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Electricity end uses, energy efficiency, and distributed energy resources baseline: *Industrial Sector Chapter*

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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.

This excerpt from the report focuses on the Industrial Sector. The table of contents included here shows the detailed scope of topics in the complete report. The full report is 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

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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).

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

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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[1] and Bureau of Economic Analysis[2] 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).[3]

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.

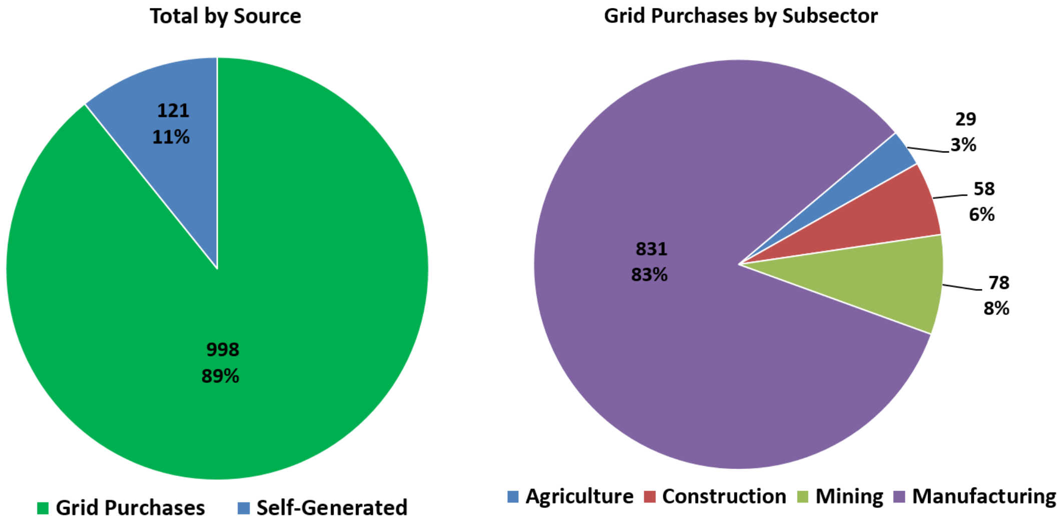
4.2 Characterization

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.[4] 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)[5]



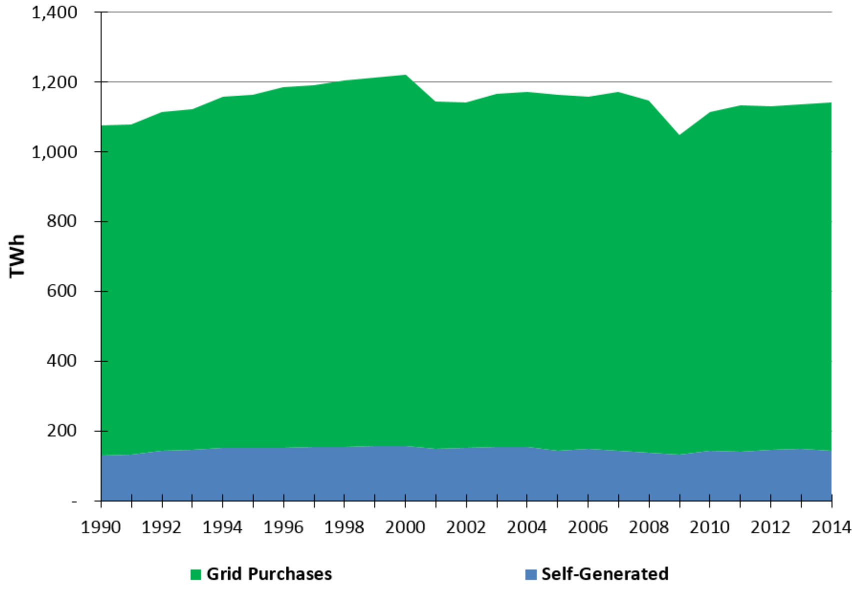
The left chart shows the industrial sector's purchased electricity consumption, CHP self-generation, and the right chart shows purchased electricity by industrial subsector.

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.[6] 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%).[7] 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.[8] 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[9]



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.[10] 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.[11]

Figure 4.3 shows that the VOS in the industrial sector grew between 1997 and 2014.[12] 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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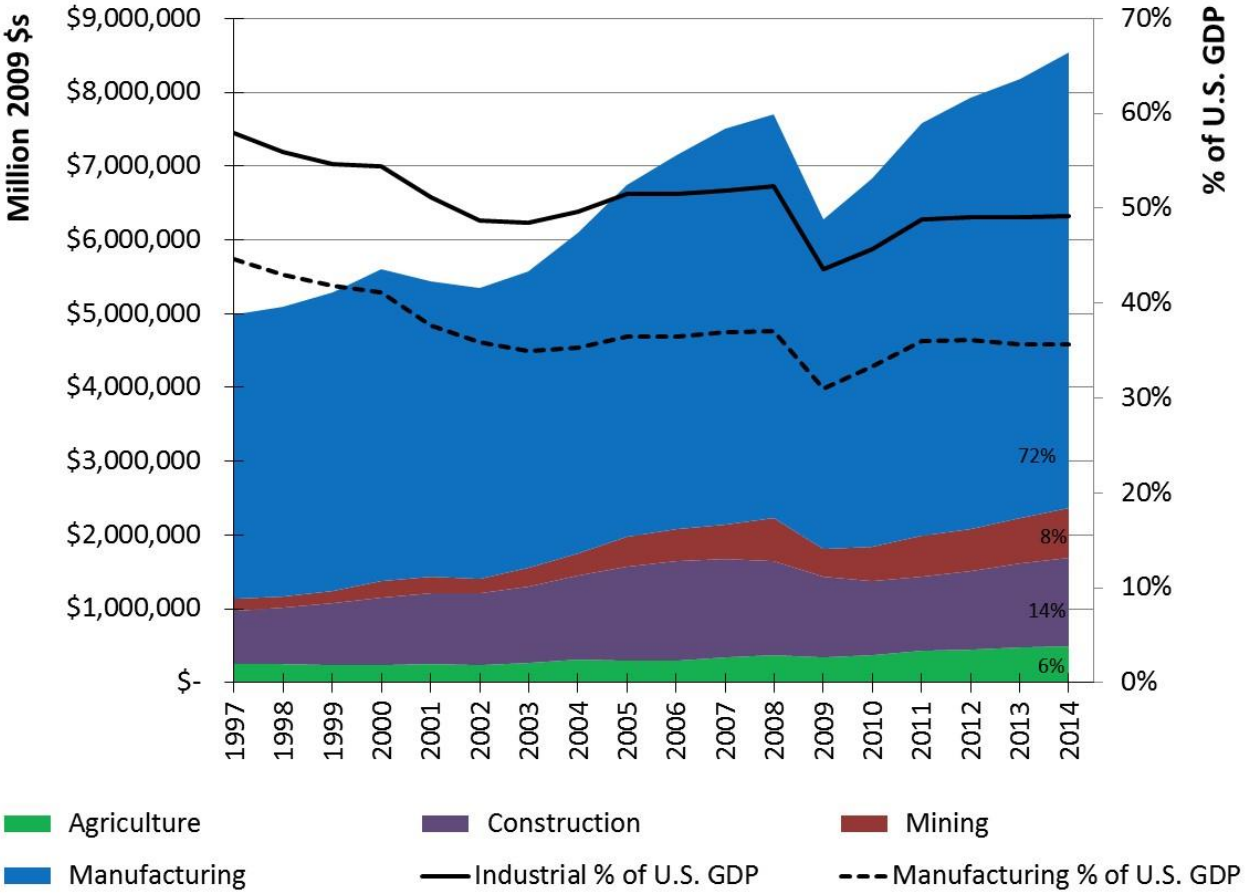
[a] In 2014, grid purchases were 1% higher than 1990 levels.

[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[13]



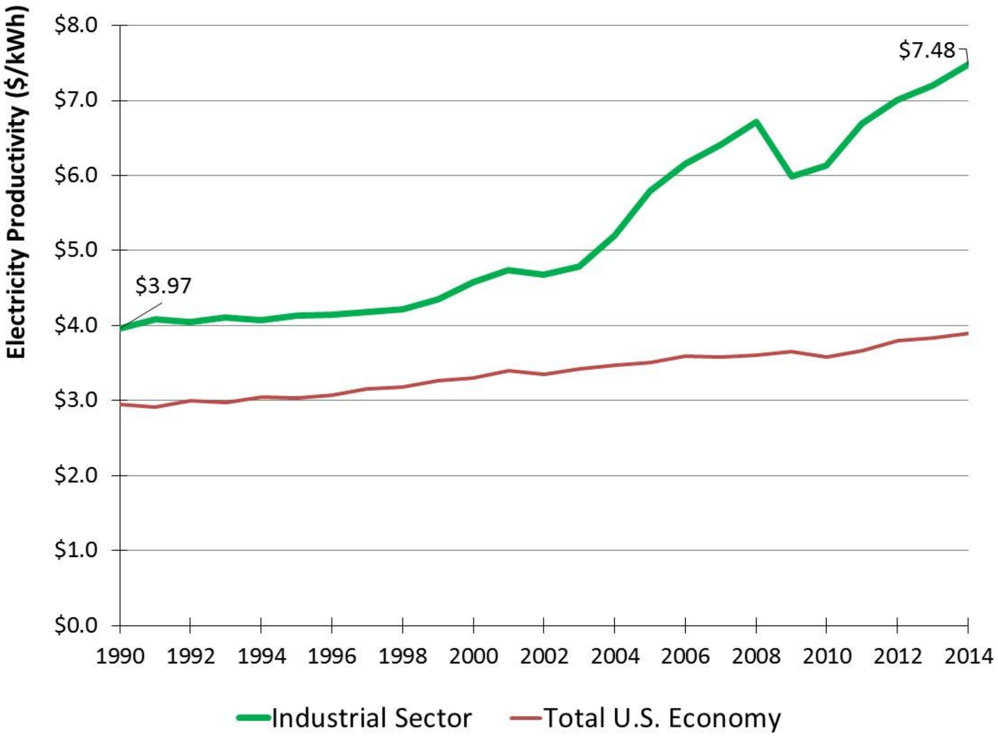
Manufacturing is the largest contributor to the total industrial value of shipments. Manufacturing contributed 72% of total industrial value of shipments in 2014, followed by construction (14%), inming (8%), and agriculture (6%).

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.[14] 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.[15] [16]

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[17]



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).

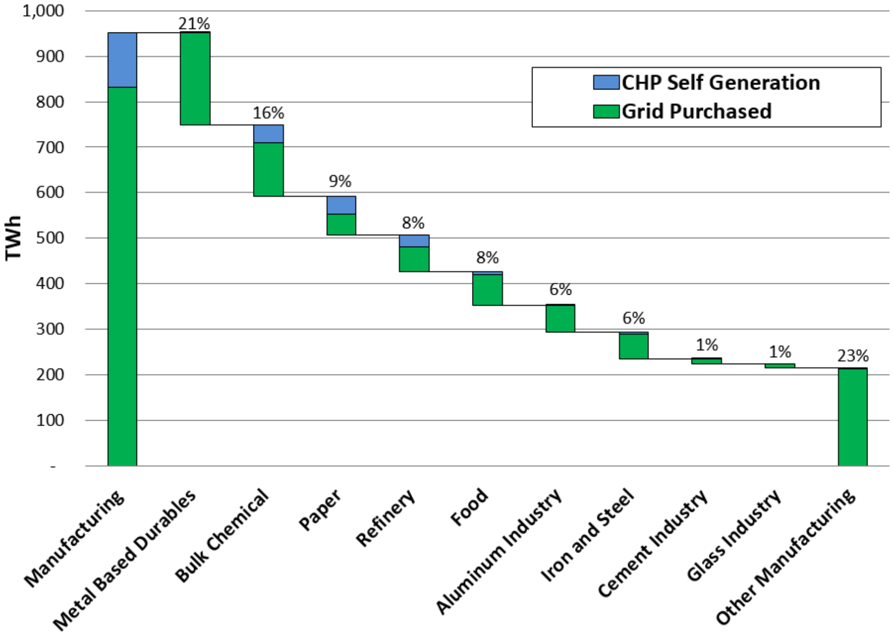
While growth in electrical productivity may indicate structural changes to less electricity-intensive manufacturing, it can also be indicative of the growth in industrial electricity efficiency, especially in electricity-intensive industries like metal-based durable goods. As Figure 4.3 shows, industrial 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.[18] 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").[19] Petroleum refining is also tracked individually in NEMS, but it is modeled in the liquid fuels market module.[20]

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[21]



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.

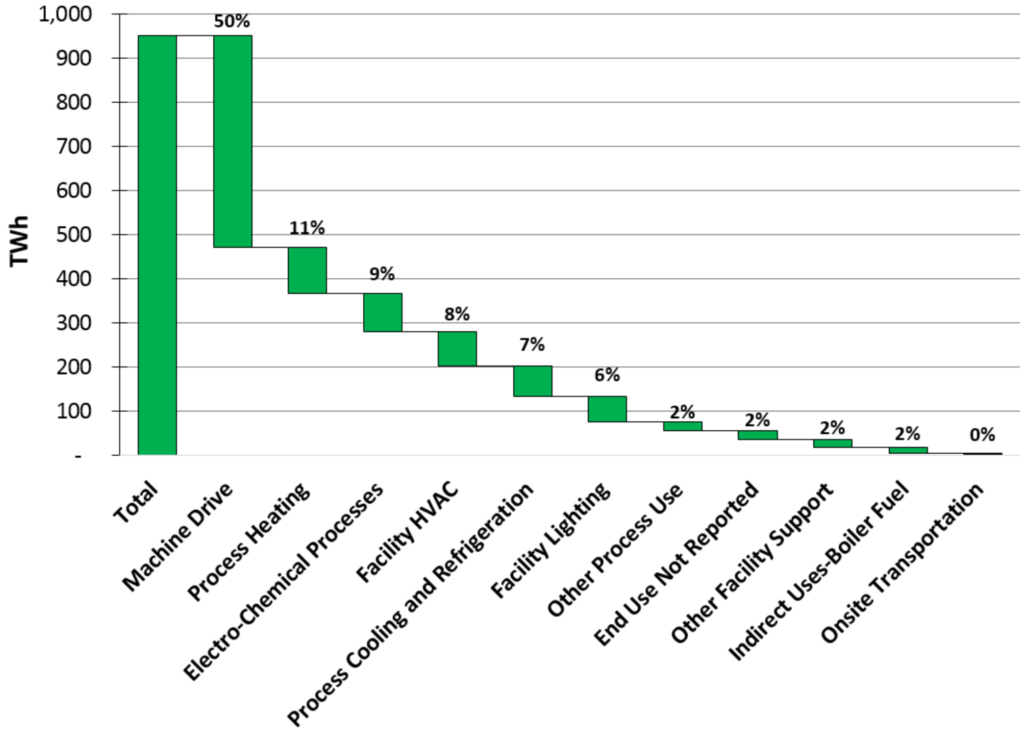
4.2.6 Manufacturing End-Use Electricity by End-Use Categories

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.[22]

The most-recent publicly available MECS data set is for the year 2010.[23] 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[24] and EPSA Side Case sum of grid-purchased and self-generated electricity[25]



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

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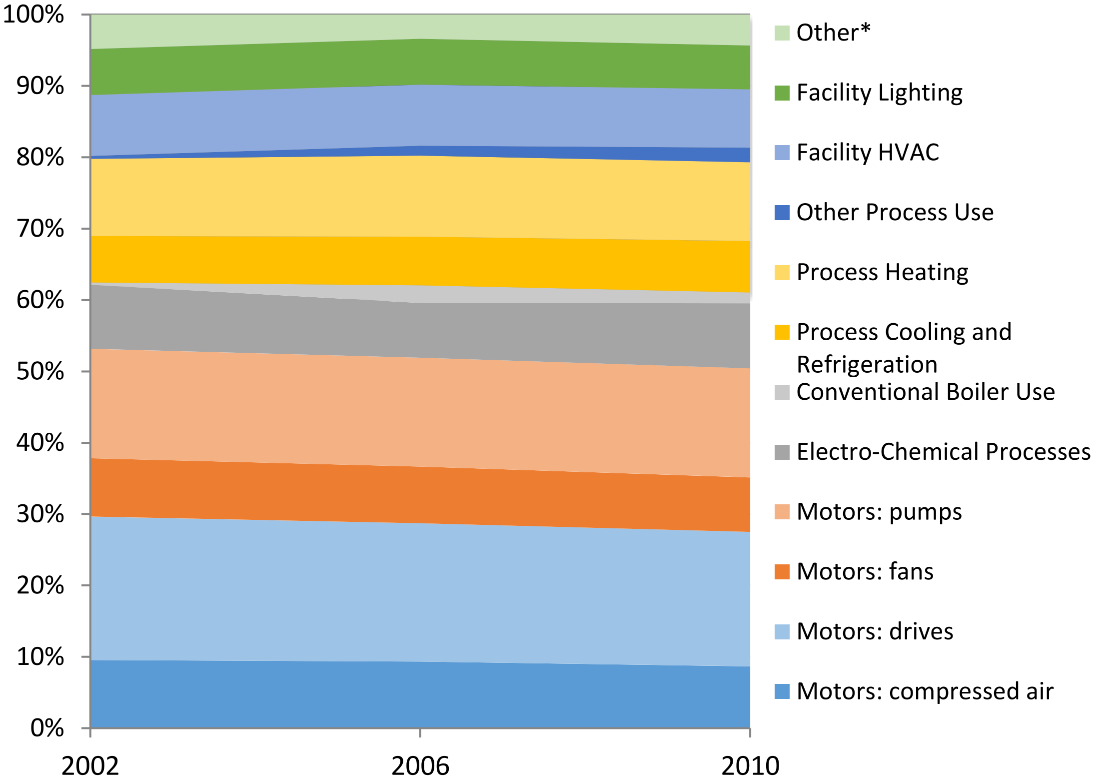
[a] MECS 2010 manufacturing subsector's total electricity end use is 845 TWh. The EPSA Side Case year 2010 manufacturing subsector's total electricity end use is 831 TWh. The ratio of each end use's MECS-reported electricity to MECS-reported total electricity is then multiplied by the total manufacturing 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[26]



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.

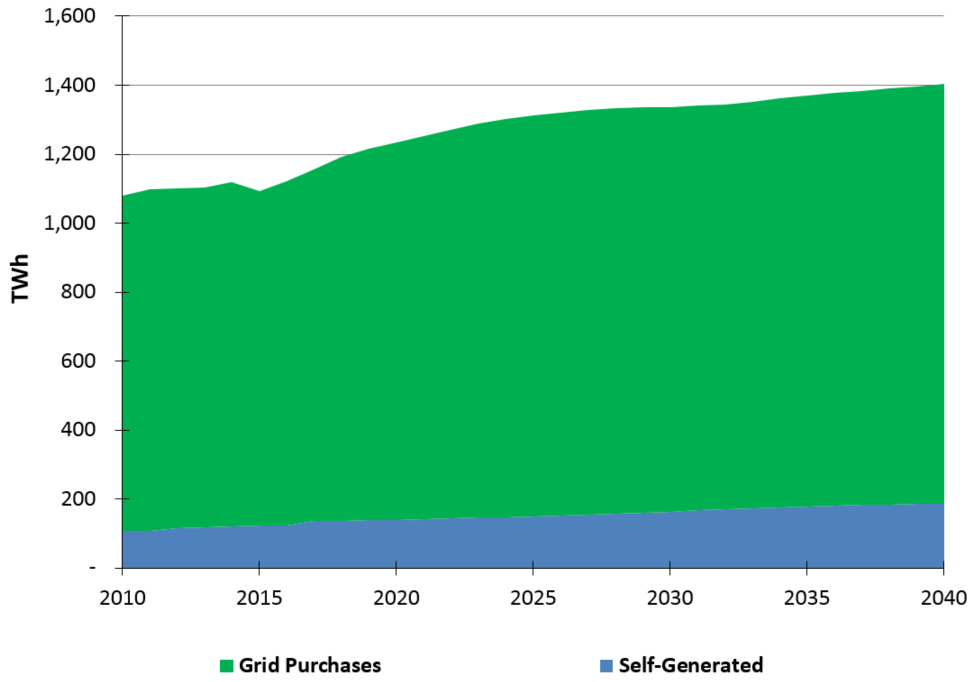
4.3 Metrics and Trends

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:

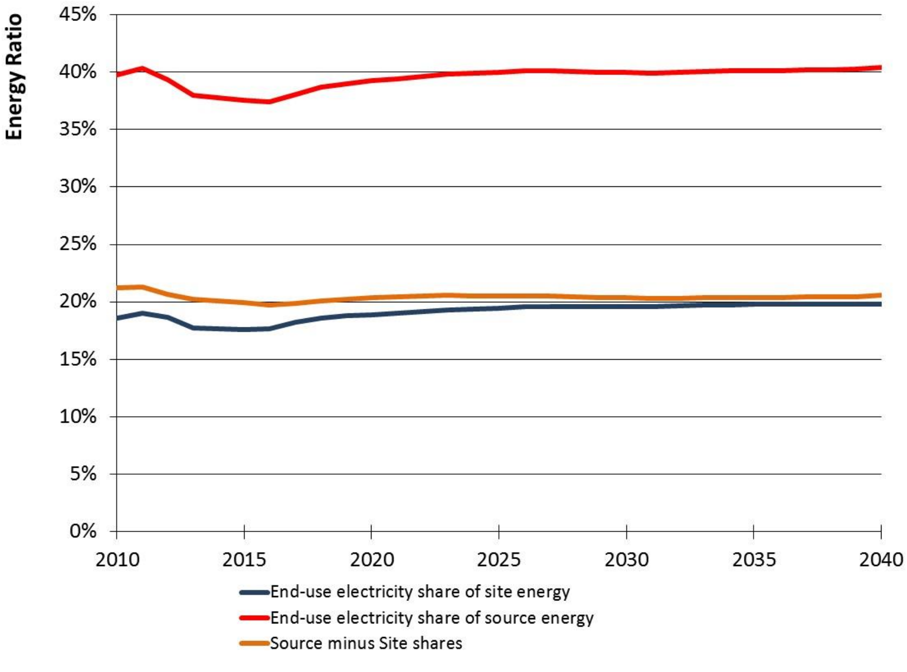
Figure 4.8 shows forecasts of end-use electricity consumption (grid purchases and self-generated) in the industrial sector for the years 2010 to 2040 using the EPSA Side Case.[27] Grid-purchased electricity increases rapidly from 2015 until 2025, after which growth slows to 2040, when it reaches its 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[28]



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[29]



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[30] and highlight, in particular, opportunities for the chemical industry.[31] 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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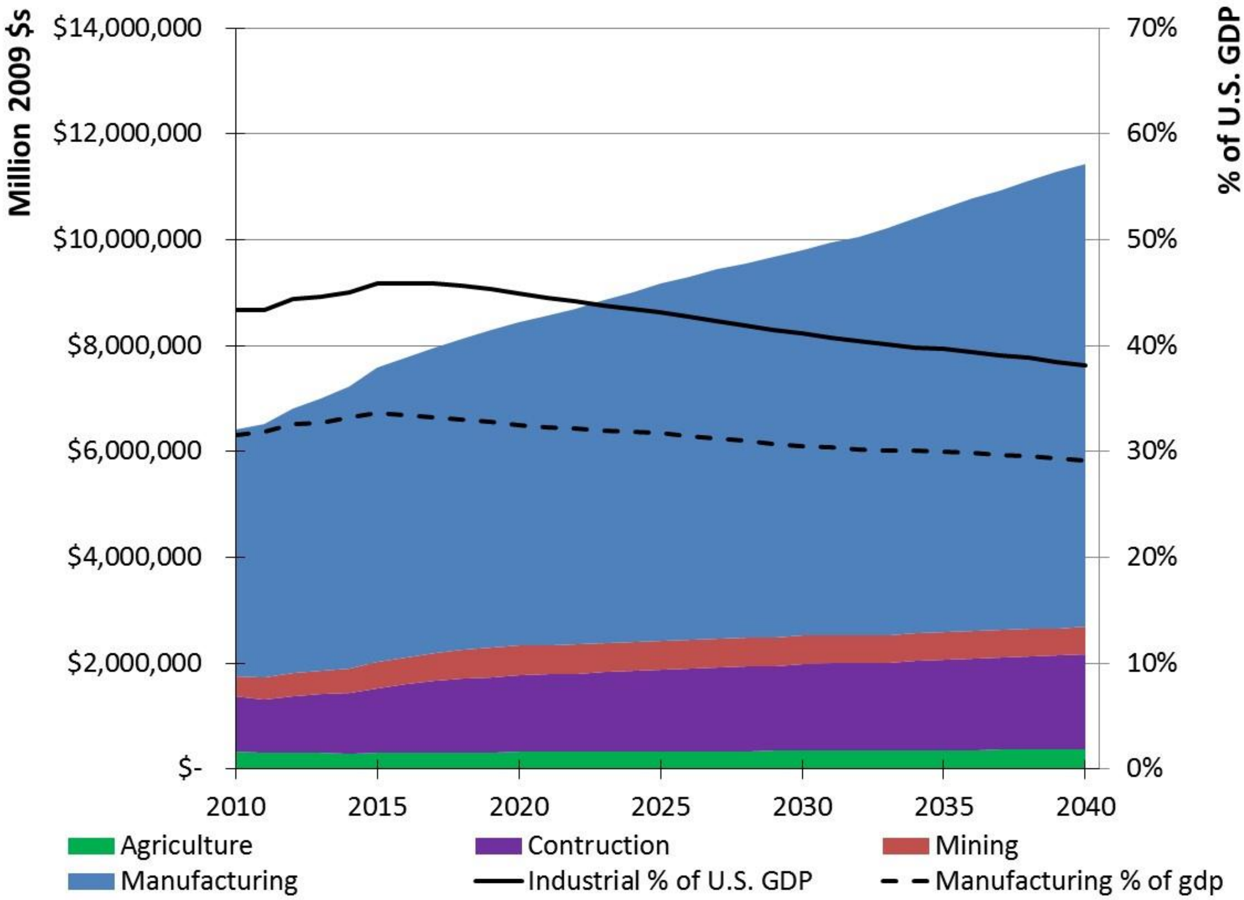
[a] An exception would be when fuel-switching from fuels to electricity is combined with on-site generation capacity.

[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[32]

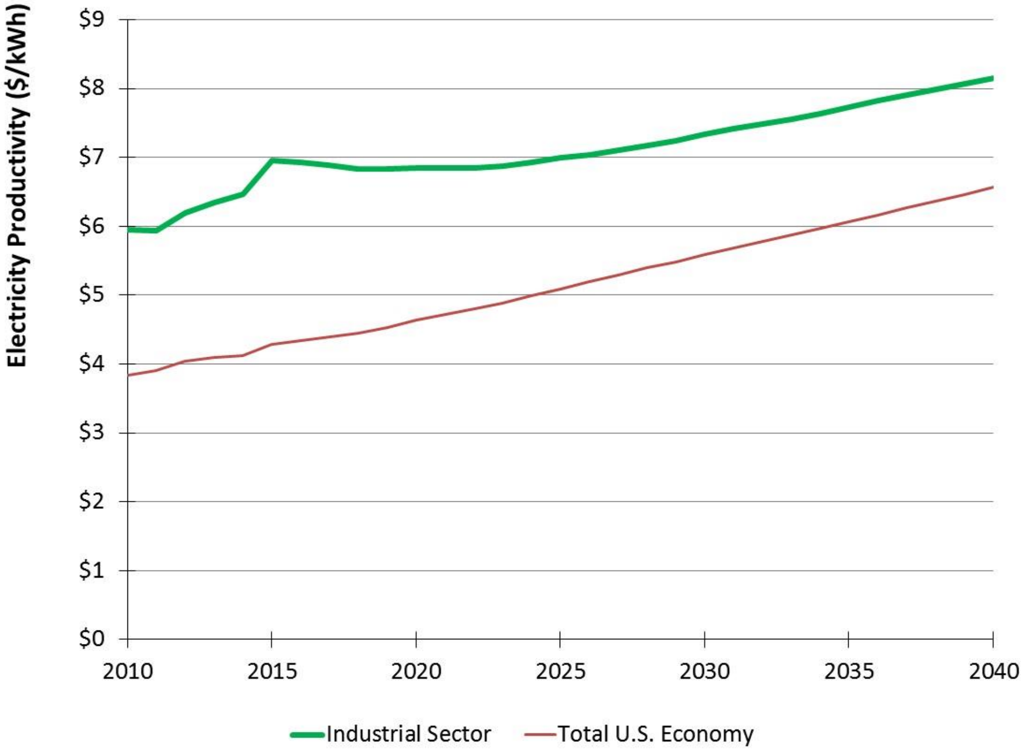


Manufacturing continues to contribute the most to the industrial sector's value of shipments through 2040.

4.3.3 End-Use Electrical Productivity Forecast

Energy productivity indicates economic output per unit of energy input.[33] *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[34]



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.[35] 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.[36] 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.

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[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[37]

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[38]	
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.	

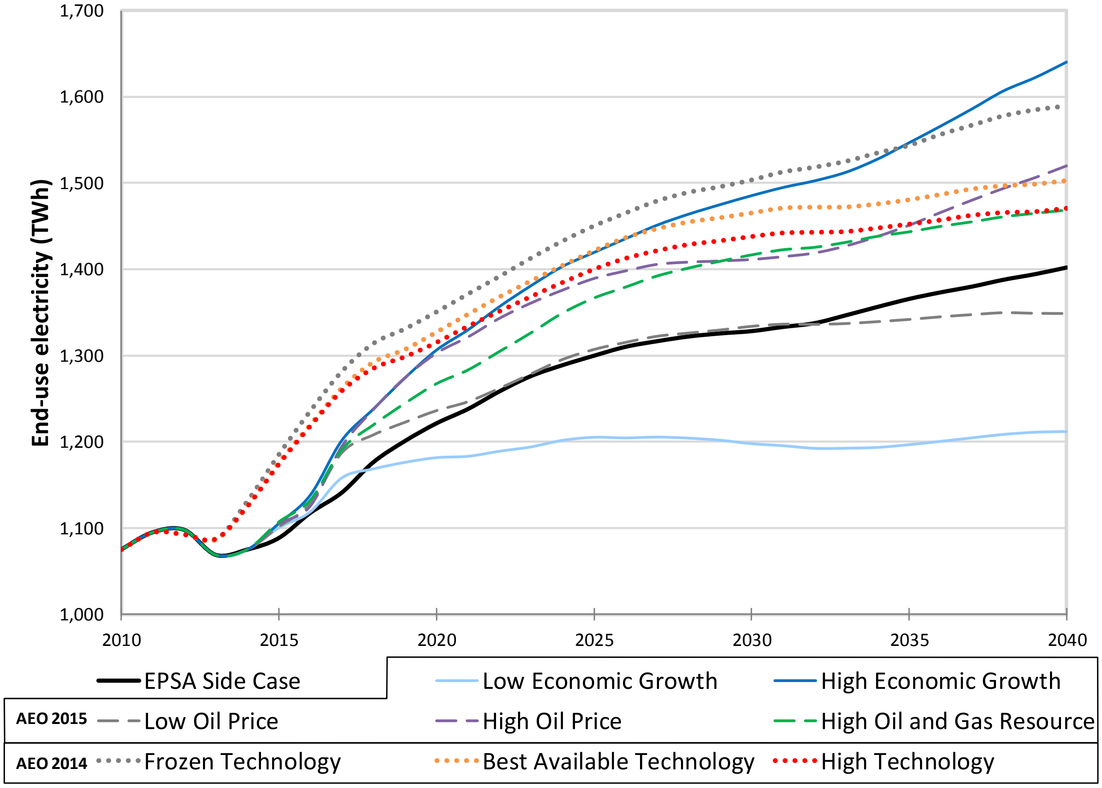
The ranges produced by the AEO cases provide insights into how high-level assumptions influence the forecast results.

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 [39]



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.[40] 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.[41] 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.[42] 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.[43]

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.[44] [45] 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%).[46] [47] 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.[48] [49] [50] 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. [51]

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.[52] 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.[53]

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.[54] 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).[55] 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.[56] 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[57]

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 More efficient variable-frequency drives and motor-speed controls
Materials for Harsh Service Conditions	Enables thermoelectric adoption in harsh service conditions 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 Thermoelectric device fabrication
Composite Materials	Lightweight materials manufacturing for life-cycle energy savings
Roll-to-Roll Processing	Thermoelectric device fabrication Advanced battery designs
Process Intensification	Real-time data acquisition and modeling for process control Enterprise-wide operations optimization Optimized heat and mass transfer in reaction, separation, heating, and cooling applications
Process Heating	Better integration with CHP systems Reduce process heating ancillary electricity loads 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 Improved controls for process unit grid integration Increasingly referred to as “smart manufacturing”
Waste Heat-Recovery Systems*	Enhanced heat recovery for CHP 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 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.[58] [59] 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.[60]

Table 4.3. Energy Efficiency Action and Investment Examples[61]

Level of Investment	Action/Investment
No- to low-cost	• Turning off lights and other equipment when not in use • Behavioral/operational change (e.g., switching to low-rate overnight power) • Strategic energy management (SEM)*
Lower cost	• Replacement lights with high-bay fixtures • Variable-frequency drive motors, new pumps • SEM*
Medium cost	• Heating, ventilating, and air conditioning replacement • New boilers, refrigerators • Back-up generator replacement • SEM*
Higher cost	• Process equipment upgrades and selective equipment replacement • Combined heat and power • SEM*
High cost	• Replacement of complete production lines • 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.[62]

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%).[63] 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
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),[64] 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.[65] 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.[66] 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.[67] 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),[68] [69] 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.[70] [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.

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[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 • ENERGY STAR labeling sets a minimum level of equipment performance. • International Organization for Standardization 50001 Energy Management Standard • Standardized Industrial Energy Management Systems (IEMS) protocols • Standardized quantification methods for non-energy benefits for policies such as emissions reduction goals	*Information/awareness, management strategies, technology interoperability* • Standards set a minimum level of performance, guarding against uninformed or inattentive purchase of inefficient devices. • ENERGY STAR guards against uninformed or inattentive purchase of inefficient devices • International Organization for Standardization 50001 guides implementation of technical and management strategies that reduce energy costs. • Standardized IEMS protocols enhance technology interoperability. • 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 • Determine cost-effective ways to submeter production lines	*Information/awareness, continued savings validation* • Benchmarking can identify savings opportunities, and auditing can validate energy savings performance over equipment lifespans. • 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* • 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* • 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. • Efficiency potential studies	*Information/awareness, materiality* • 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 - 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* - 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). - Lack of industrial participation in consumer-funded efficiency programs
RD&D for end-use technologies	- Direct support for research, development, and deployment (RD&D) - Prizes, contests, and other manufacturer incentives	*Technology availability and deployment* - Industrial RD&D often requires long time horizons. Direct support for RD&D can accelerate technology deployment.
Financing	- Financing programs through electric utility programs - Industrial energy efficiency demonstration financing offered by some state energy offices - Partnerships with financial institutions and equipment manufacturers to reduce project risk	*Lack of capital, first costs, transaction costs* - Short utility program cycles relative to capital-planning schedule creates uncertainty. - 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* - 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.[71] 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[72] 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* Electric Power: *Permanent magnets for wind turbines* 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)* Electric Power: *Water withdrawal for power plant cooling; waste heat recovery in power plants* 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* Electric Power: *Solid-state transformers for power-flow control; inverters for renewable energy* 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* Fuels: *Corrosion in offshore drilling equipment; ash fouling in biomass-conversion equipment; hydrogen embrittlement in H_2 pipelines* Transportation: *Corrosion-resistant lightweight materials*
Advanced Materials Manufacturing	Buildings: *Advanced building envelope materials* Electric Power: *Materials genome techniques to screen materials for use in carbon capture and storage (CCS) applications* Transportation: *Predictive design, modeling, and simulation for vehicle product development*
Additive Manufacturing	Buildings: *Heat exchangers for HVAC systems; window frames*

Key Technology Area	Cross-Sector Connections
	Electric Power: *Custom electrical components in substations; complex parts for power plants; tooling for large castings for power plants* Fuels: *Fuel cells* Transportation: *Prototyping and tooling in automotive applications; fuel cells*
Composite Materials Manufacturing	Electric Power: *Lightweight wind turbine blades* Fuels: *Hydrogen fuel storage* Transportation: *Compressed gas storage for mobile applications; automotive lightweighting*
Roll-to-Roll Processing	Buildings: *Window insulation films* Electric Power: *Flexible solar panels* Transportation: *Battery electrodes*
Process Intensification	Buildings: *Membranes for dehumidification* Electric Power: *Separations for CCS* Fuels: *Natural gas and modular production* 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* Buildings: *Advanced sensors for lighting and HVAC* Transportation: *Vehicles engine-control systems*
Waste Heat Recovery Systems	Electric Power: *Waste heat-recovery opportunities in electric generation* Buildings: *Heat exchangers in HVAC systems* Transportation: *Waste-heat recovery from internal combustion engines*
Combined Heat and Power	Buildings: *CHP in buildings* Electric Power: *CHP for distributed generation* *Refinery CHP*
Sustainable Manufacturing: Flow of Materials through Industry	Buildings: *Recycling and materials substitution/minimization* 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.[73] 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.

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.

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[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[74]

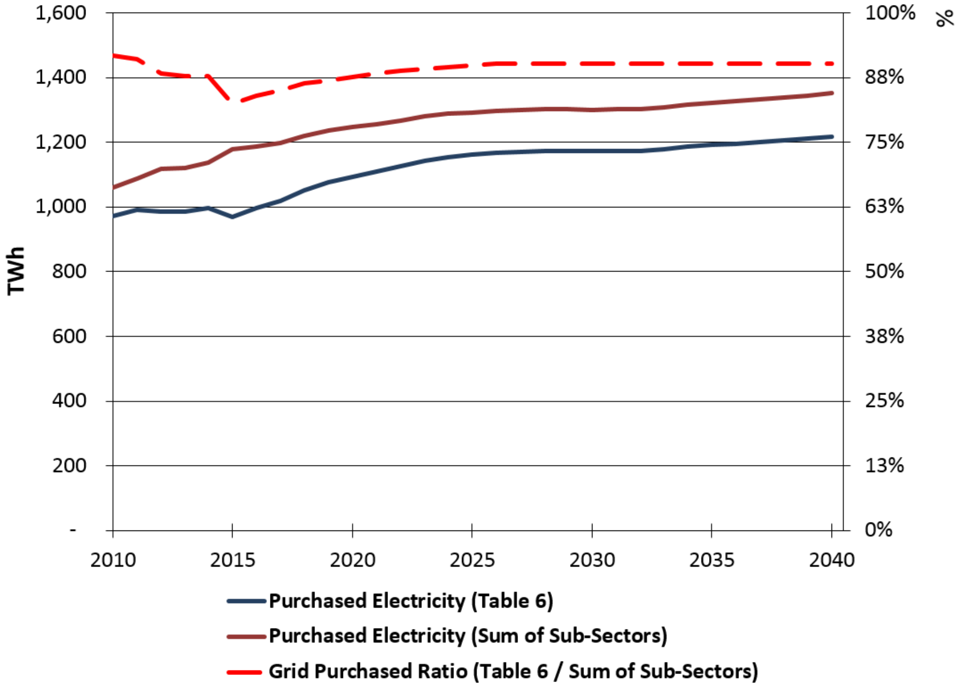
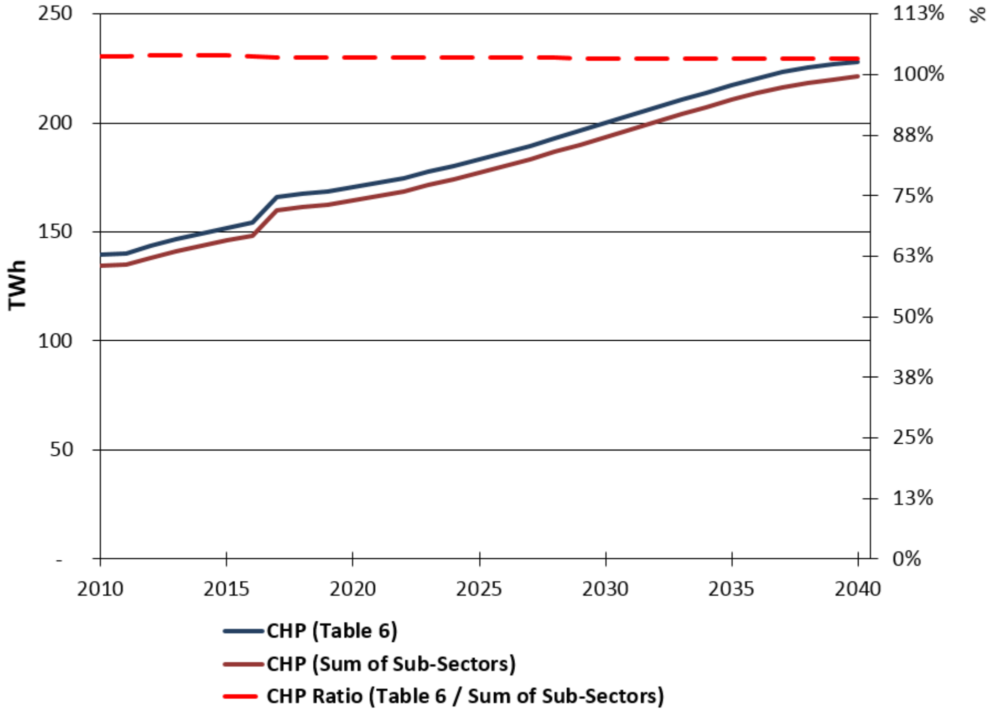
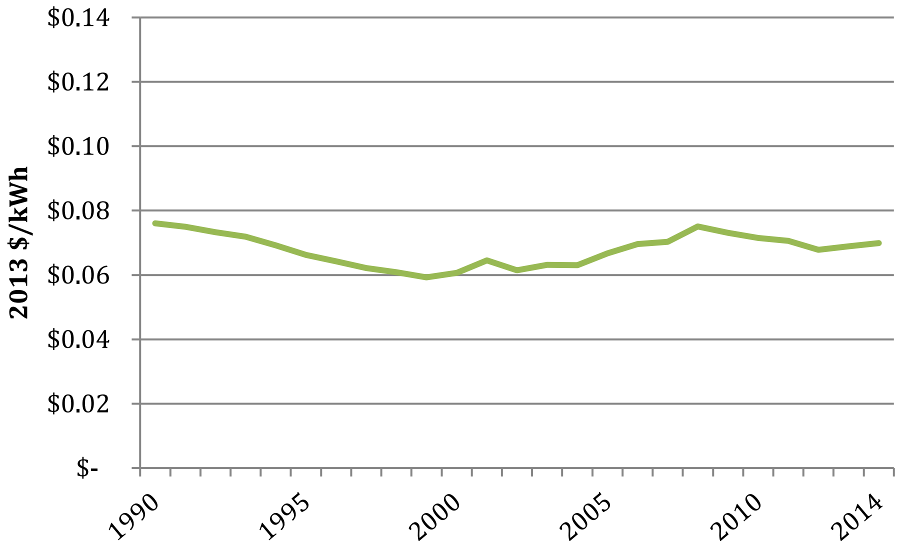


Figure 7.28. Own-use CHP: Total aggregated industrial sector reported in Table 6, sum of individual industrial subsectors, and the ratio between the two[75]



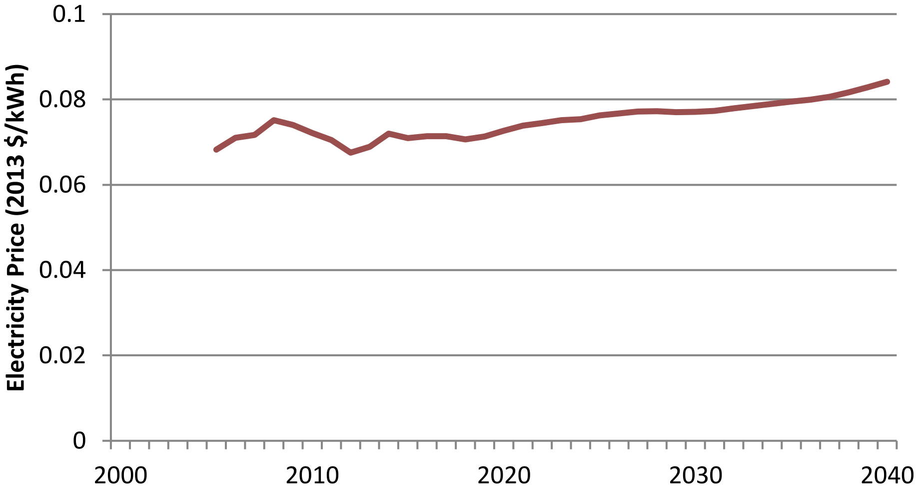
Between 1990 and 2014, electricity prices for the industrial sector fell 8% in real terms (constant 2013 dollars), from $0.076/kWh to $0.070/kWh (Figure 7.29.). Industrial electricity prices have stayed much lower than prices for other market sectors. As Figure 7.30. shows, electricity prices in the industrial sector are projected to increase modestly to 2040 in real terms.

Figure 7.29. Electricity prices for the industrial sector, 1990 to 2014[76]



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[77]



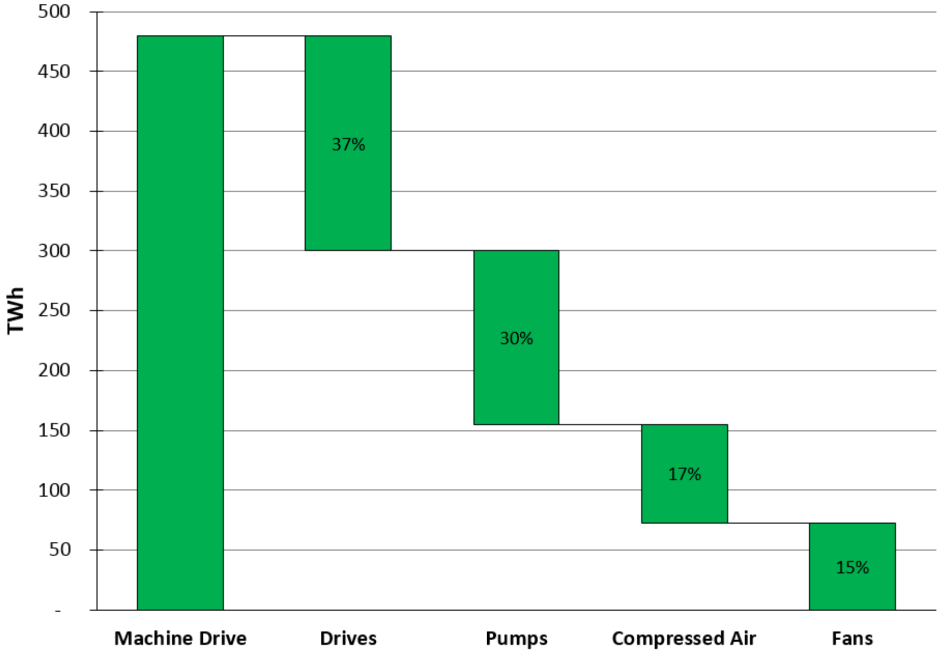
Electricity prices for the industrial sector are projected to grow modestly, at 0.6% per year.

7.5.2 Manufacturing Energy Consumption Survey (MECS) Definitions[a] [78]

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[79]



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.”

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