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Electricity end uses, energy efficiency, and distributed energy resources baseline: *Executive Summary*

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

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.

This Executive Summary is an excerpt from the report. The table of contents included here shows the detailed scope of topics in the complete report, available at https://emp.lbl.gov/publications/electricity-end-uses-energy

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

[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).

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 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

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]

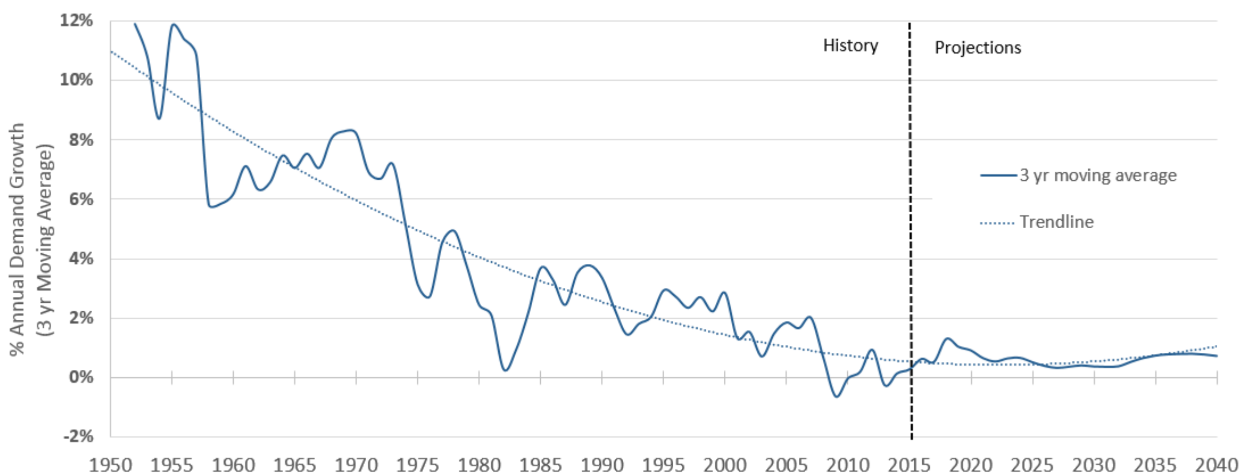
Energy efficiency policies—such as building energy codes, appliance and equipment standards and labeling, and targeted incentives—have played a significant role in slowing the growth of electricity

[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.

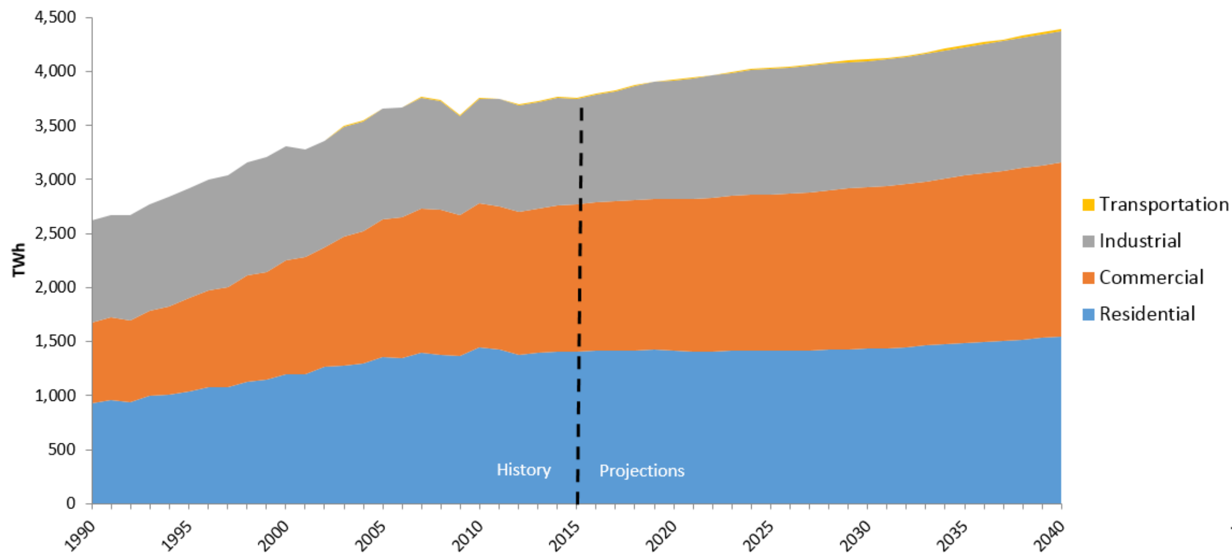
In recent years, there has been significant growth in distributed generation, particularly rooftop solar PV, which has been fostered by lower installation and hardware costs and supportive policies, such as net metering and renewable portfolio standards with set-asides or multipliers for distributed 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.

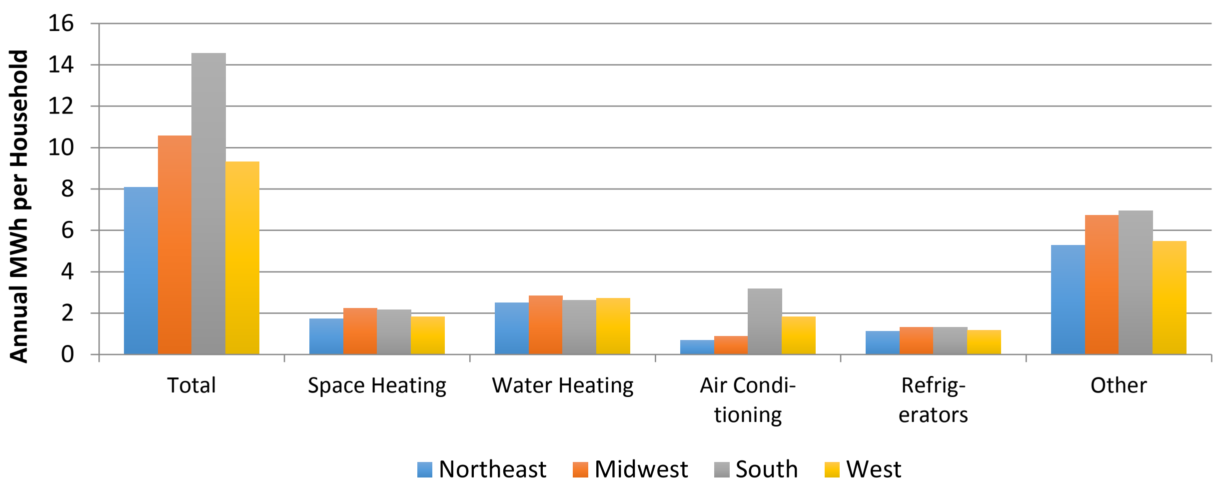
Residential, Commercial, and Industrial Sector Trends

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.

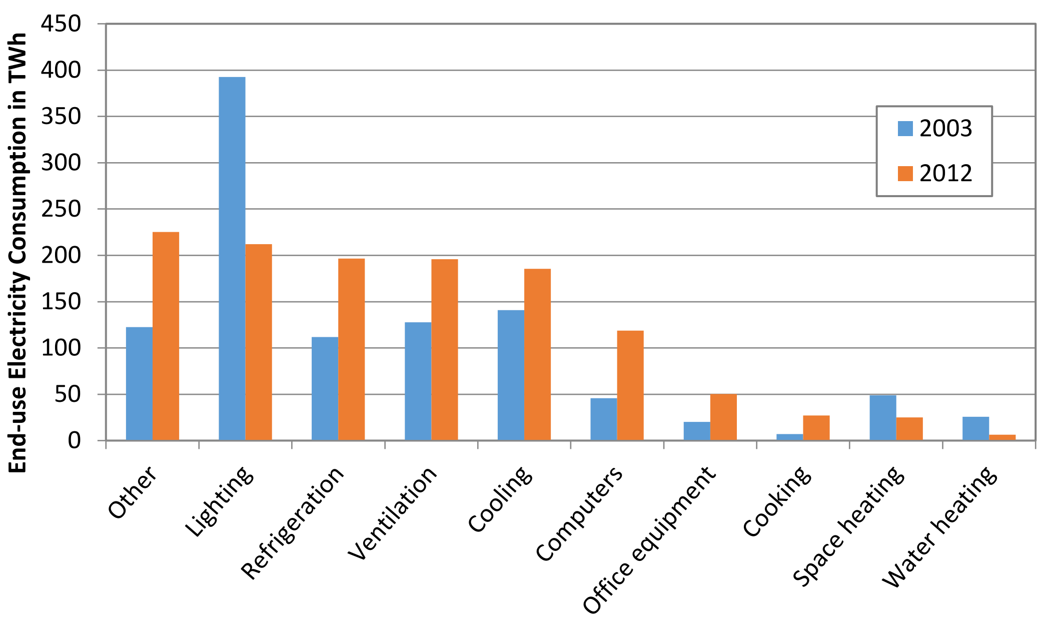
Commercial Sector Trends

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

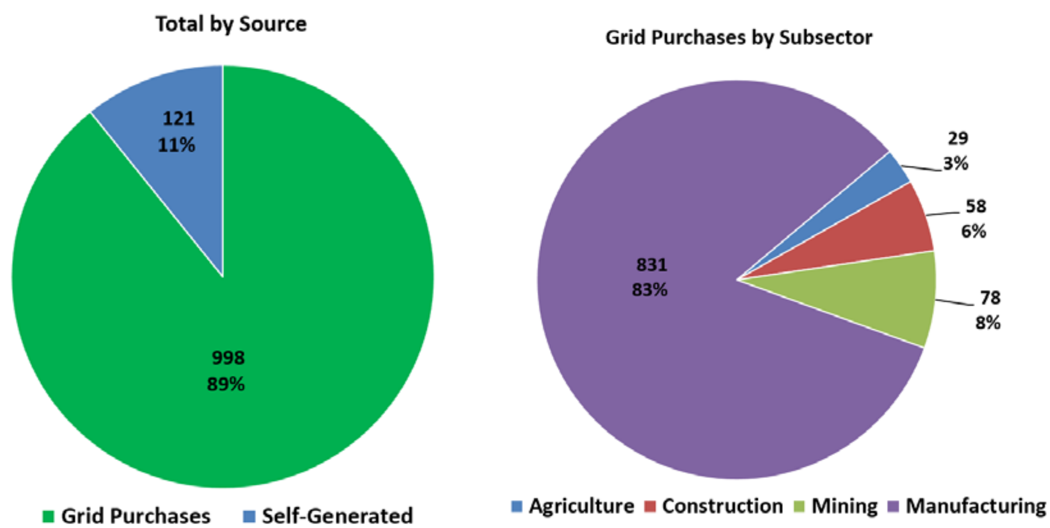
[c] MELs represent a diverse set of products defined by what they are not, rather than by what they are. They are not major appliances, such as refrigerators, and are also not linked to the major end uses—lighting, space heating and cooling, and water heating. MELs include a broad range of products across 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.

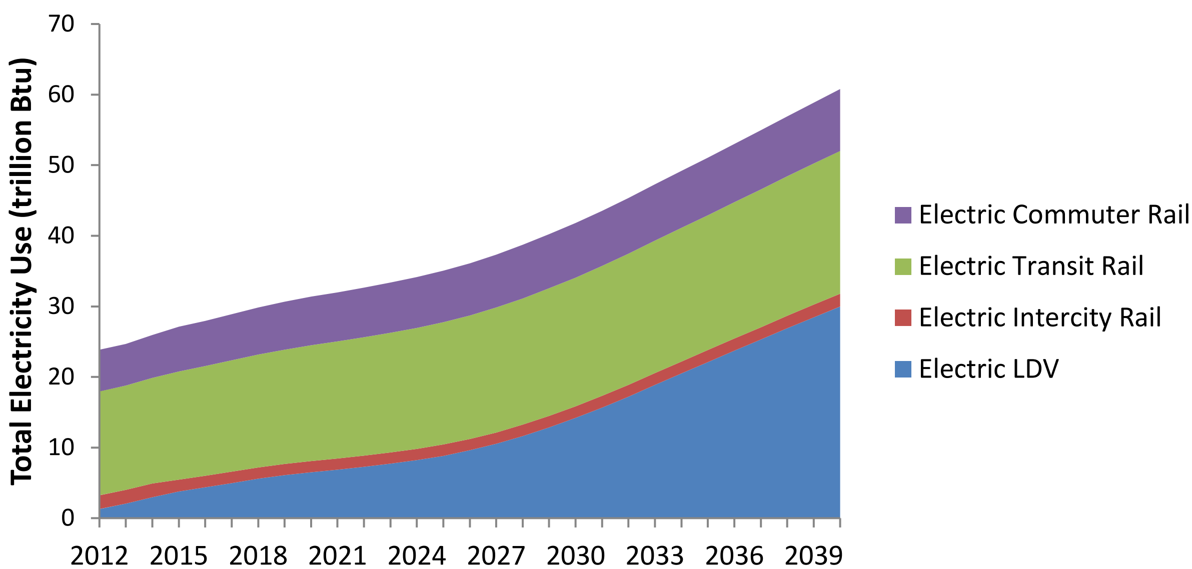
[b] The largest improvement is improving overall system designs (62% of estimated potential savings), followed by adopting variable-speed drives (25%) and upgrading motors to newer, high-efficiency technologies (13%). See Section 4.4.

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.

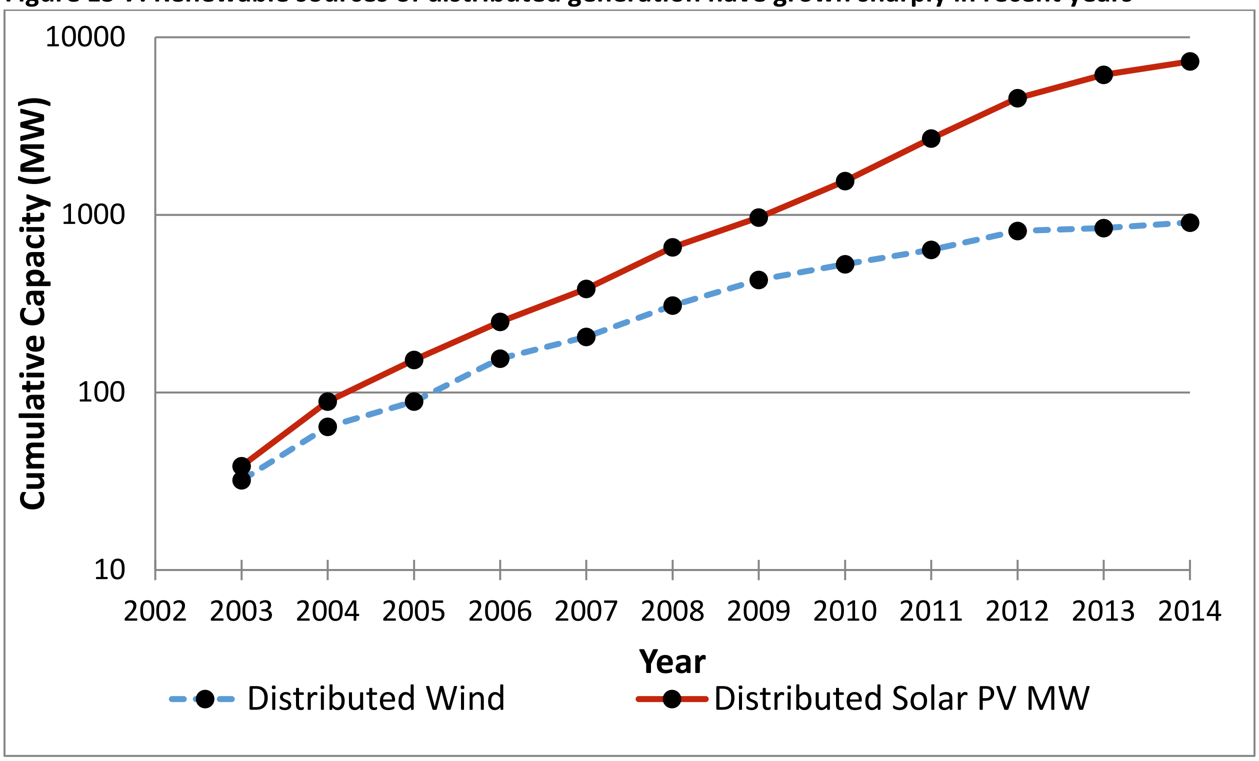
[c] A microgrid itself is not a DER, but relies on DERs within a defined electrical boundary that acts as a single controllable entity with respect to the grid (see Section 6.2.3).

[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

[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

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