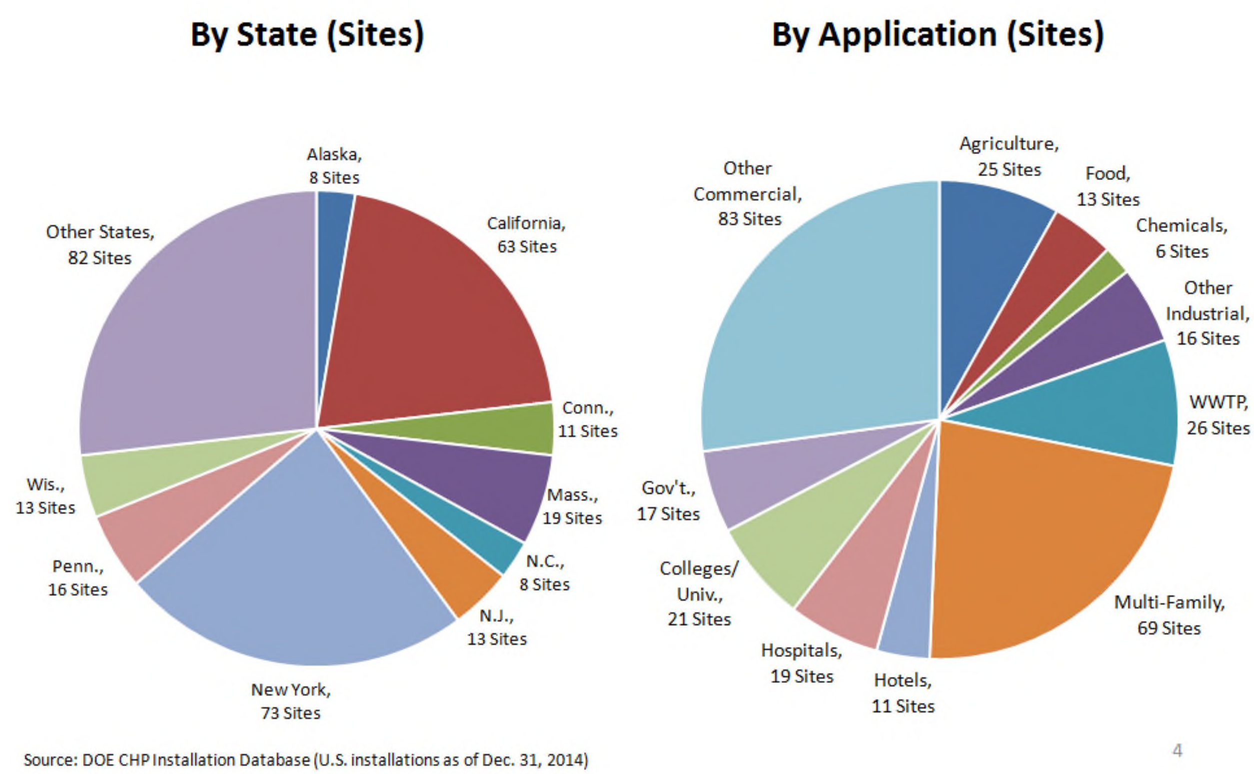



**Figure 7.37. CHP additions in 2013 and 2014[801]**




*CHP was installed at 306 sites in the two-year period. New York and California had the most new sites.*

## 7.8 Appendix: Evaluation, Measurement, and Verification of Energy Efficiency and Distributed Energy Resource Activities

This appendix describes current energy efficiency and distributed energy resource (DER) evaluation practices, issues associated with conducting reliable and cost-effective evaluation, and trends that may indicate how evaluation may be conducted and used over the next 25 years. Broadly, energy efficiency and DER evaluation activities include impact evaluations, savings projections (e.g., potential studies), process evaluations, market evaluations, and cost-effectiveness assessments. While terminology is not universally consistent within the efficiency industry, the term EM&V—evaluation, measurement, and verification—is often used as a catchall for all of these activities. Many associate the term EM&V with activities primarily designed to evaluate the impact of energy efficiency and DER programs or measures, which is a focus of this appendix. Also covered in this appendix are barriers to improving the application and quality of EM&V and the quality and availability of resulting data, policies that can help overcome those barriers, and gaps in our understanding. See the definitions of select EM&V terms that follow. Documenting the benefits of energy efficiency and DERs using credible and transparent methods is a key component of successfully implementing and expanding the role and efficacy of these resources. Therefore, providing evaluation-based data is not an end unto itself but an effective tool for supporting the adoption, continuation, and expansion of energy efficiency and DERs that are discussed in the body of this report.

**Figure 7.38. EM&V cycle[802]**


*Documenting impacts of energy efficiency and DERs can improve performance of policies, programs, and regulations supporting these activities.*

### *Definition of Select EM&V Terms[803]*

Baseline is a set of conditions that would have occurred without implementation of the energy efficiency activity. Baseline conditions are sometimes referred to as *business-as-usual.*

Deemed savings value, also called *stipulated savings value,* is an estimate of energy or demand savings for a single unit of an installed energy efficiency measure that: (1) has been developed from data sources and analytical methods that are widely considered acceptable for the measure and purpose and

(2) is applicable to the situation being evaluated. Individual parameters or calculation methods can also be deemed.

Demand savings is the reduction in electric demand from the baseline to the demand associated with the higher-efficiency equipment or installation. This term, in units of kilowatts (kW), is usually applied to billing demand to calculate cost savings or peak demand for equipment sizing purposes.

Energy savings is the reduction in electricity consumption from the baseline to the demand associated with the higher-efficiency equipment or installation. This term, in units of kilowatt-hours (kWh), can be applied to hourly, monthly, seasonal, annual, or lifetime savings.

Evaluation is the conduct of any of a wide range of assessment studies and other activities aimed at determining the effects of a program (or a portfolio of programs).

EM&V is a catchall term used to describe the processes associated with determining both program and project impacts (versus a wider range of evaluation activities).

Gross savings is the change in energy consumption, demand, or both that results directly from program-related actions taken by participants in an energy efficiency policy or program, regardless of why they participated.

Impact evaluation is an evaluation of the program-specific, directly or indirectly induced, changes associated with an energy efficiency program (e.g., changes in energy use).

Market evaluation is an evaluation of the change in the structure or functioning of a market or the behavior of participants in a market, which results from one or more program efforts. Typically, the resultant market or behavior change leads to an increase in the adoption of energy efficient products, services, or practices.

Measurement and verification (M&V*)* can be a stand-alone activity or a subset of program impact evaluation. In either case, it is associated with the documentation of energy savings at individual sites or projects.

Net savings is the change in energy consumption, demand, or both that is attributable to a particular energy efficiency policy or program.

Persistence is the duration of an energy-consuming measure, taking into account business turnover, early retirement of installed equipment, technical degradation factors, and other reasons that measures might be removed or discontinued.

Process evaluation is a systematic assessment of an energy efficiency program for the purposes of documenting program operations at the time of the examination, and identifying and recommending improvements to increase the program’s efficiency or effectiveness for acquiring energy resources while maintaining high levels of participant satisfaction.

Randomized controlled trial (RCT) is a type of experimental program evaluation design in which energy consumers in a given population are randomly assigned into two groups: a treatment group and a control group. The outcomes for these two groups are compared, resulting in program energy savings estimates.

Spillover (participant and non-participant) refers to reductions in energy consumption, demand, or both caused by the presence of an energy efficiency program, beyond the program-related gross savings of the participants and without direct financial or technical assistance from the program. There can be participant and non-participant spillover. *Participant spillover* is the additional energy savings that occur as a result of the program's influence when a program participant independently installs incremental energy efficiency measures or applies energy-saving practices after having participated in the energy efficiency program. *Non-participant spillover* refers to energy savings that occur when a program non-participant installs energy efficiency measures or applies energy savings practices as a result of a program's influence.

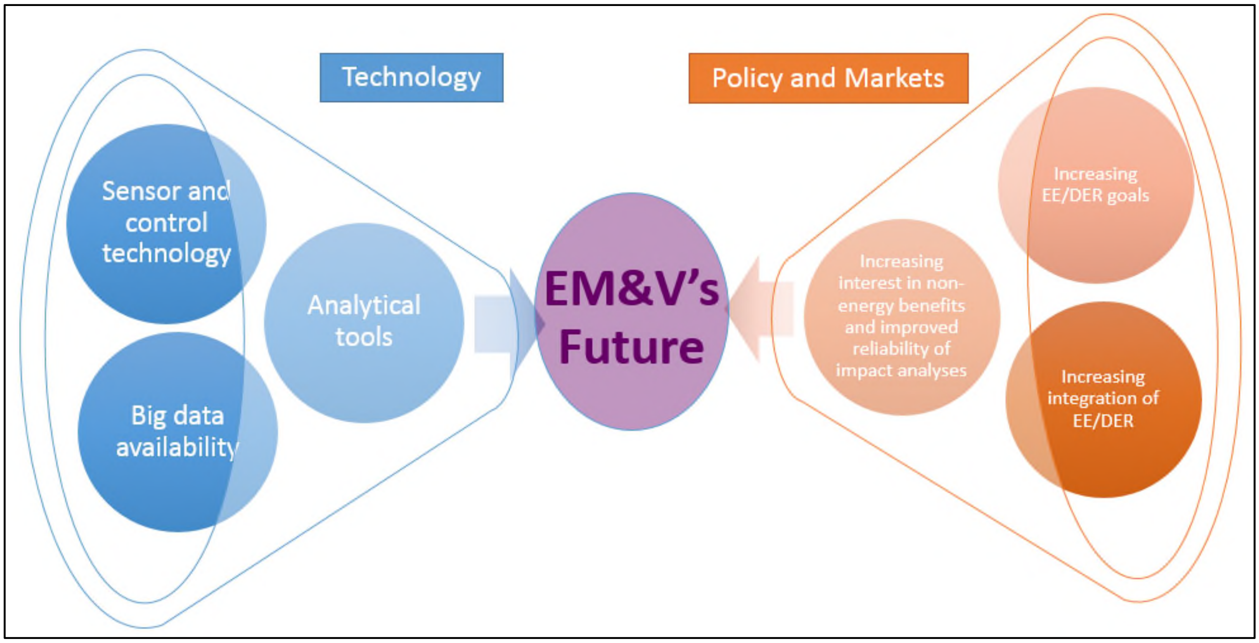
Technical reference manual (TRM) is a resource document that includes information used in program planning and reporting of energy efficiency programs. It can include savings values for measures, engineering algorithms to calculate savings, impact factors to be applied to calculated savings (e.g., net-to-gross ratio values), source documentation, specified assumptions, and other relevant material to support the calculation of measure and program savings—and the application of such values and algorithms in appropriate applications.

Verification is an assessment by an independent entity to ensure that the energy efficiency measures have been installed correctly and could generate the predicted savings. Verification may include assessing baseline conditions and confirming that the measures are operating according to their design intent. Site inspections, phone and mail surveys, and desk review of program documentation are typical verification activities.

### 7.8.1 Key Findings and Insights

A number of technology, policy, and market drivers will influence the future of EM&V for energy efficiency and DERs (Figure 7.39). The following findings are organized by these three types of drivers. These findings may help predict future trends regarding uses of EM&V and the value placed on various metrics assessed with EM&V, and thus the methods, tools, and services that will need to be developed. Together with the EM&V research gaps identified in Section 7.8.5, these findings lead to the insights described here. An overarching insight is that if stakeholders develop greater confidence in the benefits of energy efficiency and DER investments without the need to document such benefits, the importance placed on ex-post EM&V may be reduced. That may lead to greater use of ex-ante deemed savings values and simpler verification activities. On the other hand, higher goals for energy efficiency and DERs, the need to assess new energy efficiency and DER technologies and strategies, increased use of energy efficiency and DER technologies in the operation of distribution and transmission systems, increased use of performance contracting and third-party financing, and expanded goals for reducing greenhouse gas emissions may drive greater interest in all types of EM&V data (including energy and non-energy impact metrics). This will be particularly true if new tools can make EM&V more accessible by reducing EM&V transaction costs, increasing data reliability, and increasing timeliness of data availability.

**Figure 7.39. Drivers for future energy efficiency and DER EM&V**




### 7.8.1.1 *Technology Drivers*

*Findings:*

- Advances in the EM&V industry are continually occurring with more experience and accelerated development of new technologies and analytical tools. Prominent development areas include continuous energy management, top-down evaluation, M&V 2.0, and assessments of non-energy impacts.
- M&V 2.0 is an area of particular interest, where potential advances are based on access to better and more end-use energy consumption data from smart meters, advanced metering infrastructure (AMI), smart devices, and wireless and non-intrusive load metering (big data), as well as improved analytical tools. Such tools include automated M&V, benchmarking, and behavior analytics.
- While there is increased interest in M&V 2.0 advances, other approaches to evaluation (deemed savings and control group approaches), particularly for energy efficiency, are likely to continue to be highly relevant to energy and demand savings determinations.

*Insights*: Greater access to real-time and higher-time resolution data on energy consumption and independent variables (e.g., occupancy, plug load characteristics, control system settings), combined with the further development and implementation of advanced EM&V methods (e.g., M&V 2.0), may be able to provide deeper insights into energy use and energy use reduction and improve the speed at which change in energy consumption is determined at the desired levels of confidence (Section 7.8.5.2).

Further use of and refinements to (E)M&V 2.0 and auto-M&V data collection and analysis, driven in part by private sector providers of such services under the Software as a Service (SaaS) business models, could result in lower cost and more reliable and timely EM&V-based information. By flagging performance issues associated with energy efficiency and DER projects and programs (such as lower than expected savings due to equipment failures or changing occupant behaviors), these EM&V advances can support near real-time corrections that improve performance. However, to date there has been limited application of (E)M&V 2.0 processes (Sections 7.8.3.2 and 7.8.5.7).

Transmission and distribution system efficiency, building energy codes, appliance and equipment standards, and energy efficiency and DER financing programs are areas where EM&V is evolving (Sections 7.8.5.8, 7.8.5.9, and 7.8.5.10).

#### 7.8.1.2 *Policy Drivers*

*Findings:*

- Energy efficiency historically has been driven primarily by policy objectives associated with reducing energy consumption and displacing conventional, more-expensive, and more-polluting generation resources. Over time these policy objectives, as well as objectives for DER-related policies, have expanded to include other public policy goals, such as local economic development, grid resiliency, and renewable energy integration.
- These new policy drivers can affect both the metrics assessed through the EM&V process and the relative importance of accurately determining the impacts of energy efficiency and DERs. Accuracy can take on increased importance as public and private funders invest more in energy efficiency and DERs, and policy makers rely more on these resources for meeting electricity needs reliably and cleanly.
- One outcome of these higher expectations for energy efficiency and DERs is that the types of programs may expand—e.g., to include more aggressive energy codes and standards, more programs to reduce energy losses in transmission and distribution, more energy efficiency financing programs, and more integrated demand-side management (DSM) programs. This expansion of energy efficiency and DER program types will likely lead to the need for reliable EM&V for an expanding list of program types.
- For energy efficiency and DER activities supported with utility customer funds or public funds, there is a continuing interest in understanding the level of impacts—particularly electricity savings—that can be attributed to the supported intervention (often referred to as net savings) versus the total impacts (often referred to as gross savings). However, this level of interest varies depending on the perspective of involved parties. For example, a utility regulator that is connecting performance of energy efficiency programs to a utility's authorized earnings may want to know the attributable savings associated with the utility's energy efficiency programs. On the other hand, a governor or air regulator may only be interested in gross savings metrics for energy efficiency programs for the purposes of resource planning or emissions accounting.
- Supporters of M&V 2.0 may encourage jurisdictions to adopt gross savings and existing condition baselines as standards for measurement, as in California's 2015 Assembly Bill 802.[804] Such baseline standards can complicate issues of whether programs are delivering energy savings beyond what would have occurred absent the energy efficiency or DER program intervention—which can be an important objective of publicly or utility customer-funded programs. Thus, another possible outcome is that EM&V 2.0 tools eventually develop the capacity to overcome this limitation of only using existing condition baselines.

*Insights*: Increasing interest in non-energy impacts will drive increasing effort for documenting these impacts, particularly for (Sections 7.8.3.3 and Section 7.8.5.11):

- avoided emissions
- grid impacts
- economic development—e.g., jobs
- consumer benefits—e.g., increased comfort and productivity

Further development of approaches for defining baselines and assessing net savings associated with determining savings attribution will enable greater understanding of programmatic approaches to increasing the levels of energy efficiency and DER penetration and impacts (Sections 7.8.3.2 and 7.8.6.5).

Reliability of estimated measure lives and savings persistence for energy efficiency is increasingly important, indicating an increasing need for more research and documentation on these factors and better documentation of verification activities (See sections 7.8.4, 7.8.5.1, and 7.8.5.5,).
Top-down evaluation is gaining more traction as a bottom-line indicator of performance for energy efficiency and DER programs and policies. More pilot programs to test this approach, with government support, will need to be conducted, with a focus on improving access to the data required for such evaluations (Sections 7.8.3.1 and 7.8.5.7).

#### 7.8.1.3 *Market Drivers*

*Findings:*

- The objectives and perspectives of stakeholders involved in energy efficiency and DER activities also drive energy efficiency and DER markets. These diverse stakeholders include policy-makers, energy and environmental regulators, utilities, contractors, electricity consumers, businesses, and environmental advocates. Perspectives vary even within each of these groups. For example, perspectives of investor-owned utilities can be different from perspectives of municipal utilities and rural electric co-ops, and residential consumers may have different perspectives than industrial consumers. Following are three examples as they relate to EM&V:

    - Many consumers do not necessarily implement energy efficiency measures for the energy savings but to obtain other benefits such as increased system performance (e.g., variable speed drives in factories) or comfort (insulation in homes). For these consumers, the importance of a reliable energy savings determination (via M&V) may be quite limited. On the other hand, utility regulators and utilities themselves are often quite concerned with knowing, reliably, how energy efficiency and DER investments are performing.

    - It is typical to define baselines for utility customer programs, or a requirement in building energy codes or appliance or equipment standards, as some form of common practice. This is because it often makes sense from a public policy perspective not to use program funds to incent consumers to buy what they would have normally purchased or what they would be required to purchase—the attribution issue discussed above. The result is that it is common to define baselines for utility customer-funded programs based on existing building energy codes, appliance or equipment standards, or other considerations such as the remaining functional life of the equipment or systems being replaced.

- However, consumers look for savings from a baseline of what they had before they implemented a project. In effect, they want to see the savings as compared to past energy bills, not hypothetical bills. Also, for many energy service company (ESCO) contracts for large commercial customers, baselines are defined based on the existing condition of a specific building. Thus, baselines from which savings are determined can differ across the types of delivery mechanisms, particularly for energy efficiency activities.

- From an overall electric grid perspective, DERs such as demand response and energy storage can provide benefits for reliability and integration of renewable resources. For utilities and grid operators, these benefits can exceed in importance individual consumer energy savings and drive interest in new metrics and new EM&V tools and approaches. Similarly, increased interest in reducing greenhouse gas emissions also can lead to new metrics, focusing on avoided emissions from the grid.
- Therefore, EM&V uses, metrics, and even the need for EM&V, as well as requirements for reliability and timeliness of the EM&V results, vary by stakeholder. Much of the EM&V conducted in the United States to date for energy efficiency and demand response resources has been defined by the administrators and regulators of utility customer-funded programs. This could change in the future with evolving energy efficiency and DER activities and whether more or less of the funds for these activities are coming from the public (taxpayers), utility customers, or private financing providers. Meeting the needs of various stakeholders in turn drives energy efficiency and DER markets to focus on different strategies and different metrics for assessing these metrics, which in turn affects the EM&V to be conducted.

*Insights:* Standardization across the energy efficiency and DER industries of EM&V terminology, approaches, and reporting, as well as training and certification of EM&V professionals, is improving, in part driven by federal and state efforts and increased use of efficiency and DER resources for environmental protection and as bulk electric system reliability resources. Areas of particular focus for standardization could include the following (Section 7.8.5.3):

- Defining consistent baseline option definitions and when each can or should be applied, with clarifications on the difference between net savings, common practice baselines, and savings attribution
- Greater understanding of the advantages and disadvantages of the various approaches for assessing impact attribution and, thus, how savings attribution metrics can be appropriately applied
- Reporting of energy efficiency and DER metrics with consistent definitions and in consistent formats for benchmarking and comparison
    - Deemed savings are becoming more prevalent for energy efficiency equipment retrofit measures, with a corresponding increase in the validity of how the values are applied, documented, and used in order to decrease EM&V costs and increase certainty for energy efficiency funders, contractors, and consumers. The use of deemed savings requires that there be an understanding that the savings from implemented measures can vary based on usage, which requires caution in how deemed savings are applied. The appropriate use of deemed savings may be limited to behavior-based energy efficiency actions unless significant amounts of data can be provided that support such stipulation of average impacts (Sections 7.8.2.1 and 7.8.5.7).
    - Statistical analyses using control group approaches (randomized control trials and quasi-experimental) will continue as a preferred option for documenting impacts of mass-market energy efficiency and demand response strategies, such as whole-house retrofits. However, for control groups to be used more broadly, they will need to be adapted for applications where control groups cannot be readily identified (such as efficiency projects for nonresidential buildings) or where limiting access to programs in order to form control groups is seen as problematic. New efforts may be forthcoming to find ways to apply control group approaches to more program types, as well as to improve the methods themselves (Sections 7.8.2.1 and 7.8.5.7).

### 7.8.2 EM&V Characterization

This section describes current EM&V trends, approaches, and practices for determining energy savings, avoided air emissions, and other non-energy impacts. While the energy impacts of some DERs, such as distributed generation, can be directly measured, the impacts of energy efficiency and demand response activities, such as energy savings and demand savings, cannot be directly measured. Instead, impacts are estimated based on counterfactual assumptions. The need for counterfactual assumptions can create uncertainty and add time to the EM&V process, as well as create a fundamental need to balance the reliability of impact estimates with the cost of obtaining such estimates through EM&V. EM&V costs are difficult to document and even define, but are generally considered to add 1% to as much as 15% in rare cases to the cost of energy efficiency activities, with EM&V costs for third-party evaluation of utility DSM efficiency programs typically on the order of 3% to 5% of total expenditures for these programs. Thus, while EM&V has substantial benefits for providing data to assess energy efficiency and DER activities, associated uncertainty, delays in program results, and costs can limit the commitment to and confidence in energy efficiency activities.

> This appendix covers ex-post evaluation of energy efficiency and DER activities. Another form of evaluation is ex-ante determination of savings potential. These determinations are documented in feasibility studies or potential studies, which are intended to assess potential savings and benefits from future projects or programs, respectively.

> An industry standard guide to EM&V is the SEE Action Energy Efficiency Program Impact Evaluation Guide. It describes and provides guidance on approaches for determining and documenting energy and non-energy benefits resulting from energy efficiency programs and portfolios of programs. It specifically focuses on impact evaluations for ratepayer funded programs designed to reduce facility (e.g., home, commercial building, factory) energy consumption, demand, or both—as well as related air emissions. The guide is available at: www.seeaction.energy.gov.

#### 7.8.2.1 *Generic EM&V Categories and Methods*

Evaluation includes any of a range of retrospective assessment studies and other activities aimed at determining the effects of energy efficiency and DER policies, portfolios, programs, or projects. Evaluation can document metrics such as performance (e.g., energy and demand savings, avoided air emissions), changes in markets (e.g., changes in product and services availability and pricing), and cost-effectiveness. There are three broad categories of energy efficiency and DER evaluations: impact evaluations, process evaluations, and market evaluations.

This appendix focuses on impact evaluation of both (1) programs, portfolios, and policies, and (2) individual projects. Evaluation is the typical term associated with assessing programs (and program portfolios and policies); M&V is associated with assessing project impacts. There can be some overlap between M&V and evaluation since programs are often made up of individual projects. Thus, impacts determined with M&V for all, or representative, projects in a program can be combined to assess the impacts of the underlying program.

- Evaluation of energy efficiency and demand response program and portfolio evaluation started in the 1980s, with the development of programs operated by utilities. Starting in the early 1990s, handbooks, guidelines, and protocols were developed for utility DSM programs, some prepared by individual utilities or state public utility commissions and others supported by the U.S. Department of Energy (DOE). While evaluations also can be performed for other DER strategies, such as distribution generation and energy storage, the focus of EM&V activities for the last 40 years has been on energy efficiency and demand response.

- M&V focuses on assessing individual measures or project impacts using project site measurements and inspections (verification) activities. M&V was first developed for energy efficiency in the 1980s to support the nascent ESCO industry to document savings, which continues to be critical for ESCO performance-based contracts with savings guarantees. The National Association of Energy Service Companies developed the first M&V guidance documents. Shortly thereafter, in the 1990s, the North American Energy M&V Guidelines (NAEMVP), the Federal Energy Management Program (FEMP) M&V Guidelines, and the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) M&V Guidelines were developed with support from DOE and industry groups. Other efforts at individual companies, utilities, and universities also supported the creation of M&V methodologies, metering, and analysis tools. The FEMP and ASHRAE guidelines have been expanded and modified over the last two decades. The NAEMVP evolved into the International Performance Measurement and Verification Protocol (IPMVP), now the most recognized international M&V guidance document

***Examples of Industry-Standard M&V Protocols and Guidelines***

**IPM VP**: International Performance Measurement and Verification Protocol: Core Concepts 2015, Efficiency Valuation Organization. www.evo-world.com.

**FEMP**: M&V Guidelines: Measurement and Verification for Performance-Based Contracts, Version 4.0. Prepared for the U.S. Department of Energy Federal Energy Management Program. http://energy.gov/eere/femp/downloads/mv-guidelines-measurement-and-verification-performance-based-contracts-version.

**ASHRAE Guideline 14:** Measurement of Energy and Demand Savings. American Society of Heating, Refrigerating, and Air Conditioning Engineers. http://www.ashrae.org.

**U.S. DOE UMP**: Uniform Methods Project. http://energy.gov/eere/about-us/ump-protocols.

The IPMVP defines four M&V options for determining the energy and demand savings from projects: two end-use metering (retrofit isolation) approaches (IPMVP Options A and B), energy use data (billing data) regression analysis (IPMVP Option C), and calibrated computer simulation (IPMVP Option D). In addition, DOE has an M&V initiative called the Uniform Methods Project (UMP). Starting in 2013, DOE began publishing UMP protocols to determine measure and project energy savings. The protocols provide standardized, common practice M&V methods for determining gross energy savings for many of the most common residential and commercial measures and programs offered by administrators of energy efficiency programs in the United States for utility customers.

Today, most utility efficiency and DER programs have some form of evaluation guidelines in place. M&V is one way that programs are evaluated; for example, M&V is applied to a sample of projects, and the results are applied to the entire program population of projects. However, there are two other distinct methods commonly used for program assessments: (1) using deemed (also called *stipulated*) savings values and calculations, and (2) comparison group methods. Using deemed savings is not considered M&V, as M&V (as defined by the IPMVP) always requires some level of site measurements (see text box).

*Industry Standard Evaluation Approaches/Methods for Energy Efficiency and Demand Response*

***Deemed savings values*** are estimates of electricity savings for a single unit of an installed energy efficiency measure that: (1) have been developed from data sources (such as prior metering studies) and analytical methods that are widely considered acceptable for the measure and purpose, and (2) are applicable to the situation under which the measure is being implemented. When deemed savings are used to quantify electricity savings, a separate verification process is needed to confirm the quantity of units installed. Deemed savings should be updated, as needed, based on measurement-based evaluation information.

***Measurement and verification*** is the process of determining savings from individual energy efficiency measures or projects. The IPMVP defines **two retrofit isolation options** and **two whole-facility options:**

- *Retrofit isolation:* Assessing savings from each energy efficiency measure individually (IPMVP Options A & B). Verification is an integral part of Options A and B since the measurement process involves direct observation of all or a sample of the affected equipment.
- *Whole facility:* Collectively assessing savings from all energy efficiency measures in a facility (IPMVP Option C, review of energy bills, or Option D, calibrated simulation). With Option C, the energy consumption data speak for themselves with respect to savings, and thus inspections may not be required. However, it is a best practice to include some site inspections. With Option D the calibration process typically involves some level of site inspections and thus verification.

***Comparison group EM&V methods*** determine program savings based on the differences in energy consumption between a comparison group and program participants. Comparison group approaches include randomized control trials and quasi-experimental methods. Because the effects of implemented measures are reflected in the observed participant-comparison differences, separate verification is not required.

For energy efficiency, determining energy savings includes: (1) verifying that a measure or project has been installed and, in some cases, that it is properly operating, and (2) quantifying savings. With deemed savings, verification is a critical element of the overall evaluation process. As discussed in the text box, verification may or may not be an integral part of M&V activities. However, under the comparison group method, the evaluation approach may in effect include both steps in a single process.

The United States' EM&V experience has been used in other countries through programs such as those of the World Bank, United States Agency for International Development, and the International Energy Agency (IEA). An example of IEA-organized transfer of EM&V technology and experience is efforts of the IEA Demand Side Management Energy Efficiency program, an international collaboration of 16 countries and sponsors, including the United States, working together to develop and promote opportunities for DSM.[805] In addition, the Energy Efficiency Division at the IEA has relied on U.S. experts for many of its publications that address EM&V topics.[a]

[a] See the IEA's Energy Efficiency webpage for a list of publications, many featuring United States' programs and case studies, accessed February 25, 2016: http://www.iea.org/topics/energyefficiency/.

### 7.8.2.2 *EM&V Practices—Energy and Demand Savings*

*Current Industry EM&V Practices*

Impact evaluation has primarily been used for, and is most developed for, utility energy efficiency and demand response programs and projects implemented directly by ESCOs. Energy efficiency EM&V strategies in wide use today—including budget levels, oversight procedures, and preferred methods—are derived from utility regulatory agency requirements together with industry standard energy efficiency EM&V and M&V protocols (see text box). For a given program or project, the specific EM&V approach that is applied depends on the type of activity, overall policy objectives, available budgets, and other factors.

Demand response program EM&V has also been developed based primarily on utility program impact evaluations, starting with demand response programs in the 1990s in states such as California, Colorado, Minnesota, and Texas. As with energy efficiency, demand response EM&V involves comparing measured (actual) energy consumption over a specific period of time (e.g., utility coincident peak demand hours) with a counterfactual demand either in aggregate (for example, with a residential air-conditioning cycling program) or per site (such as with an industrial demand response program). Today, the most well-known documented M&V methods are those used by two Independent System Operators (ISOs)—ISO New England (ISO-NE) and PJM, first implemented in 2007 and 2009, respectively. These organizations have established forward capacity markets that pay suppliers of demand-side resources. The oversight and quality control of energy efficiency resources that are bid into the market are governed by M&V rules and requirements defined in evaluation manuals established by these organizations.[806]

For building energy codes and product energy efficiency standards, the situation is different with respect to retrospective EM&V. While ex-ante estimates of the impacts of building energy codes and product standards are completed regularly as they are developed and adopted, ex-post quantification of energy savings from building energy code adoption and compliance activities is not as common or well established. The primary code adoption and compliance impact evaluation work to date has been completed in six states (Arizona, California, Massachusetts, New York, Oregon, Rhode Island, and Washington) and at Pacific Northwest National Laboratory (PNNL)[807] for DOE. These states have regulatory structures that define acceptable procedures for quantifying savings from building energy code programs and attribute code program savings to energy efficiency program administrators.[808] Similarly, only a limited number of ex-post energy saving studies have been completed for product energy standards. California has conducted three cycles of energy code and appliance standard evaluations for its statewide Codes and Standards Program.[809]

DOE released a federal Funding Opportunity Announcement, "Strategies to Increase Residential Energy Code Compliance Rates and Measure Results,"[810] in 2014. To support the evaluation of pilot programs conducted under this initiative, PNNL is modifying evaluation procedures, released in 2010,[811] to develop a new residential energy code compliance and energy savings methodology.

EM&V performed for distributed generation and storage at utility customer sites is far more straightforward because, under current practice, it does not involve development of a counterfactual scenario. For example, the output of solar photovoltaic (PV) systems is simply measured with a utility-grade meter to determine generation output. Metrics reported for storage, such as round-trip energy losses, also use a utility-grade meter to measure electricity input and output.

Table 7.10 provides a heuristic indication of which EM&V approaches are used for various types of programs and projects. The most common EM&V approach is deemed savings values. These values, if properly developed and applied, can support reliable savings estimates. They also provide certainty for all the parties involved in an energy efficiency or DER transaction.

**Table 7.10. Common EM&V Approaches for Select Energy Efficiency and Demand Response Categories and Project Types**

| | **EM&V Methods** | | |
|---|---|---|---|
| | Deemed Savings | Measurement and Verification | Comparison Groups |
| **Program Categories** | | | |
| **Utility Programs: direct action measures**[a] | Very common | Common | Common |
| **Utility Programs: indirect action measures**[b] | Common | Not common | Common |
| **ESCO Energy Efficiency Projects** | Common | Very common | Not used |
| **Building Energy Codes** | Common | Can be used | Can be used |
| **Product Standards** | Common | Can be used | Can be used |
| **Energy Storage** | Common | Very common | Can be used |
| **Industrial Strategic Energy Management and Voluntary Efforts** | Common | Common | Not used |

[a] *Direct action programs* are those that result in the *direct, explicit* installation of pieces of equipment or systems, as well as modifications of equipment, systems, or operations. Examples include consumer product rebates, incentives or technical assistance for construction of new buildings, and street lighting retrofits.
[b] *Indirect action programs* are those intended to *facilitate or indirectly result in installation* of equipment or systems, as well as modifications of equipment, systems, or operations. Examples include consumer behavior programs; marketing, education and outreach programs; and workforce education and training programs.

| | | | |
|---|---|---|---|
| **Demand Response** | Can be used | Very common | Can be used |
| **Distributed Generation: PV** | Common | Very common | Can be used |
| **Distributed Generation: CHP** | Can be used | Very common | Can be used |
| **Storage** | Can be used | Very common | Can be used |
| **Project Types** | | | |
| **Simple, Well-Defined Individual Projects** | Very common | Can be used | Not used |
| **Complex, Unique Individual Projects** | Not used | Very common | Not used |
| **Large Number of Relatively Homogenous Projects** | Very common | Can be used | Common |

Technical Reference Manuals (TRMs) are databases of standardized, state- or region-specific deemed savings calculations and associated deemed savings values for well-documented efficiency measures. Efficiency program administrators and implementation contractors use TRMs to reduce evaluation costs and uncertainty. There are approximately 20 TRMs in use across the United States. A 2011 report found that TRMs are very valuable, but there is wide variation in methodologies for estimating savings and actual values.[812] Some TRMs include information based on prior year evaluations including, in some cases, rigorous metering and analysis. Thus, these TRMs contain robust (reliable) savings values. Many others have values based on what may be considered less rigorous analyses. With the exception of the Northwest Regional Technical Forum, which uses a public peer-review process to determine consistency with clear guidelines, TRMs typically are created by skilled teams of expert consultants, but these teams' methods and assumptions are not necessarily peer-reviewed prior to approval.

The U.S. Environmental Protection Agency (EPA) Clean Power Plan (CPP) indicates that well-crafted and documented deemed savings values are an acceptable EM&V method that can provide consistency, quality Emission Rate Credit values, and cost-effective EM&V. As indicated in the draft CPP EM&V Guidance document, "Ongoing and new state, regional, and federal efforts to improve the quality and documentation of TRMs are encouraged and can support higher-quality savings values for compliance with the EPA's emissions guidelines and reduced EM&V costs."[813] [a] Furthermore, anecdotal information indicates that deemed savings values are very commonly used for savings determinations with utility energy efficiency programs and are also applied in some ESCO projects.

Measurement and verification methods are another approach to EM&V for utility customer-funded energy efficiency and demand response programs as well as ESCO projects. The IPMVP retrofit isolation methods, IPMVP Options A and B, and the billing analysis approach of using a project's pre-project and post-project utility bills for analysis, appear to be the more common M&V methods, versus calibrated simulations, IPMVP Option D. One study of DOE's Energy Savings Performance Contract program further indicated that for those ESCO projects, the most common M&V approaches were IPMVP Options A and B.[814] These have historical limitations associated primarily with cost of metering (equipment and labor), which project participants are not interested in paying for, particularly over the life of projects. This may be changing with the M&V 2.0 developments discussed in the next section of this appendix.

A third approach, comparison group analyses with non-participant control groups, has been used for decades for residential efficiency programs with large numbers of relatively homogenous participants. There has been renewed interest in this approach for a wide range of program types, as a potential gold standard of savings determination. At least in theory, comparison group analyses assess the savings just associated with the efficiency activity or DER activity, and not changes in energy consumption or demand associated with outside factors such as changes in the economy and energy prices or savings from those consumers who would have completed the projects outside of program influences (e.g., free riders).[b] The challenges for comparison group approaches include reasonably applying them to populations of non-homogenous, customized projects (such as efficiency in commercial, institutional, and industrial facilities) and structuring a control group; particularly if done randomly (at least in part to

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[a] This is also consistent with EPA's final CPP Emission Guidelines, which indicate that state plans must require "a demonstration of how savings will be quantified and verified by applying industry best-practice protocols and guidelines, as well as explanation of the key assumption and data sources used." From FR 64909, accessed May 5, 2016, https://www.gpo.gov/fdsys/pkg/FR-2015-10-23/pdf/2015-22842.pdf.

[b] How well the control group approach, in practice, achieves true incremental and net impacts depends on the specific approach applied (randomized control trials are more reliable than quasi-experimental methods) and how well the approach is implemented.

avoid self-selection biases), that may mean that some eligible consumers do not get to participate in the efficiency activity. Costs for well-designed and implemented control group analyses, especially when randomized control groups are used, may exceed costs for other approaches, particularly the use of deemed savings.

#### 7.8.2.3 *EM&V Practices—Energy Impact Metrics*

*Energy and Demand Savings*

EM&V is used to determine both energy and demand savings. The most typical metrics for energy savings are annual and lifetime savings. In some cases, monthly or even hourly savings are determined for purposes such as detailed cost-effectiveness analyses or for troubleshooting possible deficiencies in the performance of efficiency measures. Metrics for demand savings can be more complex. They are presented in the form of annual or seasonal average savings, maximum demand reductions, or demand reductions coincident with peak demand characteristics of the electric grid. Methods used to estimate demand savings may not be the most appropriate method to estimate energy savings—and vice versa.[815] Some approaches for estimating annual energy savings (such as monthly billing data analysis) do not provide peak demand savings directly. Table 7.11 is a summary of approaches to determine peak demand and time-differentiated energy savings.

**Table 7.11. Demand Savings Determination Approaches for Peak and Time-Differentiated Savings[816]**

| Approach | Relative Cost | Relative Potential Accuracy | Comments |
|---|---|---|---|
| Engineering Algorithms | Low | Low-Moderate | Accuracy depends on the quality of the input assumptions as well as the algorithm |
| Hourly Simulation Modeling | Moderate | Moderate | Input assumptions are again important—garbage in, garbage out. Appropriate for HVAC and shell measures and HVAC interaction |
| Billing Data Analysis | Moderate | Moderate | Typically not useful for peak demand or on/off peak energy analysis |
| Interval Meter Data Analysis | Moderate | High | Interval meter data not available for many customers. Becoming more feasible with proliferation of advanced metering infrastructure (AMI) |
| End-Use Metered Data Analysis | High | High | Requires careful sampling and consideration of period to be metered |

*Gross and Net Savings*

There are two common ways in which energy savings are reported for energy efficiency programs funded by utility customers:[817]

- Gross savings: Changes in energy consumption that result directly from program-related actions taken by participants of an energy efficiency program, regardless of why they participated.
- Net savings: Changes in energy use that are attributable to a particular energy efficiency program. These changes may implicitly or explicitly include the effects of free ridership, spillover, and induced market effects.

*Free ridership* is the program savings attributable to program participants who would have implemented a program measure or practice in the absence of the program. Free ridership savings are included in gross savings, but are typically removed from net savings. *Spillover* refers to additional reductions in energy consumption or demand that are due to program influences beyond those directly associated with program participation. Spillover savings are not included in most gross savings determination methods, but are sometimes included in net savings determinations. *Market effects* refer to "a change in the structure of a market or the behavior of participants in a market that is reflective of an increase in the adoption of energy efficiency products, services, or practices and is causally related to market intervention(s)."[818]

Net savings apply only to certain energy efficiency program categories, primarily programs funded by utility customers and, in the cases where they are evaluated, building energy codes and product standards. ESCO projects and other types of individual consumer actions are only assessed on the basis of gross savings, as the issue of attribution is not relevant to the project participants and funders. In terms of how different jurisdictions define net savings, and which of the above factors are included, a 2012 American Council for an Energy-Efficient Economy study found that states are not consistent as to whether they report gross savings, net savings, or both, and in terms of net savings there appears to be more states making free rider adjustments than spillover adjustments.[819] [a]

Evaluators generally agree that net savings research can be useful for:[820]

- Gaining a better understanding of how the market responds to programs and using that information to modify the program design
- Gleaning insight into market transformation over time by tracking net savings across program years and determining the extent to which free ridership and spillover rates have changed
- Informing resource procurement plans, which require an understanding of the relationship between efficiency levels embedded in base-case load forecasts and additional net reductions from program
- Assessing the degree to which programs effect a reduction in energy use and demand.

### *Cost-Effectiveness*

Cost-effectiveness is of keen interest to policy makers, utility regulators, program providers, and consumers. Definitions of *cost-effectiveness* vary according to the perspectives of different stakeholders. Table 7.12 provides the classic definitions of cost-effectiveness as defined in the California Standard Practice Manual. More recent work to update cost-effectiveness testing frameworks for efficiency and demand response has been recently completed[821] or is underway.[822]

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[a] It is important to recognize that the study survey did not specify any particular definition of what qualifies as net or gross savings. Rather, the survey allowed states to categorize their own approach. The report states, "… 21 states (50%) said they reported net savings, 12 states (29%) said gross savings, and 9 states (21%) said they report both (or use one or the other for different purposes). We explored the net savings issue in a little more detail, and asked whether states made specific adjustments for free riders and spillover. Interestingly, while 28 states (67%) indicated they make an adjustment for free riders, only 17 states (44%) make an adjustment for free drivers/spillover."

**Table 7.12. Standard Definitions of Cost-Effectiveness for Energy Efficiency**[823]

| TEST | ACRONYM | KEY QUESTION ANSWERED | SUMMARY OF APPROACH |
|---|---|---|---|
| **Participant cost test** | PCT | Will the participants benefit over the measure life? | Comparison of costs and benefits of the customer installing the measure |
| **Program administrator cost test** | PACT | Will utility bills increase? | Comparison of program administrator costs to supply-side resource costs |
| **Ratepayer impact measure** | RIM | Will utility rates increase? | Comparison of administrator costs and utility bill reductions to supply-side resource costs |
| **Total resource cost test** | TRC | Will the total costs of energy in the utility service territory decrease? | Comparison of program administrator and customer costs to utility resource savings |
| **Societal cost test** | SCT | Is the utility, state, or nation better off as a whole? | Comparison of society's costs of energy efficiency to resource savings and non-cash costs and benefits |

The results of impact evaluations typically provide data for cost-effectiveness determinations. Data required can include monetized benefits (primarily energy and demand savings), project costs, program costs, project lifetime and, in some cases, non-energy benefits (see the next section). The findings help judge whether to retain, revise, or eliminate program elements and provide feedback on whether efficiency is an effective investment, compared with energy supply options. The quality of data used for cost-effectiveness determination, particularly factors such as project lifetimes and project costs, varies.[824] As EM&V methods become more accurate and less expensive to administer, they will also help improve the analysis of the cost-effectiveness of energy efficiency program administration.

### 7.8.3 EM&V Trends

The prior section described current EM&V practices. General trends associated with advancing current practices are improving the quality (i.e., accuracy, reliability) of energy and demand savings estimation as well as non-energy impacts, the speed at which EM&V results are available, and consistency in the terminology and procedures associated with EM&V. These are driven by changes in technologies, policies, and markets (including stakeholder perspectives) as summarized in the Findings and Insights subsection at the beginning of this appendix. In addition to these "natural" or "maturing" improvements in EM&V, this section discusses three specific EM&V approaches and metric trends: top-down evaluation, EM&V 2.0, and impact evaluation of non-energy benefits. The accompanying text box describes continuous energy management, which uses M&V-type information to directly improve the performance of energy efficiency and DER technologies and systems.

*Continuous Energy Management*

DOE has fostered the development of standardized practices to incorporate energy management into business management through programs such as Better Plants, ISO 50001 and Superior Energy Performance. These programs incorporate transparent and rigorous tracking of energy usage to regularly identify opportunities for continuous improvement in energy performance (energy savings).

*See "Current Practice: Energy Efficiency Savings Determination," SEAB Task Force on Federal Energy Management, Sept. 11, 2015, William C. Miller, Lawrence Berkeley National Laboratory*

#### 7.8.3.1 *Top-Down Evaluation*

*Top-down* evaluation involves macroeconomic modeling, in contrast to the EM&V approaches and methods described above which are sometimes referred to as *bottom-up* evaluation. Top-down evaluation involves evaluating portfolios of energy efficiency programs using: (1) aggregate (e.g., utility service area, county, Census block) energy use or per-unit energy consumption indices (e.g., energy consumption per unit of output or per capita), and (2) energy-use driver data (e.g., income, prices, population) to determine savings from portfolios of programs.

Top-down evaluation focuses on the bottom line—reductions in energy use (and/or demand) for a state, region, or utility service territory. This gives top-down evaluation a direct link to (1) demand forecasting and resource planning, and (2) emissions accounting and forecasting—for example, as used to track progress toward achieving state goals for reducing greenhouse gas emissions. A limited number of top-down evaluations and pilot studies have been performed. Perhaps the most current were prepared in 2015 as part of a multi-year initiative designed to assess the utility of top-down modeling as a viable technique for evaluating energy efficiency programs in Massachusetts.[825] These evaluations showed promising potential but also indicated that more effort is required to refine analysis tools and improve access to data.[826]

#### 7.8.3.2 *EM&V 2.0*

EM&V 2.0 is catchall term for recent advances in metering, data availability, and analytical tools associated with documenting the energy and demand savings from specific energy efficiency measures or projects. EM&V 2.0 involves applying these advances to program evaluations. One rapidly developing area of EM&V 2.0 is automated M&V (auto-M&V), which can use a combination of automated data collection (e.g., 15-minute, hourly, or monthly energy data and corresponding temperature data) and processing, machine learning, and open-source or "black-box" analytical tools to calculate savings at a site or at the program level. These tools use independent variable data that can be readily obtained (e.g., ambient temperatures and time of day, day of week, season). This is similar to energy billing analyses that have been conducted for decades, but using richer data sets and better analytics.

Another developing field is behavioral analytics, which involves drawing insights from high-frequency, human-focused data that reflect how people behave—for example, data that indicate how much energy people are consuming on an hourly basis, thus indicating which appliances they are using. This kind of analysis has the potential to provide tremendous value to a wide range of energy programs. For example, using highly disaggregated and heterogeneous information about actual energy use, program implementers may be able to target specialized energy efficiency or demand response programs to specific households, conduct EM&V of programs on a much shorter time horizon than previously possible, and provide better insights into the energy and peak-hour savings associated with specific types of energy efficiency and demand response programs (e.g., behavior-based programs).[827]

***EM&V 2.0 Methods and Data Collection Tools***

M&V 2.0 is formally defined as *"The leveraging of smart grid investments, advances in interval meter data, nonintrusive load monitoring, and equipment-embedded sensors and controls to provide new tools with potential to reduce the cost of M&V, produce more timely results with higher confidence and transparency, and thereby increase the acceptance of the savings calculations."** These concepts have been further applied to evaluation to create another term—EM&V 2.0.**

Examples of EM&V 2.0 methods and data collection tools include the following:

- "Big Data" analytics **-** process of examining large quantities of data to uncover hidden patterns, unknown correlations and other useful information that can be used to make better decisions
- Automated M&V – calculating savings without direct human interaction
- Behavior analytics **-** providing insights into how people make energy decisions
- Benchmarking **-** measuring a building's energy use and then comparing it to the average for similar buildings, to allow owners and occupants to understand their building's relative energy performance and help identify opportunities to cut energy waste
- Smart meters and advanced metering infrastructure (AMI) – utilizing short time frame interval meter data
- Smart devices—e.g., thermostats, appliances and energy management systems
- Wireless metering – utilizing transducers that do not need to be connected to monitoring stations via wires
- Non-intrusive load metering **-** analyzing changes in the voltage and current going into a building or the run times of in-house systems, and deducing what appliances or equipment are in use and measuring their energy consumption

*References:*

- Jessica Granderson, Samir Touzani, Claudine Custodio, Michael Sohn, Samuel Fernandes, and David Jump, *Assessment of Automated Measurement and Verification (M&V) Methods*, Lawrence Berkeley National Laboratory, July 2015, LBNL-187225, 5.

** Tom Eckman, "EM&V 2.0 – New Tools for Measuring Energy Efficiency Program Savings," Electric Light & Power Newsletter, February 2014, http://www.elp.com/Electric-Light-Power-Newsletter/articles/2014/02/em-v-2-0-new-tools-for-measuring-energy-efficiency-program-savings.html.

The potential benefits of (E)M&V 2.0, particularly with auto-M&V, include the following:

- The time period for analyses can be reduced from the typical 9 to 12 months of pre- and post-project implementation data to as little as just a few weeks of data collection and analyses to reliably determine savings, making results available faster.[a]
- The overall cost of (E)M&V will be lower, which reduces a barrier to investment in efficiency by consumers and utilities.
- More standardized analytics will enable a strongly constructed, reliable calculation-checking process.

In the future, determining energy and demand savings from efficiency programs has the potential to be dramatically different than the current paradigm because of smart grid investments, combined with other technological advances in residential interval meter data, nonintrusive load monitoring, and

[a] A recently released research report reviews the efficacy of short-term metering: ASHRAE RP-1404, http://www.techstreet.com/products/1872406.

equipment-embedded sensors and controls that will give evaluators new tools with the potential to reduce the cost of EM&V, produce more timely results, and increase the acceptance of the savings calculations.[828]

Two recent papers reviewed key trends in the changing EM&V paradigm and the implications new industry developments have on current and future EM&V practices and activities:

- From the American Council for an Energy-Efficient Economy (ACEEE): "The energy efficiency sector has long sought the ability to measure energy savings as they happen. While this has not been fully realized, we are getting closer. ICT [Information and Communications Technologies] is simplifying the harvesting of savings data, improving the quality of analysis, and increasing the timeliness of reporting. All of these features improve energy efficiency programs and enable energy efficiency markets. By extension, they contribute to greater energy savings throughout the economy."[829]
- From the Regional Evaluation, Measurement, and Verification Forum: "Advanced data collection and analysis tools and systems offer new opportunities for understanding and engaging customers, offering value to project and program delivery as well as to evaluation…. There remain important evaluation challenges that are not solved by greater volumes or frequency of consumption data, or higher speeds of data processing."[830]

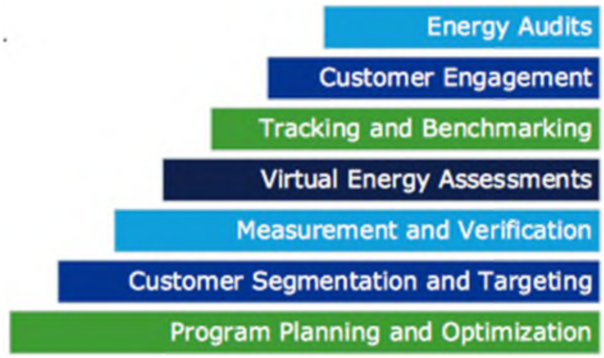
There are several challenges associated with EM&V 2.0, including the current limited availability of high-resolution data (many jurisdictions do not have AMI data) and, to date, the simple lack of experience with the application of (E)M&V 2.0 (as mentioned below). However, one particularly important possible concern is that currently automated EM&V, and EM&V 2.0 in general, only determine gross savings metrics based on baselines that are pre-project, existing conditions. These methods do not provide savings relative to standard efficiency equipment (e.g., building energy codes, equipment standards, or common practice), considered net savings under some scenarios. Nor do these methods address attribution of savings. As noted by the above-referenced ACEEE paper, attribution of savings (net savings, see discussion below) and other issues require further efforts by the efficiency industry: "The policy challenges of net versus gross savings will not go away with the addition of ICT. And issues related to data ownership, access, privacy, and security are likely to persist for a while. Other policy issues include the need for agreement on confidence levels, recovery of ICT infrastructure costs, and standardization of EM&V protocols across service territories and state lines."[831]

In some cases, these EM&V 2.0 advances may already be incorporated into current EM&V practices. However, specific EM&V 2.0 pilots and examples are difficult to identify.[832] One example is the evaluation of the PowerStream (a Canadian utility) Advanced Power Pricing pilot, a technology-enabled variable peak-pricing pilot program.[a] Evaluation of the program relies on interval data from all participants, but also from all eligible non-participants. Nonparticipant interval data over a two- to three-year period is being used to develop the set of control customers to be used, based on the matching of intra-daily, day-type specific load profiles. The evaluation (currently in progress) is leveraging thermostat-collected data to segment participants and improve estimated impact precision. Outputs include automated plotting of load profiles across a large number of cross-sectional elements of every summer day.[833]

[a] Generally, variable peak pricing is a hybrid of standard time-of-use and real-time pricing. The peak period is defined in advance, but the price established for the on-peak period varies by system or market conditions.

A number of companies offer auto-M&V products for administrators of energy efficiency and demand response programs operated by utilities or third-party administrators, primarily under the SaaS model—a software licensing and delivery model in which software is licensed on a subscription basis and is centrally hosted. Figure 7.40 indicates typical service offerings for auto-M&V.

**Figure 7.40. Typical service offerings of auto-M&V SaaS vendors**[834]




### 7.8.3.3 *Assessing Non-Energy Impacts*

Beyond energy and demand savings, there are a number of impacts associated with energy efficiency and DER programs that are commonly called *non-energy benefits* or, perhaps more accurately, *non-energy impacts* because these impacts can be positive or negative. Non-energy impacts can be categorized as those accruing to the utility system, society as a whole, and individual participants.[835] Some research indicates that the value of benefits to society as a whole and individual participants make up the bulk of the value of non-energy impacts (versus utility system non-energy benefits).[836] [837]

Examples include reduced air emissions and other environmental benefits, productivity improvements, health benefits such as reduced asthma cases, jobs created and local economic development, reduced utility customer disconnects, greater comfort for building occupants, lower maintenance costs due to better equipment or, conversely, increased maintenance costs due to new and more complex systems. Another benefit of energy efficiency programs, which could be considered either an energy or non-energy benefit, is demand reduction-induced price effects (DRIPE). This element is the potential monetary benefit to all electric consumers that comes from reduced demand for electricity.[838] Several states are now including non-energy impacts in their evaluations of energy efficiency programs funded by utility customers, but not many. In particular for cost-effectiveness analyses, the ACEEE 2012 review of evaluation practices indicated the following:[839]

> *.... while 36 states (including all the states with TRC [total resource cost] as their primary [cost-effectiveness] test) treated "participant costs" for the energy efficiency measures as a cost, only 12 states treated any type of participant "non-energy benefits" as a benefit.... [M]ost of those "non-energy" participant benefits were confined to "water and other fuel savings." Only 2 states quantified a benefit for "participant O&M savings" and none quantified any benefits for things like "comfort," "health," "safety," or "improved productivity" in their primary benefit-cost test.*

Not assigning a value to these non-energy impacts, assuming they are positive, can result in negative bias in energy efficiency and DER program investment decisions and less than fully effective program participation, designs, and marketing (if program implementers do not focus on the same benefits that participants focus on).

Also, while this discussion has primarily focused on energy efficiency activities, DERs also have non-energy impacts. The primary ones may be utility system benefits such as improved reliability and support for renewable resources integration through demand response and storage. Given the potential significant value of non-energy impacts, it is possible that more jurisdictions will analyze these impacts in the future and take them into consideration in cost-effectiveness analyses, such as in the societal cost test.[840] This may in turn create new metrics and the need for EM&V approaches that provide the values associated with these metrics.

Reduced air emissions associated with the production of electricity and thermal energy from fossil fuels is an important non-energy impact of energy efficiency. Historically, emission reductions from energy efficiency and DER activities were usually only described subjectively in program evaluations as a non-quantified (non-monetized) benefit. This is changing for at least two purposes: (1) to improve cost-effectiveness evaluation of energy efficiency and DER programs by monetizing their environmental benefits, and (2) to support state claims of emissions benefits in state air pollution plans (e.g., State Implementation Plans).

*Energy Efficiency, DERs, and Avoided Air Emissions in a Capped Emissions Regulatory Structure*

The *level* of the cap is an important aspect of an emissions cap (or cap-and-trade) program. In general, emissions may not exceed the cap, and they are also unlikely to be below the cap during any substantial period of time. The fact that capped emissions tend to remain at the cap level is relevant to the effect of energy efficiency in particular (as well as some DER activities). This is because reductions in the emissions of electricity generators do not alter the overall cap on emissions from all electricity generators. That means that freed-up emission allowances, due to the impact of energy efficiency and DERs on generators, can be sold in the market and used elsewhere or banked for use in a later year, such that total emissions will remain roughly equal to the cap level. While energy efficiency does not result in greater emission reductions than are specified by the cap, energy efficiency has been shown to be a very cost-effective way to meet the emissions cap.

Development of market mechanisms that create monetary value for energy efficiency and related environmental benefits has been a long-term goal of the energy efficiency industry.

Energy efficiency set-asides for programs such as the Acid Rain Program and the $NO_x$ SIP Call[841] provided such opportunities, although the uptake of activity was relatively low, in part due to the transaction costs and uncertainty associated with the EM&V. New regulations, such as the CPP, provide a new opportunity which may catalyze new energy efficiency activity because the CPP specifically calls out demand-side energy efficiency as a strategy for meeting the requirements of the CPP.[842] The EPA also has provided guidance for energy efficiency EM&V in the CPP documents that support industry standard best practices, while also acknowledging—and even encouraging—further advances in EM&V practices.[843]

For any type of energy efficiency program, the avoided air emissions are determined by comparing the emissions occurring after the program is implemented to an estimate of what the emissions would have been in the absence of the program (i.e., emissions under a baseline scenario). Conceptually, avoided emissions are estimated using energy savings calculated and one of two approaches:[844] [a]

- Emission factor approach—This approach involves multiplying energy savings by emission factors (e.g., pounds of carbon dioxide [$CO_2$] per megawatt-hour) representing characteristics of displaced emission sources to compute hourly, monthly, or annual avoided emission values (e.g., tons of $CO_2$ per year). There are several sources of emission factors and approaches for calculating the factors.
- Scenario analysis approach—This approach involves calculating a modeling Side Case of source (e.g., electricity generating units connected to a grid) emissions without the energy efficiency or DER programs and comparing that with the emissions of those sources operating with the reduced energy consumption associated with the programs. This approach represents an attempt to get a more accurate picture of what emissions are avoided by the actual energy use reductions from the efficiency and DER programs, based on when those reductions occur and what generation sources would have been used to meet the higher load in the Side Case. Emerging metering technologies and analytical tools are able to provide insight into the specific time of day, week, or year energy savings are occurring, which can reduce the cost and uncertainty level of this approach.

### 7.8.4 EM&V Barriers, and the Policies, Programs and Regulations That Address Them

Ensuring that EM&V plays an effective supporting role for energy efficiency and DER activities has become increasingly important as these activities have changed and expanded. In particular, interest in data-driven policies and regulations, as well as data-driven consumer investment decision-making, places increasing importance on EM&V—the source of energy efficiency and DER performance data. An overall issue in providing these data is whether EM&V is keeping up with evolving energy efficiency and DER activities and supporting greater deployment and the associated positive impacts. This section briefly describes two fundamental barriers associated with EM&V for energy efficiency and demand response, both related to the fact that savings determinations are estimates:

- The dilemma of balancing rigor with cost—i.e., how to find the right balance of impact assessment integrity and cost of implementation, and the ramifications if transaction costs are so high that they discourage appropriate energy efficiency and DER activities
- Defining appropriate baselines, the counterfactual of EM&V.

#### 7.8.4.1 *Assessing Costs Versus Benefits of Increased EM&V Rigor*[845]

Because the results from impact evaluations of energy efficiency and demand response are estimates,[b] their use as a basis for decision-making can be challenged if their sources and level of accuracy are not described. Minimizing uncertainty and balancing evaluation costs with the value of the evaluation information leads to perhaps the most fundamental evaluation question: "How good is good enough?" This question is a short version of asking: (1) what level of certainty is required for energy savings

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[a] The timing of any displaced electricity production, as well as the location of the displaced generation, can affect the amount and type of avoided emissions.

[b] Impacts from distributed generation and storage are usually directly measured and are not considered estimates. Common industry practice for EM&V for these resources does not use counterfactuals; the resources' impact is determined by measuring output.

estimates resulting from evaluation activities, and (2) is that level of certainty properly balanced against the amount of effort (e.g., resources, time, money) used to obtain that level of certainty?

An important principle associated with addressing "how good is good enough?" is that evaluation investments should consider risk management principles and thus balance the costs of evaluation against the value of the information derived from evaluation (i.e., evaluation also should be cost-effective). The value of the information is directly related to the risks of underestimating or overestimating the benefits (e.g., demand and energy savings) and costs associated with efficiency investments. These risks might be associated with errors of commission or errors of omission. An error of commission might be overestimating savings, which in turn can result in continuing programs that are not cost-effective or overpaying contractors, program administrators, and participants. An error of omission, on the other hand, might be associated with underestimating savings or not implementing efficiency actions because of the difficulty in documenting savings, both of which can result in underinvesting in energy efficiency and DERs and relying on other energy resources that have their own risks and uncertainties.

#### 7.8.4.2 *Baselines*

A major complexity of impact evaluation is defining the baseline. *Baselines* are the conditions, including energy consumption and demand, which would have occurred without implementation of the subject energy efficiency activity. Baselines can also include definitions of non-energy metrics that are being evaluated, such as air emissions and jobs.[846] Theoretically, the true energy (or demand) savings from an energy efficiency (or demand response) program are the difference between the amount of energy (or demand) that participants in a program or a project use relative to the amount of energy (or demand) that those same participants would have used had they not been in the program or implemented the project during the same time period—the counterfactual scenario. However, we can never observe how much energy those participants would have used had they not been in the program or project.[847] Developing baselines is complicated by the widespread confusion about the difference between a baseline (what would have happened in the absence of the measure) and attribution (what would have happened in the absence of the program).

Selecting an appropriate baseline is both complex and often difficult, but it is fundamental to determining the validity of EM&V results. With control group approaches, the baseline is defined by the characteristics and energy use of the control group(s). Ideally the control group is selected using randomized control trial methods, but in practice control groups are often selected using quasi-experimental methods that less reliably define a baseline scenario. For impact evaluation approaches that do not rely on control groups (deemed savings and M&V), baseline definitions are determined by the type of project being implemented, site-specific issues, and broader, policy-oriented considerations. These considerations usually result in one of three different types of baselines: (1) existing conditions, (2) building energy codes and appliance and equipment standards (C&S), and (3) common practice (which can incorporate both existing conditions and C&S baseline assumptions).

#### 7.8.4.3 *Policies, Programs, and Regulations That Address These Barriers*

With regard to balancing EM&V rigor with costs, as noted above, the evaluation process should consider risk management principles and thus balance the costs and value of information derived from evaluation. *Impact evaluation is thus about managing risk.* Conceptual approaches that draw upon risk management techniques provide a useful structure for addressing evaluation issues. Unfortunately for energy efficiency and demand response in particular, risk management is hampered by the large number of difficult-to-quantify aspects of evaluation, although the tools for addressing these difficulties are improving. Supply-side resources have uncertainty and risks as well (e.g., uncertainties associated with future fuel costs). However, perhaps the single most identifiable risk of efficiency is the inability to directly measure savings, which creates uncertainty.

To address these uncertainties and risks, current public policy approaches usually involve setting what those involved consider to be a reasonable budget first, and then relying on professional judgment of the EM&V professionals to find EM&V approaches that match that budget. However, ideally, there would be an iterative process of comparing budgets with savings certainty and achieving program goals (which can include requirements for process and market evaluations) and then having policy makers or regulators determine whether such a level of savings and program goal achievement certainty is sufficient. The research gaps section of this appendix identifies a need to improve on this current practice.

With regard to baselines, for private sector transactions—for example, between an ESCO and an industrial customer—the baseline is typically defined as the existing conditions prior to the energy efficiency or DER project implementation. As discussed in Key Findings and Insights near the beginning of this appendix, consumers tend to want to know what the savings are compared to actual past energy bills, not hypothetical bills.

However, determining baselines is different for public policies. Table 7.13 summarizes standard industry practice for determining baselines by program category. Note that these are not mandates; each jurisdiction and each program should establish its own baseline scenarios. For utility programs, the guidance for baseline definitions is typically set in regulation or implementation guidance, such as an EM&V framework. However, in at least one case, for California, the baseline issue has been addressed in legislation.[848]

**Table 7.13. Standard Practices for Selection of Baselines for Common Program Categories[849]**

| PROGRAM CATEGORY FOR PURPOSES OF BASELINE DETERMINATION | EXISTING CONDITIONS BASELINE | CODES AND STANDARDS BASELINE | COMMON PRACTICE BASELINE |
|---|---|---|---|
| Early replacement or retrofit of functional equipment still within its current useful life<br>Process improvements | X<br>Existing conditions baseline for the remaining life of the replaced equipment or process | X<br>C&S baseline for the time period after the remaining life of the replaced equipment | X<br>Common practice baseline for the time period after the remaining life of the equipment |
| Replacement of functional equipment beyond its rated useful life | | X | X |
| Unplanned replacement for (of) failed equipment | | X | X |
| New construction and substantial existing building improvements | | X | X |
| Non-equipment based programs (e.g., behavior-based and training programs) | | | X<br>What people in a control group would be doing in the absence of the program |

### 7.8.5 Research Gaps

In June 2014, the Energy Efficiency Standardization Coordination Collaborative of the American National Standards Institute (ANSI) completed a guidance document, *Standardization Roadmap: Energy Efficiency in the Built Environment.* The roadmap defines several aspects of EM&V with gap analyses.[850] Table 7.14 summarizes the EM&V aspects and identified gaps from that effort. More definitive descriptions and information are in the referenced report. The ANSI report also identifies the energy efficiency industry's need for workforce credentialing, including in the area of EM&V.

**Table 7.14. ANSI-Identified EM&V Aspects and Gaps[851]**

| EM&V Aspect | Gaps |
|---|---|
| **Baselines** | Support for defining existing conditions and common practice baselines, treatment of dual baselines, industrial baselines, non-direct dependence on production levels, and automatic benchmarking of commercial and residential buildings |
| **Methods for determining annual savings** | Addressing potential inconsistent savings estimates associated with the use of standardized documentation, different methods, and assumptions through methods to compare results |
| **Calibrated computer simulation used for M&V** | Standardization of calibration |
| **Statistical M&V methods** | Quantification of uncertainty in regression and computer simulation models, and standardized and general reporting of uncertainty |
| **Whole-building metered analysis** | Standards for data collection and analyses, statistical approaches using high-resolution data and automated analyses |
| **Methods for large complex projects** | Guidance on projects with heterogeneous measures and on how to present results for such projects |
| **Effective useful life (EUL)** | Guidance on the treatment of EULs |
| **Technical reference manuals (TRMs)** | Establishing standard formats and content |
| **Reporting and tracking systems** | Support for a standard set of terms and definitions, and standardized data collection and reporting, including addressing central data needs and standard savings definitions and program typologies |
| **Top-down evaluation** | Support for building a consistent approach to top-down analyses |
| **Evaluation in financial analyses** | Support for developing a systematic framework for analyzing parametric uncertainty of efficiency projects and programs, q framework for translating engineering uncertainties into financial instrument ratings, and q stakeholder process to assess needs |
| **Conformity assessment/accreditation** | Established relationship between conformity assessment standards that impact energy efficiency, including impact in risk and financial management |

The following subsections briefly discuss particular research issues, including those identified in Table 7.14 and others identified based on current EM&V practices and trends as noted earlier in this appendix. All of these data gaps are associated with the need for higher quality and more readily available energy efficiency and DER data to assess energy and non-energy impacts and prioritize and support appropriate investments in these electricity resources.

#### 7.8.5.1 *Reliability and Certainty of Evaluated Impacts*

A significant challenge in evaluating energy efficiency and demand response programs is defining the reliability and certainty of energy and demand savings estimates. While EM&V seeks to determine energy and demand savings reliably and with reasonable accuracy, the value of the estimates as a basis for decision-making can be called into question if the sources and uncertainty level of reported savings estimates are not understood and described. While additional investment in the estimation process can reduce uncertainty, trade-offs between evaluation costs and reductions in uncertainty are inevitably required. Thus, improved accuracy (and associated EM&V costs) should be justified by the value of the improved information. Improved methods for defining and reporting metric reliability and certainty can increase understanding and confidence in energy efficiency and demand response benefits. This would also be helpful for a more structured, risk-management approach to setting EM&V budgets (as discussed in the prior section).

#### 7.8.5.2 *Input Data Access and Availability Needs*

The availability of large amounts of reliable and short-time interval data have supported improvements in EM&V, as described earlier in this appendix. However, these big energy data sets are not necessarily all the information needed. Beyond energy use and temperature data that are potentially or already readily available are information needs related to:

1. Reliable data at the same level of granularity as the energy use data that may be necessary for accurately determining energy savings (examples of matching independent variable data are occupancy information, plug load data, and building temperature set-points)
2. Explanatory data (sometimes called thick data)[852] that may be necessary to describe the *why* of equipment and human performance—and thus the observed impacts

With respect to data availability, consumer preference, security, and privacy are issues that continue to arise and must be addressed before widespread use of data can be assured. However, these issues seem to be surmountable. For example, on January 12, 2015, President Obama announced the release of the final concepts and principles for a Voluntary Code of Conduct (VCC) related to the privacy of customer energy usage data for utilities and third parties.[853] In addition, individual states have established policies and regulations associated with protection of consumer energy data.[854]

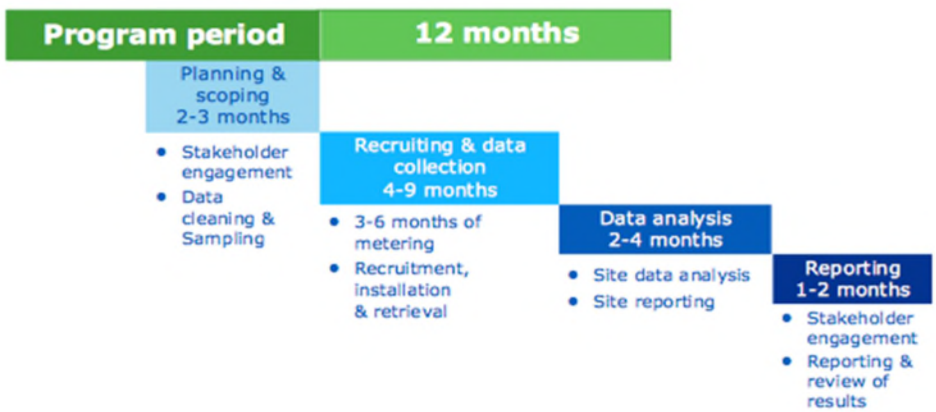
#### 7.8.5.3 *Consistent Reporting and Program Typologies*

A number of studies have noted that reporting of the savings and costs of energy efficiency (and DER) actions varies in comprehensiveness, transparency, and rigor.[855] Furthermore, other research on energy efficiency programs funded by utility customers has found that program data are often not defined and reported consistently among states. Specifically, three key concerns were found in compiling and analyzing program information on a regional or national basis, some of which could be addressed by the common typology and standardized definitions: (1) savings and program costs are not defined consistently, (2) program data are not reported consistently across states, and (3) programs and market sectors are not characterized in a standardized fashion.[856] Thus, efforts to better standardize EM&V-related terms, data taxonomy, data dictionaries, and communication specifications are needed to enable more consistent ("apples to apples") comparisons and meaningful summation of results from different activities and jurisdictions. Such efforts could also promote better understanding of the uncertainty around savings measurements.

#### 7.8.5.4 *Timeliness of EM&V Reporting and Utilization*

Delays in obtaining evaluation results from energy efficiency programs have been an ongoing issue for decades. While this problem has been less of an issue for non-utility energy efficiency programs and DER technologies with more readily available data (e.g., distributed generation) or shorter time periods of interest (e.g., demand response), the typical time required to organize evaluations, gather sufficient amounts of data, and analyze and summarize the data is 9 to 18 months from the end of a program cycle to the delivery of impact evaluation results (Figure 7.41) for utility customer-funded efficiency programs. Approaches relying heavily on deemed savings and simple project verification tend to require less time compared to approaches that require extensive data collection over a wide range of operating conditions (e.g., different seasons), such as control group and M&V approaches. Better planning and EM&V 2.0 approaches may have the potential to reduce these time frames and make EM&V information more readily valuable.

**Figure 7.41. Typical timeframe for utility energy efficiency program impact evaluation process**[857]




### 7.8.5.5 *EM&V Factors: Attribution of Savings, Measure Lifetime and Persistence of Savings, and Rebound*

Following is a discussion of development needs for three key EM&V factors: attribution determination, measure lifetime quantification, and "rebound effect" assessment.

Attribution determination—assessing net savings—involves separating out the energy efficiency and DER impacts that are a result of influences other than the program being evaluated, such as consumer self-motivation or effects of other programs. Given the range of influences on consumers' energy consumption—and the complexity in separating out both short-term and long-term market effects caused by the subject programs (and other programs)—attributing changes to one cause (e.g., a particular program) can be quite complex. This issue is compounded by a lack of consensus by policymakers and regulators as to which market influences and effects should be considered when determining net savings and the role of net savings in program design, implementation, and "crediting" of savings to program administrators.[858] While the importance of net savings in the future will depend at least in part upon the type of energy efficiency programs implemented and whether baselines defined as common practice become standard practice, further improvements in attribution assessment methods, definitions, and reporting will be helpful.

Energy efficiency measure lifetime is critical to estimating total or lifecycle benefits, calculating cost-effectiveness, and prioritizing long-term versus short-term investments in energy efficiency and DERs. Estimates of lifetime savings also impact load forecasts, estimation of savings potential, the setting of performance incentives for program administrators, recovery of lost revenue for utilities, and avoided emissions estimates. Better understanding and quantification of the variability of savings over time (persistence) also may be important for at least a subset of energy efficiency actions, measures, or programs, including some that are emerging or envisioned as significant sources of savings. However, research has found that savings lifetimes may vary significantly within a program category. While some of this variability is justified on technical grounds, savings lifetimes and persistence can also vary for reasons that may be less accurate or justified, such as different definitions, differing engineering assumptions, or different levels of rigor in EM&V.[859] Improving the quantification of measure lifetimes and understanding of persistence may provide more reliable estimates of savings from energy efficiency activities and potential cost-effectiveness of investment in energy efficiency resources.

The "rebound effect" pertains to the economic responses of consumers, firms, and ultimately the overall economy to policies and programs that promote end-use energy efficiency. Rebound has long been a controversial topic in energy efficiency impact and potential analyses, policies, and budgets. It is receiving renewed attention as energy efficiency is increasingly considered as a means of large-scale abatement of greenhouse gas emissions. Overall, the literature indicates that there is considerable uncertainty regarding the magnitude of the rebound effect. Empirical estimates of the "microeconomic rebound"—i.e., at the level of consumers, households, and firms—are consistently positive (non-zero and implying a partial offset to absolute energy consumption savings from policies and programs predicted by standard engineering calculations). In particular, there is little or no evidence of microeconomic "backfire," the conjectured phenomenon of rebound more than offsetting efficiency gains. At the same time, rebound yields an economic benefit by allowing consumers' and firms' increased consumption of energy services and other goods and services. Uncertainty regarding the magnitude of the economy-wide rebound is even greater, and considerable caution is needed in interpreting and applying quantitative estimates from the literature, indicating that further research would be valuable.

#### 7.8.5.6 *EM&V Practitioner Training, Certification, and Independence*

A relatively small, yet vibrant, industry of professionals is involved in EM&V, including:

- Professional consultants hired to conduct potential studies, impact, process, and market evaluations. Specifically, for EM&V activities, these consultants can fulfill the role of independent, third parties providing *evaluated savings* values.
- Staff within utilities and ESCOs, and other program administrators and implementers (including some large manufacturing firms and institutions that are consumers), who may conduct the same type of analyses as the EM&V consultants, but with focus on claimed savings and performance tracking for internal business purposes.

Expanding programs for energy efficiency and DERs, along with advances in EM&V—particularly with greater use of sophisticated data analysis tools and use of "smart" technologies—is driving increased interest in professional EM&V training and certification. Certifying EM&V professionals could lead to more energy efficiency and DERs because funders, regulators, policy-makers, utilities, and consumers may have more confidence in the savings determination. A recent ANSI cross-sector effort, the Energy Efficiency Standardization Coordination Collaborative, developed roadmaps on a number of energy efficiency topics, including workforce credentialing. The document notes that "…unsubstantiated claims of competency and inconsistent assessment practices have given rise to a confusing and rather chaotic assortment of workforce credentials. The good news is that a core of quality standards and credentialing schemes are in place and provide a strong launching pad from which to build a competent workforce. The challenge is sorting through the various credentials offered…."[860]

The only directly related EM&V certification is the Efficiency Valuation Organization's (EVO) Certified Measurement & Verification Professional (CMVP) designation.[a] [861] There are approximately 4,000 designated CMVPs professionals worldwide, with about 1,000 of those in the United States.[862] The training is focused on project M&V and not program evaluation. Other organizations such as the International Energy Program Evaluation Conference, EPA, and the Association of Energy Services Professionals offer education on energy efficiency evaluation. DOE has also sponsored a study to investigate the development of a certification for evaluators of energy efficiency program impacts. Another topic related to EM&V professionals is independence. There are no formal or universally agreed to definitions of independent or third-party evaluators and no well-established precedents as to who hires the entities that provide the evaluated savings reports. For utility programs, for example, the hiring entity could be the utility regulator, the program administrator, or perhaps some other entity. However, in general practice, "independent third party" means that the evaluator has no financial stake in the evaluation results (e.g., magnitude of savings) and that its organization, its contracts, and its business relationships do not create bias in favor of, or opposed to, the interests of the program administrator, implementers, participants, utility customers, or other stakeholders. State regulatory bodies have taken a variety of approaches to: (1) defining the requirements for evaluators who are asked to review the claimed savings and prepare evaluated savings reports, and (2) deciding who hires that evaluator.[863] This area has gained increased interest as the topic and requirement for independent verifiers is indicated in the CPP.[864]

#### 7.8.5.7 *Opportunities for Further Development of EM&V Methods: Deemed Savings, Randomized Control Trials, EM&V 2.0, and Top-Down Evaluation*

The following are discussions of four EM&V methods where development needs have been identified: Deemed savings can be integral to reliable and cost-effective EM&V. However, deemed savings values must be developed and used correctly (e.g., values are applied only where they are applicable). Reviews of deemed savings values and their documentation have raised concerns with consistency in methods and assumptions used to develop values, transparency, clarity, and accuracy.[865] More resources and standardization in the development and application of deemed savings could increase their use. CPP documents provide examples of criteria that could support such enhancements.[866]

Randomized control trials (RCTs) are considered to be the gold standard for documenting energy savings from energy efficiency programs. The statistical validity of more conventional approaches and EM&V 2.0 approaches, as compared to RCTs, has not been rigorously tested. Some studies have shown that alternative methods do not produce energy savings estimates that are similar to those of an RCT.[867] However, RCTs themselves have limitations related to both methodology and pragmatic concerns. These include but are not limited to population availability, data contamination, time for follow-up, external validity, cost, ethics, informed consent, and the inhibition of innovative research questions.[868] Applying practices in the broader field of statistics and econometrics may help support further development of RCTs for energy efficiency and DER programs, as well as for analyses used in EM&V 2.0.

EM&V 2.0, including auto-M&V, are fields with significant potential for improving confidence in the performance of energy efficiency and DER technologies. Diverse industry stakeholder groups have

[a] "EVO offers worldwide the Certified Measurement & Verification Professional (CMVP) designation. The right to use the CMVP title is granted to those who demonstrate proficiency in the M&V field by passing a four-hour written exam and meeting the required academic and practical qualifications. EVO's certification level training is offered as preparation for the exam and as a review of basic principles for experts."

expressed interest and engagement in the topics of streamlining the M&V process, leveraging automation and emerging analytics tools, and validating whole-building approaches to M&V. Further research is needed on validating energy savings predictions and the automated tools that develop such savings.[869] [870]

Top-down evaluation is an EM&V approach that shows promise but has not been used, or even piloted, in many applications. However, as data availability increases, analysis standards should also progress. Opportunities to advance top-down evaluation include guidance documents that could improve the reliability of top-down evaluation results; coordination among entities applying or considering top-down evaluation; additional, rigorous top-down pilot evaluations and research; efforts to increase consistency in top-down evaluation terminology; and governmental efforts to help improve the quality and availability of the underlying data used in top-down evaluations.[871]

#### 7.8.5.8 *EM&V for Transmission and Distribution (T&D) System Efficiency*

Transmission and distribution efficiency is an area of growing interest, and while EM&V is conceptually straightforward, in practice it can be complicated (and thus expensive in some cases) to determine reliable energy savings values. While T&D EM&V practices are a work in progress, EM&V for conservation voltage reduction and voltage optimization is more advanced, with several ongoing efforts to both develop protocols and evaluate programs. Further development of T&D EM&V methods would support initiatives to increase electricity savings within the T&D system.

#### 7.8.5.9 *EM&V for Codes and Standards*

As noted earlier in this appendix, ex-ante estimates of building code impacts are common, whereas ex-post evaluation and determination of energy savings from building energy code adoption and compliance activities are not as well established. Given their importance as energy and demand savings strategies, further development of EM&V methods and encouragement of ex-post evaluations documenting impacts and lessons learned would support initiatives to strengthen codes and standards.

#### 7.8.5.10 *EM&V for Financing Programs*

Utility customer–supported financing programs are receiving increased attention as a strategy for achieving energy saving goals. These financing programs have unique aspects that may create challenges in adapting traditional evaluation approaches for assessing their impacts, cost-effectiveness, and efficacy. Many consumers can finance energy efficiency projects using private options. Thus, it is important for evaluations to focus on what savings attributed to financing are truly “additional” or would have occurred even in the absence of a utility customer-funded program.

As noted in a recent report,[872] the most promising methods for assessing the impacts of energy efficiency financing are a matter of some discussion within the evaluation community. More research and field experience may be needed before best practices can be established. In particular, development of cost-effective methodologies for estimating savings that are attributable to financing efforts is needed. Data collection, including surveying methods specific to efficiency financing, require further definition as part of such methodologies. Guidance also is needed on effective experimental and quasi-experimental study designs. In addition, more research is needed on program logic models for efficiency financing programs that seek to transform markets and metrics that are appropriate for measuring progress.

#### 7.8.5.11 *EM&V for Non-Energy Impacts*

Over at least the last 20 years, the non-energy impacts of energy efficiency and DERs have been subjected to research, development, and application of EM&V methodologies, and use in various cost-effectiveness tests.[873] This experience has helped to change stakeholders' perception of non-energy impacts from one of general unfamiliarity and skepticism to acknowledgement that some non-energy impacts—particularly benefits—are important to understand, measureable, and critical to increasing the uptake of energy efficiency and DERs. However, additional effort is needed to further develop more robust methods for assessing each of the categories of non-energy impacts identified in Section 7.8.4.3: utility systems (e.g., power quality, substation infrastructure), society as a whole (e.g., water infrastructure, jobs), and individual participants (e.g., enhanced productivity, health). Related to improving these methods is the need to develop improved confidence in applying non-energy impacts in cost-effectiveness analyses as well as capacity building in terms of increased communication of such impacts and additional, trained professionals to assess the impacts.

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