U.S. DEPARTMENT OF ENERGY

Environment Baseline, Volume 1: Greenhouse Gas Emissions from the U.S. Power Sector

June 2016

Office of Energy Policy and Systems Analysis
U.S. Department of Energy

U.S. DEPARTMENT OF
ENERGY

Acknowledgements

This volume was prepared by Dr. Caitlin Murphy and Dr. Colin Cunliff, both AAAS fellows at the U.S. Department of Energy Office of Energy Policy and Systems Analysis (EPSA). The authors would like to thank the following reviewers for their valuable feedback, which helped to improve and clarify the content of the volume: Nicholas Bianco (EDF), David Hoppock (Nicholas Institute), Doug Vine (C2ES), and Nora Vogel and others (RGGI). The authors would like to thank reviewers from the Environmental Protection Agency: Barry Elman, Cole Jefferson, Brian Keaveny, Jim Ketcham-Colwill, and James McFarland. From Department of Energy, John Agan, Diana Bauer, Caitlin Callaghan, Paul Donohoo-Vallett, Carla Frisch, Sarah Forbes, Judi Greenwald, Sarah Garman, Courtney Grosvenor, Liz Hartman, Anhar Karimjee, Natalie Kempkey, Emily Lewis, and Jeanette Pablo provided review. These reviews served to make this report as technically sound as possible; however, any remaining errors or omissions are those of the authors.

This report 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 will provide a comprehensive review of the nation’s electricity system and covers 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.

To help understand how the energy systems might develop into the future under Business as Usual (BAU) conditions QER 1.1 relied upon the U.S. Energy Information Administration’s Annual Energy Outlook (AEO) 2014 Reference Case. EPSA could not rely completely upon AEO for QER 1.2 as AEO 2016 was not completed and AEO 2015 did not include the Clean Power Plan. So the EPSA Base Case was developed and it aligns as closely as possible with AEO 2016 given the timing issues.

The EPSA Base Case scenario was constructed using EPSA-NEMS,[a] a version of the same integrated energy system model used by EIA. The EPSA Base Case input assumptions were based mainly on the final release of AEO 2015, with a few exceptions as noted below, and then updated to include the Clean Power Plan and tax extenders. As with the AEO, the ESPA Base Case provides one possible scenario of base case energy sector demand, generation, and emissions from present day to 2040, and it does not include future policies that might be passed or future technological progress.

The EPSA Base Case input assumptions were based mainly on the final release of the AEO 2015, with a few updates that reflect current technology cost and performance estimates, policies, and measures. Assumptions from the EIA 2015 High Oil and Gas Resources Case were used; it has lower gas prices similar to those in AEO 2016. The EPSA Base Case achieves the broad emission reductions required by the Clean Power Plan. While states will ultimately decide how to comply with the Clean Power Plan, the EPSA Base 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 Base Case also includes the tax credit extensions for solar and wind passed in December 2015. In addition, the utility-scale solar and wind renewable cost and performance estimates have been updated to be consistent with EIA’s 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 Technologies Laboratory. An EPSA Side Case was also completed, which has higher gas prices similar to those in the AEO 2015 Reference Case.

[a] The version of the National Energy Modeling System (NEMS) used for the EPSA Base Case has been run by OnLocation, Inc., with input assumptions determined by EPSA. It uses a version of NEMS that differs from the one used by the U.S. Energy Information Administration (EIA), the model is referred to as EPSA-NEMS.

Executive Summary for the Environment Baseline, Volume 1: Greenhouse Gas Emissions from the U.S. Power Sector

Volume 1 of the Environment Baseline summarizes greenhouse gas (GHG) emissions from the electric power system, including emissions from the generation, transmission and distribution of electricity, as well as a brief discussion of life-cycle emissions. The scope includes current GHG emissions levels, recent trends and projections, an assessment of key drivers of change, and a summary of major policies that help to mitigate power sector GHG emissions.

Greenhouse gases absorb some of the heat radiated from the earth's surface and then re-radiate this heat back toward the surface, essentially acting like a blanket that makes the earth's surface warmer than it would be otherwise. Carbon dioxide (CO_2) plays a particularly important role as the primary greenhouse gas emitted from the combustion of fossil fuels, namely coal, natural gas, and oil. Atmospheric concentrations of CO_2 have increased by more than 40 percent from a pre-industrial[b] value of 280 parts per million (ppm) to over 400 ppm in 2016, with almost all of this increase attributed to anthropogenic emissions. As the concentration of CO_2 and other GHGs continue to increase, global mean temperatures are increasing.

The power sector has historically been, and continues to be, the largest source of GHG emissions in the United States. In 2014, U.S. power sector emissions were 2,080.7 million metric tonnes of carbon dioxide equivalent (MMT CO_2e), or 30% of total U.S. GHG emissions.[1] This fact highlights the important role of the power sector in mitigating the impacts of climate change and meeting international obligations to reduce GHG emissions. Carbon dioxide from fossil fuel combustion accounts for nearly all of the power sector's GHG emissions. In 2014, CO_2 from coal combustion accounted for over 75 percent of U.S. power sector GHG emissions, while CO_2 from the combustion of natural gas contributed approximately 21 percent of U.S. power sector GHG emissions.

Volume 1 provides an inventory of power sector GHG emissions by fuel and by gas across electricity generation, transmission, and distribution, and includes a brief section that discusses life-cycle emissions. Emissions are also attributed to end-use sectors according to each sector's share of electricity retail sales. Major drivers and trends that have affected recent historical power sector emissions are also examined, and the report includes projections incorporating current trends and policies. Finally, Volume 1 provides a summary of major policies that help to mitigate U.S. power sector emissions.

[b] The pre-industrial period is considered as the time preceding the year 1750. Carbon dioxide concentrations during the last 1,000 years of the pre-industrial period (i.e., 750 to 1750), a time of relative climate stability, fluctuated by about ±10 ppm around 280 ppm.

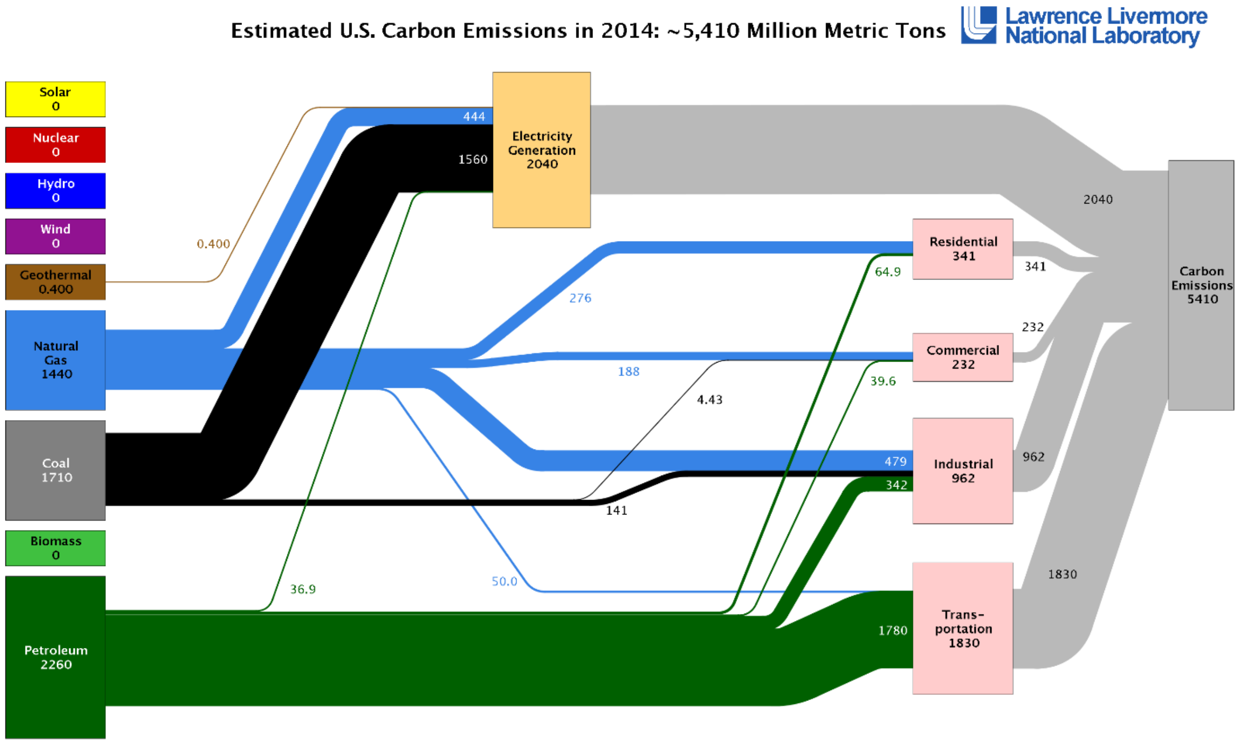


Figure ES-1. Flowchart for U.S. Energy-related Carbon Emissions, 2014 (Lawrence Livermore National Laboratory).[2] [c] [d] Electricity generation is responsible for the largest share of energy-related carbon dioxide (CO_2) emissions in the United States, and coal is responsible for the largest share of direct CO_2 emissions from the U.S. power sector. Emissions in the end-use sectors—transportation, industry, commercial, and residential—include only direct emissions and do not include emissions associated with power consumption.

Key Findings from the GHG Baseline Include:

- U.S. power sector carbon emissions have declined by 20.3 percent since 2005, largely as a result of two long-term trends: a slowing of electricity demand growth and a reduction in the carbon intensity of electric power generation.
- Growth in U.S. electricity sales has slowed to an average of 0.17 percent per year since 2005, largely due to structural changes to the economy and improvements in the efficiency of appliances, equipment, and buildings.[3]
- The carbon intensity of electricity generation (kilogram of CO_2 emitted per megawatt-hour of electricity) in the United States has declined by 21 percent relative to 2005 levels.[4] This reduction has been driven primarily by changes in the U.S. electricity generation mix, with declining generation from coal offset by increased generation from lower-emitting sources. The U.S. Energy Information Administration attributes 61 percent of this decline in the carbon intensity of electricity generation to fuel switching from coal to natural gas, and 39 percent to increased generation from renewable sources.
- Carbon emissions from the U.S. power sector have declined even as the economy has grown. Since 2005, gross domestic product (GDP) has grown by nearly 15%, even as

[c] This flowchart accounts only for CO_2 emissions from combustion and does not include other greenhouse gases or non-energy CO_2 (see Figure 3). Additionally, the flowchart uses data from the U.S. Energy Information Administration, and reported emissions may differ slightly from the *Inventory of U.S. Greenhouse Gas Emissions and Sinks*.

[d] Emissions from combustion of biomass are typically accounted for under the land-use, land-use change and forestry sector and are not accounted for in energy sectors to avoid double counting.

power sector CO_2 emissions have declined.[5] Slow growth in per capita electricity consumption, greater electricity productivity (in terms of GDP per kwh), and a decline in the carbon intensity of electricity generation have helped divorce U.S. economic growth from electricity consumption and the consequent CO_2 emissions.

- A wide array of policies and measures have been developed and implemented at the federal, state, and local levels that mitigate GHG emissions from the power sector. Categories of existing policies include performance-based regulations and standards, economic instruments, information programs, research and development, technology demonstrations, and government leading by example. These policy categories are all interconnected and complement one another.

Table of Contents

Chapter 1: Introduction and Scope

This volume of the Environment Baseline summarizes greenhouse gas (GHG) emissions associated with the electric power sector,[e] from power generation to end use, including lifecycle emissions and emissions from transmission and distribution. It was prepared by the U.S. Department of Energy Office of Energy Policy and Systems Analysis to frame the environmental questions posed by the modern grid. The scope includes a discussion of current GHG emissions levels, recent trends, and projections as well as assessments of key drivers of change and a summary of major policies that mitigate power sector GHG emissions.

Additional environmental issues associated with the U.S. electric power sector are addressed in three other volumes of the Environment Baseline. Other air pollution (including criteria air pollutants and hazardous air pollutants), land use, human health, and ecological impacts are addressed in Volume 2 – Environmental Quality and the U.S. Power Sector: Air Quality, Water Quality, Land Use and Environmental Justice. Solid waste from electricity generation, including coal ash and spent nuclear fuel, as well as waste streams from the decommissioning of power plants, is addressed in Volume 3 – Solid Waste from the Operation and Decommissioning of Power Plants. Finally, issues related to the energy-water nexus are covered in Volume 4 – Energy-Water Nexus.

Climate Change and Greenhouse Gases

Over the last century, the burning of fossil fuels, deforestation, land-use changes, and other sources have significantly increased the concentration of heat-trapping greenhouse gases in our atmosphere.[6] These gases absorb some of the heat radiated from the earth's surface and then re-radiate this heat back toward the surface, essentially acting like a blanket that makes the earth's surface warmer than it would otherwise be.[7]

Carbon dioxide (CO_2) plays a particularly important role as the primary greenhouse gas emitted from the combustion of fossil fuels, namely coal, natural gas and oil. The atmospheric CO_2 concentration has increased by more than 40 percent from a pre-industrial value of 280 parts per million (ppm) to over 400 ppm in 2016,[8] with almost all of this increase during the Industrial Era attributed to anthropogenic emissions. As the concentration of CO_2 and other GHGs continue to increase, the earth's temperature is increasing above previous levels. Since 1880, the Earth's averaged land and ocean surface temperature has increased by approximately 1.2–1.9 °F (~0.65–1.06 °C).[9,10] The science and impacts of climate change are discussed in detail in publications by the United National Framework Convention on Climate Change (UNFCCC).

The President's Climate Action Plan,[11] the current U.S. strategy for addressing climate change, was formulated to mitigate global climate change and reduce U.S. GHG emissions. Additionally, the U.S. government has set emissions reduction targets in the range of 17 percent below the 2005 level by 2020 and 26 to 28 percent below the 2005 level by 2025.[12] These 2020 and 2025 targets were formally submitted to the UNFCCC in March 2015, and they are consistent with a

---

[e] The U.S. Energy Information Administration defines the electric power sector as "the energy-consuming sector that consists of electricity only and combined heat and power plants whose primary business is to sell electricity, or electricity and heat, to the public." Throughout this document "power sector" and "electric power sector" will be used interchangeably.

straight line emission reduction pathway from 2020 to economy-wide emission reductions of 80% or more by 2050.[13] An 80 percent economy-wide reduction in the U.S., given commensurate reductions elsewhere, could help limit the increase in global mean surface temperature and mitigate the worst impacts of climate change.[14]

U.S. Greenhouse Gas Emissions

Net U.S. anthropogenic (human-caused) greenhouse gas emissions in 2014 were 6,108 million metric tonnes of carbon dioxide equivalent (MMT CO_2e),[f] 9.3 percent below the 2007 high of 6,731 MMT CO_2e and 7.9 percent above 1990 net emissions.[15] Net emissions include gross emissions across the main greenhouse gases—carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulfur hexafluoride (SF_6), and nitrogen trifluoride (NF_3)—as well as carbon sequestered in managed forests, trees in urban areas, agricultural soils, and other anthropogenic carbon sinks. Figure 1 shows annual net emissions for all years reported in the Environmental Protection Agency's (EPA) *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2014*.[g]

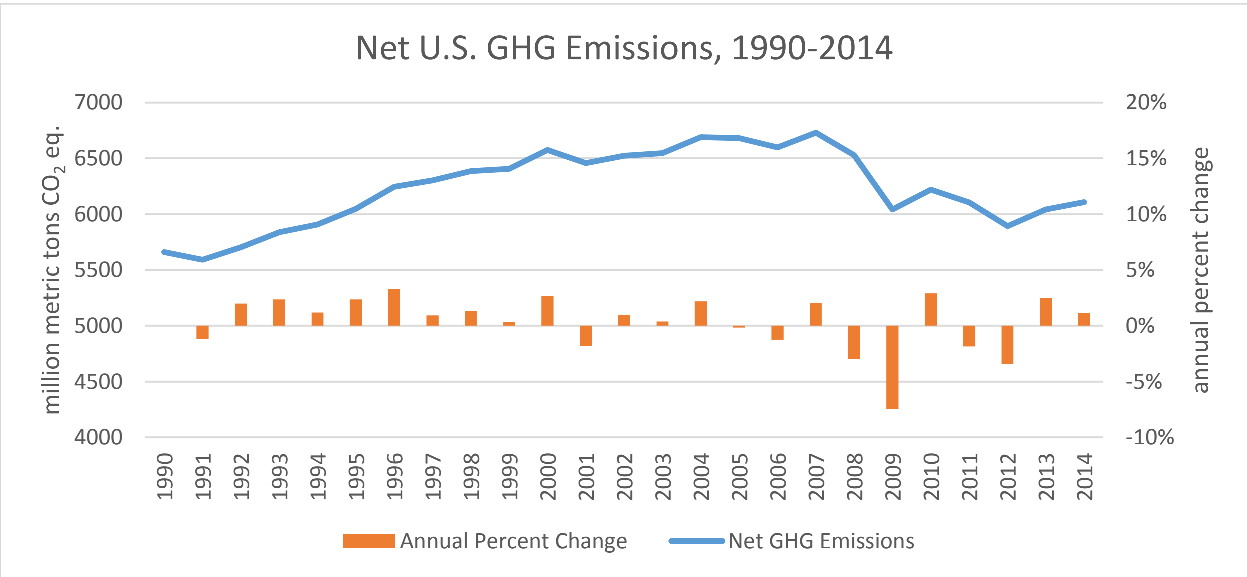


Figure 1. Net U.S. Greenhouse Gas Emissions, 1990-2014 (EPA).[16] Since economy-wide U.S. GHG emissions peaked at 6,731 million metric tonnes of carbon dioxide equivalent in 2007, emissions have fallen by 9.3 percent.

[f] All emissions are reported in units of CO_2e using global warming potentials (GWP). A GWP is defined as the ratio of the time-integrated radiative forcing from the instantaneous release of 1 kilogram (kg) of a trace substance relative to that of 1 kg of CO_2. Parties to the UNFCCC have agreed to use GWPs from the IPCC *Fourth Assessment Report* (AR4) based upon a 100-year time horizon, although other time horizons are possible. Per AR4 GWP values, methane has a GWP of 25, meaning that the release of 1 kg of methane has a heat-trapping effect equivalent to the release of 25 kg of carbon dioxide over a 100-year time horizon. The GWP of nitrous oxide is 298.

[g] The *Inventory of U.S. Greenhouse Gas Emissions and Sinks* is submitted to the UNFCCC annually. The next report covering emissions through 2015 will be submitted in April 2017.

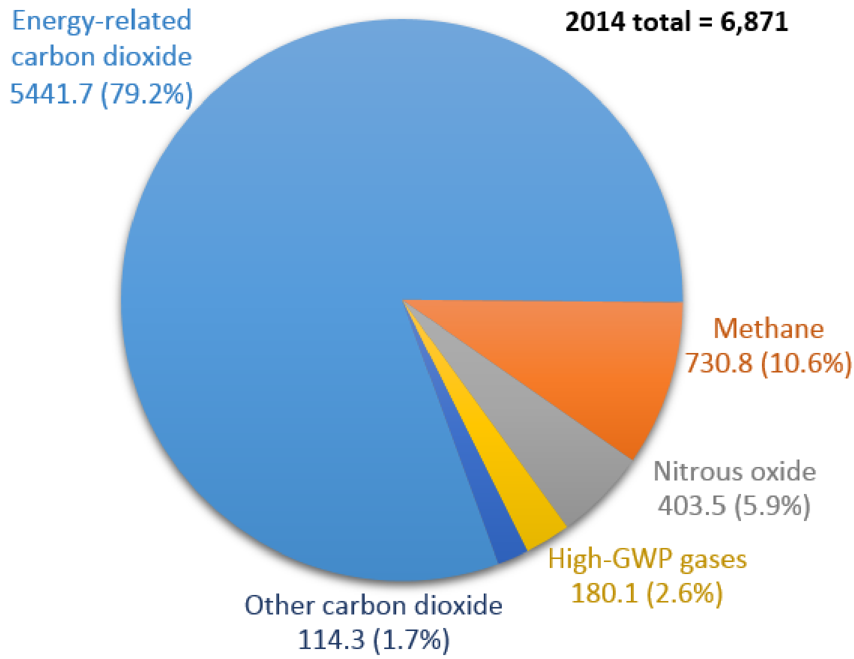


Figure 2. U.S. Greenhouse Gas (GHG) Emissions by Gas, 2014 (EPA) [17] (in units of million metric tonnes carbon dioxide equivalent). Energy-related carbon dioxide emissions comprised over 79 percent of total U.S. GHG emissions in 2014.

Figure 2 shows U.S. GHG emissions by gas in units of CO_2e for the year 2014. Energy-related CO_2 emissions make up 79.2 percent of total U.S. emissions, followed by methane (10.6 percent) and nitrous oxide (5.9 percent). The gases with high global warming potential (GWP)—HFCs, PFCs, SF_6 and NF_3—are emitted in smaller amounts and make up 2.6 percent of total U.S. emissions in 2014. Finally, non-energy emissions account for 1.7 percent of total emissions. Carbon sinks (not shown) are estimated to offset 11.1 percent of total emissions in 2014.[18]

Figure 3 displays the share of energy-related CO_2 emissions accounted for by major energy fuels and by energy sectors in 2014.[h] Petroleum is the largest fossil fuel source for energy-related CO_2 emissions, contributing 41.8 percent of the total. Coal is the second-largest fossil fuel contributor, at 31.6 percent, and natural gas accounted for 21.1 percent of total energy-related CO_2 emissions. Figure 3 also shows emissions by end use sector, including emissions from fuel consumption for transportation (primarily petroleum), emissions from industry, emissions from direct fuel consumption in residential and commercial buildings (for example, natural gas for heating), and emissions from electricity generation in the power sector.

Figure 3 also highlights the prominent role of the electric power sector as the largest source of CO_2 emissions from the U.S. energy system. In 2014, electricity generation accounted for 2,040 million metric tonnes of CO_2, or 37.7 percent of total energy-related CO_2 emissions.

[h] This flowchart accounts only for CO_2 emissions from combustion and does not include other greenhouse gases or non-energy CO_2 (see Figure 3). Additionally, the flowchart uses data from the U.S. Energy Information Administration, and reported emissions may differ slightly from the *Inventory of U.S. Greenhouse Gas Emissions and Sinks*.

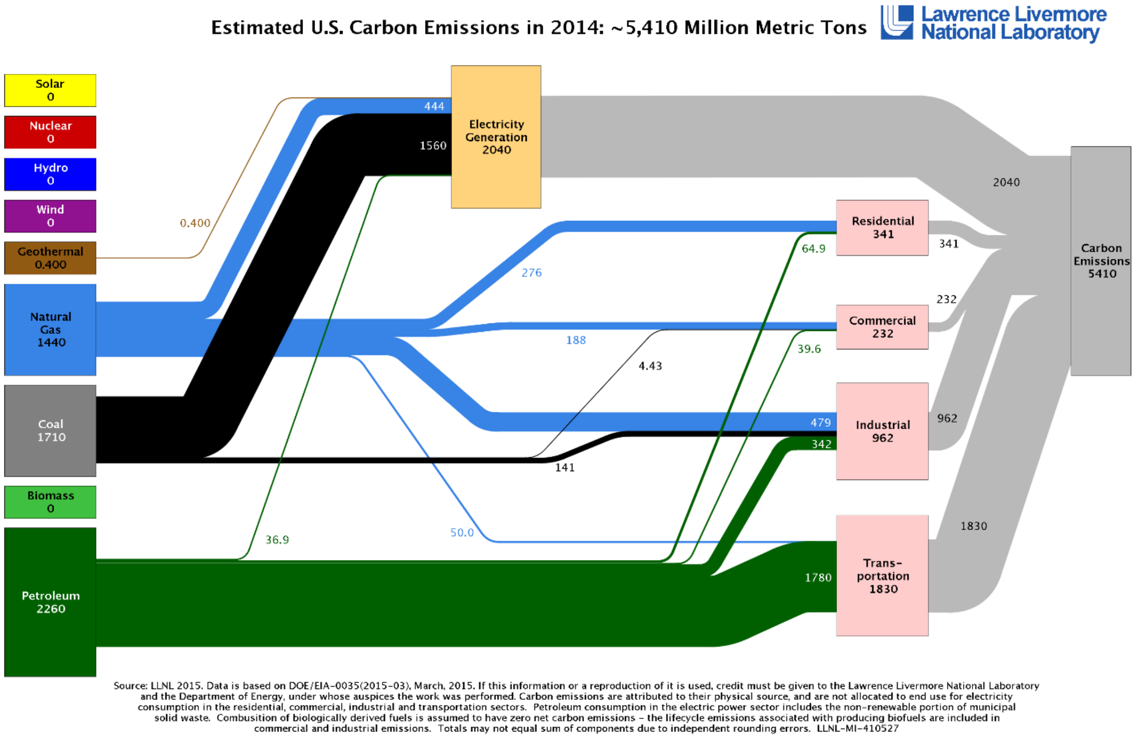


Figure 3. Flowchart for U.S. Energy-related Carbon Emissions, 2014 (Lawrence Livermore National Laboratory).[19 i j] Electricity generation is responsible for the largest share of energy-related carbon dioxide (CO_2) emissions in the U.S., and coal is responsible for the largest share of direct CO_2 emissions from the U.S. power sector.

The rest of this volume examines power sector greenhouse gas emissions in greater detail.

Chapter 2 breaks down the sources of power sector emissions by fuel and by greenhouse gas across electricity generation, transmission, and distribution, and includes a section on lifecycle emissions. Emissions are also attributed to end-use sectors according to each sector's share of electricity retail sales.

Chapter 3 examines major drivers and trends that have affected historical power sector emissions. This chapter also includes projections that incorporate current trends and policies.

Chapter 4 surveys policies aimed at mitigating power sector emissions and includes a comprehensive categorization of power sector policies, as well as illustrative examples of each policy type.

Major findings and conclusions are presented in Chapter 5.

---

[i] This flowchart accounts only for CO_2 emissions from combustion and does not include other greenhouse gases or non-energy CO_2 (see Figure 3). Additionally, the flowchart uses data from the U.S. Energy Information Administration, and reported emissions may differ slightly from the *Inventory of U.S. Greenhouse Gas Emissions and Sinks*.

[j] In the *Inventory*, emissions from combustion of biomass are accounted for under the land-use, land-use change and forestry sector and are not accounted for in energy sectors to avoid double counting.

Chapter 2: Power Sector Greenhouse Gas Emissions

The Environmental Protection Agency's (EPA) *U.S. Inventory of Greenhouse Gas Emissions and Sinks* (the *Inventory*) provides the official accounting of U.S. greenhouse gases (GHGs) and meets the reporting requirement for the United Nations Framework Convention on Climate Change (UNFCCC). Per U.N. reporting requirements, emissions are reported under five categories identified by the Intergovernmental Panel on Climate Change (IPCC):

Energy	Emissions of all greenhouse gases resulting from stationary and mobile energy activities including fuel combustion and fugitive fuel emissions, and non-energy use of fossil fuels.
Industrial processes and product use	Emissions resulting from industrial processes and product use of greenhouse gases.
Agriculture	Anthropogenic emissions from agricultural activities except fuel combustion, which is addressed under Energy.
Land Use, Land-Use Change, and Forestry	Emissions and removals of CO_2, CH_4, and N_2O from forest management, other land-use activities, and land-use change.
Waste	Emissions from waste management activities.

Table 1. IPCC Reporting Category Descriptions.[20]

In addition to IPCC reporting categories, the *Inventory* attributes sources to economic sectors, including the electricity generation sector and end-use economic sectors—residential, commercial, industrial, agricultural, and transportation. This attribution of emissions is useful for understanding emissions from the generation, transmission and distribution of electricity.

Figure 4 displays gross U.S. GHG emissions by economic sector for years 1990 to 2014. In 2014, the electric power sector was responsible for the largest portion of U.S. GHG emissions (30 percent), followed by transportation (27 percent) and industry (21 percent). Direct emissions from the commercial, residential, and agricultural sectors contributed the remaining 22 percent of U.S. GHG emissions. These emissions estimates are based on units of CO_2e.

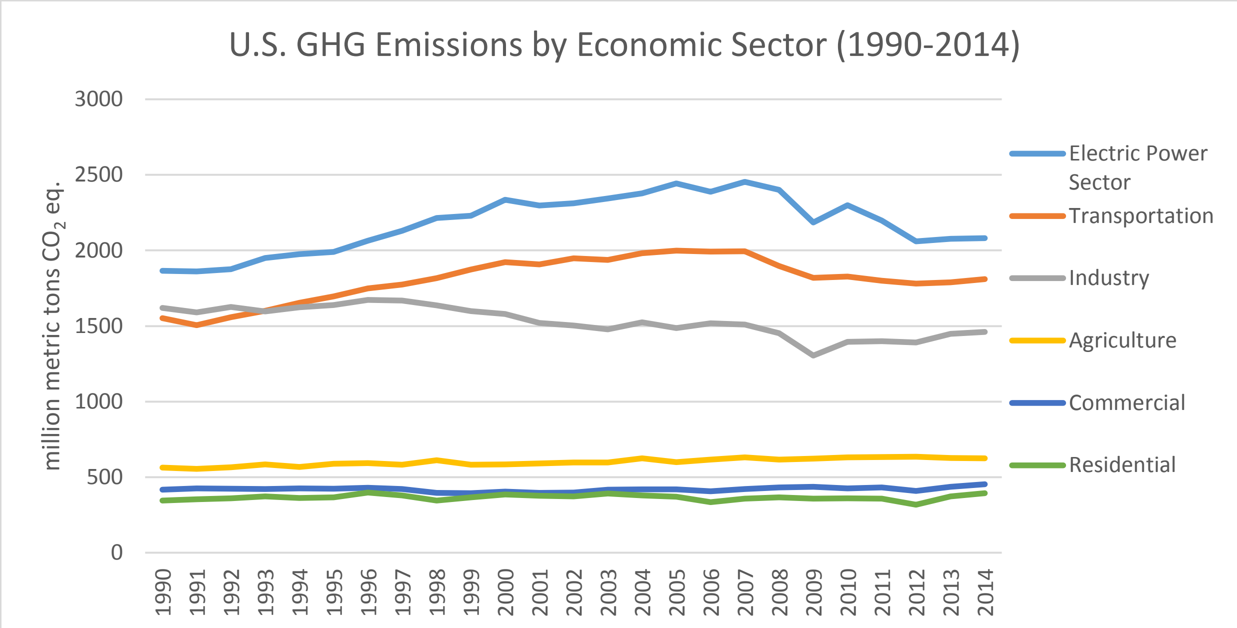


Figure 4. U.S. Greenhouse Gas Emissions Attributed to Economic Sectors, 1990-2014 (EPA).[21] [k] The electric power sector was responsible for the largest share of U.S. greenhouse gas (GHG) emissions (30 percent) in 2014, followed by transportation (27 percent) and industry (21 percent). Direct emissions from the commercial, residential, and agricultural sectors contributed the remaining 22 percent of U.S. GHG emissions in 2014.

Note: Emissions in the end-use sectors—transportation, industry, agriculture, commercial, and residential—include only direct emissions and do not include emissions associated with power consumption.

Within the electric power sector, the generation of electricity from fossil fuel combustion is responsible for the vast majority of GHG emissions (see Table 2). In 2014, fossil fuel combustion resulted in the release of 2,039 million metric tonnes of carbon dioxide (MMT CO_2), as well as smaller amounts of methane (CH_4) and nitrous oxide (N_2O), equivalent to 0.4 MMT CO_2 and 19.6 MMT CO_2 respectively.[l] Additionally, the incineration of non-biogenic waste for electricity generation led to emissions of 9.4 MMT CO_2 and nitrous oxide emissions equivalent to 0.3 MMT CO_2.

Smaller amounts of GHG emissions are associated with other aspects of the power sector. In particular, 6 MMT CO_2 were emitted from the use of carbonates for pollution control,[m] primarily in flue gas desulfurization controls. Additionally, the use of SF_6 as an insulator in electrical transmission and distribution systems resulted in fugitive emissions of SF_6 equivalent to 5.6 MMT CO_2 in 2014.

[k] The U.S. Territories account for 45 MMT CO_2e in 2014. However, these emissions are not broken down by economic sector and are not included in this volume.

[l] All emissions are reported in carbon dioxide equivalent units using global warming potentials (GWP) from the *IPCC Fourth Assessment Report (AR4)*. Methane has a GWP of 25, meaning that the release of 1 kg of methane has a heat-trapping effect equivalent to the release of 25 kg of carbon dioxide. The GWP of nitrous oxide is 298.

[m] Note that only 50 percent of the Other Process Uses of Carbonates emissions were associated with electricity generation; the remainder of Other Process Uses of Carbonates emissions were attributed to the industrial processes economic end-use sector.

Gas/Fuel Type or Source	1990	1995	2000	2005	2010	2013	2014	2014 % of total
Electricity Generation	**1837**	**1967.8**	**2318.5**	**2430.3**	**2288.7**	**2067.3**	**2069**	**99.4%**
CO_2								
Coal	1547.6	1660.7	1927.4	1983.8	1827.6	1571.3	1570.4	75.5%
Natural Gas	175.3	228.1	280.8	318.8	399	444	443.2	21.3%
Petroleum	97.5	58.7	88.4	97.9	31.4	22.4	25.3	1.2%
Incineration of Waste	8	11.3	11.1	12.5	11	9.4	9.4	0.5%
Geothermal	0.4	0.3	0.4	0.4	0.4	0.4	0.4	0.0%
Biomass	*13.3*	*12.9*	*13.9*	*19.1*	*20.2*	*21.4*	*25.9*	--
CH_4								
Fossil Fuel Combustion	0.3	0.4	0.4	0.5	0.5	0.4	0.4	0.0%
N_2O								
Fossil Fuel Combustion	7.4	7.9	9.6	16	18.5	19.1	19.6	0.9%
Incineration of Waste	0.5	0.4	0.4	0.4	0.3	0.3	0.3	0.0%
Electricity - Other	**27.9**	**23.5**	**16.3**	**13.8**	**11.8**	**10.6**	**11.6**	**0.6%**
CO_2								
Other Process Uses of Carbonates	2.5	3.1	2.3	3.2	4.8	5.2	6	0.3%
SF_6								
Electrical Transmission and Distribution	25.4	20.4	14	10.6	7	5.4	5.6	0.3%
Total	1864.8	1991.4	2334.8	2443.9	2300.5	2078	2080.7	**100%**

Table 2. U.S. Power Sector Greenhouse Gas Emissions, by Gas and by Source, 1990-2014, (in units of Million Metric Tonnes[n] of Carbon Dioxide Equivalent).[22]

Note: Totals may not sum due to independent rounding. Emissions values are presented in units of CO_2e using IPCC AR4 GWP values. Emissions from biomass combustion are reported but are not included in power sector emissions totals. Per IPCC reporting guidelines, net carbon fluxes from changes in biogenic carbon reservoirs, including emissions associated with biomass harvest for energy production, are accounted for under the Land Use, Land Use Change, and Forestry (LULUCF) category.

Emissions attributed to the power sector in the *Inventory* include only direct emissions from electricity generation, transmission and distribution. Additional energy-related emissions include emissions from coal mining (IPCC source category 1B1a), abandoned underground coal mines (IPCC source category 1B1a), petroleum systems (IPCC source category 1B2a), and natural gas systems (IPCC source category 1B2b).[o] For analysis on fugitive emissions from natural gas systems, see the first installment of the Quadrennial Energy Review.[23]

2.1 Emissions from Electricity Generation

Of the GHG emissions assigned to the power sector in the *Inventory*, the vast majority—over 99 percent—result from the combustion of fuel for electricity generation. In a steam generator, for example, fuel (coal, natural gas, petroleum, or biomass) combustion heats water to create steam, which turns a turbine that generates electricity.[24] Combustion releases primarily CO_2, as well as smaller amounts of other GHGs such as CH_4 and N_2O.

---

[n] One metric tonne (1,000 kilograms) weighs approximately 2,205 pounds and is equivalent to 1.102 short tons. For the reverse conversion, 1 short ton is equivalent to 0.907 metric tonnes.

[o] Emissions from these categories are attributed to the Industrial end-use sector in the *Inventory*.

Figure 5 shows total emissions from electricity generation by GHG from 1990 through 2014. Total emissions from electricity generation were 2,069 MMT CO_2e in 2014, 15 percent below peak emissions of 2,442 MMT CO_2e in 2007. Emissions by GHG for 2014 were as follows:[25]

- Carbon dioxide (CO_2): 2,048.7 MMT CO_2, or 99.0 percent of total generation emissions
- Methane (CH_4): 0.4 MMT CO_2e, <0.1 percent of total
- Nitrous oxide (N_2O): 19.9 MMT CO_2e, 1.0 percent of total.

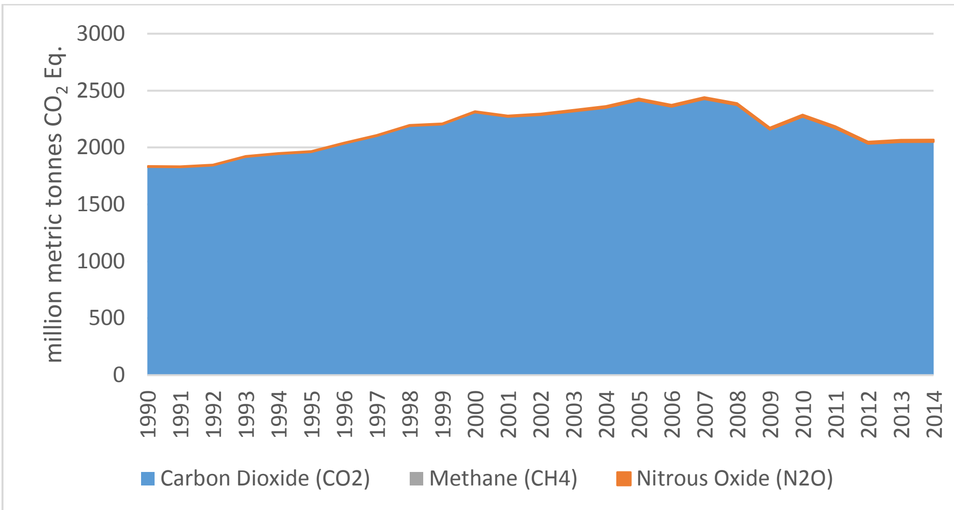


Figure 5. U.S. Greenhouse Gas Emissions from Electricity Generation, 1990-2014 (EPA).[26]
Carbon dioxide (CO_2) makes up 99.0 percent of total greenhouse gas (GHG) emissions from U.S. electricity generation. Nitrous oxide accounts for 1.0 percent, and methane accounts for less than 0.1 percent of total GHG emissions from U.S. electricity generation. Total GHG emissions from U.S. electricity generation in 2014 were 15 percent below the 2007 peak of 2,442 million metric tonnes of CO_2e.

A Note about Data

Due to their relative importance, combustion-related CO_2 emissions are considered in greater detail than other electricity-related emissions in this volume. The focus on CO_2 also allows for the use of more recent data than is provided in the *Inventory*, which generally trails the publication date by more than two years due to availability of complete datasets (i.e. the *Inventory* published in April 2016 contains data through 2014). In contrast, the U.S. Energy Information Administration (EIA) publishes the *Monthly Energy Review* each month, with power sector CO_2 emissions data lagging behind the publication date by only three months. While the *Monthly Energy Review* does not provide the official record of U.S. power sector emissions, it offers more recent insight into power sector emissions and trends.

Throughout this volume, data from the *Inventory* will be used where it is the most recent source of data, or where consideration of all greenhouse gases is required. Data from the *Monthly Energy Review* will be used when considering only CO_2 emissions from fossil fuel combustion.

2.1.1 Generation Mix

The amount of CO_2 emitted from electricity generation depends on the quantity and type of fuels consumed and the efficiency of the electric generating unit. The majority of electricity-related CO_2 emissions result from the combustion of fossil fuels, including coal, natural gas, and petroleum products. Smaller amounts of CO_2 are also emitted from the incineration of non-biogenic waste for electricity generation. In general, non-fossil fuel power sources—including nuclear power, hydropower, geothermal, wind, and solar—emit little or no CO_2 during electricity generation. Figure 6 shows the share of electricity generation and subsequent CO_2 emissions by fuel for 2015.

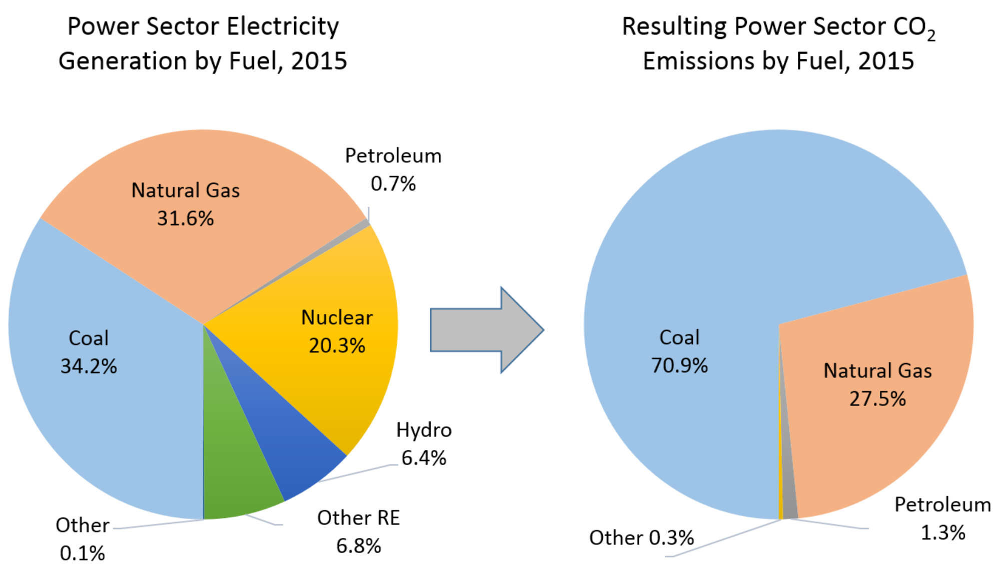


Figure 6. U.S. Power Sector Generation and CO_2 Emissions by Fuel, 2015 (EIA).[27] Coal accounted for the largest share of CO_2 emissions from the U.S. power sector at 70.9 percent, followed by natural gas at 27.5 percent.

Coal has traditionally accounted for the largest share of electricity generation and has also been responsible for over 80 percent of power sector CO_2 emissions for most years in the *Inventory*.[28] From 1990 to 2006, coal accounted for slightly more the 50 percent of power sector generation. Since then, coal's share of power sector generation has declined to 34.2 percent in 2015.[29] Similarly, coal accounted for more than 80 percent of power sector emissions from 1990 to 2010 and has since declined to 70.9 percent of power sector emissions in 2015. A discussion of the trends and drivers for this decline of power sector emissions will be presented in Chapter 3.

In contrast, natural gas has gained an increasing share of the generation mix, and emissions from natural gas consumption have seen a subsequent increase. The portion of emissions from natural gas has increased from 10 percent of 1990 emissions to 27.5 percent of emissions in 2015.[30] Petroleum has historically accounted for smaller levels of electricity generation and its share of the generation mix has fallen in recent years.[31] Consequently, petroleum's share of emissions has fallen from 5.6 percent in 1990 to 1.3 percent in 2015.

Additionally, low- or zero-emitting sources account for 33.4 percent of power sector generation. In 2015, nuclear power accounted for 20.3 percent of power sector electricity, followed by conventional hydropower at 6.4 percent, and other renewable forms of generation—including wind, solar, geothermal, and biomass—at 6.8 percent.[32]

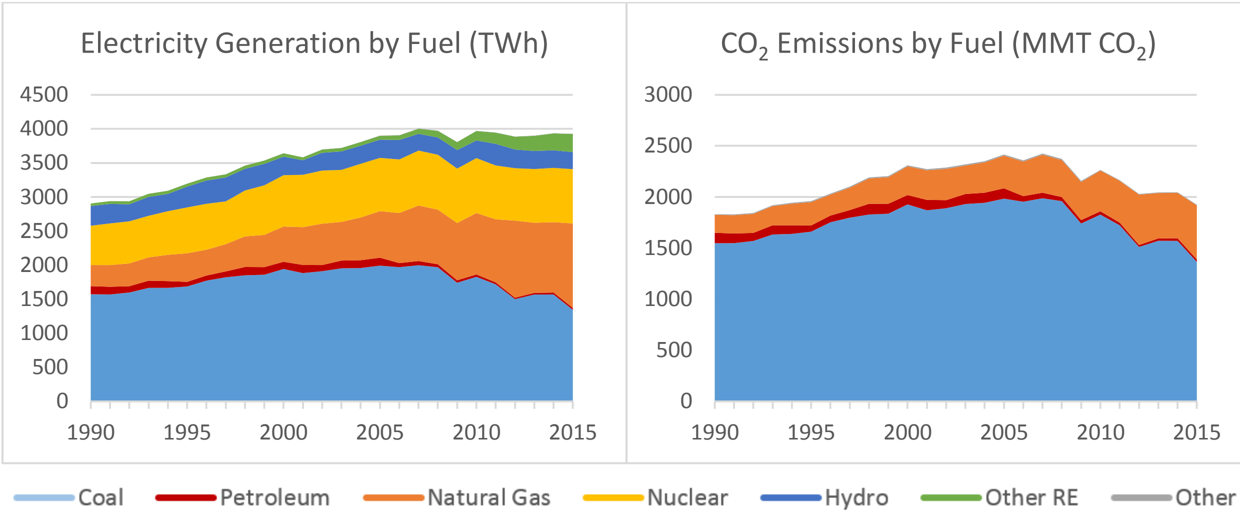


Figure 7. U.S. Power Sector Electricity Generation and CO_2 Emissions by Fuel, 1990-2015 (EIA).[33] Coal has traditionally accounted for the largest share of electricity generation and has also been responsible for over 80 percent of power sector emissions for most of the years in the *Inventory*.

2.1.2 Emission rates

The CO_2 emissions from the power sector also depend on the carbon intensity of electricity generation, which varies by fuel type and generation technology. Carbon intensity can be measured as an *emission rate*, and is often presented in terms of the mass of a given pollutant per unit of energy. For example, the emission rate of the power sector can be presented in terms of kilograms of carbon dioxide emitted per megawatt-hour[p] of electricity generated (kg CO_2/MWh).[q]

The emission rate of fossil fuel combustion is the product of two factors: the carbon content of the fuel, and the heat rate at which the energy stored in the fuel is converted into electricity. The carbon content can be measured using an emission factor, which gives the amount of CO_2 emitted per unit of thermal energy output and is measured in kilograms of CO_2 per British thermal unit (kg CO_2/Btu). The emissions factors for fossil fuels range from 95 kg CO_2/Btu for coal[r] to 53 kg CO_2/Btu for natural gas, with petroleum between coal and natural gas at about 73 kg CO_2/Btu.[34] [35]

The thermal efficiency of electricity production is measured by the heat rate, or the amount of thermal energy used to generate one kilowatt-hour of electricity, measured in British thermal

[p] One megawatt-hour (MWh) is equal to 1,000 kilowatt-hours (kWh). One gigawatt-hour (GWh) is equal to one million kWh. One terawatt-hour (TWh) is equal to 1,000 GWh.

[q] Emission rates are also commonly reported in pounds of CO_2 emitted per megawatt-hour of electricity generated (lbs. CO_2/MWh). One kilogram weighs 2.2 pounds, so the emissions rates in this volume can be converted to lbs. CO_2/MWh by multiplying by 2.2.

[r] The emission factor for coal can vary substantially by the type of coal used. Water and various elements, such as sulfur and non-combustible elements in some fuels reduce their heating values and increase their CO_2-to-heat contents.

units per kilowatt-hour (Btu/kWh).[s] A generator with a lower heat rate can generate the same quantity of electricity while consuming less fuel, compared to a unit with higher heat rate.[36] Heat rates depend in part on the type of equipment installed at a generating plant and can vary substantially across fuel and technology types. For example, in 2012 generators primarily powered by coal-fired boilers had heat rates ranging from 8,800 Btu/kWh to 25,000 Btu/kWh.[37]

Table 3 displays some average emissions factors, heat rates, and the resulting emission rate for electricity generation by fuel and generation technology. As shown in the table, the emissions rate varies widely by fuel and by technology. Natural gas combined cycle (NGCC) generators have greater thermal efficiencies (lower heat rates) than steam and combustion turbines. As a result of both greater efficiency and the lower carbon content of natural gas, natural gas generators have around 60 percent lower emissions per megawatt-hour of electricity than the average coal-fired power plant.

	CO_2 Emissions Factor (kg CO_2/Btu)	Heat Rate (Btu/kWh)	Emission rate (kg CO_2/MWh)
Coal, steam generator	95.3	10,080	960.6
Petroleum, steam generator	73.2	10,156	743.4
Natural Gas, combustion turbine	53.1	11,378	604.2
Natural gas, combined cycle	53.1	7,658	406.6

Table 3. Average Emissions Factors, Heat Rates, and Emission Rates of the U.S. Fossil Fuel Generation Fleet, 2014 (EIA).[38] [39] The emission rate of electricity generation is a key indicator of the climate impact of the power sector, and varies significantly by fuel and technology.

Note: Emissions factors and heat rates are fleet-wide averages, and actual values for a given generator and fuel can vary from the numbers presented here. The emission rate in kg CO_2/MWh is obtained by multiplying the CO_2 emission factor (kg CO_2/Btu) by the heat rate (Btu/kWh) and dividing by 1,000 (to convert from kWh to MWh).

2.1.3 Emissions by Fuel and Facility-Level Data

Fossil Fuels

Fuel consumption can be measured in physical units (e.g. short tons for coal, or billion cubic feet for natural gas) or in heat content, as measured in Btu's. In 2014, the U.S. power sector consumed 848,803 thousand short tons of coal with a thermal content of 16,441 trillion Btu, yielding a net generation of 1,569 terawatt-hours (TWh) of electricity. National consumption of natural gas for electricity generation was 7,849 billion cubic feet, or 8,362 trillion Btu, resulting in generation of 1,033 TWh of electricity. Table 4 displays national-level data by fuel type.

The *Inventory* determines national-level emissions in a top-down approach by collecting total fuel consumption data from the EIA, and using an average emissions factor to determine the

[s] The heat rate is inversely proportional to the thermal efficiency of electricity generation. To express the efficiency of a generator as a percentage, divide the Btu content of a kWh of electricity (which is 3,412 Btu) by the heat rate. For example, a heat rate of 10,500 Btu is equivalent to an efficiency of 33 percent, which means 33 percent of the thermal energy in the fuel is converted to electricity.

emissions per fuel. More granular data can be obtained from EPA's Greenhouse Gas Reporting Program (GHGRP), a bottom-up accounting of GHG emissions at the facility level.

The GHGRP's Power Plants Sector[t] consists predominantly of facilities that produce electricity from fossil fuel combustion and also includes facilities that produce steam, heated air, or cooled air from fossil fuel combustion.[40] In 2013, 1,574 facilities reported total emissions of 2,103.8 MMT CO_2e under GHGRPs Power Plants Sector.[u] In 2014, 1,544 facilities reported total emissions of 2,101.1 MMT CO_2e under GHGRP's Power Plants Sector.[41]

In the GHGRP's Power Plants Sector in 2014, 408 facilities reported using coal for electricity generation, accounting for 1,575 MMT CO_2e emissions. That same year, natural gas was consumed at 1,200 power plants, resulting in emissions of 470 MMT CO_2e. Petroleum products were consumed at 679 facilities, resulting in emissions of 19.9 MMT CO_2e. Other fuels were consumed at 112 facilities, leading to emissions of 12.2 MMT CO_2e.[42] [v]

	Coal	**Natural Gas**	**Petroleum**
Consumption, physical units[43]	848,803 thousand short tons	7,849 billion cubic feet	50,537 thousand barrels
Consumption, heat content[44]	16,441 trillion Btu	8,362 trillion Btu	295 trillion Btu
Power sector net generation[45]	1,568.774 TWh	1,033.172 TWh	25.3 TWh
CO_2 Emissions[46]	1,570.4 MMT CO_2	443.2 MMT CO_2	25.3 MMT CO_2
Avg emission rate	1,001 kg CO_2/MWh	429 kg CO_2/MWh	902 kg CO_2/MWh

Table 4. Common fossil fuel metrics for electricity generation in the U.S., 2014 (EIA, EPA).
The emission rate of electricity generation is a key indicator of the climate impact of the power sector, and varies significantly by fuel and technology. The average emission rate for electricity generated from coal in 2014 was about 1,000 kg CO_2/MWh. The average emission rate of natural gas plants in 2014 was 60 percent less than that of average coal-fired plants, averaging about 430 kg CO_2/MWh.

[t] The GHGRP generally requires facilities that emit greater than 25,000 metric tonnes CO_2e per year to report. The GHGRP power plants sector includes emissions from fossil fuel combustion reported by facilities reporting a primary NAICS code of 2211xx (Electric Power Generation, Transmission and Distribution) or 221330 (Steam and Air-Conditioning Supply). The sector also includes any other electricity generators that are required to report to the EPA CO_2 mass emissions year-round according to 40 CFR part 75, which includes some generators below 25,000 metric tonnes CO_2e per year.
[u] This number differs slightly from power sector emissions reported in the *Inventory*. This difference is due to a combination of different accounting methods (bottom-up vs. top-down) as well as different definitions for what facilities fall under the power sector.
[v] These emissions include the sum of emissions of CO_2, CH_4, and N_2O in carbon dioxide equivalent units. Note that some facilities use more than one kind of fuel, so the total number of facilities reporting under the power plants sector is less than the sum of facilities reporting emissions from coal, natural gas, petroleum products, and other fuels. Facilities reporting zero emissions in 2014 have been omitted from the facility number totals.

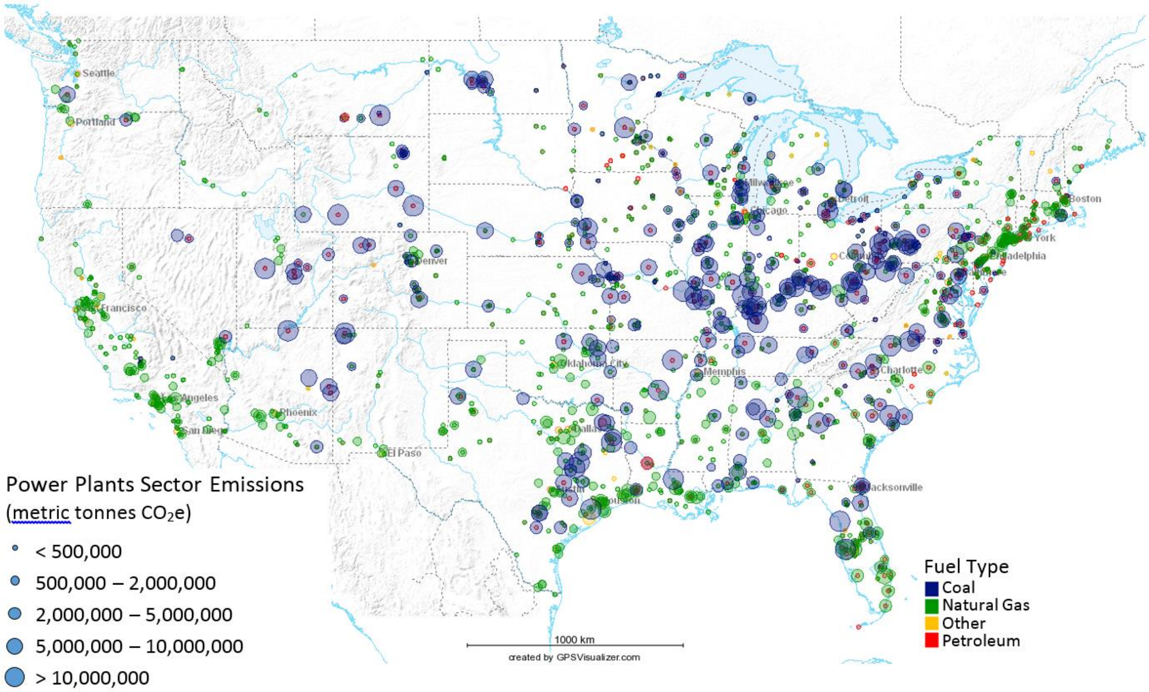


Figure 8. GHG Emitting Facilities by Fuel in the U.S. Power Plants Sector, 2014 (EPA).[47]

Note: The size of the dot indicates the magnitude of total GHG emissions—including CO_2, CH_4, and N_2O—in units of MMT CO_2e. The color indicates the fuel source—violet for coal, green for natural gas, red for petroleum, and yellow for other fuels. Some facilities use more than one fuel.

Incineration of Waste

The United States generates about 250 MMT of municipal solid waste (MSW) annually, of which 11.7 percent (26.5 MMT) is incinerated for useful energy recovery.[48] To determine emissions from waste incineration, waste is first allocated to one of two categories based on the origin of carbon in the waste. Biogenic waste CO_2 emissions are defined as emissions related to the natural carbon cycle[49] and include emissions from incineration of paper, yard trimmings, and food scraps. Per IPCC guidelines, emissions from the incineration of biogenic waste are not attributed to the power sector and instead have their net carbon flows accounted for under the Land Use, Land-Use Change, and Forestry (LULUCF) sector. Non-biogenic waste includes fossil fuel-derived waste such as plastics and synthetic rubbers. Only emissions from the incineration of non-biogenic waste are accounted for in this waste incineration category.

GHG emissions from incineration of non-biogenic waste accounted for 0.5 percent of total power sector emissions in 2014 and included 9.4 MMT CO_2 and nitrous oxide emissions equivalent to 0.3 MMT CO_2.

Figure 9 displays the distribution of emissions from waste incineration by source. The main components of non-biogenic waste include plastics, synthetic rubbers, carbon black, and synthetic fibers. Plastics in the U.S. waste stream are primarily in the form of containers, packaging, and durable goods. Rubber is found in durable goods such as carpets, and in non-durable goods such as clothing and footwear. Fibers in municipal solid wastes are predominantly from clothing and home furnishings. Tires, which contain rubber and carbon black are included in the waste incineration estimate, though waste disposal practices for tires differ from municipal solid waste.

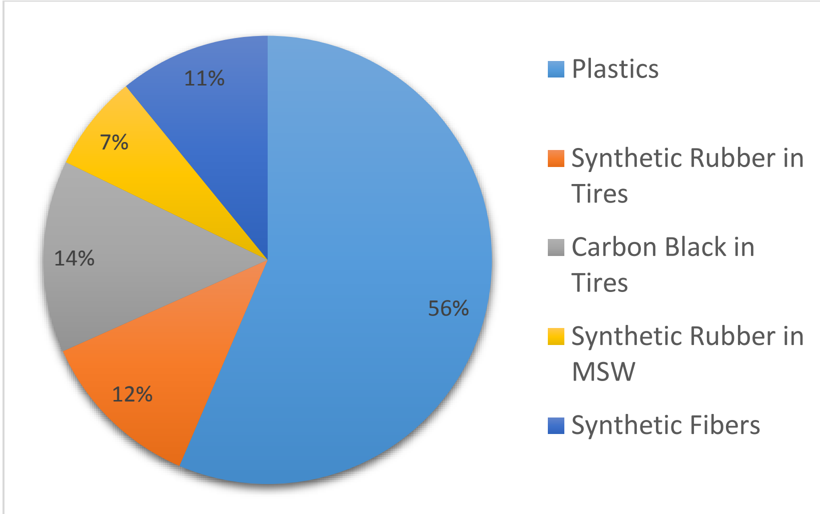


Figure 9. CO_2 Emissions from Incineration of Non-Biogenic Waste in the U.S., by Source, 2014 (EPA).[50] In 2014, incineration of non-biogenic waste accounted for 9.7 MMT CO_2e, or 0.5 percent of total U.S. power sector GHG emissions.

In 2013, a total of 68 facilities reported emissions to the EPA GHGRP under the category of Solid Waste Combustion.[w] These facilities account for a total of 9.95 MMT CO_2e, or about 95 percent of all emissions reported for this category in the *Inventory*. These numbers have remained fairly constant in 2014, with 67 facilities reporting total emissions of 9.94 MMT CO_2e.[51]

Biomass

Biomass such as wood and biogenic materials in the waste stream can be combusted[x] to generate electricity, in the process releasing CO_2 and smaller amounts of CH_4 and N_2O. In 2014, GHG emissions from the burning of woody biomass for electricity generation was 25.9 MMT CO_2e.[52]

In line with GHG accounting methods adopted by the UNFCCC, CO_2 emissions from biomass combustion are not attributed to the energy sector. Instead, net biogenic CO_2 emissions related to terrestrial carbon stocks are assigned to the LULUCF sector, even if the emissions actually take place at facilities typically associated with a different IPCC sector.[53] This approach avoids double-counting of any net emissions associated with the combustion of biomass for electricity generation.

For this reason, direct emissions from biomass combustion are reported for convenience only and are not included in the power sector totals. However, increased use of biomass could lead to land use changes (such as when forests are converted to cropland to grow feedstocks) that result in a loss of terrestrial carbon stocks. The lack of inclusion of biomass emissions in the power sector totals in this volume should not be interpreted as any assumption regarding the net carbon intensity of electricity generation from biomass.

---

[w] The GHGRP defines a Solid Waste Combustion facility as any facility reporting emissions from stationary fuel combustion in NAICS code 562213. Generally, facilities in this source category are required to report their emissions to the GHGRP if their emissions exceed 25,000 metric tonnes CO_2e per year.

[x] Other processes, such as gasification, allow for electricity generation from biomass.

2.2 Other Power Sector Emissions: Pollution Control and SF_6

Small levels of GHG emissions are associated with other facets of the power sector, including emissions from pollution control equipment and electrical transmission and distribution systems.

2.2.1 Pollution control

Limestone ($CaCO_3$) and dolomite ($CaMg(CO_3)_2$) are commonly used in environmental pollution control systems to remove sulfur dioxide (SO_2) from the flue exhaust resulting from fuel combustion. Coal and oil contain varying amounts of sulfur which, during combustion, is converted into SO_2 or SO_3 (collectively referred to as SO_x), both of which form sulfuric acid (H_2SO_4) when released into the atmosphere. As a result of environmental regulations limiting SO_x from coal-fired power plants, many plants have installed flue gas desulfurization (FGD) systems that use limestone or other carbonates as a sorbent. The typical reaction proceeds as:

$$\mathrm{CaCO_3}\ (\text{solid}) + SO_2\ (\text{gas}) \rightarrow \mathrm{CaSO_3}\ (\text{solid}) + \mathrm{CO_2}\ (\text{gas}),$$

where CO_2 is released as a byproduct. Total emissions in 2014 were 12.1 MMT CO_2, up from 4.9 MMT CO_2 in 1990, primarily as a result of greater proliferation of FGD pollution controls. Per the *Inventory*, fifty percent of these emissions are associated with electricity generation; the remainder are attributed to the industrial sector.[54]

2.2.2 Sulfur Hexafluoride (SF_6) for Electrical Transmission and Distribution

SF_6 has the highest global warming potential (GWP) of any gas evaluated by IPCC and is primarily used as an electrical insulator in transmission and distribution equipment because of its dielectric strength and arc-quenching characteristics. It is used in gas-insulated substations, circuit breakers, and other switchgear. Primary sources are fugitive emissions from gas-insulated substations and switchgear through seals, as well as emissions released during the manufacturing, installation, servicing and disposal of electrical equipment.

Emissions of SF_6 from equipment manufacturing and from electrical transmission and distribution systems were estimated to be 200 metric tonnes—equivalent to 5.6 MMT CO_2e—in 2014, a 78 percent decrease from emissions in 1990. This reduction in emissions is primarily due to an increase in the price of SF_6 during the 1990s and industry participation in EPA's voluntary SF_6 Emission Reduction Partnership for Electric Power Systems beginning in 1999. Utilities participating in this partnership have lowered their emission factor (kg SF_6 emitted per kg of nameplate capacity) by more than 80 percent since 1999.[55]

Beginning in 2011, all utilities with a total SF_6 nameplate capacity greater than 17,820 kg (the quantity that historically resulted in annual SF_6 emissions equivalent to 25,000 metric tonnes of CO_2) were required to report emissions through the EPA GHGRP. Utilities reporting emissions through the GHGRP have reduced emissions significantly since 2011, which much of the reduction seen from utilities that are not participants in the voluntary SF6 reduction partnership.[56] In 2013, a total of 121 facilities reported combined emissions of 3.3 MMT CO_2e under the category Electrical Transmission and Distribution Equipment, and six Electric Equipment Manufacturing facilities reported a combined 0.201 MMT CO_2e in emissions of SF_6. The numbers remained fairly constant in 2014. A total of 118 facilities reported combined emissions of 3.1 MMT CO_2e under the category Electrical Transmission and Distribution Equipment, and seven Electric Equipment Manufacturing facilities reported a combined 0.199 MMT CO_2e emissions of SF_6.[57]

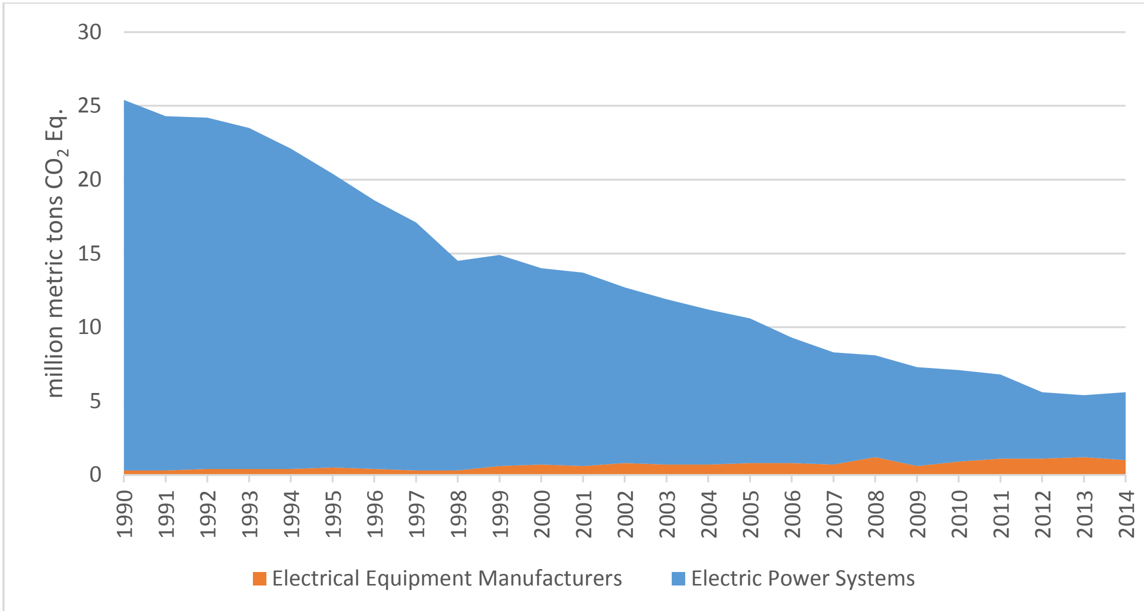


Figure 10. SF_6 Emissions from Electricity Transmission and Distribution in the U.S., 1990 – 2014 (EPA).[58] Emissions of sulfur hexafluoride (SF_6) from equipment manufacturing and from electrical transmission and distribution systems in the U.S. decreased by 78 percent between 1990 and 2014.

2.2.3 Transmission and Distribution Line Losses

About 6 percent of the electricity generated at U.S. power plants is lost each year through line losses on the power sector's transmission and distribution (T&D) system.[59] Though not explicitly included as a source of GHG emissions in the *Inventory*, electricity-related T&D losses account for about 120 MMT CO_2e of power sector emissions each year. Reducing these losses would result in less generation being needed to meet demand, leading to lower GHG emissions.

Distribution system losses are estimated to be greater than transmission system losses, although in general, aggregate statistics do not differentiate between T&D losses.[60] Losses in the transmission system include Ohmic heating, corona losses, AC-DC converter losses, and transformer losses.[61] Distribution losses include Ohmic heating and transformer losses for overhead lines, as well as additional loss mechanisms in underground distribution lines.[62] Analysis performed for the first installment of the *Quadrennial Energy Review* identified a number of loss-reduction strategies, including larger conductors, high-voltage direct current transmission lines, higher-efficiency transformers, and distribution feeder reconfiguration with strategic capacitor placement, among others.[63] [64]

2.3 Emissions by Electricity End-Use

Power sector emissions can also be attributed to end-use in order to highlight each sector's share of electricity use. As a general rule of thumb, about a quarter of electricity is consumed by industry, with the remainder split between the residential and commercial sectors.[y] Transportation and agriculture currently account for very small amounts of electricity use.

[y] Some resources refer to a single "Buildings" sector, which is a combination of the residential and commercial sectors.

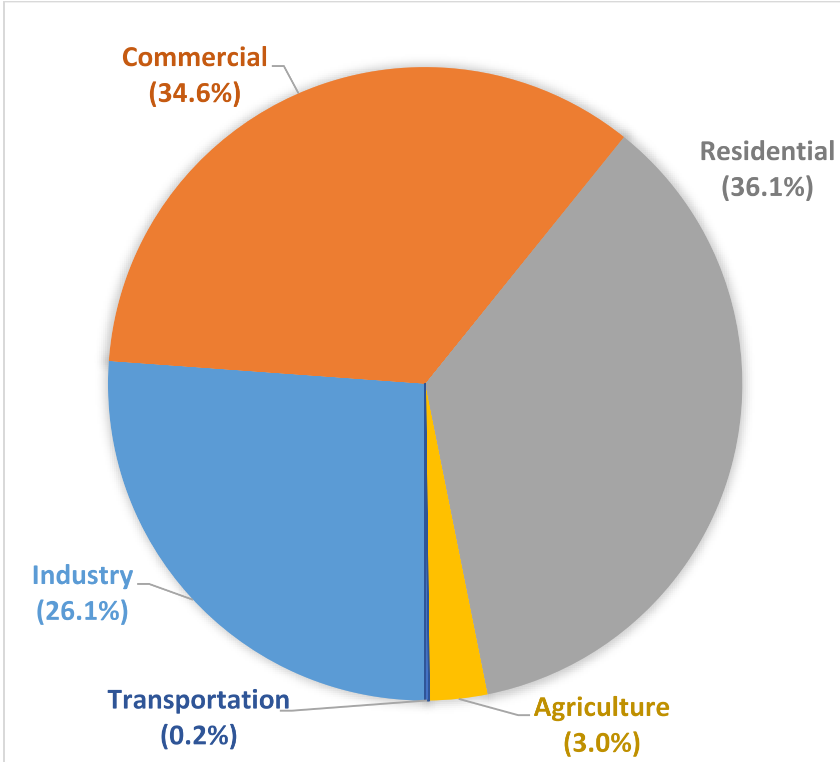


Figure 11. U.S. Electricity-related Emissions by End-Use Sector, 2014 (EPA).[65] When attributing current (2014) U.S. electricity-related emissions to end-use economic sectors, the industrial sector is responsible for approximately one-quarter of electricity-related greenhouse gas emissions, and the remainder is split evenly between the residential (36.1%) and commercial sectors (34.6%).

Note: Sectoral definitions used by the EPA differ slightly from those used by the EIA. EIA does not include a separate "Agriculture" sector and instead incorporates energy-related agricultural emissions into EIA's definition of the "Industrial" economic sector.[66]

Figure 12 shows power-sector emissions attributed to end-use sectors over time. The graph on the left displays power-sector emissions by end-use only. Total emissions (displayed in the graph on the right) include both emissions from electricity consumption and direct emissions (e.g., direct consumption of natural gas for residential heating, or combustion of gasoline for transportation).[67]

Industrial electricity-related emissions in 2014 were 15 percent below 1990 levels as manufacturing has shifted away from energy-intensive products such as steel to less-intensive products such as computers.[68] [69] Residential electricity-related emissions have increased 24 percent above 1990 levels, driven by population growth and changes in housing and building attributes (e.g., size and insulation).[70] [71] Commercial electricity-related emissions are 31 percent above 1990 levels.[72] However, residential and commercial electricity-related emissions have declined from 2005 levels by 13.9 percent and 11.9 percent respectively. Figure 13 provides a sectoral breakdown of emissions for each end-use sector and includes both total emissions and electricity-related emissions.

The U.S. Energy Information Administration (EIA) provides a slightly different sectoral breakdown that is commonly used for modeling energy use and energy-related carbon dioxide emissions by economic sector. The most significant difference is that EIA does not define a separate agricultural sector—instead, most of those energy-related CO_2 emissions are allocated to EIA's industrial sector.[73] Because EIA data and sectoral definitions are commonly used in other DOE documents, emissions by end-use are also presented here according to EIA definitions.

The *Electricity End Uses, Energy Efficiency and Distributed Energy Resources: Baseline and Outlook to 2040* provides a more granular breakdown of electricity consumption at the sub-sectoral level, including current consumption, trends and projections, and policies related to energy efficiency.

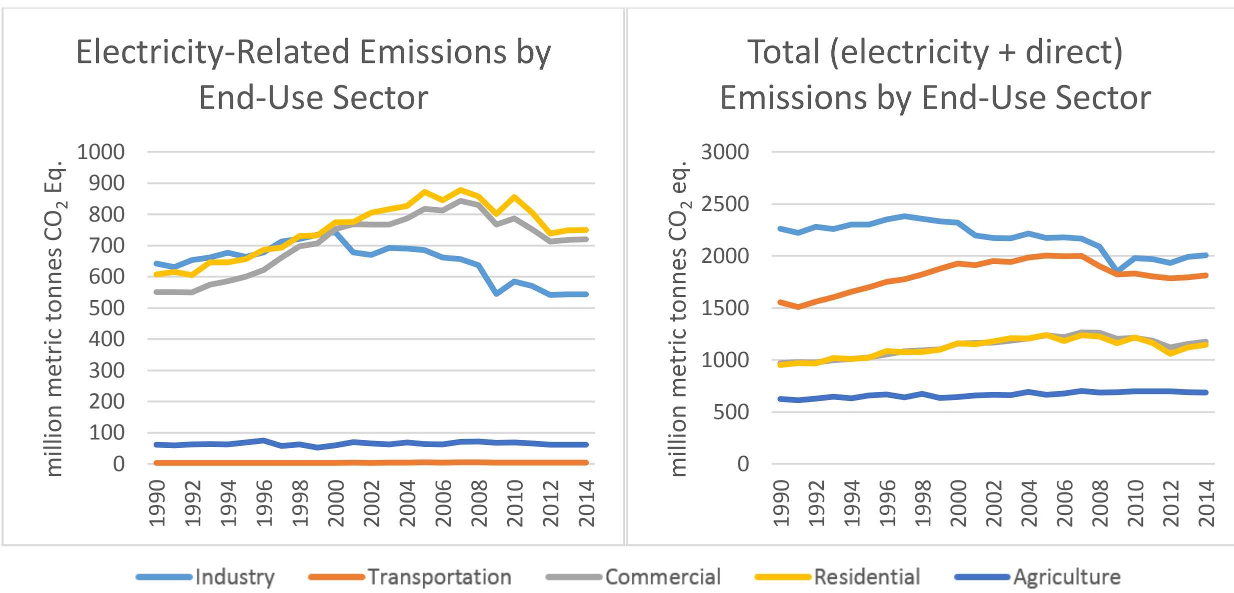


Figure 12. U.S. Electricity-Related Emissions Attributed to End-Use Sectors, 1990-2014 (EPA).[74] The current (2014) sectoral breakdown of U.S. electricity-related emissions has been relatively constant since 2010, but it has been evolving slowly over time. In 1990, the industrial sector was responsible for the largest share of U.S. electricity-related emissions. When accounting for both electricity-related and direct emissions—the latter of which corresponds to on-site use of natural gas and other fuels—the residential and commercial sectors each generated ~60 percent as much carbon emissions as the industrial and transportation sectors in 2014.

Note the difference in scale of emissions on the vertical axis.

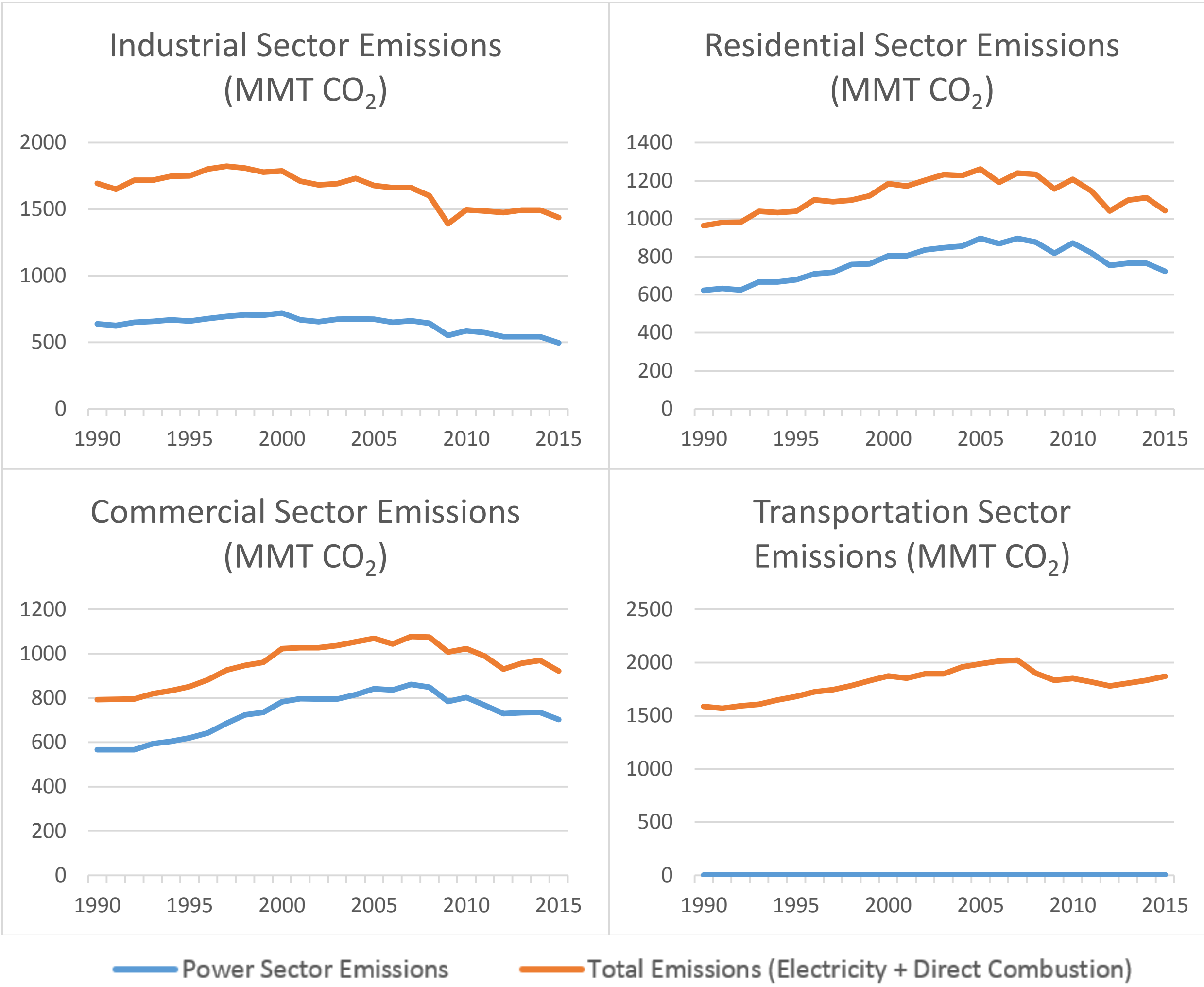


Figure 13. Total and Electricity-Related CO_2 Emissions in the U.S. by Sector, 1990-2015 (EIA).[75] In the U.S. commercial and residential sectors, power consumption accounts for the majority of electricity-related CO_2 emissions, at 76 percent and 69 percent, respectively. In the U.S. industrial sector, power consumption accounts for 34 percent of electricity-related CO_2 emissions. In contrast, power consumption accounts for less than 1 percent of U.S. transportation CO_2 emissions.

2.4 Emissions from Distributed Generation

The U.S. has more than 12 million distributed generation units,[76] including distributed wind, distributed solar photovoltaics (i.e. "rooftop solar"), and combined heat-and-power (CHP) plants. Distributed generation technologies that involve combustion—particularly burning fossil fuels—can produce many of the same types of emission as larger fossil-fuel-fired power plants, including air pollution and greenhouse gases. Emissions from distributed generation are not accounted for in the *Inventory*'s power sector,[77] [z] [aa] and instead are additional electricity-related emissions that must be accounted for separately.

In 2014—the latest year for which emissions from distributed generation is available—total distributed generation included 12.52 TWh of electricity from the commercial sector and 144.08 TWh from the industrial sector. CO_2 emissions[bb] resulting from distributed generation included 11.3 MMT CO_2e in the commercial sector and 108 MMT CO_2e in the industrial sector.

The generation mix and emissions profile of distributed generation differs in several important ways from electricity generation in the power sector. For example, in 2015, 96 percent of distributed generation (excluding small-scale solar) was generated at CHP plants, with only 4 percent of distributed electricity generated at non-CHP facilities. In the power sector, these numbers are reversed: 96 percent of electricity is generated at electricity-only utilities and independent power producers, and only 4 percent of electricity is generated at CHP plants in the power sector.[78]

CHP generates electricity and useful hot water or steam from a single system at or near the point of use. In general, CHP systems use 25–35 percent less primary energy than using grid electricity plus conventional heating end-uses (e.g., water heaters or boilers) and typically have greater efficiencies than heaters using grid electricity. Note that, because CHP systems generate both useful thermal energy and electricity, the emission rate—amount of CO_2 emitted per MWh of electricity—is not a good measure of the carbon intensity of CHP systems. A better measure of the carbon intensity would be the amount of CO_2 emitted per useful energy output, which includes both electricity and heat output. More information about distributed generation is included in the *Electricity End Uses, Energy Efficiency and Distributed Energy Resources: Baseline and Outlook to 2040*.

The on-site generation mix and subsequent emissions from distributed generation in the industrial sector differs significantly from the power sector generation mix. Natural gas comprised nearly 60 percent of generation in the industrial sector in 2015. The industrial sector also has larger relative contributions from non-hydro renewables (primarily biomass) than the power sector, accounting for over 20 percent of generation.

[z] The distinction comes from EIA's definition of the power sector, which EPA uses in its attribution of emissions by economic sector. The electric power sector is defined by EIA as the energy-consuming sector that consists of electricity-only and combined-heat-and-power plants whose primary business is to sell electricity, or electricity and heat, to the public.
[aa] Emissions from distributed generation are accounted for in the *Inventory* as emissions attributed to the direct combustion of fossil fuels in each end-use sector. See, for example, Table 2-5 or Table 2-10 in the *Inventory* to see how emissions are accounted for by end-use sector and sub-category. The *Inventory* does not have the granularity to distinguish between emissions from distributed generation and other uses of fossil fuels (for example, natural gas for heating in the commercial sector, or for process heat in industrial processes). To determine emissions from distributed generation, this volume uses data from the U.S. Energy Information Administration.
[bb] These numbers include only CO_2 from fossil fuel combustion and do not cover any of the other GHGs included in the *Inventory*. However, for the power sector, CO_2 accounts for 99 percent of total sector emissions, and this is expected to be true for electricity generation in the industrial and commercial consumers as well.

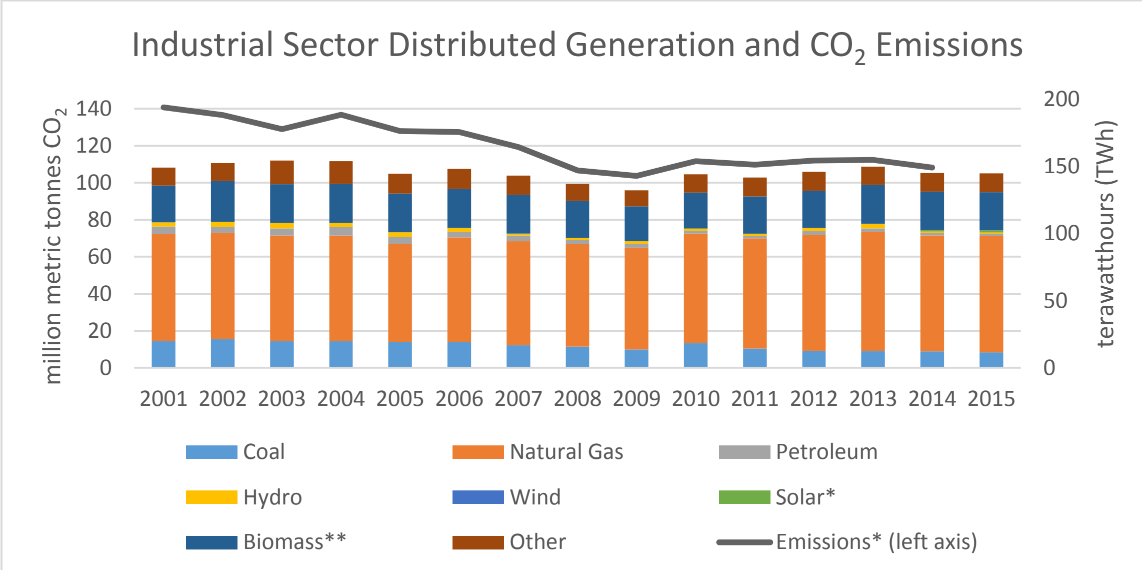


Figure 14. Distributed Generation by Fuel and CO_2 Emissions from the U.S. Industrial Sector, 2001-2015 (EIA).[79] [80] The generation mix and subsequent emissions of distributed generation in the U.S. industrial sector differs significantly from the U.S. power sector generation mix. In 2013, the U.S. industrial sector generated 150 TWh of electricity, resulting in emissions of 112 MMT CO_2.

Notes: Solar includes utility-scale solar and small-scale distributed solar. The EIA began tracking small-scale distributed solar in 2014. Biomass includes wood and wood-derived fuels and other renewable biomass sources including landfill gas, agricultural by-products, etc. As of publication, emissions data were available through 2013.

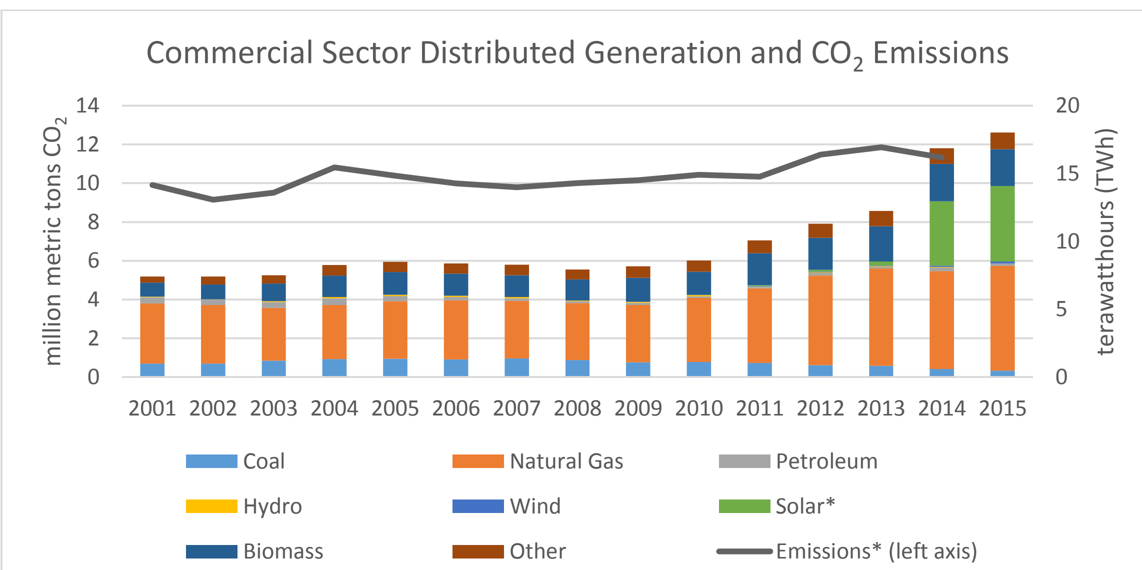


Figure 15. Distributed Generation by Fuel and CO_2 Emissions from the U.S. Commercial Sector, 2001-2015 (EIA).[81] [82] The generation mix and subsequent emissions of distributed generation in the U.S. commercial sector differs significantly from the U.S. power sector generation mix. In 2013, the U.S. commercial sector generated 12.5 TWh of electricity, resulting in emissions of 11.9 MMT CO_2.

Similarly, the U.S. commercial sector generates a larger portion of on-site electricity from natural gas and renewables than the U.S. power sector, with 43 percent of on-site generation from natural gas and 47 percent from non-hydro renewables in 2015. Note that solar generation includes utility-scale[cc] solar (>1 MW capacity) and small-scale solar (<1 MW capacity), which the EIA began tracking in 2014.[83] This lack of data for prior years explains the apparent increase in solar generation from 2013 to 2014 (Figure 15).

In addition to commercial and industrial sector distributed generation, 5.9 TWh of electricity was generated in the residential sector from small-scale solar photovoltaic installations ("rooftop solar"),[84] with a typical capacity of 5 kilowatts.[85]

2.5 Other Generation and Life Cycle Emissions

The emissions attributed to the power sector in the *Inventory* include only "stack" or direct emissions from the combustion of fossil fuels. Additional emissions are associated with other stages in the full life cycle of an electricity generation technology. "Upstream" emissions include emissions from raw material extraction, component manufacturing, and facility construction. Similarly, "downstream" emissions are one-time emissions from the decommissioning, disassembly, and disposal or recycling of equipment and other facility materials. Additional ongoing non-combustion-related emissions result from operation and maintenance activities.

The results of a life cycle assessment are typically reported in terms of GHG emissions per megawatt-hour of electricity generation (kg CO_2e/MWh) or per megawatt of installed capacity. In general, the proportion of GHG emissions from each life cycle stage differs by technology:[86]

- For fossil fuel generation, fuel combustion during operation emits the vast majority of GHGs.
- For nuclear generation, a majority of GHG emissions occur upstream of operation.
- For nuclear power, fuel processing, construction and decommissioning are significant emissions sources.
- For biomass-generated electricity, net emissions (including those related to feedstock production and harvest) are captured in the LULUCF sector.[dd]
- For renewable energy technologies (solar, wind, hydropower, and geothermal), most life cycle GHG emission occur upstream of operation, and result from component manufacturing and facility construction. See Figure 17 for a comparison of life cycle emissions for wind and coal by life cycle stage.

[cc] Here, "utility scale" refers to the size (capacity) of the electricity generating facility, and does not indicate the economic sector in which the generation takes place. EIA uses the term "utility scale" to refer to facilities with greater than 1 MW capacity. See the accompanying reference for more information.

[dd] This analysis excludes consideration of direct and indirect land use change. However, increased use of biomass for energy production could lead to land use changes that result in changes in terrestrial carbon stocks. See the section on Biomass for more information.

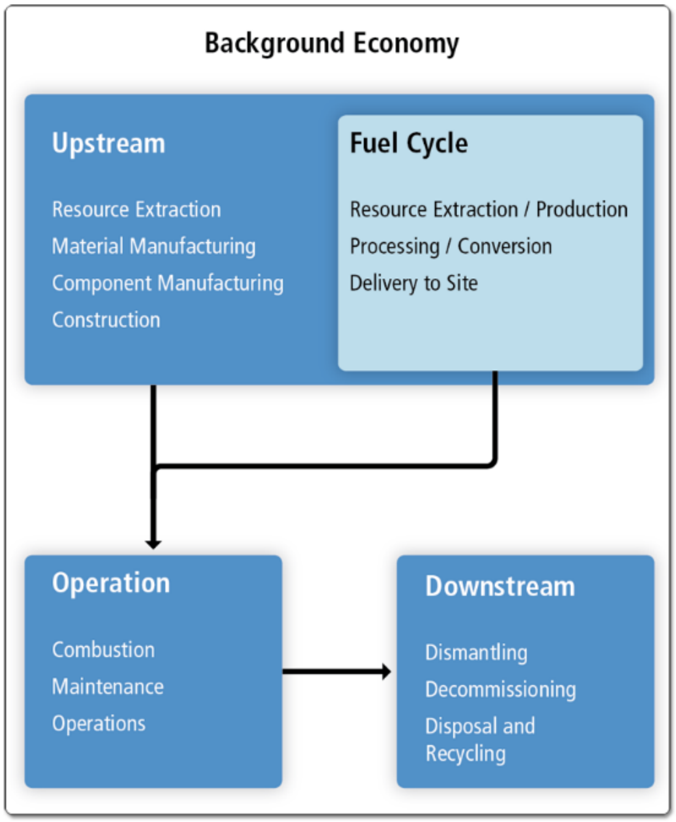


Figure 16. Generalized Life Cycle Stages for Energy Technologies.[87] The emissions attributed to the power sector in the *Inventory* include only "stack" or direct emissions from the combustion of fossil fuels. Additional emissions are associated with other stages in the full life cycle of an electricity generation technology.

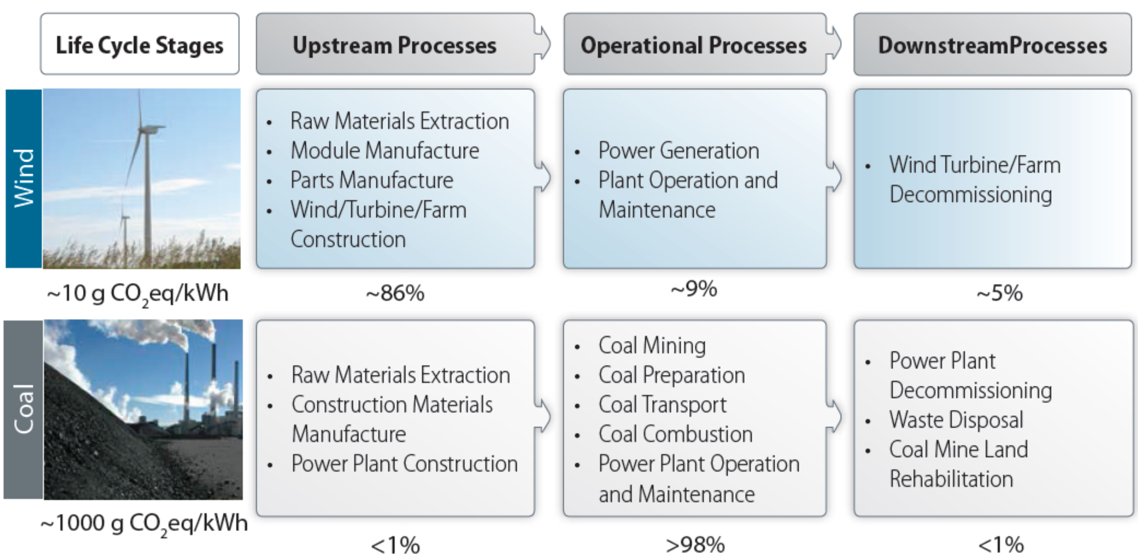
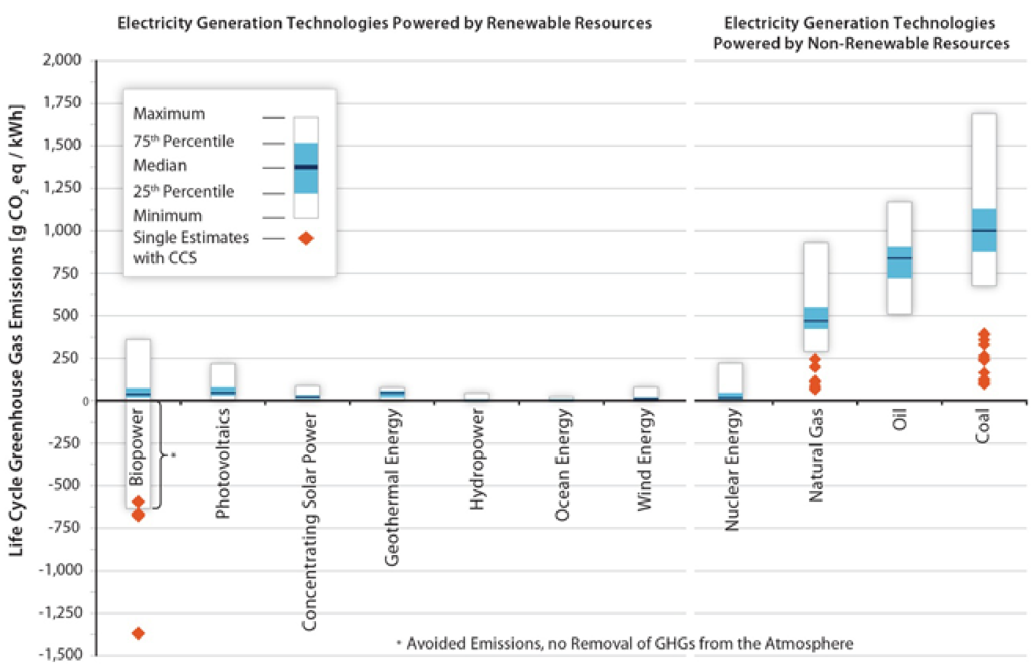


Figure 17. Comparison of Life Cycle Processes and Greenhouse Gas Emissions for Wind and Coal Power by Life Cycle Stage.[88] For fossil fuel generation, fuel combustion during operation emits the vast majority of GHGs. For renewable generation such as wind, most life cycle GHG emissions occur upstream of operation.

The National Renewable Energy Laboratory (NREL) Life Cycle Harmonization Project performed a meta-analysis of more than 2,000 references with life cycle assessments of one or more electricity generation technologies to determine the average estimated life cycle emissions across technologies.[89] [90] The results are displayed in Figure 18.

In general, total life cycle GHG emissions from renewables and nuclear energy are much lower than those from fossil fuels. For example, from cradle to grave, coal-fired electricity releases about 20 times more GHGs per megawatt-hour of electricity generated than solar, wind, and nuclear generation,[91] with a median estimate of about 1,000 kg CO_2e/MWh for coal-fired electricity. Fossil fuel generation combined with post-combustion carbon capture and storage (CCS) can bring total life cycle GHG emissions for coal-fired electricity within the range of several renewable technologies (see the red diamonds in Figure 18). Biopower with CCS shows the potential for negative life cycle GHG emissions (net removal of CO_2 from the atmosphere).[ee]



	Biopower	Photovoltaics	Concentrating Solar Power	Geothermal Energy	Hydropower	Ocean Energy	Wind Energy	Nuclear Energy	Natural Gas	Oil	Coal
Count of Estimates	222(+4)	124	36	8	28	10	126	125	83(+7)	24	169(+12)
Count of References	52(+0)	26	10	6	11	5	49	32	36(+4)	10	50(+10)

Figure 18. Comparison of Published Life Cycle GHG Estimates by Electricity Generation Technology.[92] In general, total life cycle GHG emissions from renewables and nuclear energy are much lower than those from fossil fuels.

Note: Impacts of land use change are excluded from this analysis. The numbers at the bottom of the figure are the number of references and number of life cycle estimates used for each technology.

[ee] This analysis excludes consideration of direct and indirect land use change. However, increased use of biomass could lead to land use changes that result in changes in terrestrial carbon stocks. See the ‘Biomass’ section above for more information.

Chapter 3: Drivers and Trends

Changes in electricity sector emissions are influenced by a number of long-term and short-term factors, including population and economic growth, fuel price fluctuations, technology changes, seasonal weather, government policies, and other factors affecting electricity generation and demand. On an annual basis, electricity generation fluctuates primarily in response to general economic conditions, weather, relative fuel prices for coal and natural gas, and the availability of nuclear and renewable alternatives. For example, a year with higher economic growth, low coal prices, nuclear plant closures, and extreme weather is likely to have greater power sector emissions than a year with lower economic growth, high coal prices, and greater output from nuclear and renewable electricity sources.[93]

Additionally, electric sector emissions are affected by trends in the changing electricity generation mix (including declining generation from coal and increasing generation from natural gas and renewables), and factors influencing the scale of electricity consumption, including population growth, per capita electricity consumption, government policies, and the efficiency with which electricity is used in appliances and equipment. These trends and drivers are examined in more detail in the next sections.

3.1 Short-Term Drivers of CO_2 Emissions Changes

Annual changes in electricity-related GHG emissions are driven by a variety of factors that affect both the generation and demand for electricity. On the generation side, a key element in generation dispatch decisions is the relative price of coal and natural gas. All other things being equal, a year with lower gas prices relative to coal would likely see a greater share of electricity generation from natural gas—and lower CO_2 emissions—than a year with high gas prices.[94] The availability of zero emissions generation—including nuclear power, hydropower, and non-hydro renewables—also affects annual power sector emissions. For example, a year with extreme drought could see lower generation from hydropower, with the lost generation replaced by generation from fossil fuels, leading to increased emissions.

In addition, the demand for electricity is driven by factors such as population growth, daily and annual changes in weather, economic conditions, and government policy. Heating and cooling degree days are important drivers of heating and air conditioning energy use.[95] A warm year with higher than average cooling degree days would likely result in greater electricity use for air conditioning.

The impact of various drivers on annual CO_2 emissions can be exemplified by looking at a couple of recent years. For example, from 2012 to 2013, power sector CO_2 emissions increased by 0.87 percent, despite a longer-term downward trend from peak emissions in 2007.[96] Analyses from EPA[97] and EIA[98] find that this increase was primarily driven by an increase in the carbon intensity of electricity generation due to shifting generation from natural gas to coal. Natural gas prices increased 27 percent above 2012 prices, while coal prices declined by 1 percent.[99] Consequently, coal-fired generation increased 4.8 percent in 2013, while natural gas generation dropped by 10 percent, leading to an increase in the carbon intensity of electricity generation.[100] On the demand side, colder weather in 2013 led to increased electricity consumption in the residential and commercial sectors of 1.2 percent and 0.9 percent, respectively, due to regions that heat their homes with electricity.[101] However, industry consumption declined slightly, and overall demand across all sectors decreased by 0.1 percent from 2012 levels.[102]

These factors also play out on a regional level. For example, California lost substantial zero-emissions generation in 2012 due to the closure of the San Onofre Nuclear Generating Station and lower than normal hydropower generation due to drought. Most of this lost power was replaced by in-state generation from NGCC generation.[103] As a result, California power-sector emissions increased from 2011 to 2012 in spite of long-term downward trends in electricity generation-related emissions and California state regulations such as AB-32.[ff]

Changes in power sector emissions can also be examined from the context of economic drivers, including population growth, economic growth, the electricity intensity of the economy, and the carbon intensity of electricity generation.[gg] All other factors being equal, population growth generally correlates with greater power sector emissions, as more people use electricity. The same is also true for economic growth. For most of the 20th century—both in the United States and globally—energy-related CO_2 emissions have been correlated with economic growth. In other words, emissions typically increase when gross domestic product (GDP) increases, and emissions decline during periods of economic contraction.[104]

However, recently, U.S. power sector CO_2 emissions have declined after peaking in 2007, even as the economy has grown. The explanation for the decoupling of economic growth and electricity-related CO_2 emissions comes from two factors: a decline in the electricity intensity of the economy, and a decrease in the carbon intensity of electricity generation.

The electricity intensity of the economy is the amount of electricity required to produce one dollar of GDP. In the U.S. economy, electricity intensity has declined in eight of the last ten years. The main drivers include structural changes in the economy, including a trend to less electricity-intensive manufacturing, and improved energy efficiency, i.e. greater value output per unit of electricity consumption.[hh]

Additionally, the carbon intensity (or emission rate) of electricity generation—the amount of CO_2 emitted per unit of electricity generated—has declined in seven of the last ten years. On an annual basis, the carbon intensity of electricity generation fluctuates in response to any changes that impact the generation mix. For example, a year in which the price of natural gas declines relative to coal (as compared to the previous year) might see fuel switching from coal to natural gas as a result, and a subsequent decline in emissions owing to the lower carbon intensity of natural gas.

Figure 19 displays these emissions drivers for 2015. Relative to 2014 levels:

- Carbon intensity (kg CO_2/MWh of electricity) decreased by 5.8 percent,
- Electricity intensity (MWh per $ GDP) decreased by 2.5 percent,
- Per capita GDP increased by 1.6 percent, and
- Population grew by 0.8 percent.

The net effect is that electricity-related CO_2 emissions in 2015 decreased by 5.9 percent below 2014 levels.

[ff] See Section 4.1.1 for a more complete discussion of AB-32.

[gg] This relationship between CO_2 emissions and economic drivers is known as the Kaya identity, and is discussed more in the Appendix A.

[hh] See Appendix A for a table of economic drivers and percent changes from 2006-2015.

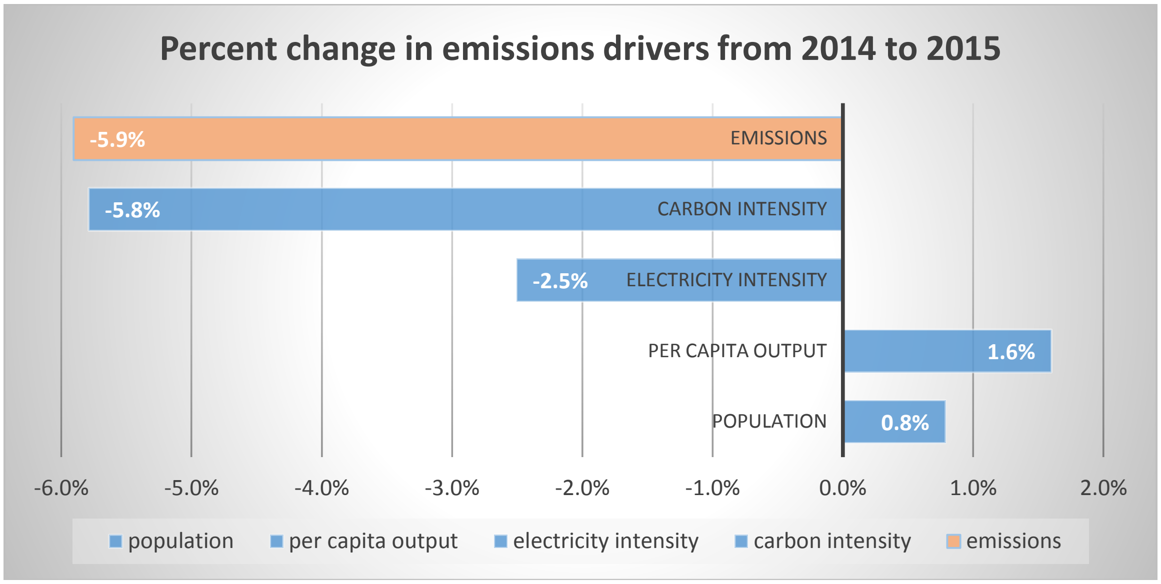


Figure 19. Economic Drivers for Changes in U.S. Power Sector Carbon Emissions, 2015.[105 106 107] From 2014 to 2015, the CO_2 emissions from the U.S. power sector declined by 5.9 percent, primarily due to a decline in the carbon intensity of electricity generation in the U.S.

Note: Economic drivers are in blue. The projected emissions percent change is colored a light orange. All terms are percent changes relative to 2014 levels.

Despite short-term and regional variations in emissions, national power sector CO_2 emissions declined by 20.3 percent from 2005 to 2015, equivalent to an average annual decline of 2.2 percent. This decline can be understood in terms of trend lines for these drivers (Figure 20).

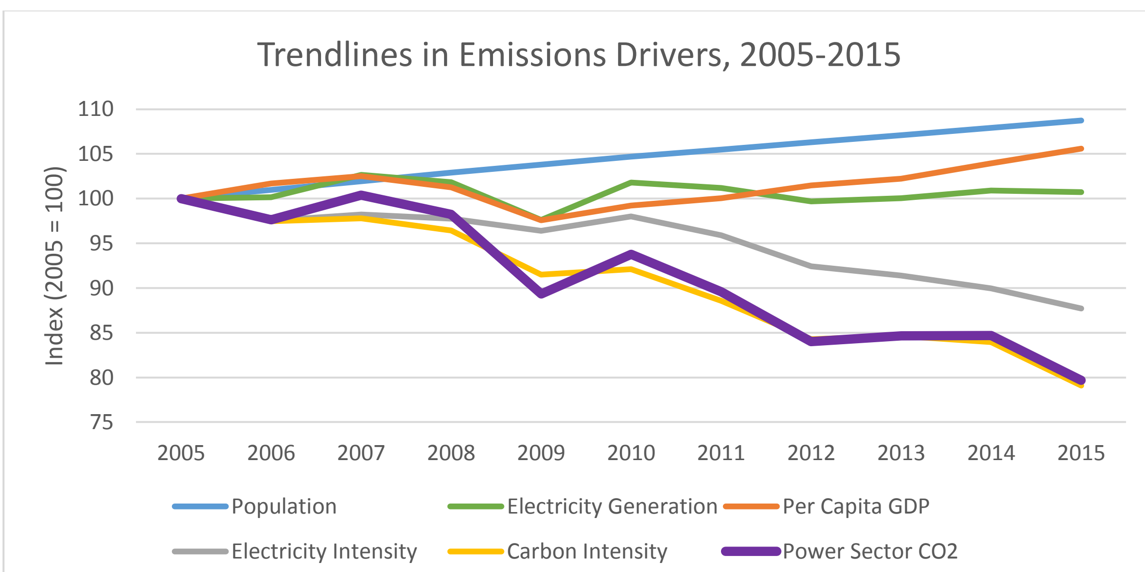


Figure 20. Trends in U.S. Power Sector Emissions Drivers, Indexed to 2005 Levels, 2005-2015 (EIA).[108 109 110] U.S. power sector CO_2 emissions have declined by 20.3 percent since 2005.

As shown in Figure 20, the U.S. population has grown at a steady rate of about 0.8 percent per year for the past decade. Per capita GDP grew from 2005 to 2007, declined for two years during an economic downturn, and then resumed growth from 2009 to 2015 and is now 5.6 percent above 2005 levels. The electricity intensity of the economy has declined in eight of the last ten years, and leading to an overall decline of 12 percent since 2005. The carbon intensity of electricity generation declined by over 20 percent from 2005 to 2015, equivalent to an average annual decline of 2.3 percent.

These data reveal two overarching trends affecting power sector emissions in the past decade: near-flat growth in electricity demand, and a substantial decline in the carbon intensity of electricity generation. These findings can be seen in the trend lines in Figure 20. The population growth, per capita GDP, and electricity intensity of the economy all factor into total U.S. electricity demand. While growth in population and per capita GDP has placed upward pressure on power sector demand, this growth has been partially offset by a decline in the electricity intensity of the economy. As a result, total electricity generation (the green line in Figure 20) has remained fairly flat since 2005.

The second overarching trend is the decline in the carbon intensity (the yellow line in Figure 20) of electricity generation as a result of changes in the generation mix. Because of near-flat growth in the amount of electricity generated, power sector emissions have tracked the carbon intensity fairly closely.

These trends are examined in more detail in the next two sections.

3.2 Trend of Low Growth in Electricity Demand from 2005 to 2015

One of the recent trends affecting electricity sector emissions is nearly flat electricity demand. Historically, electricity demand has outpaced population growth, with per capita electricity consumption increasing with greater electrification of the residential, commercial and industrial sectors. From 1950-2000:

- Per capita annual consumption increased from 1,920 kilowatt-hours per person (kWh/person) in 1950 to 12,730 kWh/person in 2000, with an average annual growth rate of 3.9 percent.[111] [112]

- The U.S. population grew from 152 million in 1950 to 282 million in 2000, with an average annual growth rate of 1.2 percent.[113]

- Growth in total electricity consumption grew from 291 billion TWh in 1950 to 3,590 billion TWh in 2000 at an annual growth rate of 5.2 percent.[114]

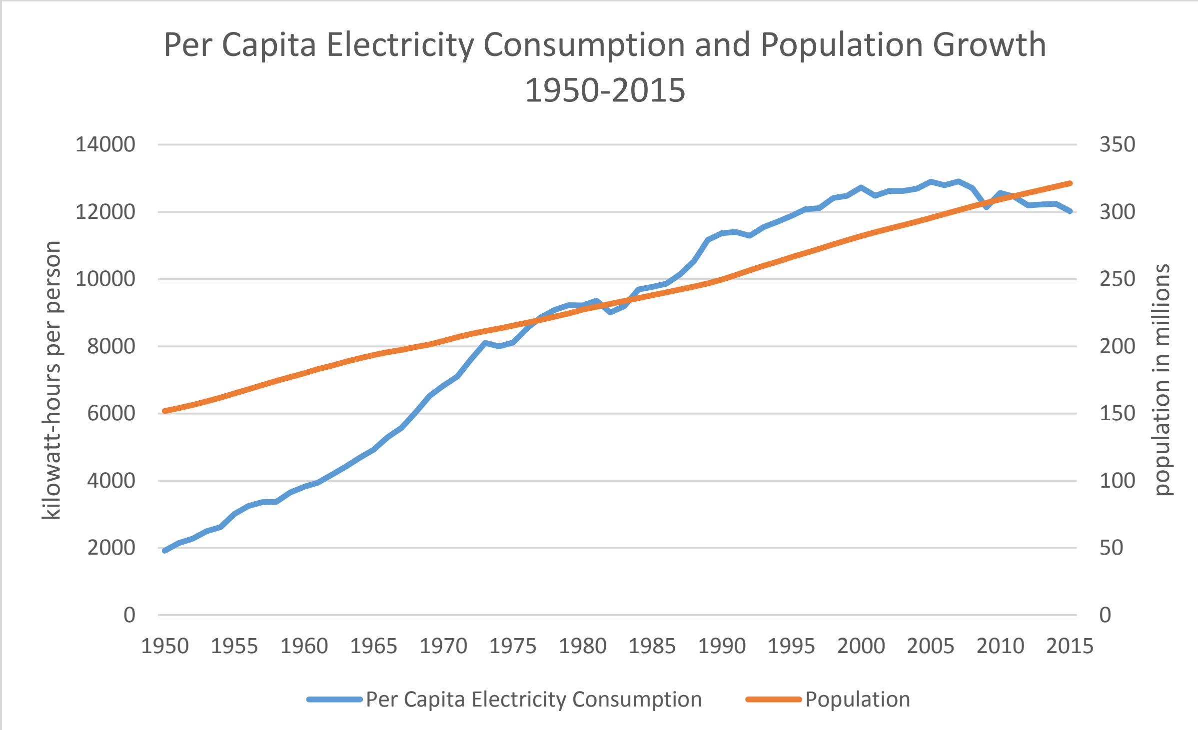


Figure 21. U.S. Population Growth and Per Capita Electricity Consumption, 1950-2015 (EIA).[115] [116] From 2005 to 2015, the rate of population growth in the U.S. declined slightly (compared to the 1950-2000 growth rate) to about 0.84 percent annually. In addition, per capita electricity consumption in the U.S. has declined at an average annual rate of about 0.7 percent.

Recently, growth in electricity retail sales has slowed, averaging 0.17 percent per year from 2005 to 2015.[117] During this time, the rate of population growth declined slightly (compared to the 1950-2000 growth rate) to about 0.84 percent annually.[118] In addition, per capita electricity consumption has declined from 12,900 kWh/person in 2005 to 12,021 kWh/person in 2015, an average annual decline of about 0.7 percent.[119]

Greater granularity can be obtained by looking at electricity sales by economic sector, as shown in Figure 22. Industrial electricity consumption has changed little since 1990, reflecting a shift to less electricity-intensive industries.[120] Residential and commercial sector electricity consumption is more dependent on population growth. On average, residential and commercial sector electricity purchases continued to outpace population growth through 2005; however, since 2005, residential electricity consumption growth has slowed to an average of 0.3 percent annually, and commercial growth is at an average of 0.64 percent annually.[121] [ii]

[ii] More detailed information on end uses of electricity—including trends and projections by subsector, as well as end-use energy efficiency policies and measures—can be found in *Electricity End Uses, Energy Efficiency and Distributed Energy Resources: Baseline and Outlook to 2040*.

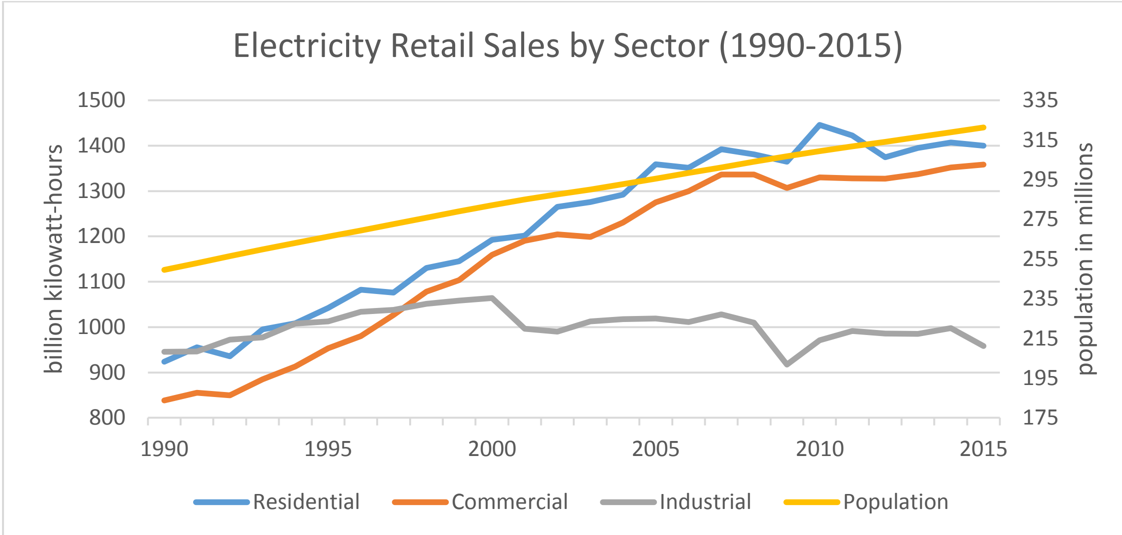


Figure 22. U.S. Electricity Retail Sales by End-Use Sector, 1990-2015 (EIA).[122] [123] U.S. industrial electricity consumption has been relatively constant since 1990, reflecting a shift to less electricity-intensive industries. Since 2005, the growth in annual residential and commercial electricity consumption in the U.S. has slowed to an average of 0.3 percent and 0.64 percent, respectively.

The recent slow rate of growth in electricity demand is the result of two main factors. First, during the economic downturn of 2008–2009, electricity consumption was depressed in all sectors, with the greatest impact in the industrial sector. While electricity consumption has returned to previous levels, growth in electricity demand has remained slow. Additionally, structural changes in the economy have resulted in a shift to less electricity-intensive manufacturing, resulting in nearly flat electricity demand in the industrial sector.

Second, market- and policy-driven efficiency improvements in appliances, equipment, and processes have factored into slowing demand growth.[124] Industrial and residential consumers have adopted more energy efficient processes and technologies (i.e. increased electricity productivity) in order to reduce their energy costs. At the federal level, appliance and equipment efficiency standards result in less energy-intensive appliances and energy savings for consumers. Building codes, which are adopted at the state and local levels, have also played a role in decreasing energy used for heating and cooling in residential and commercial buildings. Additionally, increased utility and third-party energy efficiency programs have promoted, or directly supported the adoption of cost-effective energy efficiency measures in nearly all sectors of the economy.[125] [jj]

On a small scale, an example of greater efficiency can be seen by looking at the energy usage of a single appliance over time. For example, the energy usage of a new refrigerator has declined by more than 70 percent since 1974, even as refrigerator size has increased and price has declined (Figure 23).[126] The result is that the efficiency of refrigerators, defined here as the ratio of the volume refrigerated to the electricity used, has increased by 430 percent since 1974.

[jj] Further discussion of how both structural economic change and improved energy efficiency have contributed to declining electricity consumption is available in a joint report from DOE, the Alliance to Save Energy, and the Council on Competitiveness: "Accelerate Energy Productivity 2030: A Strategic Roadmap for American Energy Innovation, Economic Growth, and Competitiveness", available at www.energy2030.org.

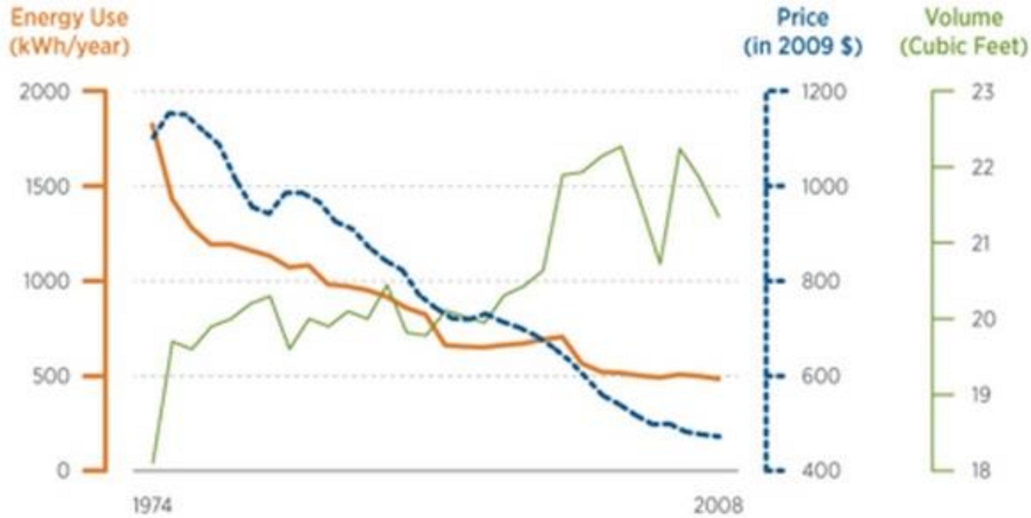


Figure 23. Annual Energy Use, Volume, and Real Price of New Refrigerators.[127] The energy usage of a new refrigerator has declined by more than 70 percent since 1974, even as refrigerator size has increased and price has declined.

On a larger scale, one measure of electricity productivity in the industrial sector is the ratio of the value of shipments to electricity consumption, measured in dollars per kilowatt-hour ($/kWh).[128] As shown in Figure 24, industrial electricity productivity nearly doubled from $3.97/kWh in 1990 to $7.76/kWh in 2014.[129]

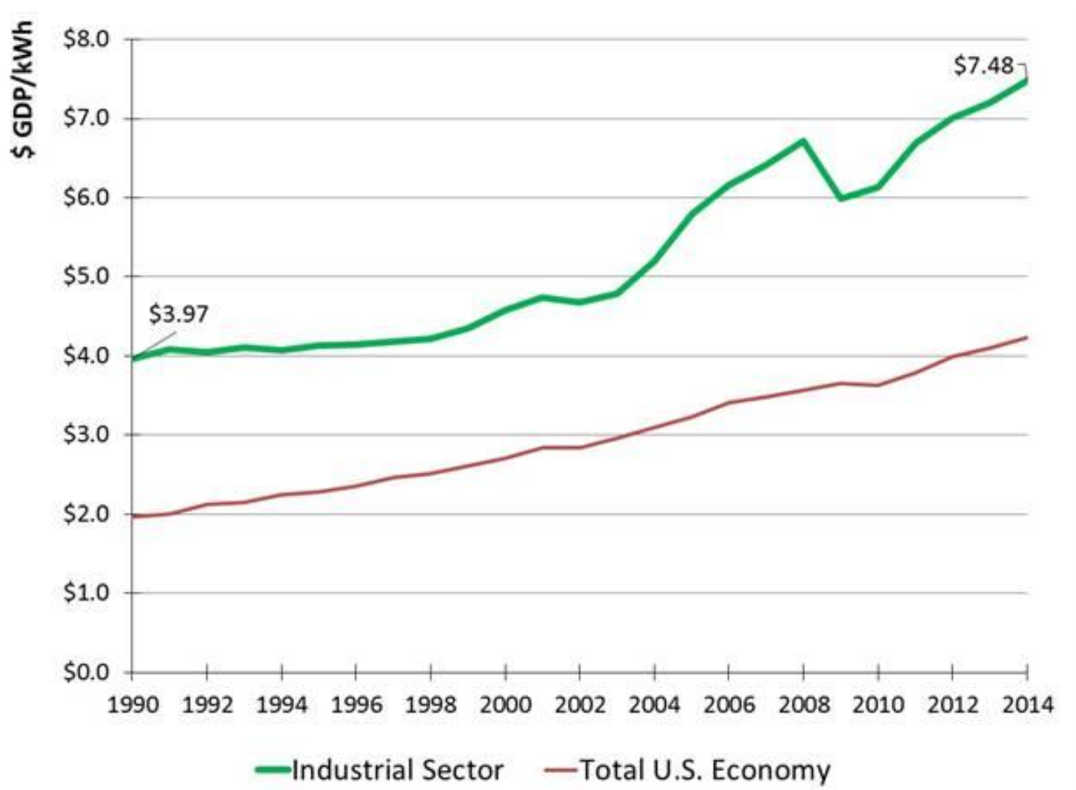


Figure 24. U.S. Industrial electricity productivity, 1990-2014.[130] Electricity productivity in the U.S. industrial sector nearly doubled between 1990 and 2014.

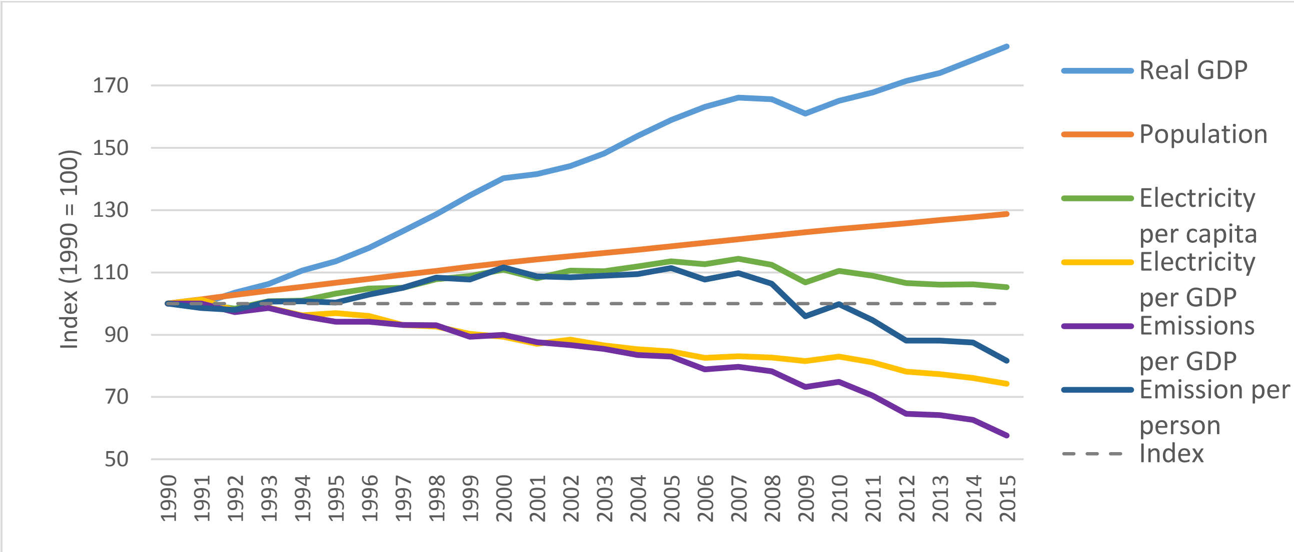


Figure 25. Changes in Key U.S. Power Sector and Economic Indicators, Indexed to 1990 Levels (EIA).[131 132 133] Since 1990, electricity-related CO_2 emissions per dollar GDP have declined by 42 percent, even as the total GDP has increased by 83 percent.

Note: Emissions per GDP includes power sector emissions only. For total energy-related emissions—including emissions from end-use sectors—please refer to the *Inventory of U.S. Greenhouse Gas Emissions and Sinks*.[134]

Together, slow growth in per capita electricity consumption and greater electricity productivity have helped divorce economic growth from electricity consumption (and consequently electricity generation-related carbon dioxide emissions). Overall, the electricity intensity[kk] of the economy, as measured in kilowatt-hours per GDP, has declined. Figure 25 displays both per capita electricity consumption (kWh/person) and the energy intensity of the economy (kWh/GDP) indexed to 1990 levels.

Also shown in Figure 25 are electricity-related CO_2 emissions per GDP. From 1990 through 2005, both electricity-related emissions per capita and per GDP have tracked electricity demand per capita and per GDP. However, since 2005, power sector emissions per GDP have declined at a steeper rate than electricity per GDP. This reduction is because the emission rate for electricity generation, while fairly steady from 1990 to 2005, has declined in recent years. This trend is examined in the next section.

3.3 Trend of Declining CO_2 Emission Rate from 2005 to 2015

There has been a significant change in the electricity generation mix over the past decade, as generation has shifted to lower carbon-intensity fuels and technologies. In particular, the emission rate—as measured in kg CO_2/MWh—has been declining in recent years. After a gradual decline from 700 kg CO_2/MWh in 1970 to 620 kg CO_2/MWh in 2005—equivalent to 1,540 lbs CO_2/MWh and 1,360 lbs CO_2/MWh, respectively—the CO_2 emission rate of electricity generation has declined to 490 kg CO_2/MWh (1,085 lbs CO_2/MWh) in 2015, or 20.9 percent below 2005 levels.[135 136] This is equivalent to an average annual decline of 2.32 percent.

[kk] Electricity intensity (kWh/GDP) is the inverse of electricity productivity ($/kWh). As electricity productivity increases, electricity intensity decreases.

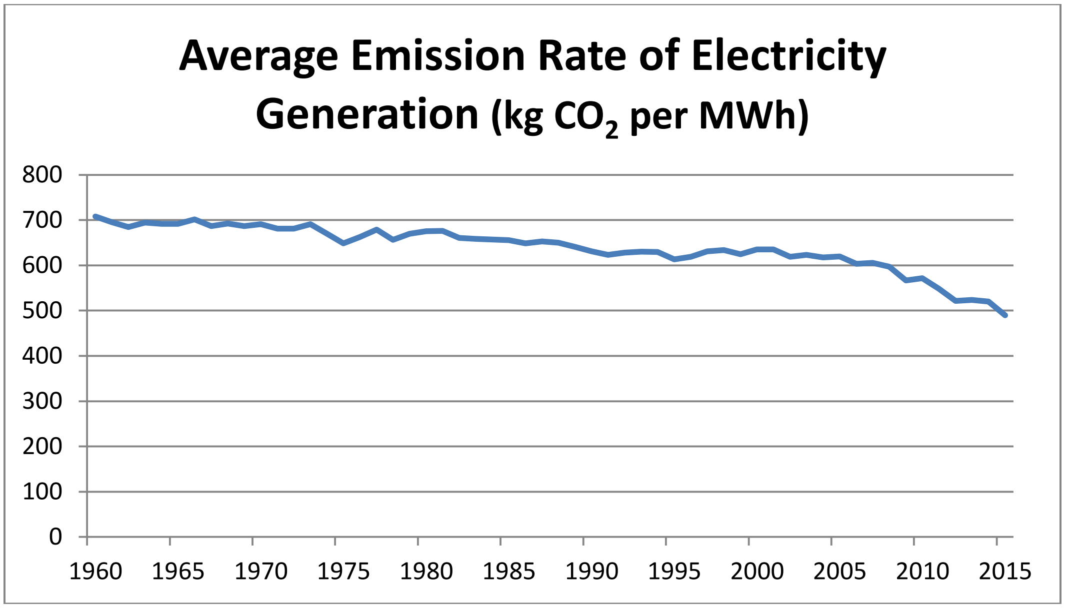


Figure 26. Average Emission Rate of Electricity Generation in the U.S. Power Sector, 1960-2015 (EIA).[137] The emission rate of the U.S. power sector is a key indicator of the climate impact of electricity generation, and varies significantly by fuel and technology. Between 2005 and 2015, the emission rate of U.S. electricity generation declined by 21 percent, primarily due to generation from coal being offset by increased generation from lower-emitting sources.

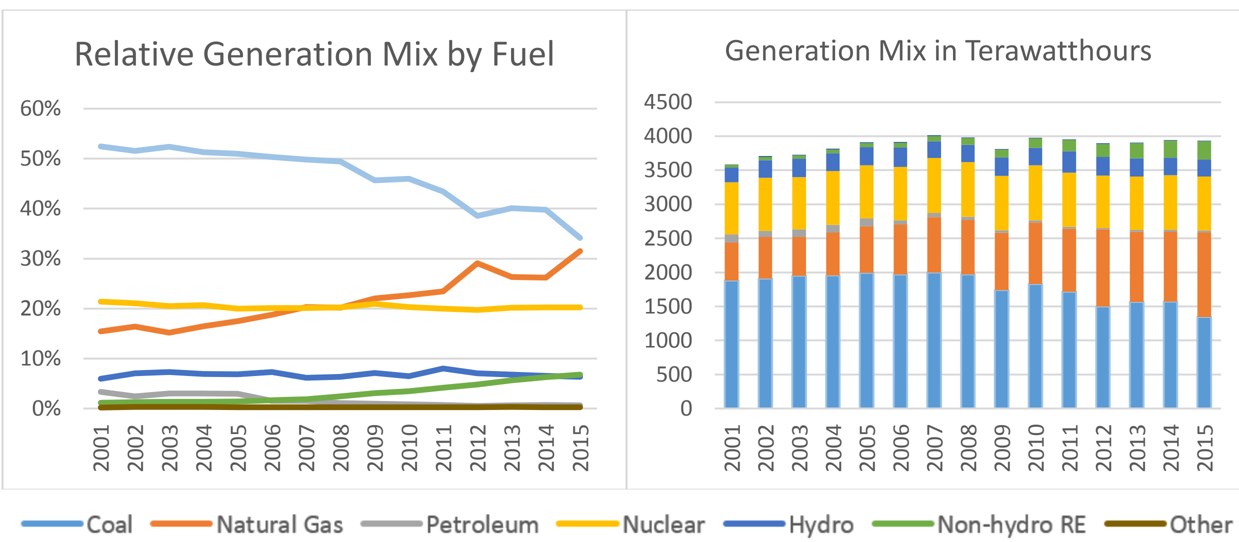


Figure 27. U.S. Power Sector Generation Mix by Fuel, 2001-2015 (EIA).[138] Coal's share of power sector generation in the U.S. has fallen from 51.1 percent in 2005, to 34.2 percent in 2015. This trend is primarily driven by two forces: a market-driven shift from coal to natural gas in the U.S., and a policy- and technology-driven increase in the share of electricity generation from non-carbon sources, such as wind and solar.

Note: Non-Hydro Renewables include wind, solar, biomass, geothermal and other renewable sources other than hydroelectric dams. Other includes all other sources of electric generation, including other gases and waste heat.

The recent decline in power sector emission rates is reflected by the shift in electricity generation toward lower-carbon fuels (Figure 27). Since the 1950s, coal has accounted for more than half of total U.S. electricity generation. However, since 2005, coal's share of power sector generation has fallen from 51.1 percent to 34.2 percent in 2015.[139] This trend is primarily driven by two forces: a market-driven shift from coal to natural gas and a policy- and technology-driven increase in the share of electricity generation from non-carbon sources.

The result has been a decline in power sector CO_2 emissions over the last decade. The effect of these forces can be measured by looking at the avoided CO_2 emissions caused by shifting to natural gas and non-carbon generation relative to the 2005 generation mix. According to analysis from the EIA,[140] the shift towards natural gas is responsible for 1,254 MMT of avoided CO_2 emissions from 2005 to 2014, or about 61 percent of total avoided emissions (Figure 28). Increased generation from zero-emissions sources, such as wind and solar, is responsible for the remaining 39 percent of avoided emissions, equivalent to 789 MMT CO_2 (Figure 28). These two factors are examined in greater detail in the following sections.

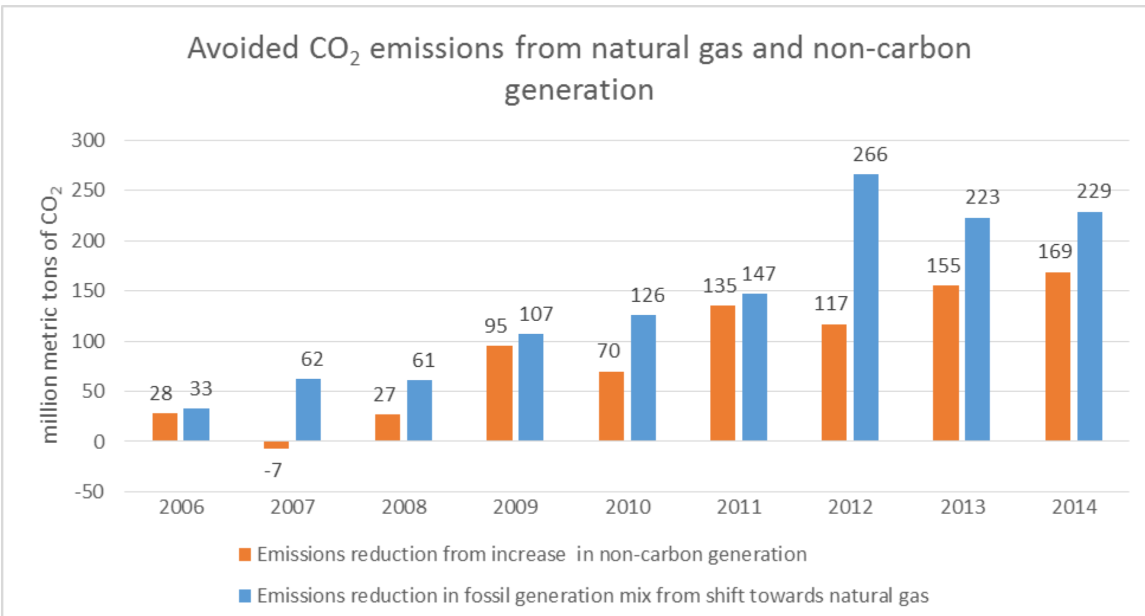


Figure 28. U.S. Power Sector CO_2 Emissions Reductions from Shifting to Natural Gas and Non-Carbon Generation in Years 2006 through 2014, Relative to 2005 Generation Fuel Mix and Efficiency (EIA).[141] [ll] Changes in the U.S. electricity generation mix have been a major driver of the observed 21 percent reduction in the emission rate of electricity generation, relative to 2005 levels. Analysis from the EIA attributes 61 percent of this decline to fuel switching from coal to natural gas and 39 percent to increased generation from renewables.

[ll] These numbers reflect only combustion-related CO_2 emissions and do not include other greenhouse gases or other life cycle impacts. EIA determined avoided emissions as follows. First, the fossil fuel carbon factor (fossil fuel CO_2/fossil fuel generation) was calculated for 2005. This factor was then multiplied by the actual fossil fuel generation for subsequent years. The difference between the calculated value and the actual emissions for fossil generation is the avoided emissions attributed to the shift to natural gas. For 2014, avoided emissions from this factor was 229 MMT CO_2. Next, the overall reduction in total carbon intensity was applied to total generation. The savings in fossil fuel generation was subtracted from the total and the difference was credited to non-carbon generation. For example, the total savings in 2014 was 398 MMT CO_2, so the amount attributed to non-carbon generation is 398 MMT CO_2 – 229 MMT CO_2 = 169 MMT CO_2.

3.3.1 Shale gas and low natural gas prices

The combination of advances in horizontal drilling and hydraulic fracturing has enabled access to large volumes of domestic oil and natural gas reserves that were previously uneconomic to produce.[142] By 2010, the United States surpassed Russia as the world's largest producer of natural gas. From 2005 to 2014, domestic production of natural gas grew by over 44 percent,[143] and the large supply began driving down natural gas prices sharply in 2009.

	Coal Cost ($ / MMBtu)	Coal % Gen Mix	NG Cost ($ / MMBtu)	NG % Gen Mix
2005	1.54	49.6%	8.21	18.8%
2006	1.69	49.0%	6.94	20.1%
2007	1.77	48.5%	7.11	21.6%
2008	2.07	48.2%	9.01	21.4%
2009	2.21	44.4%	4.74	23.3%
2010	2.27	44.8%	5.09	23.9%
2011	2.39	42.3%	4.72	24.7%
2012	2.38	37.4%	3.42	30.3%
2013	2.34	38.9%	4.33	27.7%
2014	2.37	38.6%	5.00	27.5%
2015	2.22	33.2%	3.22	32.7%

Table 5. Fuel Costs and Generation Share for Coal and Natural Gas in the U.S. (EIA).[144]
Generation dispatch decisions reflect relative fuel prices. While natural gas prices have dropped substantially below pre-2008 levels in the U.S., they have continued to exhibit more volatility than coal prices.

Note: These numbers include electric generation across all sectors, including distributed generation at utility-scale facilities.

Table 5 shows the average annual fuel costs for coal and natural gas in dollars per million Btu, a measure of energy content. While natural gas prices have dropped substantially below pre-2008 levels, they have continued to exhibit far more volatility than coal prices. Because generation dispatch decisions reflect relative fuel prices, the share of electricity generation from coal and natural gas has also mirrored this volatility, as seen from the fact that the increase in generation from natural gas displayed in Figure 27 is not a smooth incline.

The fuel component of operational costs[mm] of electricity generation depends on two factors: fuel prices (dollars per million Btu), and the thermal efficiency for converting the fuel into electricity. Because NGCC generators consume only about 75 percent as much fuel per kilowatt-hour of electricity generated as a typical coal-fired plant, the fuel cost of generation using natural gas can be lower than the fuel cost of generation using coal even if natural gas is 33 percent more expensive than coal per Btu. This differential can be even greater on a regional basis for power grids containing older-vintage and less-efficient coal-fired generation.
In April 2015, electricity generation from natural gas surpassed coal generation for the first time since the EIA began tracking monthly generation data in 1973.[145]

[mm]In addition to the fuel component, other costs (e.g., capital costs and fixed and variable operating and maintenance costs) also contribute to the operational costs of electricity generation.

Because NGCC plants have an average CO_2 emission rate less than half that of the average coal plant, electricity generation-related emissions track the relative generation share from natural gas and coal. Higher natural gas prices in 2014 led to a slight increase in generation from coal above 2013 levels, which caused a slight increase in electricity-related carbon dioxide emissions. As natural gas prices fell in 2015, the share of generation from natural gas increased relative to coal. Power sector emissions in 2015 were down 5.9 percent compared to the same time in 2014.

3.3.2 Increased share of electricity from renewables

In the past 10 years, the share of electricity generation from low- and zero-emitting energy technologies has also been growing. Nuclear power and conventional hydropower comprise the majority of zero carbon electricity generation, at about 20 percent and 6 percent of total generation, respectively. However, generation from these sources has been relatively flat. Most of the growth in electricity generation from low- and zero-emitting energy technologies since 2005 is due to increased capacity of renewable sources, such as wind and solar power.

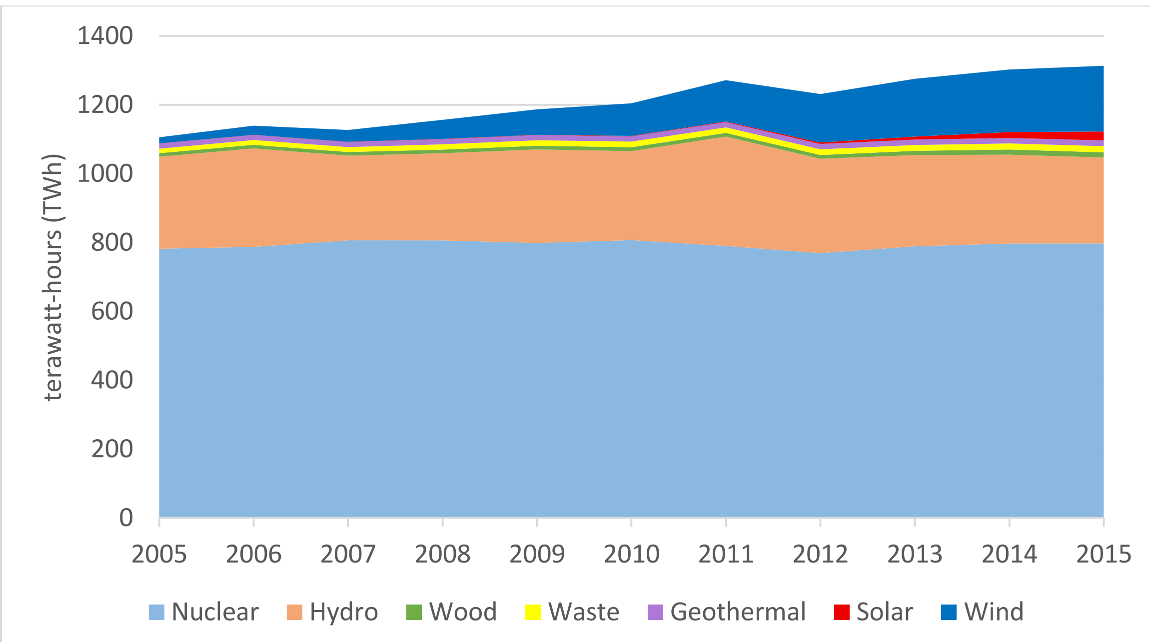


Figure 29. Non-Fossil Fuel Electricity Generation in the U.S., 2005-2015 (EIA).[146] Electricity generated from nuclear power and conventional hydropower in the U.S. has been fairly constant in the last ten years. Since 2005, most of the growth in electricity generation from low- and zero-emitting energy technologies in the U.S. is due to increased generation from wind and solar.

In 2015, wind accounted for 41 percent of new electric generation capacity,[147] and wind provided 4.7 percent of total electricity generation in 2015.[148] Cumulative wind capacity has grown from 25 GW in 2008 to nearly 75 GW in 2015.[149] Similarly, utility-scale solar generation capacity has grown from less than 0.1 GW in 2008 to 13.4 GW in 2015.[150] Distributed solar PV generation capacity has grown similarly from substantially less than a gigawatt in 2008 to 8.4 GW in 2015.[151] Together, both utility and distributed solar capacity accounted for 26 percent of all new electric generation capacity,[152] and provided approximately 0.6 percent of total electricity generation in 2015.[153]

This trend is a consequence of many factors, including falling costs due to technology improvements and federal and state policies incenting new renewable deployment. Solar provides one example of these cost improvements, with the installed cost for utility-scale PV falling from \$5.70/W_{DC} in 2008 to \$1.64/W_{DC} in 2015, or a decrease of 71 percent in six years.[154]

Similarly, technology improvements in wind turbines—including taller turbines, longer blades, and advanced turbine designs—have enabled substantial cost-reductions for wind power. Power purchase agreements for wind have fallen from rates as high as 7 cents/kWh in 2009 to an average of 2.4 cents/kWh in 2014, driven by wind deployment in excellent resource locations in the interior regions of the country.[155] It is also projected that these technology improvements will enable an expansion of the geographic distribution of wind power's technical potential to new regions of the United States.[156]

Technology improvements and declining costs for wind and solar have been spurred by industry innovation as well as a variety of federal and state policies. Major policies include the renewable energy tax credits at the federal level, and renewable portfolio standards at the state level. More on policies and measures aimed at decreasing GHG emissions from electricity generation is presented in Chapter 4.

3.4 Outlook and Projections to 2040

The recent trends affecting power sector emissions—low demand growth and a declining emissions rate—are projected to continue in the near term. EIA's *Short-Term Energy Outlook* projects total electricity retail sales to grow by 0.4 percent in 2016 and 1.6 percent in 2017,[157] consistent with recent low rates of growth. Additionally, power generation from fossil fuels is projected to decline. The share of generation from natural gas is projected to decline slightly from 32.7 percent in 2015 to 32.3 percent in 2017, and generation from coal is projected to decline from 33.2 percent to 32.3 percent.[158] Over the same time period, electricity generation from renewable sources is projected to grow from 13.3 percent of total generation in 2015 to 15.1 percent in 2017.[159]

In the long term, power sector emissions are projected to continue to decline as a result of market trends, including low growth in demand for electricity and greater penetration of natural gas and renewables. Additionally, many policies and measures at both the state and federal levels mitigate power sector GHG emissions. In particular, EPA's *Clean Power Plan* (CPP), finalized in August 2015, requires all states to establish carbon pollution standards for existing power plants.[nn] The CPP sets CO_2 emission targets which are expected to reduce power sector CO_2 emissions by 32 percent below 2005 levels by 2030.[160] The CPP and other policies addressing power sector emissions are addressed in more detail in the next section.

[nn] On February 9, 2016, the Supreme Court stayed implementation of the Clean Power Plan pending judicial review. The Court's decision was not on the merits of the rule. EPA firmly believes the Clean Power Plan will be upheld when the merits are considered because the rule rests on strong scientific and legal foundations. For the states that choose to continue to work to cut carbon pollution from power plants and seek the agency's guidance and assistance, EPA will continue to provide tools and support.

Projections to 2040 and the EPSA Base Case

The *EPSA Base Case* (Base Case) models the energy sector out to 2040 using EPSA-NEMS,[oo] an integrated energy system model. The Base Case is similar to EIA's *Annual Energy Outlook*[pp] and provides projections of the evolving power sector that incorporates the latest data on market trends, including low natural gas prices, decreasing costs of renewables, and low growth in electricity demand. The Base Case projections were originally developed as part of the *Current Measures* scenario in the *Second U.S. Biennial Report*[161] to the UNFCCC (see Box 3.1) and have been updated to incorporate all policies enacted or finalized as of January 2016, including the December 2015 extension of the renewable electricity tax credits[162] and the CPP.[qq] The Base Case incorporates one particular implementation scenario for the CPP; however, states will ultimately determine how to comply with the rule.[rr] The Base Case does not include representations of policies that are currently under development.

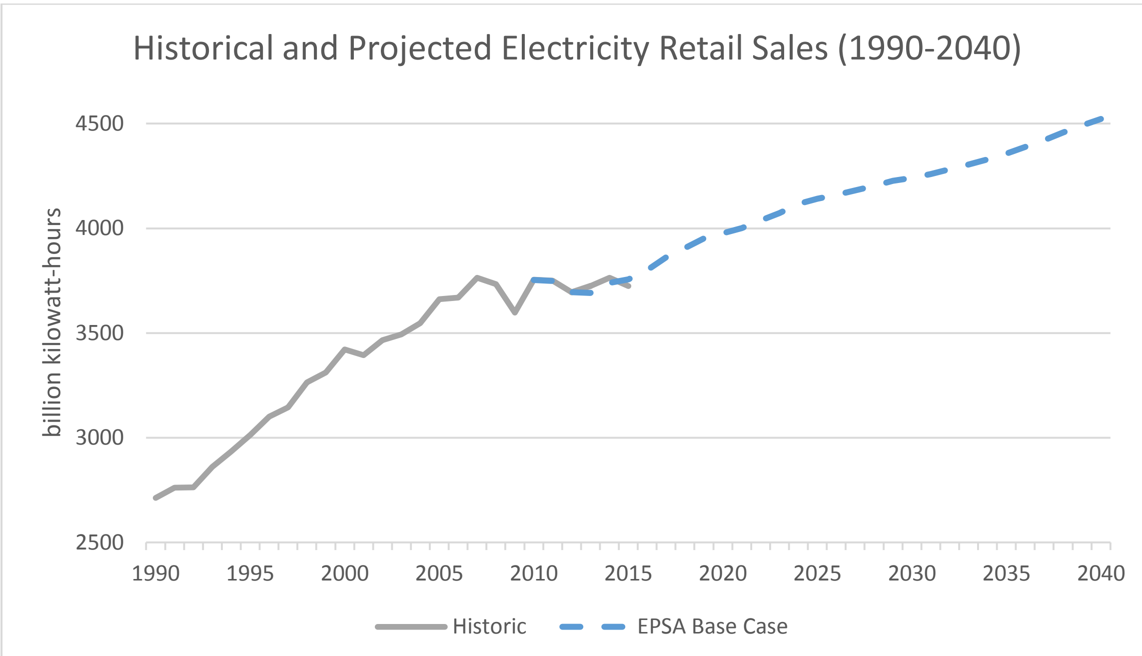


Figure 30. Historical and Projected Electricity Retail Sales in the U.S., 1990-2040.[163] [164]
Under current policies and measures, total electricity retail sales in the U.S. are projected to grow by 20.4 percent above 2015 levels by 2040.

[oo] The version of the National Energy Modeling System (NEMS) used in this volume has been run by OnLocation, Inc., with input assumptions determined by DOE's Office of Energy Policy and Systems Analysis (EPSA). Since this analysis was commissioned by EPSA and uses a version of NEMS that differs from the one used by the U.S. Energy Information Administration, the model is referred to as EPSA-NEMS.
[pp] The Base Case uses the same assumptions as *AEO2015 High Oil and Gas Resource Case*, with two exceptions. The Base Case uses the Annual Technology Baseline costs for utility-scale wind and solar developed by the National Renewable Energy Laboratory. Additionally, the Base Case incorporates policies finalized after publication of *AEO2015*, including the Clean Power Plan and extension of renewable energy tax credits.
[qq] As noted previously, on February 9, 2016, the Supreme Court stayed implementation of the Clean Power Plan pending judicial review. See footnote jj for more information.
[rr] In particular, the Base Case modeled national mass-based goals with new source complement and allows national trading of credits, with no banking or borrowing. Additionally, the Base Case assumes 80 percent adoption of the Clean Energy Incentive Program, a voluntary program that incentivizes early investment in renewable energy and low-income energy efficiency.

Projections 1: Low Growth in Electricity Demand

Electricity demand is projected to continue to grow, but at a rate that is lower than population growth, as per capita consumption declines slightly. Between 2015 and 2040, total electricity retail sales are projected to grow by 20.4 percent, equivalent to an annual growth of 0.74 percent, with total retail sales reaching 4,522 TWh in 2040. U.S. population is expected to grow 18.2 percent over the same time, indicating that per capita electricity consumption declines slightly.[165]

Projections 2: Declining Emission Rate of Electricity Generation

The emission rate of electricity generation is expected to continue to decline as trends—fuel-switching from coal to natural gas, and increased generation from renewables—continue to lower the carbon intensity of electricity generation. From 2015 to 2040, the emission rate is projected to decline by 34 percent, reaching 340 kg CO_2/MWh in 2040.

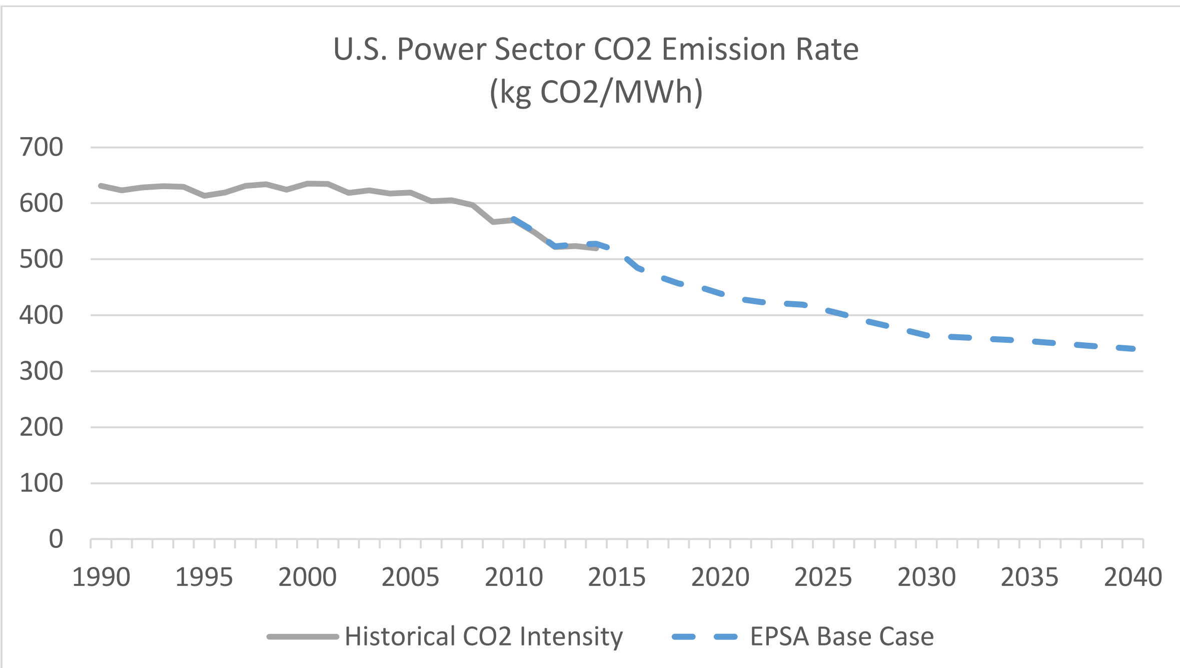


Figure 31. CO_2 Emission Rate of the U.S. Power Sector, 1990-2040.[166] [167] Under current policies and measures, the CO_2 emission rate of the U.S. power sector is projected to continue its recent decline, reaching 340 kg CO_2/MWh (750 lb CO_2/MWh) in 2040.

Total Power Sector CO_2 Emissions and Sectoral Breakdowns

Total power sector emissions converge to the limits established in the CPP. Emissions are projected to decline to about 1,600 MMT CO_2 by 2030, at which point the CPP emission limits remain fixed under this representation of the rule.

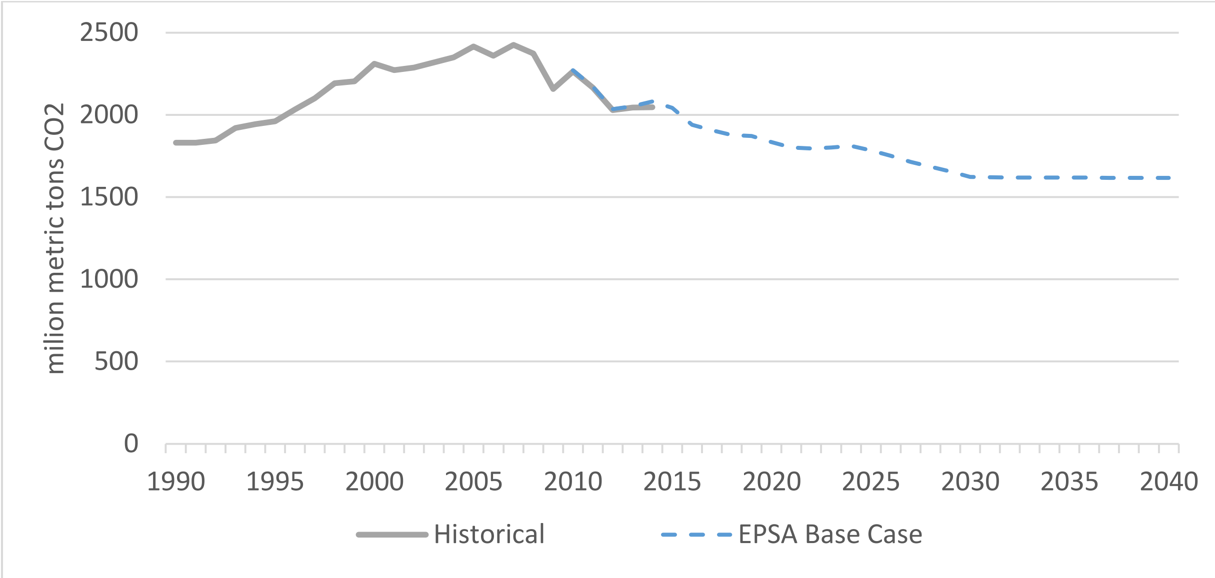


Figure 32. Historical and Projected U.S. Power Sector CO_2 Emissions, 1990-2040.[168 169]
Annual U.S. power sector CO_2 emissions are projected to decline to ~1,600 MMT CO_2 by 2040.

In the **industrial sector**, electricity-related CO_2 emissions decline slightly while emissions from direct combustion (not shown) increase (Figure 33a). From 2015 to 2040, power sector emissions attributable to the industrial sector (the blue line) are projected to decline by 14.6 percent, from 529 MMT CO_2 in 2015 to 452 MMT CO_2 in 2040. Direct end-use emissions (the difference between the orange and blue lines) are projected to increase from 1,056 MMT CO_2 in 2015 to 1,284 MMT CO_2 in 2040. Total industrial emissions (the orange line) increase by 9.5 percent, from 1,585 MMT CO_2 in 2015 to 1,736 MMT CO_2 in 2040.[170]

In the **commercial sector,** electricity-related CO_2 emissions (the blue line) are projected to decrease by 20.7 percent, from 743 MMT CO_2 in 2015 to 589 MMT CO_2 in 2040 (Figure 33b). Emissions from direct fuel consumption increase by 18.5 percent, from 227 MMT CO_2 in 2015 to 269 MMT CO_2 in 2040. Total commercial sector emissions (the orange line) are projected to decline by 11.5 percent over the same time period.[171]

In the **residential sector**, both electricity-related emissions and emissions from direct fuel consumption decline (Figure 33c). Power sector emissions attributable to the residential sector (the blue line) are projected to decline by 25.5 percent, from 766 MMT CO_2 in 2015 to 571 MMT CO_2 in 2040. Direct end-use emissions decline by 12.5 percent from 313 MMT CO_2 in 2015 to 274 MMT CO_2 in 2040. Total residential sector emissions (the orange line) are projected to decline by 21.7 percent from 1,079 MMT CO_2 in 2015 to 845 MMT CO_2 in 2040.[172]

In the **transportation sector**, electricity-related emissions are projected to grow from 4.32 MMT CO_2 in 2015 to 6.36 MMT CO_2 in 2040 (Figure 33d) as a result of greater electrification of vehicles. However, even with greater use of electrified transport, electricity-related emissions are projected to account for only 0.36 percent of total transportation emissions. Direct combustion emissions (primarily from petroleum) are projected to decline slightly from 1,807 MMT CO_2 in 2015 to 1,787 MMT CO_2 in 2040 as a result of greater fuel economy. Note that, because electricity-related emissions are such a small portion of total transportation emissions, direct combustion emissions have been left out of Figure 33d in order to show greater detail in electricity-related emissions in the transportation sector.[173 ss]

Figure 33a-d display top-level emissions by sector from 1990 to 2040, including both power sector emissions and direct combustion-related emissions. Greater granularity in Base Case projections—e.g. electricity consumption for lighting in buildings, electrification of vehicles and industrial processes, and other projections by subsector and end-use—are addressed in the *Electricity End Uses, Energy Efficiency and Distributed Energy Resources: Baseline and Outlook to 2040*.

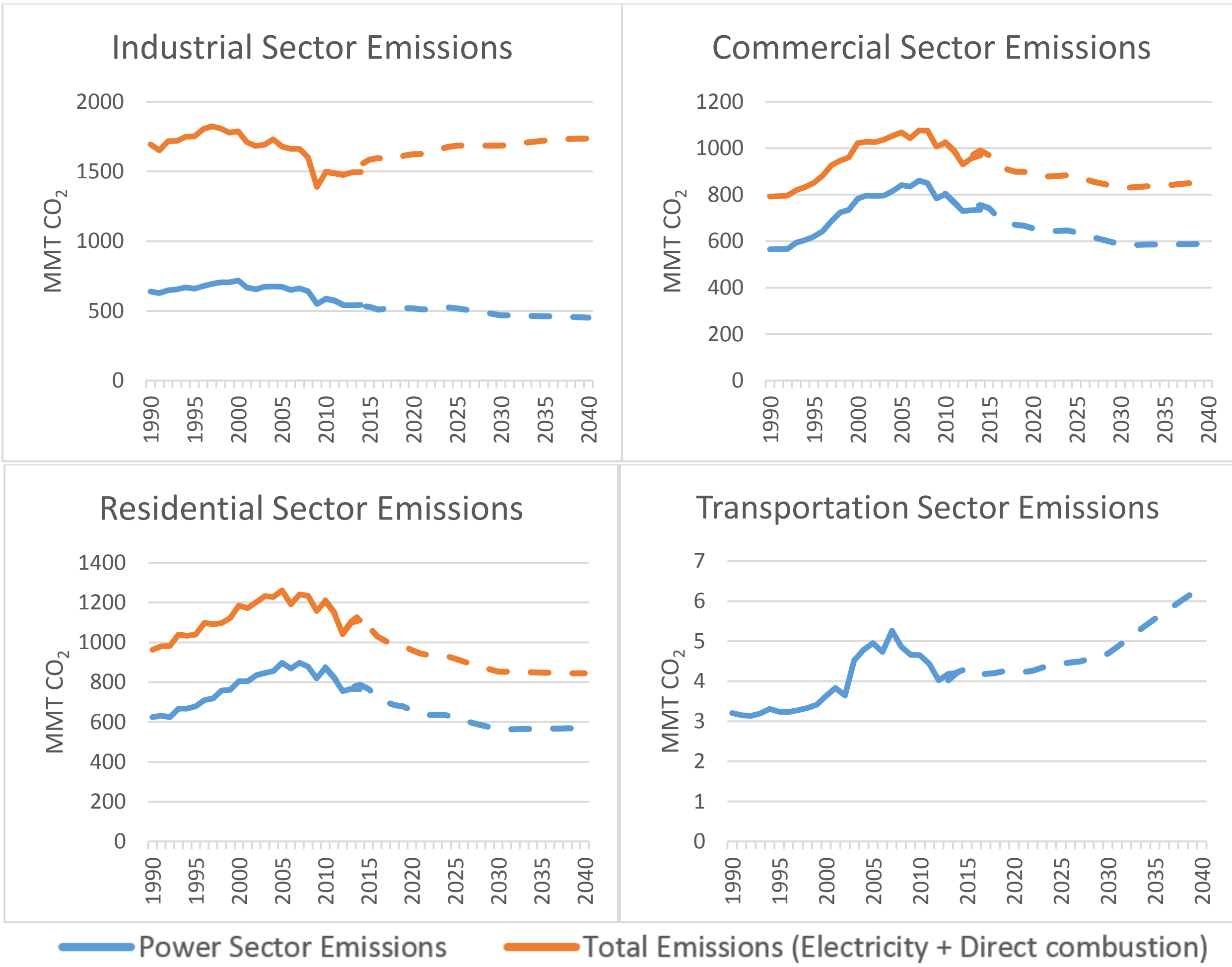


Figure 33a-d. U.S. Power Sector and Total Energy-Related CO_2 Emissions by End-Use Sector, 1990-2040.[174 175] Electricity-related CO_2 emissions are projected to decline for the U.S. industrial, commercial and residential sectors as a result of the declining carbon intensity of electricity generation. In the U.S. transportation sector, electricity-related emissions are projected to increase due to greater demand for electricity from the electrification of vehicles.

[ss] Several models show greater electrification of vehicles than the EPSA Base Case. This topic is addressed in greater detail in the forthcoming volume, *Electricity End Uses, Energy Efficiency, and Distributed Energy Resources: Baseline and Outlook to 2040.*

Box 3.1 The *Second U.S. Biennial Report*

Among the most current projections of U.S. greenhouse gas emissions are those provided in the *Second U.S. Biennial Report* to the UNFCCC, which includes projections for total U.S. greenhouse gas (GHG) emissions across all gases and all IPCC reporting categories. The projections cover two policy scenarios: the *Current Measures* scenario and the *Additional Measures* scenario. Both scenarios reflect current trends in population growth, long-term economic growth, historic rates of technology improvement, continuation of demand-side efficiency gains, and other anticipated trends. The *Current Measures* scenario includes all policies and measures that have been implemented or finalized through mid-2015, including the *Clean Power Plan* for the electricity sector (finalized in August 2015)[tt], as well as light-duty vehicle fuel efficiency standards, appliance and equipment efficiency standards, and other policies impacting GHG emissions. The *Additional Measures* scenario includes all current measures and also reflects reductions from planned policies and measures that have been proposed, but not finalized, including additional measures that fall under the initiatives laid out in the President's *Climate Action Plan*.[176,177]

Under the *Current Measures* scenario, total U.S. GHG emissions are projected to decline by between 2 and 7 percent from 2013 to 2025, resulting in emissions between 12 and 16 percent below the 2005 level in 2025. The *Second Biennial Report* marks the first time that a U.S. Climate Action Report or Biennial Report projects GHG emissions to decline in the existing policies baseline.

The *Additional Measures* scenario includes implementation of the Phase II heavy-duty vehicle fuel economy standards, finalization of proposed, new, or updated appliance and equipment efficiency standards, increased efficiency in buildings and the industrial sector, and additional policies to reduce GHG emissions. Under the *Additional Measures* scenario, emissions are projected to be 22 to 27 percent below 2005 levels in 2025.

Figure 34 shows both the *Current Measures* and *Additional Measures* projections. It also includes projections from previous U.S. Climate Action Reports as an indication of how much the emissions trajectory has been driven down in the past decade, with some of the major policy drivers indicated on the right. Some uncertainty is associated with projected emissions and removals from the Land Use, Land Use Change, and Forestry (LULUCF) sector, and this is indicated by the gray shading. In addition, a portion of the *Additional Measures* range results from uncertainty in policy implementation, which is represented graphically by the darker solid shading.

[tt] As noted previously, on February 9, 2016, the Supreme Court stayed implementation of the Clean Power Plan pending judicial review. See footnote jj for more information.

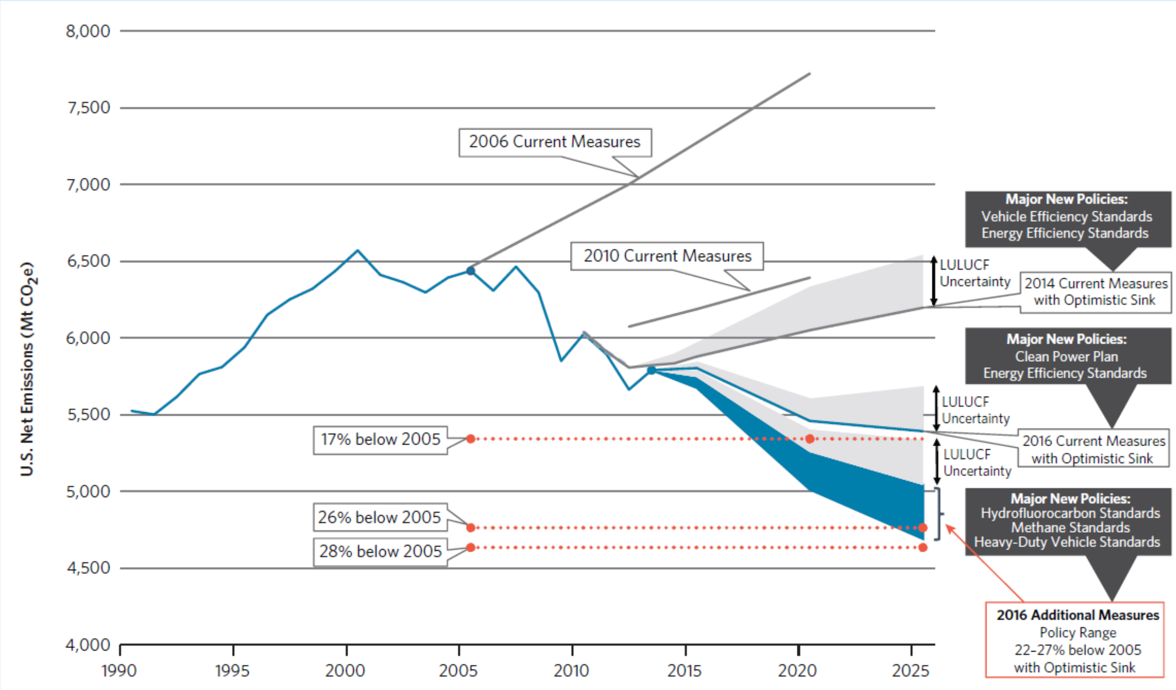


Figure 34. U.S. Emissions Projections—2016 *Current Measures* and *Additional Measures* Scenarios Consistent with the *Climate Action Plan*.[178] Also shown are previous projections from the 2006, 2010, and 2014 U.S. Climate Action Reports. The *Second Biennial Report* marks the first time that a U.S. Climate Action Report or Biennial Report projects GHG emissions to decline in the existing policies baseline.

Chapter 4: Policies and Measures that Reduce Power Sector GHG Emissions

Federal, state, and local governments have implemented a variety of policies, measures, and technology programs that address externalities. Policies often serve many functions, with one objective or co-benefit being the mitigation of greenhouse gas (GHG) emissions from the power sector. In broad terms, these policies can be characterized by the following six categories:

1. Performance-Based Regulations and Standards
2. Economic Instruments
3. Information Programs
4. Research and Development
5. Technology Demonstrations
6. Government Leading by Example

Performance-based regulations and standards require regulated entities to meet a specified level of performance for their facilities, portfolios, or products. These policies address emissions from the power sector by reducing GHG emissions from electricity generating units directly, increasing electricity generation from low- and zero-emitting sources, or by reducing overall electricity demand. Such measures can also be combined into a single policy, which often includes an emissions trading component.

Economic instruments are used to encourage more rapid and extensive adoption of clean energy technologies, which mitigates GHG emissions in the power sector. In particular, monetary incentives or disincentives—often in the form of a tax or tax credit—can be applied to a wide class of projects or activities that help reduce GHG emissions, or they can be applied to specific projects in the form of grants, loans, or technical assistance.

Information programs are another policy category that can help to reduce GHG emissions through the reporting of data and information to the federal government, and/or labeling of highly-efficient products for consumers. In addition, such programs can be used to make information available to the public or targeted groups, in order to encourage greater adoption of efficient and low- or zero-emitting energy technologies.

The government helps to mitigate GHG emissions from the power sector by supporting research & development (R&D) programs that drive technology innovation in critical clean energy technology areas. Moreover, the government plays a critical role in providing financial support for projects that demonstrate the effectiveness of new technologies which, in turn, encourages the adoption of pre-commercialized products that have the potential to substantially reduce GHG emissions from the power sector.

Finally, government entities have an important role to play in leading by example in reducing GHG emissions from its electricity use. Such policies can often be characterized by one of the aforementioned categories, but they apply specifically to federal facilities and activities.

Select examples of federal- and state-level policies that fall under these six categories are provided in Table 6. However, it is worth noting that some policy approaches cross category lines. For example, state and federal emissions trading programs combine performance-based regulation with trading of marketable credits or allowances. Trading is an economic instrument that can increase compliance flexibility, reduce costs, and incentivize new technologies.

Definition	Illustrative Examples
Performance-Based Standards and Regulations	
Mandatory regulations that require regulated entities (e.g., manufacturers, power plant operators, building developers, etc.) to meet a specified level of performance for their facilities, portfolios, or products. Such programs can be implemented at either a federal or state level, and often include an emissions trading component.[uu]	*State activities under the Clean Power Plan; Regional Greenhouse Gas Initiative; DOE Appliance, Equipment, and Lighting Energy Efficiency Standards; Renewable Portfolio Standards*
Economic Instruments	
Monetary incentives or disincentives applied to a wide class of projects or activities that are often, but not always implemented through the tax code; also includes targeted grants, loans, and technical assistance that support the deployment of specific technologies and projects.	*Investment Tax Credits; Production Tax Credits; State Energy Program; Loan Guarantee Program; Tribal Energy Program; Community Renewable Energy Deployment Grants*
Information Programs	
Programs that require or encourage the reporting of data and information to the federal government and/or labeling of products for consumers; also includes programs that make information available to the public and/or communicate information to targeted groups.	*Energy Star Products; Superior Energy Performance; Appliance Labeling Rule; Greenhouse Gas Reporting Program; WINDExchange; Green Power Partnership*
Research and Development	
Programs that drive technology innovation through support for foundational and transformational research and development in critical technology areas.	*DOE Energy Program Offices; Advanced Research Projects Agency – Energy (ARPA-E)*
Technology Demonstrations	
Programs that support the demonstration of pre-commercial technologies.	*Petra Nova CCS Project; Photovoltaic Manufacturing Initiative*
Government Leading by Example	
Government purchases of specified types of products or services, and other GHG-reducing actions that apply specifically to government facilities and activities.	*Executive Order 13693; Federal GHG Accounting and Reporting; Energy Savings Performance Contracts*

Table 6. A categorization of existing policies that mitigate GHG emissions from the power sector. A wide array of policies and measures—developed for many reasons and implemented at the federal, state, and local levels—provide the benefit of mitigating GHG emissions from the U.S. power sector.

[uu]Emissions trading is one example of a policy measure that crosses category lines: It is an economic instrument that can provide greater flexibility on means of compliance for a performance-based standard or regulation.

There are also a number of activities that have been initiated outside of the government which help to reduce GHG emissions from the power sector. One example is the voluntary "green power" market,[179] in which consumers and institutions voluntarily purchase renewable energy to match all or part of their electricity needs. Voluntary markets allow consumers to choose to do more than policy decisions require to reduce the environmental impact of their electricity use, such as through the installation of zero-emitting distributed generation sources. Moreover, voluntary markets help develop nationwide renewable energy capacity by providing a revenue stream for renewable energy projects and raising consumer awareness of the benefits of green power, such as GHG emissions reductions, economic development, and potential electricity cost savings. Government programs often support the voluntary "green power" market and other market-based mechanisms, but since they are largely maintained outside of the government, they lie beyond the scope of this volume and will not be discussed further.

Finally, it is worth noting that GHG emissions reductions are often a co-benefit of policies designed for other purposes. For example, building energy codes and other energy efficiency programs drive energy savings, which simultaneously produce GHG emissions reductions, reductions in electricity expenditures for consumers, and the deferral of new generation, transmission, and distribution investments for electric utilities. While these co-benefits are important aspects of the presented policies, they are beyond the scope of this volume—which is focused on GHG emissions from the electric power sector—and will not be discussed further. For more information about the co-benefits of energy efficiency programs, see the *Electricity End Uses, Energy Efficiency and Distributed Energy Resources: Baseline and Outlook to 2040.*

The remainder of this chapter provides brief explanations and select examples of the policies and programs that have been, or are expected to be responsible for the bulk of GHG emissions reductions from the U.S. power sector. For a comprehensive list of all federal policies and programs that address GHG emissions from the power sector, see Appendix 3 in the *Second Biennial Report of the United States of America*.[180] In addition, a listing of relevant state-level policies (and several federal policies) is maintained by the Database of State Incentives for Renewables and Efficiency (DSIRE)[181], and can be found in the EPA's recently published *Survey of Existing State Policies and Programs that Reduce Power Sector CO_2 Emissions*,[182] as well as in EPA's *Energy and Environment Guide to Action*.[183] Finally, a number of databases exist for tracking the actions that state and local governments have taken to address electricity-related GHG emissions:

- The National Association of State Energy Officials' (NASEO's) Data on Key Energy Activities.[vv]
- The National Conference of State Legislatures' (NCSL's) Energy and Environment Legislation Tracking Database.[ww]
- The American Council for an Energy Efficient Economy's (ACEEE's) State Energy Efficiency Policy database.[xx]
- The Advanced Energy Legislation tracker.[yy]

[vv] NASEO's Data on Key Energy Activities is available at www.naseo.org/state-energy-data.
[ww] NCSL's Energy and Environment Legislation Tracking Database is available at www.ncsl.org/research/energy/energy-environment-legislation-tracking-database.aspx.
[xx] ACEEE's State Energy Efficiency Policy database is available at aceee.org/sector/state-policy.
[yy] The AEL tracker is available at www.aeltracker.org.

4.1 Performance-Based Regulations and Standards

Performance-based regulations and standards require regulated entities to meet a specified level of performance for their facilities, portfolios, or products. For example, regulations can be used to directly address GHG emissions from the power sector by setting emissions standards for new and existing electricity generating units. In addition, clean or renewable energy targets can help to reduce GHG emissions by encouraging the deployment of low- and zero-emitting sources. Finally, energy efficiency standards can be established for appliances, equipment, buildings, and utilities, in order to decrease overall electricity demand. Below we offer some example policies, but this is not a comprehensive list. For a comprehensive list of all federal Performance-Based Regulations and Standards for the power sector, see Appendix 3 in the *Second Biennial Report of the United States of America*.[184] In addition, a complete presentation of existing efficiency standards and policies is provided in the *Electricity End Uses, Energy Efficiency and Distributed Energy Resources: Baseline and Outlook to 2040*.

4.1.1 Emissions Performance Standards

Federal Standards for Existing Units:

At the federal level, the EPA finalized the Clean Power Plan (CPP) in August 2015.[zz] Under authority from Section 111(d) of the *Clean Air Act*, the CPP regulates carbon emissions from power plants, which accounted for 30 percent of the U.S. GHG emissions in 2014. In particular, the new rule requires states to adopt state plans to limit emissions from existing fossil fuel-fired power plants. The rule calls for states to either implement specified emissions performance rates for two categories of affected electricity generating units, or to implement an equivalent state-specific rate-based or mass-based goal for those emitters.

This flexible approach leaves it up to each state to determine which suite of technologies and policies it wants to employ to meet its target. Moreover, it allows each state to reduce its emissions through market-based trading of emissions credits—in the form of allowances for states that opt for a mass-based approach, or Emission Reduction Credits for states that opt for a rate-based approach—both within the state and with other states that have opted for the same approach (i.e., either mass- or rate-based). EPA estimates that state actions under the CPP, in combination, would reduce power sector CO_2 emissions by 32 percent from 2005 levels by 2030, cutting carbon pollution by approximately 870 million short tons (790 MMT).[185]

Federal Standards for New Units:

Under Section 111(b) of the *Clean Air Act*, the EPA also established New Source Performance Standards (NSPS) for new fossil fuel-fired electricity generating units in the summer of 2015.[186] These NSPS require new NGCC units in the United States to have an emission rate lower than 1,000 lbs CO_2/MWh-gross, which is the equivalent of 454 kg CO_2/MWh-gross. In addition, they require new coal-fired units to have an emission rate lower than 1,400 lbs CO_2/MWh-gross (or 635 kg CO_2/MWh-gross), which is the performance achievable by a supercritical pulverized coal unit capturing about 20 percent of its CO_2.[187] The CO_2 implications of these NSPS for fossil fuel-fired electricity generating units will depend on future capacity additions, which are difficult to predict given the uncertainty of future market conditions for fuels and generating technologies.

[zz] As noted above, on February 9, 2016, the Supreme Court stayed implementation of the Clean Power Plan pending judicial review. See footnote jj for more information.

State-Level Standards:

At the state level, four states have set emissions limits for new and/or expanded electric generating units through emissions standards, and two additional states have implemented policies to encourage new coal plants to install CCS systems.[188] For example, electric utilities in California may only enter into long-term power purchase agreements for baseload power if the electric generator supplying the power has a CO_2 emission rate that does not exceed 1,100 lbs CO_2/MWh (or 500 kg CO_2/MWh).[189] Moreover, new coal-fired plants in Montana are required to capture and store at least 50 percent of their CO_2 emissions, [190] and Illinois utilities will be required to purchase at least 5 percent of their electricity from coal-fired plants that capture and store at least 90 percent of their carbon emissions by 2017.[191]

In a slightly different approach, Colorado has mandated power sector emissions reductions through legislative action. The 2010 Clean Air-Clean Jobs Act established specific goals for investor-owned utilities in Colorado to reduce nitrogen oxide emissions from their electricity generation.[192] The Act encourages utilities to consider replacing or repowering their coal-fired generation with natural gas-fired generation and other low-emitting resources, including energy efficiency. Each utility must develop its own emissions reduction plan, but the Colorado Governor's Energy Office estimates that the law will reduce nitrogen oxide emissions by 88 percent by the end of 2017. Moreover, it is projected that the Act will reduce Colorado's CO_2 emissions by 28 percent[193]—or 3.6 MMT CO_2 annually[194]—by the end of 2017. One example utility that is covered by the Act is Xcel Energy, which had already reduced its annual CO_2 emissions by 2.1 MMT in 2014. Xcel projects that the measures it has adopted under the Clean Air-Clean Jobs Act will result in a 35 percent reduction in system-wide CO_2 emissions by 2020 (compared to 2005 levels), in addition to 86 percent reductions in N_2O and 83 percent reductions in SO_x.[aaa][195]

Ten states have implemented programs that cap the total allowable GHG emissions from a state or region. For example, in response to California's Assembly Bill 32 (AB-32) – which requires the state to reduce GHG emissions to 1990 levels by 2020 – the California Air Resources Board (ARB) established an economy-wide cap-and-trade program. Under the cap-and-trade program – which covers sources that are responsible for 85 percent of statewide GHG emissions, including electricity generators and large industrial facilities – the economy-wide emissions cap is lowered by 3 percent each year from 2015 to 2020. [196] A specific target for the electricity sector is not established under AB-32 or the cap-and-trade program. However, the ARB projects that California's power sector will reduce its GHG emissions to less than 80 MMT CO_2e by 2025, which corresponds to a 25 percent reduction from 2005 levels.[197] Moreover, to build upon this target, California's Governor issued an executive order in April 2015 establishing a GHG reduction target of 40 percent below 1990 levels by 2030.[198]

Finally, the Regional Greenhouse Gas Initiative (RGGI) is a regional cap-and-trade program[bbb] that includes nine states in the Northeast and Mid-Atlantic United States: Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New York, Rhode Island, and Vermont. The RGGI program sets a mass-based emissions cap for the entire region, which is met through CO_2

[aaa] These measures will also impact non-GHG emissions, and are projected to reduce mercury emissions by 82 percent by 2020 (compared to 2005 levels).

[bbb] RGGI is not usually referred to as a performance standard, since the program does not set rate-based targets. RGGI is a cap-and-trade program, which sets a mass-based emissions cap for the entire region. In some policy databases, RGGI may fall under the Economic Instruments category, which reflects the trading component of a cap-and-trade program.

allowances that are primarily distributed through auctions. The proceeds from these auctions are largely reinvested in greenhouse gas abatement programs and a wide array of consumer benefit programs, such as energy efficiency, clean and renewable energy, and direct bill assistance.[199]

At its inception, the RGGI states agreed to cap regional emissions at a level of 165 million short tons of CO_2 (150 MMT CO_2) per year from 2012-2013. However, after a comprehensive review in 2012, the participating states agreed to strengthen the target by 45 percent in 2014, lowering the emissions cap to 91 million short tons of CO_2 (83 MMT CO_2). The cap will continue to decrease by 2.5 percent each year from 2015 through 2020, when it reaches 78 million short tons of CO_2 (71 MMT CO_2).[200] To date, RGGI states have reduced power sector CO_2 emissions[ccc] by over 40 percent since 2005,[201] and they are on track to achieve a 50 percent reduction in power sector GHG emissions by 2020 (compared to 2005 levels).[202]

4.1.2 Appliance and Equipment Efficiency Standards

The U.S. Department of Energy (DOE) Appliance and Equipment Standards Program[203] has served as one of the nation's most effective policies for improving energy efficiency and, in turn, has simultaneously driven significant carbon emission reductions. The program implements minimum energy conservation standards for more than 60 products that consume about 90 percent of home energy use, 60 percent of commercial building energy use, and 30 percent of industrial energy use.[204] Since 2009, the United States has issued 40 new or updated standards to make appliances, buildings, and equipment more efficient. For example, in January 2016, DOE finalized efficiency standards for commercial air conditioning and heating equipment, which is projected to avoid 77 MMT CO_2 by 2030.[205] With the finalization of this standard, DOE is more than two-thirds of the way toward achieving its goal of avoiding 3 billion metric tonnes of carbon pollution[ddd] through standards set between 2008 and 2016.[206]

Beyond implementing federal appliance and equipment standards, states also have the option of developing their own appliance standards for energy-consuming products that are not already covered by the federal government. In addition, states can apply to DOE for a waiver to implement more stringent standards for products that are covered by the federal government. To date, nine states and the District of Columbia have enacted standards for equipment not covered federally, or obtained waivers to enact tougher appliance standards.[207] California currently has the most active state standards, which have been developed for 23 categories of appliances. These categories include consumer audio and video products, pool pumps and hot tubs, vending machines, televisions, battery chargers, and various lighting applications.[208]

For a more detailed discussion of Appliance and Equipment Efficiency Standards, please see the *Electricity End Uses, Energy Efficiency and Distributed Energy Resources: Baseline and Outlook to 2040*.

[ccc] Primary data for the emissions generated specifically from RGGI-affected sources is available via public reports of the RGGI CO_2 Allowance Tracking System (RGGI COATS), and via the Historical Emissions Data page of the RGGI, Inc. website (for years prior to the start of the program). Note that these primary data differ slightly compared to data available from EIA.

[ddd] The projected reduction in carbon pollution from the DOE Appliance and Equipment Standards Program reflects cumulative emissions savings through 2030, and corresponds to 43.8 quadrillion Btus of energy savings.

4.1.3 Building Energy Codes

Each year, buildings are responsible for 70 percent of electricity-related emissions in the U.S. (Figure 11). In order to eliminate inefficient technologies and reduce overall energy demand, states and localities adopt building energy codes, which establish mandatory prescriptive or performance-based metrics that regulate building energy efficiency in new construction, major renovations, and remodels. The International Energy Conservation Code (IECC) is the prevailing model code for the residential sector,[209] and the current version of the code (at the time of this publication) is IECC-2015. In the commercial sector, ASHRAE 90.1 is the model code,[210] and the current version of the code is ASHRAE 90.1-2013.

Building energy codes also offer a significant opportunity to reduce emissions from the residential and commercial sectors. In 2012 alone, it is estimated that building energy codes helped to avoid 36 MMT CO_2 in the U.S. If current trends in code adoption and compliance continue, it is estimated that building energy codes will help to avoid an estimated 3,178 MMT CO_2 between 2013 and 2040. At the state level, adoption of the newest versions of the building energy codes could reduce energy use and costs of new buildings and major renovations by 12–40 percent.[eee] [211]

As of April 2016, the IECC is currently in use or adopted in 48 states, the District of Columbia, the U.S. Virgin Islands, New York City, and Puerto Rico, with IECC-2012 being the most commonly adopted version of the code.[fff] [212] Oregon estimates that its adoption of IECC-2009 generated 3.5 GWh of energy savings in residential and commercial buildings in 2009.[213] In addition, California has developed its own Building Energy Efficiency Standards. Over the lifetime of this program—which was first implemented in 1978—these standards have helped avoid 250 MMT of GHG emissions.[214] Moreover, California recently updated the standards in 2013, proposing new measures for hot water, air conditioning, windows, and envelop insulation, as well as its Solar Ready Measures. It is estimated that the new standards will achieve 215 thousand metric tonnes of GHG emissions reductions per year.[215]

For a more detailed discussion of Building Energy Codes, see the *Electricity End Uses, Energy Efficiency and Distributed Energy Resources: Baseline and Outlook to 2040*.

4.1.4 Portfolio Standards

Another common tool that states use to diversify supply, drive technology innovation, and mitigate power sector GHG emissions is a clean portfolio standard, which is often called a clean energy standard or a renewable portfolio standard (RPS). State-level RPSs typically require electric utilities to supply a specific amount of their electricity generation from low- or zero-emitting sources. These requirements typically start at a modest level and ramp up over a period of several years. Compliance with these state mandates are substantiated through renewable

---

[eee] The specific savings depend upon factors such as the key characteristics of the buildings being improved (e.g. size, type) and prevailing climate conditions.
[fff] As of April 2016, IECC-2012 was in use or adopted in 21 states. The next most commonly adopted or used code was IECC-2009 (16 states), followed by IECC-2015 (6 states), IECC-2006 (3 states), and IECC-2003 (2 states). Finally, Puerto Rico adopted IECC-2009, and the U.S. Virgin Islands adopted IECC-2012. Note that some states have adopted building energy codes on a voluntary basis, and Alabama's adoption of IECC-2015 does not go into effect until October 2016.

energy certificate instruments, similar to how voluntary market participants also substantiate renewable electricity generation and usage claims, as well as GHG emissions claims.

As of October 2015, 29 states and the District of Columbia had adopted a mandatory RPS, and an additional 8 states had voluntary renewable goals.[216] One example is Colorado, which enacted an RPS by ballot initiative in 2004, and later modified the RPS in 2005, 2007, 2010, and 2013. In its current form, Colorado's RPS requires investor-owned electric utilities to generate 30 percent of their electricity from renewable resources by 2020, with lower targets for cooperative and municipal utilities (20 percent and 10 percent, respectively).[217] In addition, Ohio's Alternative Energy Portfolio Standard requires its utilities to generate 25 percent of their retail electricity sales from clean energy sources by 2026. Half of this requirement is to be met by renewable energy sources, and the other half is to be met with advanced energy sources such as clean coal, advanced nuclear, and distributed CHP generation.[218] California's RPS requires electric utilities to derive 33 percent of their retail sales from eligible renewable energy resources by 2020, with the target increasing to 50 percent by 2030.[219] Finally, Hawaii's RPS requires its electric utilities to generate 40 percent of their electricity from renewable sources by 2030, and establishes an ultimate goal of 100 percent renewable electricity generation by 2045.[220]

State RPS obligations have helped to drive significant investment in new renewable electricity resources, as well as the corresponding GHG emissions reductions. The ARB estimates that the state RPS will help to avoid 21.3 MMT CO_2e by 2020.[221] In addition, a recent study performed by DOE's Lawrence Berkeley National Laboratory and National Renewable Energy Laboratory (NREL) estimates that new renewable electricity resources that were used to meet all state RPS obligations totaled 5,600 MW of capacity additions, as well as 98 TWh of generation in 2013. Further, the life cycle GHG emissions analysis performed in the same study indicates that this new renewable electricity generation helped to avoid 59 MMT CO_2e in 2013 (Figure 35).[222]

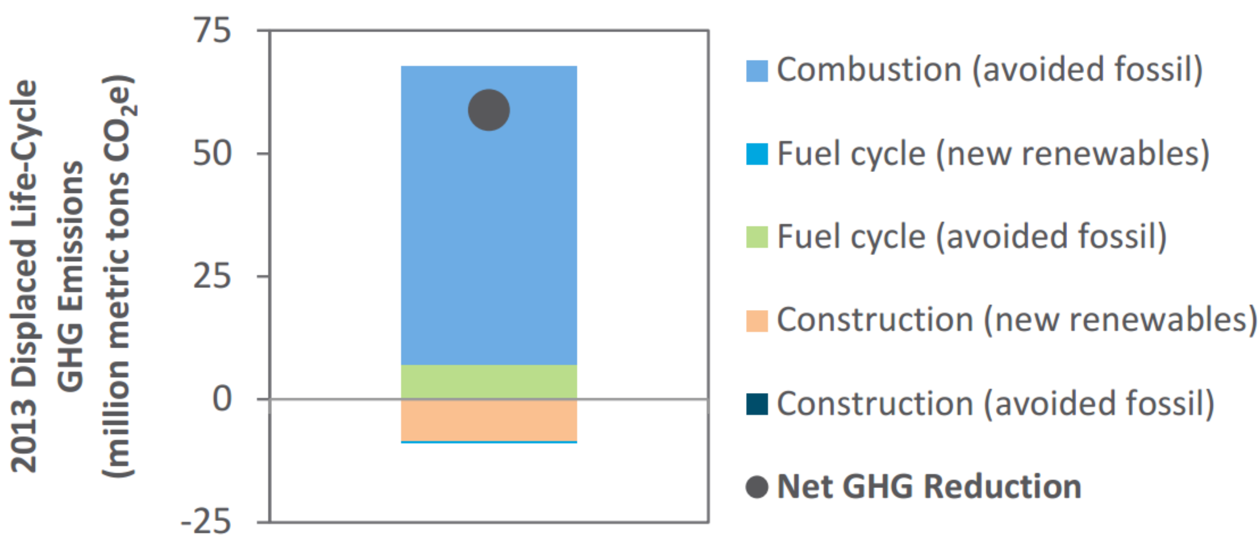


Figure 35. Lifecycle GHG Emissions Impacts of RPS Compliance, 2013. [223] Lawrence Berkeley National Laboratory and the National Renewable Energy Laboratory estimate that new renewable electricity generation that was driven by state-level renewable portfolio standards helped to avoid 59 million metric tonnes of U.S. carbon emissions in 2013.

4.1.5 Energy Efficiency Programs

Energy efficiency policies and programs help to avoid GHG emissions associated with electricity generation, and are a central part of climate change mitigation in many states. For example, energy efficiency is expected to avoid 21.9 MMT CO_2 in California by 2020, which corresponds to 48 percent of the state's expected power sector emissions reductions.[224] In addition, over 60 percent of cumulative RGGI investments have gone towards supporting energy efficiency programs that have already avoided 1.3 million short tons of CO_2. Over their lifetime, it is projected that these programs will avoid more than 7.5 million short tons of CO_2.[225]

Demand-side management programs can also take the form of an energy efficiency resource standard (EERS), which is a binding energy savings target or portfolio standard. Under an EERS, retail electricity suppliers must meet this energy savings target by developing end-use programs that incentivize customers' investments in more energy-efficient technologies and practices. To date, the states that have implemented EERS programs are on track to meet their incremental savings targets, which are typically 0.25–2.5 percent annual electricity demand reductions.[226] In 2013, states with an EERS achieved incremental electricity savings of 1.1 percent of retail sales on average, compared to average savings of 0.3 percent in states without an EERS.[227]

EERS programs are currently being implemented in 26 states,[228] and two additional states[229,230] have combined RPS-EERS programs[ggg]. In 1990, Texas became the first state to implement an EERS, which mandated that investor-owned utilities meet 30 percent of its incremental load growth through energy efficiency by the year 2013.[231] In addition, Arizona's EERS was implemented in 2010, and established incremental savings targets of 1.25 percent of sales in 2011, ramping up to 2.5 percent in 2016 through 2020.[232] Finally, under the Next Generation Energy Act, electric utilities in Minnesota are required to pursue energy efficiency programs that result in reductions of 1.5 percent of average electricity sales per year.[233]

For a more detailed discussion of EERS programs, see the *Electricity End Uses, Energy Efficiency and Distributed Energy Resources: Baseline and Outlook to 2040*.

4.2 Economic Instruments

Economic instruments can be used to encourage the more rapid and extensive deployment of clean energy technologies. In particular, monetary incentives or disincentives can be applied to a wide class of projects or activities that help reduce GHG emissions—often in the form of a tax or tax credit—or they can be applied to specific projects in the form of grants, loans, or technical assistance.

4.2.1 Tax Incentives

Energy Efficiency Tax Incentives:

At the federal level, economic instruments that are applied to a wide class of projects are often implemented through the federal tax code. For example, federal tax provisions provide incentives for investments to improve energy efficiency in buildings, reducing electricity demand and

[ggg] The count of 26 states includes only those that currently have energy efficiency resource standards or goals. It does not include Indiana, whose EERS was officially eliminated in 2014.

lowering emissions. Owners of existing homes can receive a tax credit of up to $500 for high-efficiency heating, cooling, and other types of equipment.[234] Builders of new energy efficient homes can also receive a corporate tax credit of up to $2,000.[235] For commercial buildings, a tax deduction of up to $1.80 per square foot is available for firms that install high-efficiency equipment.[236] It is worth noting, however, that all of these programs are currently set to expire at the end of 2016.

CCS Tax Incentives:

Tax incentives are also available for CCS, including a 30 percent investment tax credit for projects that capture and store 65 to 75 percent of CO_2 emissions (Sections 48A and 48B, respectively). Additionally, the Section 45Q production tax credit for CCS provides $20 per metric tonne of CO_2 stored, and $10 per metric tonne of CO_2 used and stored through enhanced oil recovery.[237] These incentives for CCS indicate support for CCS, but have not driven high levels of deployment to date.

Renewable Electricity Tax Incentives:

In addition, the federal government supports the deployment of zero-emission electricity generating sources through renewable electricity tax credits.[238] The Renewable Electricity Production Tax Credit (PTC) provides a per-kilowatt-hour tax credit to facilities that generate electricity from qualified energy resources, the duration of which extends for 10 years after the facility is placed in service. Wind, closed-loop biomass, and geothermal energy resources can receive a 2.3 cents per kWh tax credit, while open-loop biomass, landfill gas, municipal solid waste, qualified hydroelectric, and marine and hydrokinetic energy resources can receive a 1.2 cents per kWh tax credit. For most energy resources, the PTC is set to expire at the end of 2016, but the PTC for wind facilities will be phased-down through 2019.[239]

The Renewable Electricity Investment Tax Credit (ITC) provides a tax credit that is based on the capital that business owners[240] and households[241] invest in a wide array of clean energy systems. Currently, the ITC allows for a 30 percent tax credit for fuel cells and solar power generation projects—both centralized utility-scale and distributed generation—and for small and large wind turbine systems that elect to claim the ITC instead of the PTC. In addition, the ITC allows for a 10 percent tax credit for microturbines, geothermal, and CHP systems. The ITC for geothermal electric systems is permanent, but the tax credit for geothermal heat pumps, fuel cells, small wind, microturbines, and CHP systems is set to expire at the end of 2016. The ITC for large wind systems will be phased down through 2019, and most residential solar systems[hhh] will be eligible for a reduced tax credit through 2022. Finally, the solar ITC for business owners will step down to 10 percent in 2022 and beyond.

The PTC and ITC have helped to accelerate the construction of renewable electricity projects, and it is projected that their recent extension will continue this trend up to and beyond 2020. A recent NREL study estimates that the extension of the ITC and PTC, among other factors, will drive a peak in incremental renewable electricity capacity additions of 53 GW in 2020. In turn, the corresponding new renewable electricity generation will help to avoid between 540 and 1,420 MMT CO_2e by 2030, where the range reflects the uncertainty associated with other market factors, such as the price of natural gas.[242]

[hhh] The solar technologies that will be available for a 30 percent ITC through 2019, and a reduced ITC thereafter, include photovoltaic, solar water heating, solar space heating/cooling, and solar process heating systems.

State-Level Tax Incentives:

More than 200 state-level tax incentive programs have been implemented across the nation, and all 50 states have demand-side energy efficiency financial incentive programs. For example, New Mexico is helping its citizens invest in clean energy for their homes or businesses by offering a 30 percent tax credit for the installation of geothermal ground-coupled heat pump systems.[243] Oregon offers residential tax credits for renewable energy and energy efficiency installations in the state. In particular, Oregon residents can apply for a state tax credit of 50 percent of the installation costs for fuel cells, wind turbines, and rooftop solar systems,[244] and the state also offers an energy efficiency tax credit of 60 cents/kWh of first year energy savings.[245]

For a more comprehensive listing of existing state and local incentives for clean energy technologies, see the Database of State Incentives for Renewables and Efficiency (DSIRE)[246], EPA's recently published *Survey of Existing State Policies and Programs that Reduce Power Sector CO_2 Emissions*,[247] EPA's *Energy and Environment Guide to Action,*[248] and the Alternative Fuels Data Center.[249]

4.2.2 Grants and Technical Assistance Programs

The federal government employs targeted grants and technical assistance programs that help achieve a variety of objectives, such as reducing GHG emissions from the electric power sector. For example, DOE's State Energy Program (SEP) provides financial assistance to state and territory energy offices, in order to help them advance their clean energy economies.[250] Through the SEP, DOE awards grants that support the more rapid adoption of clean energy technologies, as well as the implementation of programs to improve energy sustainability.

The SEP also makes it possible for states to establish their own grant programs, which can most effectively encourage the deployment of GHG mitigating technologies at the state level. One example is Ohio's "Energy Efficiency Program for Manufacturers," which is supported by SEP funds. This program helps manufacturers identify and implement cost-effective energy efficiency improvements at their facilities, and it is estimated that the program will help avoid over 110,000 short tons (100,000 metric tonnes) of CO_2e emissions per year.[251]

Technical assistance is another tool that the federal government can use to accelerate the deployment of clean energy technologies. DOE-wide technical assistance is available at www.energy.gov/ta, and select examples of DOE's technical assistance programs include:

- The SEP has a technical assistance component, which helps to enhance the likelihood of program success, and to improve the efficiency and effectiveness with which clean energy technologies are deployed at the state level.
- The Combined Heat & Power Program provides technical assistance for CHP plants and industrial processes, to help increase energy efficiency and reduce energy costs.[252]
- DOE's Office of Electricity Delivery and Energy Reliability provides technical assistance to states, regions, and tribes as they develop electricity-related policies through its Electricity Policy Technical Assistance Program. This Program's activities include analysis assistance to help understand the impacts of policy options and technology and market strategies; stakeholder-convened discussions to tackle key issues and build consensus for state, regional, or tribal preferred courses of action; education and training to better equip policy makers to address local and regional needs; and consultations with technical experts.[253]

4.2.3 Loan Programs

Through its Loan Guarantee Program, DOE provides financial support for projects that employ innovative technologies and seek to avoid, reduce or sequester GHG emissions. These loan guarantees help to accelerate the commercialization of new or significantly improved clean energy technologies, such as advanced nuclear energy, advanced fossil energy, renewable energy, and energy efficiency technologies, as well as efficient transmission and distribution technologies.[254] For example, in Fiscal Year 2016, the Loan Guarantee Program issued a solicitation for $12.5 billion in loan guarantees for advanced nuclear projects, such as advanced nuclear reactors with innovative improvements in the areas of fuel technology, thermal efficiency, modularized construction, safety systems, and standardized design.[255] The Loan Guarantee Program also has an open solicitation for $8 billion in loan guarantees for advanced fossil energy projects that use new or significantly improved technologies to avoid, reduce, or sequester anthropogenic GHG emissions.[256]

The U.S. Department of Agriculture's Office of Rural Development is also active in renewable energy financing, offering both loans and loan guarantees for clean energy projects that improve electric service in rural areas. Through the Rural Energy for America Program (REAP), Rural Development offers loan financing to agricultural producers and rural small businesses for clean energy projects. REAP loans may be used to install and construct renewable energy systems—such as biomass, geothermal, hydrogen systems—or to improve energy efficiency through high efficiency HVAC, insulation, lighting, doors, and windows.[257] In addition, Rural Development helps to finance demand-side management, energy efficiency, and conservation programs, as well as on- and off-grid renewable energy systems, through loans and loan guarantees that are available to electric utilities for improving electric service in rural areas.[258]

Finally, states have also been active in offering financing for clean energy projects that will help reduce GHG emissions from the power sector. For example, the National Association of State Energy Officials (NASEO) maintains the State Energy Loan Fund (SELF) database, which tracks energy loan programs and includes key statistics such as funding source, fund size, and program purpose (see http://naseo.org/state-energy-financingprograms). According to the SELF database, the state clean energy financing landscape includes approximately $1.7 billion in available financing across 35 states, which is overseen by the State Energy Offices.[iii] This state-level financing is largely facilitated through direct lending, and it is highly complementary to existing private sector and federal loan programs. In particular, financing that is overseen by the State Energy Offices is often focused on site-specific projects that help to accelerate the deployment of available energy efficiency and renewable energy technologies, and targets specific sectors of the energy economy in a way that conventional financing is not already doing.

One specific example of a state-level loan program is the Mass Solar Loan Program, through which Massachusetts offers fixed low-interest loans to residents purchasing rooftop solar systems. This program is an effort to expand the state's solar market to 1600 MW by 2020, by helping more residents invest in rooftop solar systems or a share in a community solar project.[259]

[iii] This figure does not include additional non-State Energy Office funds leveraged for loans (for instance by credit enhancements or interest rate buy-downs), but it does include funds that states received from secondary market transactions whose proceeds they used to expand the capital for their programs. It does not include capital associated with PACE or QECBs, but it does include green bank capital in the states where green banks are operated by the State Energy Office (Hawaii and New York, but not Connecticut).

4.3 Information Programs

Information programs that help address GHG emissions from the power sector exist in a variety of forms. Programs that require or encourage the reporting of GHG emissions data help communities and businesses to identify major sources of GHG emissions, as well as cost, fuel, and emissions-saving opportunities. These programs also work to ensure that GHG claims are substantiated through market instruments that support such claims. In addition, the labeling of highly-efficient products helps to inform consumers about the products that can help them maximize their savings of energy and associated GHG emissions. Finally, information programs can be used to make data and information available to the public or targeted groups, in order to encourage greater adoption of efficient and low- or zero-emitting energy technologies, as well as inform policies at the state and local levels.

One example of an information program is ENERGY STAR®, which was designed to accelerate the adoption of energy efficient products, practices, and services through partnerships, objective measurement tools, and consumer education. For more than 20 years, American consumers have looked to EPA's ENERGY STAR® program for guidance on how to save energy, save money, and protect the environment. Behind each blue label is a product, building, or home that is independently certified to use less energy and cause fewer of the emissions that contribute to climate change. ENERGY STAR® is the most widely recognized symbol for energy efficiency in the world, helping families and businesses save $360 billion on utility bills, while reducing greenhouse gas emissions by more than 2.4 billion metric tonnes since 1992.[260]

By helping to reduce energy use in homes, buildings, and industry—which account for two-thirds of end-use GHG emissions in the United States[261]—the ENERGY STAR® program has significantly reduced end-use GHG emissions. Between 1992 and 2014, the program helped to prevent more than 2,400 MMT CO_2e in the residential, commercial, and industrial sectors. Moreover, the program's GHG emissions reductions have grown steadily over time. In the year 2000, it is estimated that the ENERGY STAR® program helped to avoid 53.5 MMT of CO_2 emissions. The magnitude of avoided GHG emissions grew to more than 280 MMT CO_2 in 2014, approximately half of which were avoided through the use of more than 70 categories of EPA's ENERGY STAR® products.[262]

Local governments and states are also active in reducing GHG emissions from the power sector through information programs. One example is Minneapolis' Commercial Building Benchmarking and Disclosure Ordinance, which requires the cities' largest commercial and municipal buildings—which account for over half of the city's total energy use—to measure and report their energy consumption to the city in a process called benchmarking[jjj]. In turn, the city discloses all required benchmarking data publicly, with the goals of increasing building owner and public awareness of building energy performance information, and motivating more energy efficiency actions. A 2015 report on the benchmarking results estimates that the buildings that benchmarked their energy consumption in 2013 have the combined potential to avoid more than 62,000 metric tonnes of CO_2e emissions annually.[263]

[jjj] Energy benchmarking involves compiling and reporting building energy consumption data, and calculating summary metrics that can be compared to peer buildings or the same building's historical consumption. For a more complete discussion of benchmarking, see the *Electricity End Uses, Energy Efficiency and Distributed Energy Resources: Baseline and Outlook to 2040*.

4.4 Technology Demonstrations

The federal government has an important role to play in supporting demonstration projects, which are essential for accelerating the deployment of cutting-edge technologies that can help mitigate GHG emissions from the power sector. In particular, the federal government's support of technology demonstration projects helps address key challenges associated with installing clean energy technologies in first-of-their-kind projects, by eliminating uncertainties, mitigating risks, and helping to reduce installation costs and timelines.

For example, DOE is helping to accelerate the deployment of offshore wind projects by providing funding, technical assistance, and government coordination through its Offshore Wind: Advanced Technology Demonstrations program. The goal of this program is to help bring down the cost of offshore wind energy systems by supporting innovative installations in the most rapid and responsible manner possible. Currently, this program is supporting three advanced offshore wind demonstration projects that are on an accelerated timeframe for commencing operations.[264]

Another example lies in DOE's Clean Coal Research, Development, and Demonstration Program within the Office of Fossil Energy. In order to help advance CCS technologies, this program supports demonstration projects that will help address technical and economic barriers, reduce the cost of implementation, and provide data and information to inform regulators and industry on the safety and permanence of CCS. For example, the Regional Carbon Sequestration Partnerships comprise more than 400 diverse organizations covering 43 states and four Canadian provinces, and were established to develop the technology, infrastructure, and regulations needed to implement large-scale CO_2 storage in different regions and geologic formations. In addition, the Major Demonstration Program includes commercial scale CCS projects that are underway at industrial sources, including a steam methane reformer in Texas and an ethanol production facility in Illinois. In part because of these programs and other activities within DOE's Clean Coal Research, Development, and Demonstration Program, over 11 MMT CO_2 had been injected in the United States as of October 2015.

Finally, ongoing projects in the power sector that are being supported by the Office of Fossil Energy are expected to accelerate the deployment of CCS on next-generation power plants in the near future. One example is the Petra Nova CCS Project in Texas, which is designed to capture approximately 90 percent of the CO_2 emissions from a 240 MW plant, and use or sequester approximately 1.4 MMT CO_2 annually. The project will utilize a proven carbon capture process, which uses a high-performance solvent for CO_2 absorption and desorption. The captured CO_2 will then be compressed and transported through an 80 mile pipeline to an operating oil field where it will be utilized for enhanced oil recovery and ultimately sequestered.[265]

4.5 Research and Development

The United States is making major investments in research and development (R&D) to support the climate change mitigation technologies of tomorrow. For example, the United States and other world leaders launched Mission Innovation at the UN climate negotiations in Paris in November 2015. This initiative represents a landmark commitment that will help mitigate GHG emissions through a dramatic acceleration of investments in global clean energy innovation. In particular, as part of this initiative, the United States has agreed to double its R&D investments in clean energy innovation by 2020.[266]

To accelerate the transition to a clean energy economy, DOE plays a major role by investing in cutting-edge energy R&D. These investments target critical technology areas, such as grid modernization, renewable energy, energy efficiency, advanced energy storage, fossil energy technologies with CCS, and advanced safe nuclear reactor technology. For example, the Consolidated Appropriations Act of 2016 includes $291 million in funding to continue the innovative work of the Advanced Research Projects Agency–Energy (ARPA-E).[267] As of January 2015, ARPA-E had funded more than 400 high-potential, high-impact energy projects. For example, the goal of ARPA-E's "Generators for Small Electrical and Thermal Systems" is to facilitate the development and commercialization of economical, durable, and highly efficient residential CHP systems. Once fully commercialized, these small, natural gas-fueled systems could fulfill most of the country's residential electricity and hot water needs, and have the potential to reduce CO_2 emissions associated with electricity generation by 10 percent.[268]

In addition, clean energy R&D is a primary focus of DOE's energy program offices. One example is the Office of Nuclear Energy's R&D program, which targets advanced reactor technologies, as well as light water and small modular reactors. In January 2016, DOE announced that it will fund cost-shared R&D efforts by X-Energy, which is developing the Xe-100 Pebble Bed Advanced Reactor. This reactor is smaller than traditional nuclear reactors and has advanced safety features, thus making it a potential candidate technology for future deployment in more densely populated areas. In addition to helping to address key technical challenges to the design, construction, and operation of this next generation nuclear reactor technology, DOE's R&D support is also designed to help get this project ready for demonstration by 2035.[269]

Similarly, R&D funding through DOE's Solar Energy Program has played a major role in accelerating the research, development, and deployment of solar energy technologies, such as photovoltaic (PV) energy systems. A retrospective benefit-cost evaluation found that DOE's investment in PV energy systems helped to accelerate the development of high-quality, lower-cost PV modules by 12 years.[270] The same evaluation also determined that DOE's investment helped to avoid 1 MMT CO_2e before 2008, when annual generation from solar PV was less than 0.2 percent what it is today.[271]

For a more complete discussion of DOE's R&D activities across its energy program offices, see the *Quadrennial Technology Review* (QTR) 2015. The QTR presents the current status of the science and technology that are the foundation of our energy system, and explores the R&D, demonstration, and deployment opportunities within the energy sector. In addition, the QTR discusses various trade-offs that energy technologies must balance, such as cost, reliability, and environmental impacts.[272]

State and local governments also operate many energy research centers, which are driving clean energy technology innovation by working with industry and researchers to get new energy technologies from the lab to the market. One example is Montana State University's Energy Research Institute,[273] which conducts fuel cell research that is focused on making solid oxide fuel cells an affordable and practical source of energy. The Energy Research institute also has an active research program in carbon sequestration, which seeks to develop novel approaches for safe and viable long-term carbon storage. One notable project is the Kevin Dome Large Scale

Carbon Storage Project[kkk], which is currently testing two carbon sequestration wells in an attempt to assess the region's geologic structure is suitable for safely storing CO_2.

For a more complete discussion of existing state and local energy research centers, see the Association of State Energy Research & Technology Transfer Institutions' *National Guide to State Energy Research Centers*.[274]

4.6 Government Leading by Example

The federal government is the single largest consumer of energy in the United States. Therefore, it has an important role to play in leading by example when it comes to reducing its GHG emissions. For example, the federal government holds itself to a high standard when it comes to building energy codes. In particular, DOE recently updated the efficiency standards for new federal commercial buildings, which now must be designed to consume a minimum of 30 percent less energy than the levels established by the 2013 edition of ASHRAE 90.1. Similarly, new federal residential buildings must be designed to consume a minimum of 30 percent less energy than the levels established by the 2009 edition of the IECC (see section 4.1.3).[275]

Another federal government example lies in Executive Order 13693,[276] "Planning for Federal Sustainability in the Next Decade." This Order aims to reduce the federal government's GHG emissions by 40 percent—or 26 MMT CO_2e—over the next decade, compared to 2008 levels. A major piece of this will be accomplished through an update to the federal government's Green Power Purchasing Goal, which now requires 30 percent of the electricity consumed by the federal government to come from renewable energy by 2025.

DOE's Federal Energy Management Program (FEMP) has an important role to play in helping federal agencies to meet these energy-related goals. In particular, FEMP provides agencies with the information, tools, and assistance they need to plan and implement the energy efficiency and renewable energy projects that will help them meet the aforementioned targets.[277]

Another example of federal leadership is the Department of Defense's (DOD's) goal of deploying 3,000 MW of renewable energy on military installations by 2025. In particular, the Air Force have committed to developing 1 gigawatt of on-site renewable electricity capacity by 2016,[278] and is aiming to ensure that all new buildings are designed to achieve zero-net-energy by 2030.[279] Similarly, the Army has goals to deploy 1 GW of renewable energy on Army installations by 2025, and to reach net-zero energy consumption by 2030.[280] Finally, the Navy was on track to bring 1 GW of renewable energy into procurement by the end of 2015, approximately years ahead of schedule.[281]

The Department of Housing and Urban Development (HUD) has a goal of installing 300 MW of renewable capacity through community and shared solar installations across federally subsidized housing by 2020. So far, HUD is on track to meeting its 2020 goals, thanks to existing commitments from 45 affordable housing and service providers to install more than 180 MW of on-site renewable energy.[282]

[kkk] The Kevin Dome Large Scale Carbon Storage Project is run by the Big Sky Carbon Sequestration Partnership, which is part of DOE's Regional Carbon Sequestration Partnerships program.

State governments are also leading by example when it comes to reducing their GHG emissions. For example, in December 2015, the Governor of Rhode Island issued an executive order establishing a renewable energy and energy efficiency goal for the state's buildings and facilities. The order requires 100 percent of the electricity consumed by the state government to come from renewable sources by 2025. In addition, energy consumption in state buildings must be reduced by at least 10 percent below 2014 levels by 2019. The ultimate goal of these efforts is to help Rhode Island meet its voluntary goal of reducing GHG emissions to 45 percent below 1990 levels by 2035, and to 80 percent below 1990 levels by 2050.[283]

In addition, the Governor of Tennessee established EmPower TN, which is an initiative to reduce the state's energy bill and promote energy-saving best practices to local governments and citizens. The goal of the initiative is to reduce energy consumption by 28 percent over eight years[284] through improved energy management practices within state-owned and managed buildings, as well as through investments in energy efficiency and renewable energy projects. The focus of EmPower TN is state-owned and managed facilities, but the goal is for the program to serve as a model and training tool for local Tennessee government, and that it will attract the support of private and nonprofit organizations interested in promoting energy conservation, as well as clean and renewable energy development.[285]

Finally, local governments are also leading the way in reducing GHG emissions in their jurisdictions, particularly from locally owned or operated assets. Improving the energy efficiency of these assets may be an easy starting point for jurisdictions that want to improve energy efficiency in their locale, due to a high degree of control and influence. One example lies in Arlington County, Virginia, which launched the Arlington Initiative to Reduce Emissions (AIRE[lll]) program in 2007.[286] The AIRE program focused on improving the county's energy practices, and set an initial goal of reducing the County government's GHG emissions by 10 percent (compared to 2000 levels) by 2012. In order to meet this goal, the county adopted low-cost and no-cost measures such as adjusting operating settings for building equipment, and made longer-term capital upgrades for county assets, such as streetlights and the wastewater treatment plant. The program was considered to be so successful—driving 11.7 percent reductions in the county's GHG emissions by 2012—that in 2013, the county adopted a new goal of reducing GHG emissions from the County government's activities by more than 70 percent (compared to 2007 levels) by 2050.[287]

Another example lies in the city of Minneapolis which, in 2012, adopted goals of reducing citywide GHG emissions by 15 percent by 2015, and 30 percent by 2025, compared to a 2006 baseline. The aforementioned Building Benchmarking and Disclosure Ordinance (Section 4.3) was established to help the city achieve these goals, and the first stage of the program actually began with benchmarking and disclosure of the energy consumption for city buildings.[288]

[lll] This acronym is sometimes defined as the "Arlington Initiative to Rethink Energy."

Chapter 5: Findings

This chapter provides a summary of findings about the current state of greenhouse gas (GHG) emissions from the power sector, as well as supporting recent trends, projections, and policies.

1. **The power sector has historically been the largest source of greenhouse gas emissions in the United States (Figure 4).**
    - In 2014, U.S. power sector emissions were 2,081 million metric tonnes of carbon dioxide equivalent (MMT CO_2e) (Table 2). Total U.S. emissions in 2014 (not including GHG sinks) were 6,871 MMT CO_2e (Figure 2).
    - Carbon dioxide (CO_2) from fossil fuel combustion accounts for nearly all of the U.S. power sector's greenhouse gas (GHG) emissions (Figure 5). In 2014, CO_2 from coal combustion accounted for over three-quarters of U.S. power sector GHG emissions, while CO_2 from the combustion of natural gas contributed approximately 21 percent of U.S. power sector GHG emissions (Table 2, Figure 7).
    - Minor sources of U.S. power sector GHG emissions include CO_2 from the combustion of petroleum products and municipal solid waste, pollution control technologies, geothermal electricity generation, and sulfur hexafluoride (SF_6) from electrical transmission and distribution systems, the combination of which accounted for less than 2 percent of power sector emissions in 2014 (Table 2).

2. **When attributing current U.S. power sector greenhouse gas emissions to end-use economic sectors, the industrial sector is responsible for approximately 26 percent of electricity-related emissions, and the remainder is split evenly between the residential and commercial sectors at 36 percent and 35 percent, respectively (Figure 11).**
    - Other sectors that account for minor amounts of electricity-related emissions in the U.S. include agriculture (3 percent) and transportation (0.2 percent) (Figure 11).
    - This sectoral breakdown of the major consumers of electricity (and, in turn, power sector emissions) has been relatively constant since 2010, but it has been evolving slowly over time. Electricity-related emissions in the U.S. were split evenly between the industrial, commercial, and residential sectors in the year 2000, and in 1990, the industrial, residential, and commercial sectors were responsible for 35.5 percent, 33.5 percent, and 31 percent of U.S. electricity-related emissions, respectively (Figure 12).

3. **The emission rate of the U.S. power sector is a key indicator of the climate impact of electricity generation, and varies significantly by fuel and technology (Table 3).**
    - The emission rate is the amount of carbon dioxide emitted per unit of electricity generated, and is often presented in terms of the mass of a given pollutant per unit of energy. For example, the emission rate of the electric power sector can be presented in terms of kilograms of carbon dioxide per megawatt-hour (kg CO_2/MWh) or pounds of CO_2 per megawatt-hour (lbs CO_2/MWh).
    - The current, average emission rate for electricity generated from coal in the U.S. is ~1,000 kg CO_2/MWh (2,200 lbs CO_2/MWh), considering only stack emissions (Table 3).
    - The current, average emission rate of natural gas combined cycle plants in the U.S. is 60 percent less than that of average coal-fired plants, averaging ~430 kg CO_2/MWh (950 lbs CO_2/MWh), considering only stack emissions (Table 3, Figure 6).
    - Nuclear power and renewable electricity generation have no direct emission rate associated with electricity generation (Figure 6).

4. **Annual U.S. power sector emissions fluctuate in response to a wide range of factors, such as economic, demographic, and market factors, in addition to weather.**
   - Changes in U.S. power sector emissions are influenced by a number of long-term and short-term factors, including fuel price fluctuations (Table 5), population and economic growth, technology changes, seasonal weather, government policies, and other factors affecting electricity generation and demand (Figure 20).
   - On an annual basis, U.S. electricity-related emissions fluctuate primarily in response to general economic conditions, weather, relative fuel prices for coal and natural gas (Table 5), and the availability of nuclear and renewable alternatives. For example, a year with higher economic growth, low coal prices, nuclear plant closures, and extreme weather is likely to have greater power sector emissions than a year with lower economic growth, high coal prices, and greater output from nuclear and renewable electricity sources.

5. **U.S. power sector carbon emissions declined by 20.3 percent between 2005 and 2015 (Figure 20), equivalent to an average decline of 2.2 percent per year. This is largely the result of two long-term trends: a slowing of electricity demand growth (Figure 22), and a reduction in the emissions rate of electric power generation in the U.S. (Figure 26).**
   - Growth in U.S. electricity sales has slowed to an average of 0.17 percent per year since 2005 (Figure 22), largely due to structural changes to the economy and improvements in the efficiency of appliances, equipment, and buildings. This rate of electricity demand growth is slower than the rate of U.S. population growth, which indicates that per-capita electricity consumption has also declined over the same time period (Figure 21).
   - The second major trend that has led to a reduction in power sector emissions is a 21 percent reduction in the emission rate of U.S. electric power generation relative to 2005 levels (Figure 26), equivalent to an average annual decline of 2.3 percent. This reduction has been driven primarily by changes in the electricity generation mix (Figure 27), with declining generation from coal offset by increased generation from lower-emitting sources. In particular, analysis from the Energy Information Administration attributes 61 percent of this decline in the carbon intensity of electricity generation to fuel switching from coal to natural gas and 39 percent to increased generation from renewable sources (Figure 28).

6. **Carbon emissions from the U.S. power sector (Finding #5) have declined as the U.S. economy has grown (Figure 20).** This decoupling of economic growth and electricity-related CO_2 emissions comes from two factors: a decrease in the carbon intensity of electricity generation, and a decline in the electricity intensity of the economy.
   - Since 2005, power sector carbon dioxide (CO_2) emissions have declined by 20.3 percent even as the gross domestic product (GDP) has grown by 14.8 percent (Figure 20). Slow growth in per capita electricity consumption, greater electricity productivity (measured in dollars per kilowatt hour of electricity), and a decline in the CO_2 emission rate of electricity generation have helped divorce economic growth from electricity consumption (and consequently electricity generation-related carbon dioxide emissions) (Figure 25).
   - Additionally, the electricity intensity of the economy—the amount of electricity consumed per dollar gross domestic product ($/GDP)—has declined by 12 percent since 2005 as a result of greater economic productivity per kWh of electricity consumed (Figure 20).

7. A wide array of policies and measures that have been developed and implemented at the federal, state, and local levels help to mitigate greenhouse gas emissions from the U.S. power sector (Table 6).

- We have identified six categories for the existing policies that help to mitigate greenhouse gas (GHG) emissions from the U.S. power sector: Performance-Based Regulations and Standards, Economic Instruments, Information Programs, Research and Development, Technology Demonstrations, and Government Leading by Example. However, it is important to note that many policy approaches cross category lines. For example, federal and state emissions trading programs combine performance-based regulation with trading of marketable credits or allowances, the latter of which are economic instruments.
- These policy categories are all interconnected and complement one another. In order to drive GHG emissions reductions from the power sector, it is necessary to support research, development and demonstration that will lead to improvements and innovation in clean energy technologies, in addition to the deployment of those clean energy technologies.
- Federal, state, and local governments in the U.S. have demonstrated leadership in reducing GHG emissions from their assets and within their jurisdictions, and they have an important role to play in driving deeper GHG emissions reductions.

Appendix A: Kaya Identity

The **Kaya identity** is an equation relating anthropogenic carbon dioxide emissions to energy consumption, population, and wealth. The full Kaya equation focuses on energy-sector CO_2 emissions, which includes emissions from electricity generation as well as emissions from the direct consumption of fossil fuels in the transportation and buildings sectors. The Kaya identity can be written as

$$C = \frac{C}{E} \times \frac{E}{G} \times \frac{G}{P} \times P$$

where
C is global CO_2 emissions from human sources,
P is global population,
G is world GDP, and
E is global energy consumption.

Though originally applied to global carbon dioxide emissions, the equation has often been applied to single nations, and can even be applied to states or regions. The equation is exact (not an approximation), since all the terms appearing in both the numerator and denominator on the right hand side of the equation cancel out, leaving the identity $C = C$. However, writing the equation in this form allows examination of each term independently.

C/E: Carbon Intensity
The first term appearing on the right hand side of the equation is commonly referred to as the carbon intensity of energy consumption and is expressed as a rate of carbon dioxide emitted per energy consumed.

E/G: Energy Intensity of the Economy
The next term relates the energy consumption to economic production and gives the amount of energy required to produce a given amount of wealth. All other things being equal, a country with lower energy intensity produces more wealth per energy consumed than a country with high energy intensity. Note that the energy intensity of the economy is the inverse of "energy productivity", which is the ratio of GDP (wealth produced) per energy consumed.

G/P: GDP per capita
GDP per capita is a common economic measure equal to the total gross domestic product divided by global population.

The identity can also be used to focus on emissions from a single country, and even emissions from a single sector. When narrowing focus to U.S. electricity sector emissions, it is helpful to use the same equation with slightly different definitions:

$$C = \frac{C}{E} \times \frac{E}{G} \times \frac{G}{P} \times P = cegP$$

where
C is U.S. power sector CO_2 emissions.
P is U.S. population
G is U.S. GDP
E is U.S. power sector electricity generation.

Lower-case variables are used to denote rates: c is the carbon intensity[mmm] (g CO_2/kWh) of electricity generation; e is the electricity intensity (kWh/GDP) of the economy; and g is the per capita GDP. We refer to this equation as the "Kaya identity for the electricity sector."

The Kaya identity for the electricity sector can also be written in terms of proportional growth rates:[289]

$$\frac{1}{C}\frac{dC}{dt} = \frac{1}{c}\frac{dc}{dt} + \frac{1}{e}\frac{de}{dt} + \frac{1}{g}\frac{dg}{dt} + \frac{1}{P}\frac{dP}{dt}$$

Again, this equation is exact, and no approximations have been made.

This equation can be integrated to determine how the Kaya factors change over the course of a given period of time:

$$\ln\left(1+\frac{\Delta C}{C_i}\right) = \ln\left(1+\frac{\Delta c}{c_i}\right) + \ln\left(1+\frac{\Delta e}{e_i}\right) + \ln\left(1+\frac{\Delta g}{g_i}\right) + \ln\left(1+\frac{\Delta P}{P_i}\right),$$

where $\Delta\chi = \chi_f - \chi_i$ represents the change in a quantity χ from an initial value χ_i to a final value χ_f. Over short periods of time (usually not longer than one year), the equation can be approximated by[nnn]

$$\frac{\Delta C}{C_i} \approx \frac{\Delta c}{c_i} + \frac{\Delta e}{e_i} + \frac{\Delta g}{g_i} + \frac{\Delta P}{P_i} \quad \text{or} \quad \%\Delta C \approx \%\Delta c + \%\Delta e + \%\Delta g + \%\Delta P$$

where $\%\Delta\chi$ is the percent change in quantity χ relative to the previous year. The Kaya identity can also be written as

$$\%\Delta \mathrm{CO_2} \approx \%\Delta(\mathrm{pop}) + \%\Delta\left(\frac{\mathrm{GDP}}{\mathrm{pop}}\right) + \%\Delta\left(\frac{\mathrm{Electricity}}{\mathrm{GDP}}\right) + \%\Delta\left(\frac{\mathrm{CO_2}}{\mathrm{Electricity}}\right).$$

This equation says that, over the course of a year, the percent change in electricity-related CO_2 emissions can be approximated by the sum of the percent changes in the carbon intensity of electricity generation, the electricity intensity of the economy, per capita GDP, and population. These terms are commonly referred to as Kaya factors.

Table 7 displays Kaya factors for the electricity sector for 2006 through 2015.[ooo] The ability of the Kaya equation to approximate changes in CO_2 emissions is measured by the difference between the actual electricity sector CO_2 emissions (row 6 in the table) and the sum of the Kaya factors (rows 1 through 4). This difference between actual and estimated CO_2 emissions is shown in the bottom row of Table 7. In every year except 2009, the Kaya approximation differed from the actual change in CO_2 emissions by less than 0.1 percent, with an average deviation of 0.024 percent.

[mmm] "Carbon intensity" commonly refers to CO_2 emissions per energy *consumed* (measured in British thermal units). As both a consumer and producer of energy, the electricity sector offers the choice of looking at either emissions per energy consumed or per electricity generated, also called the emission rate. We find it convenient to use the latter definition.

[nnn] This approximation makes use of the power series expansion for the natural log, $\ln(1+x) = x - \frac{1}{2}x^2 + \frac{1}{3}x^3 - \frac{1}{4}x^4 + \cdots$, which converges for $|x| < 1$.

[ooo] Actual emissions for 2015 were unavailable at the time of publication. The emission rate for 2015 was estimated using the twelve-month average emission rate for November 2014 to November 2015.

Kaya factors	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
population percent change	0.97%	0.96%	0.95%	0.88%	0.84%	0.77%	0.77%	0.76%	0.75%	0.79%
per capita output percent change	1.68%	0.82%	-1.23%	-3.62%	1.68%	0.83%	1.45%	0.72%	1.67%	1.60%
electricity intensity percent change	-2.45%	0.70%	-0.48%	-1.40%	1.69%	-2.18%	-3.61%	-1.13%	-1.56%	-2.50%
carbon intensity percent change	-2.52%	0.33%	-1.38%	-5.13%	0.66%	-3.84%	-4.85%	0.42%	-0.77%	-4.96%
Sum of Kaya factors	**-2.32%**	**2.80%**	**-2.15%**	**-9.28%**	**4.87%**	**-4.42%**	**-6.25%**	**0.78%**	**0.08%**	**-5.07%**
Actual power sector emissions change	**-2.37%**	**2.82%**	**-2.15%**	**-9.06%**	**4.95%**	**-4.43%**	**-6.25%**	**0.77%**	**0.05%**	---
Actual minus Kaya	-0.053%	0.028%	0.000%	0.220%	0.085%	-0.005%	0.002%	-0.010%	-0.032%	

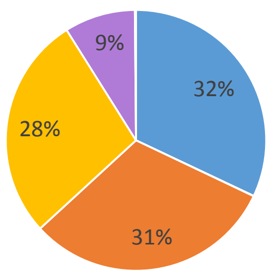
Table 7. Kaya Factors for the U.S. Electricity Sector, 2006-2015.

Sources: U.S. Census Bureau (2015), International Data Base.[290] Bureau of Economic Analysis (2016), Gross Domestic Product.[291] U.S. Energy Information Administration (2015), Monthly Energy Review.[292]

Appendix B: State Power Sector Electricity Generation, Retail Sales, and CO_2 Emissions

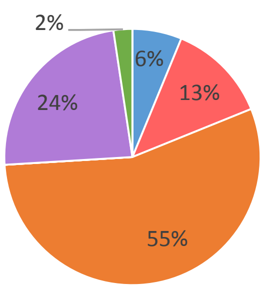
These tables include power sector emissions,[293] generation,[294] and retail sales[295] by state in 2005 and 2013.[ppp] For each state, the generation mix in 2013 is shown.[qqq]

Alabama



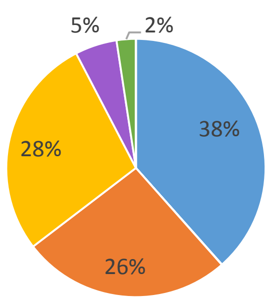
	2005	2013	% change
Emissions	81.3 MMT CO_2	64.2 MMT CO_2	-21%
Generation	133 TWh	146 TWh	9%
Retail Sales	89.2 TWh	87.9 TWh	-1.5%

Alaska



	2005	2013	% change
Emissions	3.2 MMT CO_2	2.6 MMT CO_2	-19%
Generation	6.1 TWh	6.1 TWh	-0.6%
Retail Sales	5.9 TWh	6.3 TWh	6%

Arizona



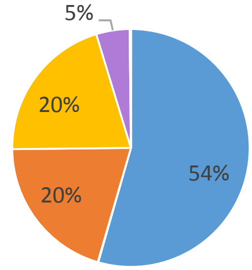
	2005	2013	% change
Emissions	50.8 MMT CO_2	54.7 MMT CO_2	8%
Generation	101 TWh	113.2 TWh	10.8%
Retail Sales	69.4 TWh	75.7 TWh	9%

Note: Other RE includes all renewable sources other than hydroelectric dams, including wind, solar, biomass, and geothermal. Other includes all other sources of electric generation, including other gases and waste heat.

[ppp] The estimates presented here are based on aggregations of fuel types – for example, coal. Where the values presented here differ from estimates made by the U.S. Environmental Protection Agency, or other federal or state regulatory bodies, those estimates should be used for the purposes of regulatory analysis and compliance.

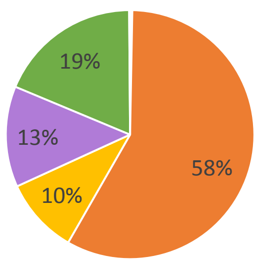
[qqq] Generation and retail sales data for each state is available through 2015. However, state emissions data from EIA is only available through 2013, so only 2013 generation and retail sales data are included.

Arkansas



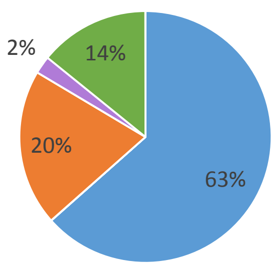
	2005	2013	% change
Emissions	25.3 MMT CO_2	35.5 MMT CO_2	40%
Generation	45.8 TWh	58.4 TWh	21.7%
Retail Sales	46.2 TWh	46.7 TWh	1.1%

California



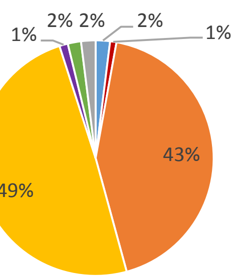
	2005	2013	% change
Emissions	41.9 MMT CO_2	45.7 MMT CO_2	9%
Generation	182 TWh	182 TWh	0%
Retail Sales	254 TWh	261 TWh	2.8%

Colorado



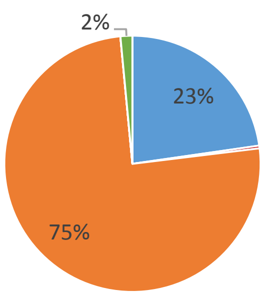
	2005	2013	% change
Emissions	40.6 MMT CO_2	38.5 MMT CO_2	-5%
Generation	49.5 TWh	52.8 TWh	6.3%
Retail Sales	48.4 TWh	53.4 TWh	10.5%

Connecticut



	2005	2013	% change
Emissions	10 MMT CO_2	6.8 MMT CO_2	-32%
Generation	33.3 TWh	34.6 TWh	3.9%
Retail Sales	33.1 TWh	29.8 TWh	-9.9%

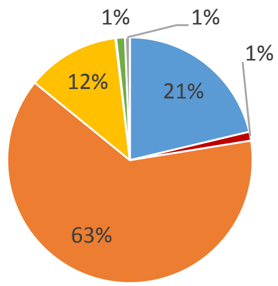
Delaware



	2005	2013	% change
Emissions	6.4 MMT CO_2	4.1 MMT CO_2	-36%
Generation	7.2 TWh	6.8 TWh	-6.4%
Retail Sales	12.1 TWh	11.3 TWh	-6.5%

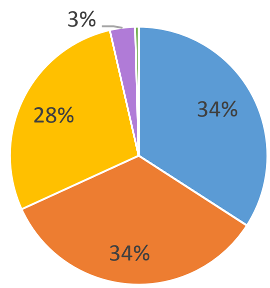
Coal Petroleum Natural Gas Nuclear Hydro Other RE Other

Florida



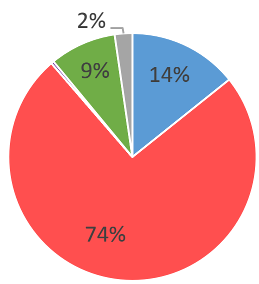
	2005	2013	% change
Emissions	127 MMT CO_2	105 MMT CO_2	-18%
Generation	215 TWh	217 TWh	0.9%
Retail Sales	225 TWh	222 TWh	-1.4%

Georgia



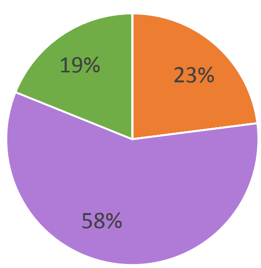
	2005	2013	% change
Emissions	85.1 MMT CO_2	53.6 MMT CO_2	-37%
Generation	132 TWh	116 TWh	-13%
Retail Sales	132 TWh	131 TWh	-1.3%

Hawaii



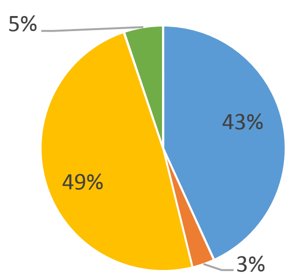
	2005	2013	% change
Emissions	8.3 MMT CO_2	6.8 MMT CO_2	-18%
Generation	11 TWh	9.5 TWh	-15%
Retail Sales	10.5 TWh	9.5 TWh	-10%

Idaho



	2005	2013	% change
Emissions	0.6 MMT CO_2	1.3 MMT CO_2	117%
Generation	10.2 TWh	14.6 TWh	30%
Retail Sales	21.9 TWh	24.2 TWh	11%

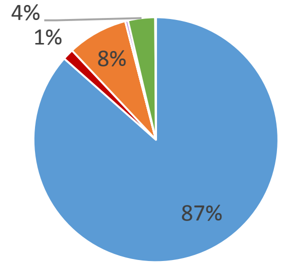
Illinois



	2005	2013	% change
Emissions	93.3 MMT CO_2	89 MMT CO_2	-5%
Generation	191 TWh	200 TWh	4.5%
Retail Sales	145 TWh	142 TWh	-2%

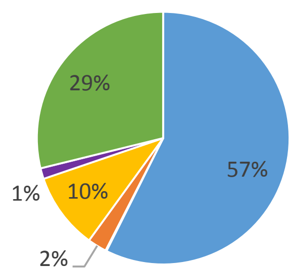
Coal Petroleum Natural Gas Nuclear Hydro Other RE Other

Indiana



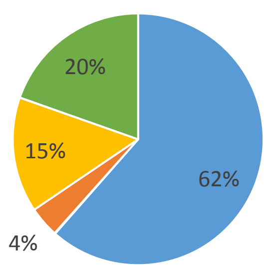
	2005	2013	% change
Emissions	122 MMT CO_2	98 MMT CO_2	-19%
Generation	127 TWh	107 TWh	-19%
Retail Sales	107 TWh	106 TWh	-1%

Iowa



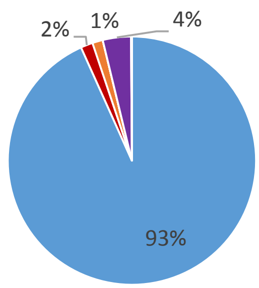
	2005	2013	% change
Emissions	36 MMT CO_2	32 MMT CO_2	-10%
Generation	43 TWh	54 TWh	22%
Retail Sales	43 TWh	47 TWh	9%

Kansas



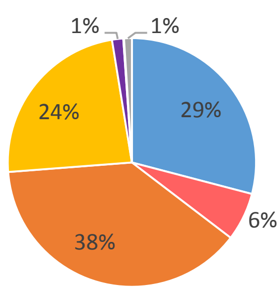
	2005	2013	% change
Emissions	37 MMT CO_2	32 MMT CO_2	-14%
Generation	46 TWh	48 TWh	5%
Retail Sales	39 TWh	40 TWh	2%

Kentucky



	2005	2013	% change
Emissions	92 MMT CO_2	86 MMT CO_2	-7%
Generation	97 TWh	89 TWh	-9%
Retail Sales	89 TWh	85 TWh	-5%

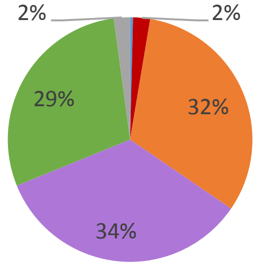
Louisiana



	2005	2013	% change
Emissions	43 MMT CO_2	41 MMT CO_2	-5%
Generation	71 TWh	72 TWh	1.6%
Retail Sales	77 TWh	86 TWh	11%

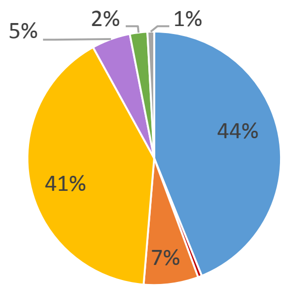
Coal Petroleum Natural Gas Nuclear Hydro Other RE Other

Maine



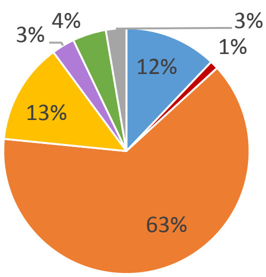
	2005	2013	% change
Emissions	3.8 MMT CO_2	1.4 MMT CO_2	-63%
Generation	13.9 TWh	9.1 TWh	-52%
Retail Sales	12.4 TWh	11.9 TWh	-4%

Maryland



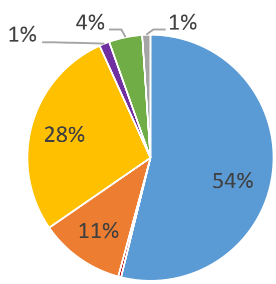
	2005	2013	% change
Emissions	32.2 MMT CO_2	17.4 MMT CO_2	-46%
Generation	52.0 TWh	35.1 TWh	-48%
Retail Sales	68.4 TWh	61.9 TWh	-10%

Massachusetts



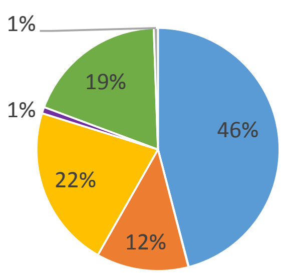
	2005	2013	% change
Emissions	24.6 MMT CO_2	12.6 MMT CO_2	-49%
Generation	46.6 TWh	32.2 TWh	-45%
Retail Sales	57.2 TWh	55.3 TWh	-3%

Michigan



	2005	2013	% change
Emissions	75.7 MMT CO_2	62.1 MMT CO_2	-18%
Generation	119.3 TWh	103.0 TWh	-16%
Retail Sales	110.4 TWh	103.0 TWh	-7%

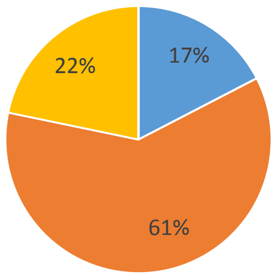
Minnesota



	2005	2013	% change
Emissions	35.5 MMT CO_2	25.7 MMT CO_2	-28%
Generation	51.1 TWh	49.6 TWh	-3%
Retail Sales	66.0 TWh	68.6 TWh	4%

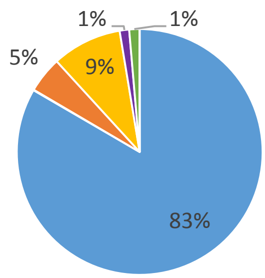
Coal Petroleum Natural Gas Nuclear Hydro Other RE Other

Mississippi



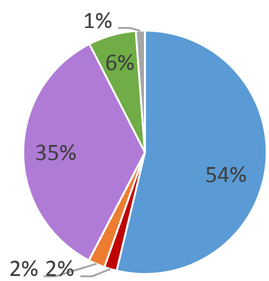
	2005	2013	% change
Emissions	25.0 MMT CO_2	21.6 MMT CO_2	-14%
Generation	43.3 TWh	50.0 TWh	13%
Retail Sales	45.9 TWh	48.8 TWh	6%

Missouri



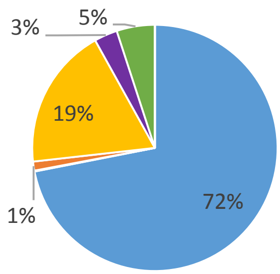
	2005	2013	% change
Emissions	78.1 MMT CO_2	75.8 MMT CO_2	-3%
Generation	90.5 TWh	91.4 TWh	1%
Retail Sales	80.9 TWh	83.4 TWh	3%

Montana



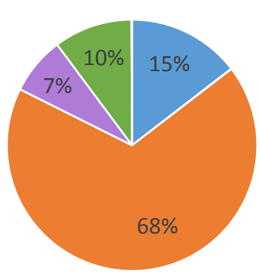
	2005	2013	% change
Emissions	19.2 MMT CO_2	16.4 MMT CO_2	-15%
Generation	27.9 TWh	27.7 TWh	-1%
Retail Sales	13.5 TWh	14.0 TWh	4%

Nebraska



	2005	2013	% change
Emissions	21.3 MMT CO_2	26.0 MMT CO_2	22%
Generation	31.4 TWh	36.8 TWh	15%
Retail Sales	27.0 TWh	30.7 TWh	14%

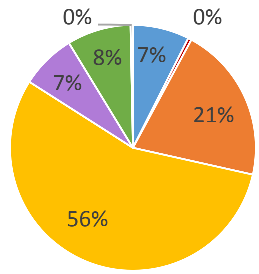
Nevada



	2005	2013	% change
Emissions	26.4 MMT CO_2	15.4 MMT CO_2	-42%
Generation	40.2 TWh	36.1 TWh	-11%
Retail Sales	32.5 TWh	35.2 TWh	8%

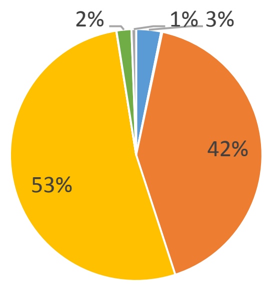
Coal Petroleum Natural Gas Nuclear Hydro Other RE Other

New Hampshire



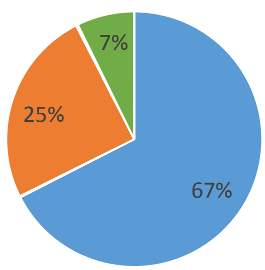
	2005	2013	% change
Emissions	7.8 MMT CO_2	3.3 MMT CO_2	-58%
Generation	24.1 TWh	19.7 TWh	-22%
Retail Sales	11.2 TWh	11.0 TWh	-2%

New Jersey



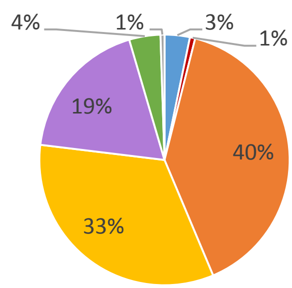
	2005	2013	% change
Emissions	19.3 MMT CO_2	14.4 MMT CO_2	-25%
Generation	59.4 TWh	63.4 TWh	6%
Retail Sales	81.9 TWh	74.6 TWh	-9%

New Mexico



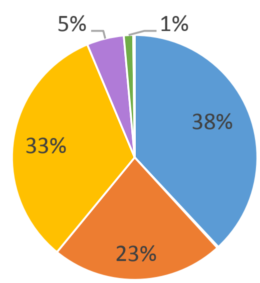
	2005	2013	% change
Emissions	32.1 MMT CO_2	28.2 MMT CO_2	-12%
Generation	34.8 TWh	35.8 TWh	3%
Retail Sales	20.6 TWh	23.1 TWh	12%

New York



	2005	2013	% change
Emissions	56.0 MMT CO_2	30.0 MMT CO_2	-46%
Generation	144.7 TWh	134.0 TWh	-8%
Retail Sales	150.1 TWh	147.9 TWh	-2%

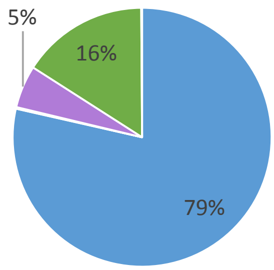
North Carolina



	2005	2013	% change
Emissions	74.5 MMT CO_2	55.5 MMT CO_2	-26%
Generation	126.6 TWh	122.8 TWh	-3%
Retail Sales	128.3 TWh	129.8 TWh	1%

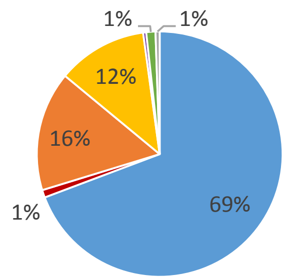
Coal Petroleum Natural Gas Nuclear Hydro Other RE Other

North Dakota



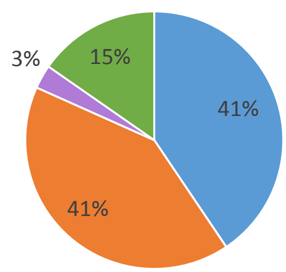
	2005	2013	% change
Emissions	31.6 MMT CO_2	28.7 MMT CO_2	-9%
Generation	31.7 TWh	34.9 TWh	9%
Retail Sales	10.8 TWh	16.0 TWh	48%

Ohio



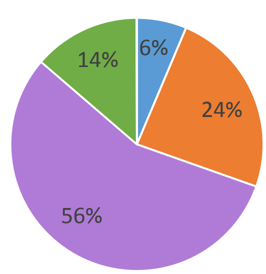
	2005	2013	% change
Emissions	133 MMT CO_2	102 MMT CO_2	-23%
Generation	155.9 TWh	136.2 TWh	-14%
Retail Sales	160.2 TWh	150.3 TWh	-6%

Oklahoma



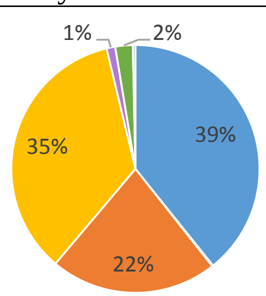
	2005	2013	% change
Emissions	49.3 MMT CO_2	44.2 MMT CO_2	-10%
Generation	67.4 TWh	72.9 TWh	8%
Retail Sales	53.7 TWh	59.9 TWh	12%

Oregon



	2005	2013	% change
Emissions	8.1 MMT CO_2	9.0 MMT CO_2	11%
Generation	47.8 TWh	59.2 TWh	19%
Retail Sales	46.4 TWh	47.6 TWh	3%

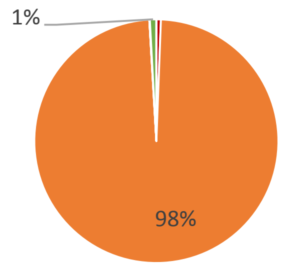
Pennsylvania



	2005	2013	% change
Emissions	125 MMT CO_2	106 MMT CO_2	-15%
Generation	214.5 TWh	223.6 TWh	4%
Retail Sales	148.3 TWh	146.3 TWh	-1%

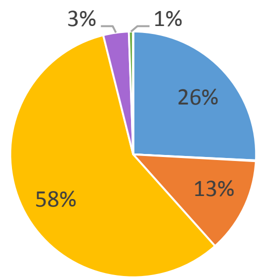
Coal Petroleum Natural Gas Nuclear Hydro Other RE Other

Rhode Island



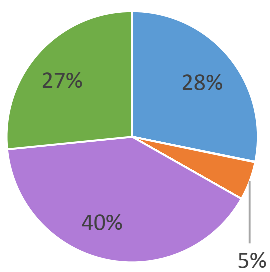
	2005	2013	% change
Emissions	2.4 MMT CO_2	2.6 MMT CO_2	8%
Generation	6.0 TWh	6.2 TWh	3%
Retail Sales	8.0 TWh	7.8 TWh	-3%

South Carolina



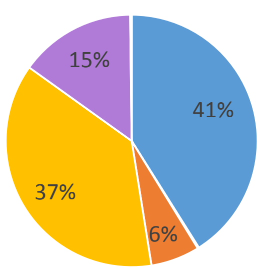
	2005	2013	% change
Emissions	39.9 MMT CO_2	28.2 MMT CO_2	-29%
Generation	100.4 TWh	93.3 TWh	-8%
Retail Sales	81.3 TWh	78.6 TWh	-3%

South Dakota



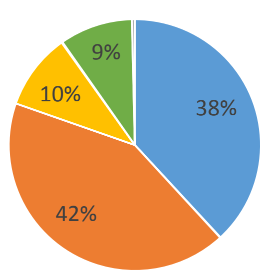
	2005	2013	% change
Emissions	3.3 MMT CO_2	3.1 MMT CO_2	-6%
Generation	6.5 TWh	10.1 TWh	36%
Retail Sales	9.8 TWh	12.2 TWh	24%

Tennessee



	2005	2013	% change
Emissions	54.8 MMT CO_2	33.6 MMT CO_2	-39%
Generation	94.0 TWh	76.1 TWh	-23%
Retail Sales	103.9 TWh	96.9 TWh	-7%

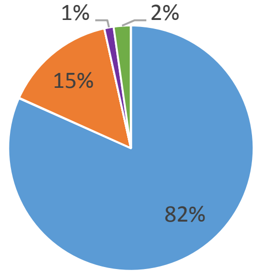
Texas



	2005	2013	% change
Emissions	229 MMT CO_2	226 MMT CO_2	-1%
Generation	356.9 TWh	391.9 TWh	9%
Retail Sales	334.3 TWh	378.8 TWh	13%

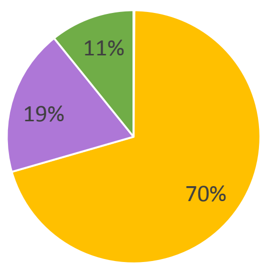
Coal Petroleum Natural Gas Nuclear Hydro Other RE Other

Utah



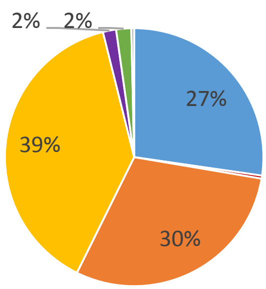
	2005	2013	% change
Emissions	35.8 MMT CO_2	34.9 MMT CO_2	-3%
Generation	37.4 TWh	41.4 TWh	10%
Retail Sales	25.0 TWh	30.5 TWh	22%

Vermont



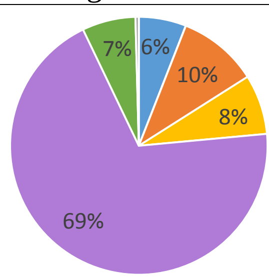
	2005	2013	% change
Emissions	0.0 MMT CO_2	0.0 MMT CO_2	--
Generation	5.7 TWh	6.9 TWh	17%
Retail Sales	5.9 TWh	5.6 TWh	-5%

Virginia



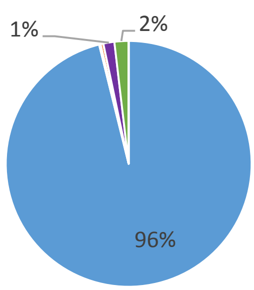
	2005	2013	% change
Emissions	41.8 MMT CO_2	30.9 MMT CO_2	-26%
Generation	76.0 TWh	74.4 TWh	-2%
Retail Sales	108.8 TWh	110.5 TWh	2%

Washington



	2005	2013	% change
Emissions	14.0 MMT CO_2	11.7 MMT CO_2	-16%
Generation	101.1 TWh	112.7 TWh	10%
Retail Sales	83.4 TWh	92.9 TWh	11%

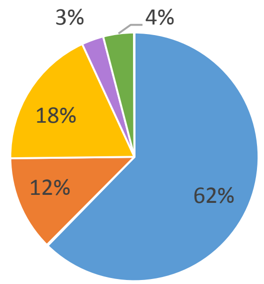
West Virginia



	2005	2013	% change
Emissions	85.1 MMT CO_2	68.7 MMT CO_2	-19%
Generation	92.3 TWh	74.7 TWh	-24%
Retail Sales	30.2 TWh	31.4 TWh	4%

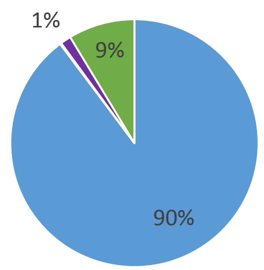
Coal · Petroleum · Natural Gas · Nuclear · Hydro · Other RE · Other

Wisconsin



	2005	2013	% change
Emissions	48.7 MMT CO_2	43.3 MMT CO_2	-11%
Generation	59.2 TWh	63.9 TWh	7%
Retail Sales	70.3 TWh	69.1 TWh	-2%

Wyoming



	2005	2013	% change
Emissions	43.3 MMT CO_2	46.2 MMT CO_2	7%
Generation	44.7 TWh	51.2 TWh	13%
Retail Sales	14.1 TWh	17.1 TWh	21%

■ Coal ■ Petroleum ■ Natural Gas ■ Nuclear ■ Hydro ■ Other RE ■ Other

[1] Environmental Protection Agency. "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2014." Table 2-10 and Figure 2-12. April 2016. http://www3.epa.gov/climatechange/ghgemissions/usinventoryreport.html. Accessed June 14, 2016.
[2] Lawrence Livermore National Laboratory. 2015. "Estimated U.S. Carbon Emissions in 2014." https://flowcharts.llnl.gov/. LLNL-MI-410527. Accessed April 13, 2016.
[3] EIA. Monthly Energy Review. Table 7.6. http://www.eia.gov/totalenergy/data/monthly. U.S. Census Bureau. International Data Base (IDB). http://www.census.gov/ipc/www/idb/tables.html. Accessed April 20, 2016.
[4] EIA. "Annual Energy Review." Table 11.2e. http://www.eia.gov/totalenergy/data/annual/index.cfm. EIA. "Monthly Energy Review." Table 12.6 and 7.1. http://www.eia.gov/totalenergy/data/monthly. Accessed April 20, 2016.
[5] Bureau of Economic Analysis. "Gross Domestic Product." http://www.bea.gov/national/index.htm#gdp. Accessed March 22, 2016.
[6] NOAA. "Vital Signs of the Planet." http://climate.nasa.gov/causes/. Accessed February 4, 2016.
[7] Environmental Protection Agency. "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2014." p.1-4. April 2016. http://www3.epa.gov/climatechange/ghgemissions/usinventoryreport.html. Accessed June 14, 2016.
[8] NOAA. "Trends in Atmospheric Carbon Dioxide: Recent Global CO2." Accessed May 6, 2016. http://www.esrl.noaa.gov/gmd/ccgg/trends/global.html.
[9] Environmental Protection Agency. "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2014." p.1-4. April 2016. http://www3.epa.gov/climatechange/ghgemissions/usinventoryreport.html. Accessed June 14, 2016.
[10] Intergovernmental Panel on Climate Change (2013). Summary for Policymakers, In: *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Stocker, T.F., D. Qing, G.-K. Plattner, M.Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex, and P.M. Midgley (eds.)]. Page 5. www.ipcc.ch/pdf/assessment-report/ar5/wg1/WG1AR5_SPM_FINAL.pdf. Accessed April 19, 2016.
[11] The White House. "President Obama's Climate Action Plan." June 2013. https://www.whitehouse.gov/sites/default/files/image/president27sclimateactionplan.pdf. Accessed February 4, 2016.
[12] The White House. "Fact Sheet: U.S. Reports its 2025 Emissions Target to the UNFCCC." March 2015. https://www.whitehouse.gov/the-press-office/2015/03/31/fact-sheet-us-reports-its-2025-emissions-target-unfccc. Accessed February 4, 2016.
[13] "United States of America's Nationally Determined Contribution to the United Nations Framework Convention on Climate Change" (March 2015). Page 2. Accessed August 16, 2016. http://www4.unfccc.int/Submissions/INDC/Published%20Documents/United%20States%20of%20America/1/U.S.%20Cover%20Note%20INDC%20and%20Accompanying%20Information.pdf
[14] Intergovernmental Panel on Climate Change (2014). "Climate Change 2014 Mitigation of Climate Change: Working Group III Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change." Summary for Policymakers, page 10. Accessed May 9, 2016. http://www.ipcc.ch/pdf/assessment-report/ar5/wg3/ipcc_wg3_ar5_full.pdf.
[15] Environmental Protection Agency. "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2014." Table 2-1. April 2016. http://www3.epa.gov/climatechange/ghgemissions/usinventoryreport.html. Accessed June 14, 2016.
[16] Environmental Protection Agency. "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2014." Table 2-1. April 2016. http://www3.epa.gov/climatechange/ghgemissions/usinventoryreport.html. Accessed June 14, 2016.
[17] Environmental Protection Agency. "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2014." Table 2-1. April 2016. http://www3.epa.gov/climatechange/ghgemissions/usinventoryreport.html. Accessed June 14, 2016.
[18] Environmental Protection Agency. "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2014." Table 2-1. April 2016. http://www3.epa.gov/climatechange/ghgemissions/usinventoryreport.html. Accessed June 14, 2016.
[19] Lawrence Livermore National Laboratory. 2015. "Estimated U.S. Carbon Emissions in 2014." https://flowcharts.llnl.gov/. Accessed April 13, 2016.
[20] Environmental Protection Agency. "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2014." Table 1-6. April 2016. http://www3.epa.gov/climatechange/ghgemissions/usinventoryreport.html. Accessed June 14, 2016.
[21] Environmental Protection Agency. "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2014." Table 2-10 and Figure 2-12. April 2016. http://www3.epa.gov/climatechange/ghgemissions/usinventoryreport.html. Accessed June 14, 2016.
[22] Environmental Protection Agency. "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2014." Table 2-11 and 3-68. April 2016. http://www3.epa.gov/climatechange/ghgemissions/usinventoryreport.html. Accessed

June 14, 2016.
[23] DOE Office of Energy Policy and Systems Analysis. "Quadrennial Energy Review." Figure 7-1. http://www.energy.gov/epsa/quadrennial-energy-review-qer. Accessed January 31, 2016.
[24] EIA. "Electricity Explained – How Electricity is Generated." http://www.eia.gov/energyexplained/index.cfm?page=electricity_generating. Accessed January 13, 2016.
[25] Environmental Protection Agency. "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2014." Table 2-11. April 2016. http://www3.epa.gov/climatechange/ghgemissions/usinventoryreport.html. Accessed June 14, 2016.
[26] Environmental Protection Agency. "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2014." Table 2-11. April 2016. http://www3.epa.gov/climatechange/ghgemissions/usinventoryreport.html. Accessed June 14, 2016.
[27] EIA. Monthly Energy Review. Table 7.2b and 12.6. http://www.eia.gov/totalenergy/data/monthly/. Accessed April 20, 2016.
[28] Environmental Protection Agency. "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2014." Table 2-11. April 2016. http://www3.epa.gov/climatechange/ghgemissions/usinventoryreport.html. Accessed June 14, 2016.
[29] EIA. "Monthly Energy Review." Table 7.2b. February 2016. http://www.eia.gov/totalenergy/data/monthly/. Accessed April 20, 2016.
[30] EIA. "Monthly Energy Review." Table 12.6. http://www.eia.gov/totalenergy/data/monthly/. Accessed April 20, 2016.
[31] EIA. "Monthly Energy Review." Tables 7.2b and 12.6. http://www.eia.gov/totalenergy/data/monthly/. Accessed April 20, 2016.
[32] EIA. "Monthly Energy Review." Table 7.2b. http://www.eia.gov/totalenergy/data/monthly/. Accessed April 20, 2016.
[33] EIA. "Monthly Energy Review." Tables 7.2b and 12.6. http://www.eia.gov/totalenergy/data/monthly/. Accessed April 20, 2016.
[34] EIA (2013). Carbon Dioxide Emissions Coefficients. http://www.eia.gov/environment/emissions/co2_vol_mass.cfm. Accessed January 15, 2016.
[35] EIA (2015). "How much carbon dioxide is produced when different fuels are burned?" http://www.eia.gov/tools/faqs/faq.cfm?id=73&t=11. Accessed January 15, 2016.
[36] EIA (2015). "What is the efficiency of different types of power plants?" http://www.eia.gov/tools/faqs/faq.cfm?id=107&t=3. Accessed January 19, 2016.
[37] EIA. "Analysis of Heat Rate Improvement Potential at Coal-Fired Power Plants." May 2015. http://www.eia.gov/analysis/studies/powerplants/heatrate/. p. 1. Accessed January 21, 2016.
[38] EIA. "Electric Power Annual." Table 8.2. www.eia.gov/electricity/annual/html/epa_08_02.html. Accessed March 22, 2016.
[39] EIA. "Carbon Dioxide Emissions Coefficients." http://www.eia.gov/environment/emissions/co2_vol_mass.cfm. Accessed March 28, 2016.
[40] Environmental Protection Agency. GHGRP Power Plants Sector Industrial Profile: 2013. http://www.epa.gov/ghgreporting/ghgrp-power-plants-sector-industrial-profiles. Accessed January 18, 2016.
[41] Environmental Protection Agency. "Facility Level Information on GreenHouse gases Tool." http://ghgdata.epa.gov/ghgp/main.do. Accessed March 22, 2016.
[42] Environmental Protection Agency. "Greenhouse Gas Reporting Program." Draft data provided on March 22, 2016.
[43] EIA (2015). Monthly Energy Review. Table 7.3b. http://www.eia.gov/totalenergy/data/monthly/. Accessed January 18, 2016.
[44] EIA (2015). Monthly Energy Review. Table 2.6. http://www.eia.gov/totalenergy/data/monthly/. Accessed January 18, 2016.
[45] EIA (2015). Monthly Energy Review. Table 7.2b. http://www.eia.gov/totalenergy/data/monthly/. Accessed January 18, 2016.
[46] Environmental Protection Agency. "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2014." Table 2-11. April 2016. http://www3.epa.gov/climatechange/ghgemissions/usinventoryreport.html. Accessed June 15, 2016.
[47] Environmental Protection Agency. "Greenhouse Gas Reporting Program." Draft data provided by EPA on March 22, 2016.
[48] Environmental Protection Agency. "Municipal Solid Waste in the United States: Facts and Figures." 2014. Office

of Solid Waste and Emergency Response. http://www.epa.gov/osw/nonhaz/municipal/msw99.htm. Accessed January 19, 2016.

[49] Environmental Protection Agency. "CO2 Emissions Associated with Biomass Use at Stationary Sources." http://www3.epa.gov/climatechange/ghgemissions/biogenic-emissions.html. Accessed January 31, 2016.

[50] Environmental Protection Agency. "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2014." Table 3-24. April 2016. http://www3.epa.gov/climatechange/ghgemissions/usinventoryreport.html. Accessed June 14, 2016.

[51] Environmental Protection Agency. "Facility Level Information on GreenHouse gases Tool." http://ghgdata.epa.gov/ghgp/main.do. Accessed March 22, 2016.

[52] Environmental Protection Agency. "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2014." Table 3-68. April 2016. http://www3.epa.gov/climatechange/ghgemissions/usinventoryreport.html. Accessed June 14, 2016.

[53] Intergovernmental Panel on Climate Change (IPCC). "2006 IPCC Guidelines for National Greenhouse Gas Inventories. Volume 4: Agriculture, Forestry and Other Land Use." p. 12.6. http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_12_Ch12_HWP.pdf. Accessed March 29, 2016.

[54] Environmental Protection Agency. "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2014." p. 2-25 and 4-17 through 4-20. April 2016. http://www3.epa.gov/climatechange/ghgemissions/usinventoryreport.html. Accessed June 14, 2016.

[55] Environmental Protection Agency. "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2014." p. 4-103 through 4-108. April 2016. http://www3.epa.gov/climatechange/ghgemissions/usinventoryreport.html. Accessed June 14, 2016.

[56] Environmental Protection Agency. "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2014." p. 4-103. April 2016. http://www3.epa.gov/climatechange/ghgemissions/usinventoryreport.html. Accessed June 14, 2016.

[57] Environmental Protection Agency. "Facility Level Information on GreenHouse gases Tool." http://ghgdata.epa.gov/ghgp/main.do. Accessed March 22, 2016.

[58] Environmental Protection Agency. "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2014." Table 4-100. April 2016. http://www3.epa.gov/climatechange/ghgemissions/usinventoryreport.html. Accessed June 14, 2016.

[59] Energy Information Administration. "FAQ: How much electricity is lost in transmission and distribution in the United States?" http://www.eia.gov/tools/faqs/faq.cfm?id=105&t=3. Accessed January 28, 2016.

[60] Quadrennial Energy Review Analysis: Jackson, R. et al. "Opportunities for Energy Efficiency Improvements in the U.S. Electricity Transmission and Distribution System." Page 12. Oak Ridge National Laboratory, Pacific Northwest National Laboratory, Savannah River National Laboratory, Lawrence Berkeley National Laboratory. April 2015. http://www.energy.gov/epsa/downloads/opportunities-energy-efficiency-improvements-us-electricity-transmission-and. Accessed January 28, 2016.

[61] Quadrennial Energy Review Analysis: Jackson, R. et al. "Opportunities for Energy Efficiency Improvements in the U.S. Electricity Transmission and Distribution System." pages 3-11. Oak Ridge National Laboratory, Pacific Northwest National Laboratory, Savannah River National Laboratory, Lawrence Berkeley National Laboratory. April 2015. http://www.energy.gov/epsa/downloads/opportunities-energy-efficiency-improvements-us-electricity-transmission-and. Accessed January 28, 2016.

[62] Quadrennial Energy Review Analysis: Jackson, R. et al. "Opportunities for Energy Efficiency Improvements in the U.S. Electricity Transmission and Distribution System." pages 12-14. Oak Ridge National Laboratory, Pacific Northwest National Laboratory, Savannah River National Laboratory, Lawrence Berkeley National Laboratory. April 2015. http://www.energy.gov/epsa/downloads/opportunities-energy-efficiency-improvements-us-electricity-transmission-and. Accessed January 28, 2016.

[63] Quadrennial Energy Review Analysis: Jackson, R. et al. "Opportunities for Energy Efficiency Improvements in the U.S. Electricity Transmission and Distribution System." Tables 1 and 2. Oak Ridge National Laboratory, Pacific Northwest National Laboratory, Savannah River National Laboratory, Lawrence Berkeley National Laboratory. April 2015. http://www.energy.gov/epsa/downloads/opportunities-energy-efficiency-improvements-us-electricity-transmission-and. Accessed January 28, 2016.

[64] DOE Office of EPSA. "Quadrennial Energy Review Appendix C – Electricity." p. EL-47. http://www.energy.gov/epsa/downloads/quadrennial-energy-review-full-report. Accessed January 28, 2016.

[65] Environmental Protection Agency. "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2014." Table 2-12. April 2016. http://www3.epa.gov/climatechange/ghgemissions/usinventoryreport.html. Accessed June 14, 2016.

[66] Environmental Protection Agency. "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2014." p. 2-31. April 2016. http://www3.epa.gov/climatechange/ghgemissions/usinventoryreport.html. Accessed June 14, 2016.
[67] Environmental Protection Agency. "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2014." Table 2-12. April 2016. http://www3.epa.gov/climatechange/ghgemissions/usinventoryreport.html. Accessed June 14, 2016.
[68] EIA. "Monthly Energy Review." Table 12.4. December 2015. http://www.eia.gov/totalenergy/data/monthly. Accessed January 20, 2016.
[69] Environmental Protection Agency. "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2014." 2-28. April 2016. http://www3.epa.gov/climatechange/ghgemissions/usinventoryreport.html. Accessed June 14, 2016.
[70] Environmental Protection Agency. "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2014." p. 2-30. April 2016. http://www3.epa.gov/climatechange/ghgemissions/usinventoryreport.html. Accessed June 14, 2016.
[71] EIA. "Monthly Energy Review." Table 12.2. December 2015. http://www.eia.gov/totalenergy/data/monthly/. Accessed December 28, 2015.
[72] EIA. "Monthly Energy Review." Table 12.3. December 2015. http://www.eia.gov/totalenergy/data/monthly/. Accessed December 28, 2015.
[73] Environmental Protection Agency. "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2014." p. 2-31. April 2015. http://www3.epa.gov/climatechange/ghgemissions/usinventoryreport.html. Accessed January 20, 2016.
[74] Environmental Protection Agency. "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2014." Table 2-12. April 2016. http://www3.epa.gov/climatechange/ghgemissions/usinventoryreport.html. Accessed June 14, 2016.
[75] EIA. "Monthly Energy Review." Tables 12.2—12.5. Accessed March 22, 2016.
[76] Environmental Protection Agency. "Distributed Generation." https://www.epa.gov/energy/distributed-generation. Accessed June 15, 2016.
[77] Environmental Protection Agency. "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2014." Box 2-1. April 2016. http://www3.epa.gov/climatechange/ghgemissions/usinventoryreport.html. Accessed June 14, 2016.
[78] EIA. "Electricity Data Browser." http://www.eia.gov/electricity/data/browser/. Accessed March 18, 2016.
[79] EIA. "Electric Power Monthly." Table 1.2.D. February 26, 2016. http://www.eia.gov/electricity/monthly/. Accessed March 18, 2016.
[80] EIA. "Detailed State Data." U.S. Electric Power Industry Estimated Emissions by State. October 21, 2015. http://www.eia.gov/electricity/data/state. Accessed March 18, 2016.
[81] EIA. "Electric Power Monthly." Table 1.2.C. February 26, 2016. http://www.eia.gov/electricity/monthly/. Accessed March 18, 2016.
[82] EIA. "Detailed State Data." U.S. Electric Power Industry Estimated Emissions by State. October 21, 2015. http://www.eia.gov/electricity/data/state. Accessed March 18, 2016.
[83] EIA. "Today in Energy: EIA electricity data now include estimated small-scale solar PV capacity and generation." December 2015. http://www.eia.gov/todayinenergy/detail.cfm?id=23972. Accessed June 17, 2016.
[84] EIA. "Electric Power Monthly." Table 1.2.E. February 26, 2016. http://www.eia.gov/electricity/monthly/. Accessed March 20, 2016.
[85] EIA. "Today in Energy: EIA electricity data now include estimated small-scale solar PV capacity and generation." December 2, 2015. http://www.eia.gov/todayinenergy/detail.cfm?id=23972. Accessed June 15, 2016.
[86] National Renewable Energy Laboratory. "Life cycle Assessments of Energy Technologies." http://www.nrel.gov/analysis/sustain_lca_about.html. Accessed January 8, 2016.
[87] Sathaye et al. "Renewable Energy in the Context of Sustainable Development." Figure 9.7, p. 730. 2011. http://srren.ipcc-wg3.de/report/IPCC_SRREN_Ch09.pdf. Accessed January 8, 2016.
[88] National Renewable Energy Laboratory. "Wind LCA Harmonization." http://www.nrel.gov/docs/fy13osti/57131.pdf. Accessed January 28, 2016.
[89] National Renewable Energy Laboratory. "Life Cycle Assessment Harmonization Results and Findings." http://www.nrel.gov/analysis/sustain_lca_results.html. Accessed January 8, 2016.
[90] Sathaye, J., O. Lucon, A. Rahman, J. Christensen, F. Denton, J. Fujino, G. Heath, S. Kadner, M. Mirza, H. Rudnick, A. Schlaepfer, A. Shmakin. "Renewable Energy in the Context of Sustainable Development." Figure 9.8, p. 732. 2011. http://srren.ipcc-wg3.de/report/IPCC_SRREN_Ch09.pdf. Accessed January 8, 2016.
[91] National Renewable Energy Laboratory. "Life Cycle Greenhouse Gas Emissions from Electricity Generation." p. 2. January 2013. http://www.nrel.gov/docs/fy13osti/57187.pdf. Accessed January 8, 2016.
[92] Sathaye, J., O. Lucon, A. Rahman, J. Christensen, F. Denton, J. Fujino, G. Heath, S. Kadner, M. Mirza, H. Rudnick, A. Schlaepfer, A. Shmakin. "Renewable Energy in the Context of Sustainable Development." Figure

9.8, p. 732. 2011. http://srren.ipcc-wg3.de/report/IPCC_SRREN_Ch09.pdf. Accessed January 8, 2016.
[93] Environmental Protection Agency. "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2013." p. 2-2 and 2-3. April 2015. http://www3.epa.gov/climatechange/Downloads/ghgemissions/US-GHG-Inventory-2015-Main-Text.pdf. Accessed December 3, 2015.
[94] Environmental Protection Agency. "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2013." p. 2-2 and 2-3. April 2015. http://www3.epa.gov/climatechange/Downloads/ghgemissions/US-GHG-Inventory-2015-Main-Text.pdf. Accessed December 3, 2015.
[95] EIA. "RECS Terminology." http://www.eia.gov/consumption/residential/terminology.cfm. Accessed January 12, 2016.
[96] Environmental Protection Agency. "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2014." Table 2-11. April 2016. http://www3.epa.gov/climatechange/ghgemissions/usinventoryreport.html. Accessed June 14, 2016.
[97] Environmental Protection Agency. "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2013." p. 2-2 to 2-3. April 2015. http://www3.epa.gov/climatechange/Downloads/ghgemissions/US-GHG-Inventory-2015-Main-Text.pdf. Accessed December 3, 2015.
[98] EIA. "U.S. Energy-Related Carbon Dioxide Emissions, 2013." October 2014. http://www.eia.gov/environment/emissions/carbon/archive/2013/pdf/2013_co2analysis.pdf. Accessed January 12, 2016.
[99] EIA. "U.S. Energy-Related Carbon Dioxide Emissions, 2013." p. 1. October 2014. http://www.eia.gov/environment/emissions/carbon/archive/2013/pdf/2013_co2analysis.pdf. Accessed January 12, 2016.
[100] EIA. "U.S. Energy-Related Carbon Dioxide Emissions, 2013." p. 7. October 2014. http://www.eia.gov/environment/emissions/carbon/archive/2013/pdf/2013_co2analysis.pdf. Accessed January 12, 2016.
[101] Environmental Protection Agency. "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2013." p. 2-3. April 2015. http://www3.epa.gov/climatechange/Downloads/ghgemissions/US-GHG-Inventory-2015-Main-Text.pdf. Accessed December 3, 2016.
[102] Environmental Protection Agency. "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2013." p. 2-3. April 2015. http://www3.epa.gov/climatechange/Downloads/ghgemissions/US-GHG-Inventory-2015-Main-Text.pdf. Accessed December 3, 2016.
[103] CARB (California Air Resources Board) 2015. "California Greenhouse Gas Emissions for 2000 to 2013 – Trends of Emissions and Other Indicators." Sacramento, CA: CARB. Accessed December 2015, http://www.arb.ca.gov/cc/inventory/pubs/reports/ghg_inventory_trends_00-13%20_10sep2015.pdf.
[104] International Energy Agency (IEA). "Decoupling of global emissions and economic growth confirmed." March 16, 2016. https://www.iea.org/newsroomandevents/pressreleases/2016/march/decoupling-of-global-emissions-and-economic-growth-confirmed.html. Accessed March 22, 2016.
[105] EIA. "Monthly Energy Review." Tables 7.1 and 12.6. http://www.eia.gov/totalenergy/data/monthly. Accessed March 22, 2016.
[106] U.S. Census Bureau. "International Database." http://www.census.gov/population/international/data/idb/informationGateway.php. Accessed March 22, 2016.
[107] Bureau of Economic Analysis. "Gross Domestic Product." http://www.bea.gov/national/index.htm#gdp. Accessed March 22, 2016.
[108] EIA. "Monthly Energy Review." Tables 7.1 and 12.6. http://www.eia.gov/totalenergy/data/monthly. Accessed March 22, 2016.
[109] U.S. Census Bureau. "International Database." http://www.census.gov/population/international/data/idb/informationGateway.php. Accessed March 22, 2016.
[110] Bureau of Economic Analysis. "Gross Domestic Product." http://www.bea.gov/national/index.htm#gdp. Accessed March 22, 2016.
[111] EIA. Monthly Energy Review. Table 7.6. http://www.eia.gov/totalenergy/data/monthly. U.S. Census Bureau. International Data Base (IDB). http://www.census.gov/ipc/www/idb/tables.html. Accessed December 28, 2015.
[112] EIA. Monthly Energy Review. Table 7.6. http://www.eia.gov/totalenergy/data/monthly. U.S. Census Bureau. International Data Base (IDB). http://www.census.gov/ipc/www/idb/tables.html. Accessed December 28, 2015.
[113] EIA. Monthly Energy Review. Table 7.6. http://www.eia.gov/totalenergy/data/monthly. U.S. Census Bureau. International Data Base (IDB). http://www.census.gov/ipc/www/idb/tables.html. Accessed December 28, 2015.
[114] EIA. Monthly Energy Review. Table 7.6. http://www.eia.gov/totalenergy/data/monthly. U.S. Census Bureau. International Data Base (IDB). http://www.census.gov/ipc/www/idb/tables.html. Accessed December 28, 2015.

[115] EIA. Monthly Energy Review. Table 7.6. http://www.eia.gov/totalenergy/data/monthly. Accessed April 20, 2016.
[116] U.S. Census Bureau. International Data Base (IDB). http://www.census.gov/ipc/www/idb/tables.html. Accessed April 20, 2016.
[117] EIA. Monthly Energy Review. Table 7.6. http://www.eia.gov/totalenergy/data/monthly. U.S. Census Bureau. International Data Base (IDB). http://www.census.gov/ipc/www/idb/tables.html. Accessed April 20, 2016.
[118] EIA. Monthly Energy Review. Table 7.6. http://www.eia.gov/totalenergy/data/monthly. U.S. Census Bureau. International Data Base (IDB). http://www.census.gov/ipc/www/idb/tables.html. Accessed December 28, 2015.
[119] EIA. Monthly Energy Review. Table 7.6. http://www.eia.gov/totalenergy/data/monthly. U.S. Census Bureau. International Data Base (IDB). http://www.census.gov/ipc/www/idb/tables.html. Accessed April 20, 2016.
[120] Environmental Protection Agency. "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2013." p. 2-28. April 2015. http://www3.epa.gov/climatechange/Downloads/ghgemissions/US-GHG-Inventory-2015-Main-Text.pdf. Accessed January 25, 2016.
[121] EIA (2015). Monthly Energy Review. Table 7.6. http://www.eia.gov/totalenergy/data/monthly. U.S. Census Bureau (2014). International Data Base (IDB). http://www.census.gov/ipc/www/idb/tables.html. Accessed December 28, 2015.
[122] EIA (2015). Monthly Energy Review. Table 7.6. http://www.eia.gov/totalenergy/data/monthly. Accessed December 28, 2015.
[123] U.S. Census Bureau (2014). International Data Base (IDB). http://www.census.gov/ipc/www/idb/tables.html. Accessed December 28, 2015.
[124] DOE. "Accelerate Energy Productivity 2030: A Strategic Roadmap for American Energy Innovation, Economic Growth, and Competitiveness." September 2015. http://www.energy2030.org/roadmap. Accessed January 25, 2016.
[125] DOE Office of Energy Efficiency and Renewable Energy. "SEE Action Guide for States: Energy Efficiency as a Least-Cost Strategy to Reduce Greenhouse Gases and Air Pollution and Meet Energy Needs in the Power Sector." p. 30. February 2016. https://www4.eere.energy.gov/seeaction/system/files/documents/SEE%20Action%20Pathways%20Guide%20for%20States_web_0.pdf. Accessed March 20, 2016.
[126] DOE Office of Energy Efficiency and Renewable Energy. http://www.energy.gov/eere/downloads/annual-energy-use-volume-and-real-price-new-refrigerators. Accessed January 12, 2016.See also http://www.energy.gov/articles/proof-pudding-how-refrigerator-standards-have-saved-consumers-billions. Accessed January 12, 2016.
[127] DOE Building Technologies Program. "The Proof is in the Pudding: How Refrigerator Standards Have Saved Consumers $Billions." July 11, 2011. http://energy.gov/articles/proof-pudding-how-refrigerator-standards-have-saved-consumers-billions. Accessed March 29, 2016. For supporting data, see http://iopscience.iop.org/1748-9326/9/11/114010/media/erl503748suppdata3.xlsx.
[128] DOE EPSA. "Electricity End Uses, Energy Efficiency and Distributed Energy Resources: Baseline and Outlook to 2040." Draft version. Section 4.1.2. p. 10. Accessed February 5, 2016.
[129] DOE EPSA. "Electricity End Uses, Energy Efficiency and Distributed Energy Resources: Baseline and Outlook to 2040." Draft version. Section 4.1.2. p. 10. Accessed February 5, 2016.
[130] DOE EPSA. "Electricity End Uses, Energy Efficiency and Distributed Energy Resources: Baseline and Outlook to 2040." Figure 4.1.5. Draft version accessed March 22, 2016.
[131] EIA. "Monthly Energy Review." Tables 7.1 and 12.6. http://www.eia.gov/totalenergy/data/monthly. Accessed March 22, 2016.
[132] U.S. Census Bureau. "International Database." http://www.census.gov/population/international/data/idb/informationGateway.php. Accessed March 22, 2016.
[133] Bureau of Economic Analysis. "Gross Domestic Product." http://www.bea.gov/national/index.htm#gdp. Accessed March 22, 2016.
[134] Environmental Protection Agency. "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2014." Figure 3-14. April 2016. http://www3.epa.gov/climatechange/ghgemissions/usinventoryreport.html. Accessed June 14, 2016.
[135] EIA (2015). Monthly Energy Review. Table 12.6 and Table 7.1. https://www.eia.gov/totalenergy/data/monthly/. Accessed December 28, 2015.
[136] EIA (2015). Annual Energy Review. Table 11.2e. http://www.eia.gov/totalenergy/data/annual/index.cfm. Accessed December 28, 2015.
[137] EIA. "Annual Energy Review." Table 11.2e. http://www.eia.gov/totalenergy/data/annual/index.cfm. EIA. "Monthly Energy Review." Table 12.6 and 7.1. http://www.eia.gov/totalenergy/data/monthly. Accessed April 20, 2016.

[138] EIA. "Electricity Data Browser." http://www.eia.gov/electricity/data/browser/. Accessed March 29, 2016.
[139] EIA (2016). Monthly Energy Review. Table 7.2b. http://www.eia.gov/totalenergy/data/monthly/. Accessed April 20, 2016.
[140] EIA (2015). "U.S. Energy-Related Carbon Dioxide Emissions, 2014." http://www.eia.gov/environment/emissions/carbon/. Accessed December 2015.
[141] EIA. "U.S. Energy-Related Carbon Dioxide Emissions, 2014." Figure 12. November 2015. http://www.eia.gov/environment/emissions/carbon/. Accessed March 29, 2016.
[142] EIA (2015). "Shale in the United States" Washington, D.C.:EIA. http://www.eia.gov/energy_in_brief/article/shale_in_the_united_states.cfm. Accessed December 2015.
[143] EIA (2015). Monthly Energy Review. Table 4.1. http://www.eia.gov/totalenergy/data/monthly/. Accessed January 17, 2016.
[144] EIA. "Electric Power Monthly." Table 4.2 and Table 1.1. http://www.eia.gov/electricity/monthly/index.cfm. Accessed March 29, 2016.
[145] EIA (2015). "Electricity from natural gas surpasses coal for first time but just for one month." Washington, D.C.:EIA. http://www.eia.gov/todayinenergy/detail.cfm?id=22312. Accessed January 17, 2016.
[146] EIA. "Monthly Energy Review." Table 7.2b. http://www.eia.gov/totalenergy/data/monthly. Accessed March 22, 2016.
[147] EIA. "Today in Energy." March 23, 2016. http://www.eia.gov/todayinenergy/detail.cfm?id=25492. Accessed March 23, 2016.
[148] EIA. "Electricity Data Browser." http://www.eia.gov/electricity/data/browser. Accessed March 23, 2016.
[149] AWEA. "U.S. Wind Energy Fourth Quarter 2015 Report." p. 1. January 27, 2016. http://awea.files.cms-plus.com/FileDownloads/pdfs/4Q2015%20AWEA%20Market%20Report%20Public%20Version.pdf. Accessed March 23, 2016.
[150] EIA. "Electric Power Monthly" Washington, D.C.: EIA. Table 6.1. http://www.eia.gov/electricity/monthly/. Accessed March 23, 2016.
[151] EIA. "Electric Power Monthly" Washington, D.C.: EIA. Table 6.1. http://www.eia.gov/electricity/monthly/. Accessed March 23, 2016.
[152] EIA. "Today in Energy." March 23, 2016. http://www.eia.gov/todayinenergy/detail.cfm?id=25492. Accessed March 23, 2016
[153] EIA. "Electricity Data Browser." http://www.eia.gov/electricity/data/browser. Accessed March 23, 2016.
[154] Department of Energy, Office of Solar Energy Technologies (2016). Solar Energy Technologies Office FY17 Budget At-A-Glance. http://energy.gov/sites/prod/files/2016/03/f30/At_A_GLANCE%20(SETO).pdf. Accessed April 11, 2016.
[155] Wiser, Ryan, and Mark Bolinger (2015). "2014 Wind Technologies Market Report." LBNL. p. viii. http://go.usa.gov/3SRFQ. Accessed January 17, 2016.
[156] U.S. Department of Energy (2015). Enable Wind Power Nationwide. Accessed April 18, 2016. http://energy.gov/sites/prod/files/2015/05/f22/Enabling%20Wind%20Power%20Nationwide_18MAY2015_FINAL.pdf.
[157] EIA. "Short-Term Energy Outlook." Table 7a: U.S. Electricity Industry Overview. January 2016. http://www.eia.gov/forecasts/steo/. Accessed February 2, 2016.
[158] EIA. "Short-Term Energy Outlook." p. 1. January 2016. http://www.eia.gov/forecasts/steo/. Accessed February 2, 2016.
[159] EIA. "Short-Term Energy Outlook." Figure 25. March 8, 2016. http://www.eia.gov/forecasts/steo/. Accessed March 21, 2016.
[160] Environmental Protection Agency. Clean Power Plan. August 2015. http://www.epa.gov/cleanpowerplan/clean-power-plan-existing-power-plants. Accessed January 13, 2016.
[161] U.S. Department of State (2016). "Second Biennial Report of the United States of America." See Chapter 4 Projections (p. 30) and Appendix 2: Methodologies (p. 62). The Base Case is equivalent to the energy CO_2 portion of the Biennial Report "Current Measures" projections. http://unfccc.int/national_reports/biennial_reports_and_iar/submitted_biennial_reports/items/7550.php. Accessed January 13, 2016.
[162] United States Congress (2015). Consolidated Appropriations Act. Pub. L. 114-113. https://www.congress.gov/114/bills/hr2029/BILLS-114hr2029enr.xml. Accessed January 21, 2016.
[163] EIA. "Monthly Energy Review." Table 7.6. http://www.eia.gov/totalenergy/data/monthly. Accessed March 22, 2016.
[164] Analysis conducted by the DOE Office of Energy Policy and Systems Analysis (EPSA), February 2016.

165 Analysis conducted by the DOE Office of Energy Policy and Systems Analysis (EPSA), January 2016.
166 EIA. "Monthly Energy Review." Table 7.1 and 12.6. http://www.eia.gov/totalenergy/data/monthly. Accessed March 22, 2016.
167 Analysis conducted by the DOE Office of Energy Policy and Systems Analysis (EPSA), February 2016.
168 EIA. "Monthly Energy Review." Table 12.6. http://www.eia.gov/totalenergy/data/monthly. Accessed March 22, 2016.
169 Analysis conducted by the DOE Office of Energy Policy and Systems Analysis (EPSA), February 2016.
170 Analysis conducted by the DOE Office of Energy Policy and Systems Analysis (EPSA), February 2016.
171 Analysis conducted by the DOE Office of Energy Policy and Systems Analysis (EPSA), February 2016.
172 Analysis conducted by the DOE Office of Energy Policy and Systems Analysis (EPSA), February 2016.
173 Analysis conducted by the DOE Office of Energy Policy and Systems Analysis (EPSA), February 2016.
174 EIA. "Monthly Energy Review." Tables 12.2—12.5. http://www.eia.gov/totalenergy/data/monthly. Accessed March 22, 2016.
175 Analysis conducted by the DOE Office of Energy Policy and Systems Analysis (EPSA), February 2016.
176 U.S. Department of State (2016). "Second Biennial Report of the United States of America." See Chapter 4 Projections (p. 30) and Appendix 2: Methodologies (p. 62). http://unfccc.int/national_reports/biennial_reports_and_iar/submitted_biennial_reports/items/7550.php. Accessed January 13, 2016.
177 https://www.whitehouse.gov/climate-change. Accessed February 2, 2016.
178 U.S. Department of State (2016). Second Biennial Report of the United States of America. Figure 6, p. 39. http://unfccc.int/national_reports/biennial_reports_and_iar/submitted_biennial_reports/items/7550.php.
179 U.S. Department of Energy, National Renewable Energy Laboratory. Status and Trends in the U.S. Voluntary Green Power Market (2014 Data), by Eric O'Shaughnessy, Jenny Heeter, Chang Liu, and Erin Nobler. NREL/TP-6A20-65252. (Golden, Colorado: National Renewable Energy Laboratory, 2015).
180 U.S. Department of State (2016). Second Biennial Report of the United States of America. See Appendix 3, Pages 65-73. http://unfccc.int/national_reports/biennial_reports_and_iar/submitted_biennial_reports/items/7550.php. Accessed April 22, 2016.
181 "Database of State Incentives for Renewables & Efficiency (DSIRE)." Accessed April 22, 2016. http://www.dsireusa.org.
182 U.S. Environmental Protection Agency (2014). "Survey of Existing State Policies and Programs that Reduce Power Sector CO_2 Emissions." Accessed April 22, 2016. http://www.epa.gov/cleanpowerplantoolbox/survey-existing-state-policies-and-programs-reduce-power-sector-co2-emissions.
183 U.S. Environmental Protection Agency. Energy and Environment Guide to Action: State Policies and Best Practices for Advancing Energy Efficiency, Renewable Energy, and Combined Heat and Power. 2015 Edition. https://www.epa.gov/statelocalclimate/energy-and-environment-guide-action-full-report. EPA430-R-15-003. (Washington, DC: U.S. Environmental Protection Agency, May 2015).
184 U.S. Department of State (2016). Second Biennial Report of the United States of America. See Appendix 3, Pages 65-73. http://unfccc.int/national_reports/biennial_reports_and_iar/submitted_biennial_reports/items/7550.php. Accessed April 22, 2016.
185 U.S. Environmental Protection Agency (2015). "Fact Sheet: The Clean Power Plan, By The Numbers." Accessed April 22, 2016. https://www.epa.gov/sites/production/files/2015-08/documents/fs-cpp-by-the-numbers.pdf.
186 U.S. Environmental Protection Agency (2015). Standards of Performance for Greenhouse Gas Emissions from New, Modified, and Reconstructed Stationary Sources: Electric Utility Generating Units (Final Rule). Federal Register, Vol. 80, No. 205. (Washington, DC: United States Government Printing Office, 2015).
187 U.S. Environmental Protection Agency (2015). "Fact Sheet: Carbon Pollution Standards." Accessed April 22, 2016. http://www.epa.gov/sites/production/files/2015-11/documents/fs-cps-overview.pdf.
188 U.S. Environmental Protection Agency (2014). "Survey of Existing State Policies and Programs that Reduce Power Sector CO_2 Emissions." Accessed April 22, 2016. http://www.epa.gov/cleanpowerplantoolbox/survey-existing-state-policies-and-programs-reduce-power-sector-co2-emissions. Pages 17-20.
189 California Energy Commission. "SB 1368, Emission Performance Standards." Accessed April 22, 2016. www.energy.ca.gov/emission_standards/.
190 Montana Legislature (2007). House Bill No. 25, Introduced by A. Olson, Laslovich. HB0025.05, Page 25. Accessed April 22, 2016. http://leg.mt.gov/bills/2007/billpdf/HB0025.pdf.
191 Illinois General Assembly (2009). SB1987, Clean Coal Portfolio Standard Law. Public Act 095-1027, Pages 4-5, 19-21. Accessed April 22, 2016. http://ilga.gov/legislation/publicacts/95/PDF/095-1027.pdf.
192 State of Colorado (2010). "Clean Air-Clean Jobs Act." House Bill 10-1365, LLS No. 10-0144.01, Pages 2, 5-8.

http://www.leg.state.co.us/clics/clics2010a/csl.nsf/fsbillcont/0CA296732C8CEF4D872576E400641B74?Open&file=1365_ren.pdf. Accessed April 22, 2016.

[193] Colorado Governor's Energy Office (2011). House Bill 10-1365_Clean Air-Clean Jobs Act: Fact Sheet. Page 1. http://hermes.cde.state.co.us/drupal/islandora/object/co%3A9510/datastream/OBJ/download/Colorado_s_clean_air-clean_jobs_act___a_holistic_approach_to_energy__economy_and_environment.pdf. Accessed April 22, 2016.

[194] Colorado Department of Public Health and Environment (2015). "News: U.S. EPA finalizes Clean Power Plan; Colorado committed to meeting goals." https://www.colorado.gov/pacific/cdphe/news/epa-finalizes-clean-power-plan-colorado-committed-meeting-goals. Accessed April 22, 2016.

[195] Xcel Energy. "Colorado Clean Air-Clean Jobs Plan." Accessed April 22, 2016. https://www.xcelenergy.com/Environment/Programs/Colorado_Clean_Air-Clean_Jobs_Plan.

[196] California Air Resources Board (2015). Overview of ARB Emissions Trading Program. http://www.arb.ca.gov/cc/capandtrade/guidance/cap_trade_overview.pdf. Accessed April 22, 2016.

[197] U.S. Environmental Protection Agency (2014). "Survey of Existing State Policies and Programs that Reduce Power Sector CO_2 Emissions." Accessed April 22, 2016. http://www.epa.gov/cleanpowerplantoolbox/survey-existing-state-policies-and-programs-reduce-power-sector-co2-emissions. Page 17.

[198] Office of Governor Edmund G. Brown Jr. (2015). "Governor Brown Establishes Most Ambitious Greenhouse Gas Reduction Target in North America." Accessed April 22, 2016. https://www.gov.ca.gov/news.php?id=18938.

[199] RGGI, Inc (2015). "Investment of RGGI Proceeds Through 2013." Pages 3, 6–13. Accessed April 25, 2016. www.rggi.org/docs/ProceedsReport/Investment-RGGI-Proceeds-Through-2013.pdf.

[200] RGGI, Inc. "The RGGI CO_2 Cap." http://www.rggi.org/design/overview/cap. Accessed April 22, 2016.

[201] RGGI, Inc (2015). "Investment of RGGI Proceeds Through 2013." Pages 4–5. Accessed April 25, 2016. www.rggi.org/docs/ProceedsReport/Investment-RGGI-Proceeds-Through-2013.pdf.

[202] RGGI, Inc. (2014). RGGI States Make Major Cuts to Greenhouse Gas Emissions from Power Plants. Page 1. http://www.rggi.org/docs/PressReleases/PR011314_AuctionNotice23.pdf. Accessed April 22, 2016.

[203] U.S. Department of Energy, Appliance and Equipment Standards Program. Accessed April 25, 2016. http://energy.gov/eere/buildings/appliance-and-equipment-standards-program.

[204] U.S. Department of Energy, Building Technologies Office (2015). Appliance and Equipment Standards Fact Sheet. http://energy.gov/eere/buildings/downloads/appliance-and-equipment-standards-fact-sheet. Accessed April 25, 2016.

[205] U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy (2016). "Energy Conservation Program for Certain Industrial Equipment: Energy Conservation Standards for Small, Large, and Very Large Air-Cooled Commercial Package Air Conditioning and Heating Equipment and Commercial Warm Air Furnaces; Direct final rule." *Federal Register*, Vol. 81, No. 10, Part 431. Pages 2423–2424. Accessed April 25, 2016.

[206] U.S. Department of Energy (2015). "Energy Department Announces Largest Energy Efficiency Standard in History." http://energy.gov/articles/energy-department-announces-largest-energy-efficiency-standard-history. Accessed April 25, 2016.

[207] U.S. Environmental Protection Agency (2014). "Survey of Existing State Policies and Programs that Reduce Power Sector CO_2 Emissions." Page 33. http://www.epa.gov/cleanpowerplantoolbox/survey-existing-state-policies-and-programs-reduce-power-sector-co2-emissions. Accessed April 22, 2016.

[208] California Energy Commission (2015). 2015 Appliance Efficiency Regulations, by H. Singh, K. Rider, and J. Babula. Publication Number: CEC –400–2015–021, Abstract, Page i. Accessed April 25, 2016. http://www.energy.ca.gov/2015publications/CEC-400-2015-021/CEC-400-2015-021.pdf.

[209] International Code Council (2012). International Energy Conservation Code. Accessed April 25, 2016. http://publicecodes.cyberregs.com/icod/iecc/.

[210] ASHRAE. "Standard 90.1." https://www.ashrae.org/resources--publications/bookstore/standard-90-1. Accessed April 25, 2016.

[211] U.S. Department of Energy (2015). "Achieving Energy Savings and Emission Reductions from Building Energy Codes: A Primer for State Planning." Pages 1–4. Accessed April 25, 2016. https://www.energycodes.gov/sites/default/files/documents/Codes_Energy_Savings_State_Primer.pdf.

[212] International Code Council. "International Codes-Adoption by State (February 2016)." http://www.iccsafe.org/wp-content/uploads/stateadoptions.pdf. Accessed April 26, 2016.

[213] Oregon Department of Energy (2010). 2011-2013 State of Oregon Energy Plan. Pages 66–67. Accessed April 25, 2016. http://www.oregon.gov/energy/docs/reports/legislature/2011/energy_plan_2011-13.pdf.

[214] California Energy Commission. "2013 Building Energy Efficiency Standards Infographics." http://www.energy.ca.gov/title24/2013standards/rulemaking/documents/2013_Building_Energy_Efficiency_Standards_infographics.pdf. Accessed April 25, 2016.

[215] California Energy Commission (2012). 2013 Building Energy Efficiency Standards for Residential and Nonresidential Buildings. Title 24, Part 6 and Associated Administrative Regulations in Part 1. CEC-400-2012-004-CMF-REV2. Abstract, Page 9. http://www.energy.ca.gov/2012publications/CEC-400-2012-004/CEC-400-2012-004-CMF-REV2.pdf. Accessed April 25, 2016.
[216] Database of State Incentives for Renewables & Efficiency (2015). "Renewable Portfolio Standard Policies." http://ncsolarcen-prod.s3.amazonaws.com/wp-content/uploads/2015/11/Renewable-Portfolio-Standards.pdf. Accessed April 25, 2016.
[217] Database of State Incentives for Renewables & Efficiency (2015). "Colorado's Renewable Energy Standard." http://programs.dsireusa.org/system/program/detail/133. Accessed April 25, 2016.
[218] Database of State Incentives for Renewables & Efficiency (2014). "Ohio's Alternative Energy Portfolio Standard." http://programs.dsireusa.org/system/program/detail/2934. Accessed April 25, 2016.
[219] Database of State Incentives for Renewables & Efficiency (2015). "California's Renewables Portfolio Standard." http://programs.dsireusa.org/system/program/detail/840. Accessed April 25, 2016.
[220] Hawaii State Energy Office (2015). "Hawaii Energy Facts & Figures, November 2015." Page 6. http://energy.hawaii.gov/wp-content/uploads/2011/10/HSEO_FF_Nov2015.pdf. Accessed April 25, 2016.
[221] California Air Resources Board (2014). "Climate Change Scoping Plan." Table 2 and Figure 3. Accessed April 25, 2016. http://www.arb.ca.gov/cc/scopingplan/document/adopted_scoping_plan.pdf.
[222] Wiser, R., G. Barbose, J. Heeter, T. Mai, L. Bird, M. Bolinger, A. Carpenter, G. Heath, D. Keyser, J. Macknick, A. Mills, and D. Millstein (2016). A Retrospective Analysis of the Benefits and Impacts of U.S. Renewable Portfolio Standards. Lawrence Berkeley National Laboratory and National Renewable Energy Laboratory. NREL/TP-6A20-65005. http://www.nrel.gov/docs/fy16osti/65005.pdf. Accessed April 27, 2016.
[223] Wiser, R., G. Barbose, J. Heeter, T. Mai, L. Bird, M. Bolinger, A. Carpenter, G. Heath, D. Keyser, J. Macknick, A. Mills, and D. Millstein (2016). A Retrospective Analysis of the Benefits and Impacts of U.S. Renewable Portfolio Standards. Lawrence Berkeley National Laboratory and National Renewable Energy Laboratory. NREL/TP-6A20-65005. http://www.nrel.gov/docs/fy16osti/65005.pdf. Accessed April 27, 2016.
[224] California Air Resources Board (2014). "Climate Change Scoping Plan." Table 7. Accessed April 25, 2016. http://www.arb.ca.gov/cc/scopingplan/document/adopted_scoping_plan.pdf.
[225] RGGI, Inc. (2015). "Investment of RGGI Proceeds Through 2013." Pages 8–9, Table 4. www.rggi.org/docs/ProceedsReport/Investment-RGGI-Proceeds-Through-2013.pdf. Accessed April 26, 2016.
[226] National Renewable Energy Laboratory (2014). State Energy Efficiency Resource Standards: Design, Status, and Impacts. Technical Report NREL/TP-6A20-61023, May 2014.
[227] American Council for an Energy Efficient Economy (2015). "State Energy Efficiency Resource Standards (EERS)." http://aceee.org/sites/default/files/eers-04072015.pdf. Accessed April 26, 2016.
[228] Database of State Incentives for Renewables & Efficiency (2016). "Energy Efficiency Resource Standards (and Goals)." http://ncsolarcen-prod.s3.amazonaws.com/wp-content/uploads/2015/03/Energy-Efficiency-Resource-Standards.pdf. Accessed April 26, 2016.
[229] Database of State Incentives for Renewables & Efficiency (2016). Nevada's Energy Portfolio Standard. http://programs.dsireusa.org/system/program/detail/373. Accessed February 4, 2016.
[230] Database of State Incentives for Renewables & Efficiency (2016). North Carolina's Renewable Energy and Energy Efficiency Portfolio Standard. http://programs.dsireusa.org/system/program/detail/2660. Accessed February 4, 2016.
[231] Database of State Incentives for Renewables & Efficiency (2015). "Texas's Required Energy Efficiency Goals." http://programs.dsireusa.org/system/program/detail/4622. Accessed April 26, 2016. See also https://www.puc.texas.gov/agency/rulesnlaws/subrules/electric/25.181/25.181.pdf, §25.181—8.
[232] Database of State Incentives for Renewables & Efficiency (2015). "Arizona's Energy Efficiency Standards." http://programs.dsireusa.org/system/program/detail/4488. Accessed April 26, 2016.
[233] Minnesota Department of Commerce, State Energy Office. "Minnesota's Next Generation Energy Initiative." http://mn.gov/commerce-stat/pdfs/summary-next-generation-energy-initiative.pdf. Accessed April 26, 2016.
[234] Energy Star. "Federal Income Tax Credits for Energy Efficiency." Accessed April 26, 2016. http://www.energystar.gov/taxcredits.
[235] Database of State Incentives for Renewables & Efficiency (2015). "Energy-Efficient New Homes Tax Credit for Home Builders." http://programs.dsireusa.org/system/program/detail/1272. Accessed April 26, 2016.
[236] Database of State Incentives for Renewables & Efficiency (2015). "Energy-Efficient Commercial Buildings Tax Deduction." Accessed April 26, 2016. http://programs.dsireusa.org/system/program/detail/1271.
[237] Brookings Energy Security and Climate Initiative (2015). "Foster Low Carbon Energy: Next Generation Policy to Commercialize CCS in the United States", by J.P. Banks and T. Boersma. Accessed April 26, 2016.

http://www.brookings.edu/~/media/Research/Files/Papers/2015/10/low-carbon-energy-ccs-banks-boersma/low_carbon_energy_ccs_banks_boersma_FINAL.pdf?la=en. Exhibits 3 and 5.
[238] United States Congress (2015). Consolidated Appropriations Act. Pub. L. 114-113. https://www.congress.gov/114/bills/hr2029/BILLS-114hr2029enr.xml. Sections 301–304, Accessed April 26, 2016.
[239] Database of State Incentives for Renewables & Efficiency (2015). "Renewable Electricity Production Tax Credit (PTC)." http://programs.dsireusa.org/system/program/detail/734. Accessed April 26, 2016.
[240] Database of State Incentives for Renewables & Efficiency (2015). "Business Energy Investment Tax Credit (ITC)." http://programs.dsireusa.org/system/program/detail/658. Accessed April 26, 2016.
[241] Database of State Incentives for Renewables & Efficiency (2016). "Residential Renewable Energy Tax Credit." http://programs.dsireusa.org/system/program/detail/1235. Accessed April 26, 2016.
[242] U.S. Department of Energy, National Renewable Energy Laboratory (2016). "Impacts of Federal Tax Credit Extensions on Renewable Deployment and Power Sector Emissions," by Mai, T., W. Cole, E. Lantz, C. Marcy, and B. Sigrin. NREL/TP-6A20-65571. Pages 18–21, Figure 6. Accessed April 26, 2016.
[243] New Mexico Energy, Minerals and Natural Resources Department. "Geothermal Ground-Coupled Heat Pump Tax Credit." http://www.emnrd.state.nm.us/ECMD/RenewableEnergy/geothermal.html. Accessed April 26, 2016.
[244] Oregon Department of Energy. "About Oregon's Residential Energy Tax Credit Program." Accessed April 26, 2016. http://www.oregon.gov/energy/RESIDENTIAL/Pages/residential_energy_tax_credits.aspx.
[245] Database of State Incentives for Renewables & Efficiency (2016). "Oregon's Residential Energy Tax Credit." Accessed April 26, 2016. http://programs.dsireusa.org/system/program/detail/638.
[246] Database of State Incentives for Renewables & Efficiency (DSIRE). http://www.dsireusa.org.
[247] U.S. Environmental Protection Agency (2014). "Survey of Existing State Policies and Programs that Reduce Power Sector CO_2 Emissions." Page 33. http://www.epa.gov/cleanpowerplantoolbox/survey-existing-state-policies-and-programs-reduce-power-sector-co2-emissions. Accessed April 22, 2016.
[248] U.S. Environmental Protection Agency. Energy and Environment Guide to Action: State Policies and Best Practices for Advancing Energy Efficiency, Renewable Energy, and Combined Heat and Power. 2015 Edition. https://www.epa.gov/statelocalclimate/energy-and-environment-guide-action-full-report. EPA430-R-15-003. (Washington, DC: U.S. Environmental Protection Agency, May 2015).
[249] U.S. Department of Energy, Office of Energy Efficiency & Renewable Energy. "Alternative Fuels Data Center: Federal and State Laws and Incentives." http://www.afdc.energy.gov/laws. Accessed May 6, 2016.
[250] U.S. Department of Energy, Office of Energy Efficiency & Renewable Energy. "State Energy Program." http://energy.gov/eere/wipo/state-energy-program. Accessed April 28, 2016.
[251] Ohio Development Services Agency, Advanced Energy and Efficiency Programs. "Energy Efficiency Program for Manufacturers." www.development.ohio.gov/bs/bs_energyefficprograms.htm. Accessed April 28, 2016.
[252] U.S. Department of Energy, Office of Energy Efficiency & Renewable Energy. "CHP Technical Assistance Partnerships (CHP TAPS)." http://energy.gov/eere/amo/chp-technical-assistance-partnerships-chp-taps. Accessed April 28, 2016.
[253] U.S. Department of Energy, Office of Electricity Delivery & Energy Reliability. "Electricity Policy Technical Assistance Program." http://energy.gov/oe/services/electricity-policy-coordination-and-implementation/electricity-policy-technical. Accessed April 28, 2016.
[254] U.S. Department of Energy, Loan Programs Office. "Section 1703 Loan Program." http://energy.gov/lpo/services/section-1703-loan-program. Accessed April 28, 2016.
[255] U.S. Department of Energy, Loan Programs Office (2016). "Advanced Nuclear Energy Projects Solicitation." http://www.energy.gov/lpo/advanced-nuclear-energy-projects-solicitation. Accessed April 28, 2016.
[256] U.S. Department of Energy, Loan Program Office (2015). "Advanced Fossil Energy Projects Solicitation." http://energy.gov/lpo/services/solicitations/advanced-fossil-energy-projects-solicitation. Accessed April 28, 2016.
[257] U.S. Department of Agriculture, Rural Development. "Rural Energy for America Program: Renewable Energy Systems & Energy Efficiency Improvement Loans & Grants." www.rd.usda.gov/programs-services/rural-energy-america-program-renewable-energy-systems-energy-efficiency. Accessed April 28, 2016.
[258] U.S. Department of Agriculture, Rural Development. "Electric Programs." www.rd.usda.gov/programs-services/all-programs/electric-programs. Accessed April 28, 2016.
[259] Massachusetts Clean Energy Center. "Mass Solar Loan Program." www.masscec.com/programs/mass-solar-loan. Accessed April 28, 2016.
[260] U.S. Environmental Protection Agency, Office of Atmospheric Programs. Climate Protection Partnerships, 2014 Annual Report." Table 1, Figure 1. Accessed April 28, 2016. https://www.energystar.gov/sites/default/files/asset/document/ENERGYSTAR_2014AnnualReport_508_0.pdf.
[261] U.S. Environmental Protection Agency. "U.S. Greenhouse Gas Inventory Report." Figure: Sources of

Greenhouse Gases." http://www3.epa.gov/climatechange/ghgemissions/usinventoryreport.html. Accessed April 28, 2016.

[262] U.S. Environmental Protection Agency, Office of Atmospheric Programs. Climate Protection Partnerships, 2014 Annual Report." Table 1, Figure 1. Accessed April 28, 2016. https://www.energystar.gov/sites/default/files/asset/document/ENERGYSTAR_2014AnnualReport_508_0.pdf.

[263] City of Minneapolis (2015). 2013 Energy Benchmarking Report. Accessed April 28, 2016. http://www.minneapolismn.gov/www/groups/public/@health/documents/images/wcms1p-141979.pdf. Page 5.

[264] U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy. "Offshore Wind Advanced Technology Demonstration Projects." http://energy.gov/eere/wind/offshore-wind-advanced-technology-demonstration-projects. Accessed April 28, 2016.

[265] National Energy Technology Laboratory (2014). "Petra Nova Parish Holdings: W.A. Parish Post-Combustion CO2 Capture and Sequestration Project." Accessed April 28, 2016. http://www.netl.doe.gov/File%20Library/Research/Coal/major%20demonstrations/ccpi/FE0003311.pdf.

[266] The White House. Announcing: "Mission Innovation". https://www.whitehouse.gov/blog/2015/11/29/announcing-mission-innovation. Accessed April 28, 2016.

[267] United States Congress (2015). Consolidated Appropriations Act. Pub. L. 114-113. https://www.congress.gov/114/bills/hr2029/BILLS-114hr2029enr.xml. Title III—Department of Energy Programs, Advanced Research Projects Agency—Energy. Accessed April 28, 2016.

[268] Advanced Research Projects Agency—Energy (2015). "GENSETS Program Overview." http://arpa-e.energy.gov/sites/default/files/documents/files/GENSETS_ProgramOverview.pdf. Accessed April 28, 2016.

[269] U.S. Department of Energy (2016). "Energy Department Announces New Investments in Advanced Nuclear Power Reactors to Help Meet America's Carbon Emission Reduction Goal." http://www.energy.gov/articles/energy-department-announces-new-investments-advanced-nuclear-power-reactors-help-meet. Accessed April 28, 2016.

[270] U.S. Department of Energy, Office of Energy Efficiency & Renewable Energy (2010). "Retrospective Benefit-Cost Evaluation of DOE Investment in Photovoltaic Energy Systems," by Alan C. O'Connor, Ross J. Loomis, and Fern M. Braun. Pages ES-4 and 5-5 to 5-21. Accessed April 28, 2016. http://www1.eere.energy.gov/analysis/pdfs/solar_pv.pdf.

[271] U.S. Energy Information Administration (2015). Annual Energy Outlook 2015, Table: Renewable Energy Generating Capacity and Generation. http://www.eia.gov/forecasts/aeo/data/browser/#/?id=16-AEO2015. Accessed March 16, 2016.

[272] U.S. Department of Energy (2015). Quadrennial Technology Review 2015. http://energy.gov/qtr. Accessed April 28, 2016.

[273] Montana State University. Energy Research Institute. http://www.montana.edu/energy/. Accessed April 28, 2016.

[274] ASERTTI (2011). "National Guide to State Energy Research Centers," by Weigman, L., A. Preefer, J. M. Santana, and L. Vosmeier. Accessed April 28, 2016. http://www.asertti.org/researchcenters/ASERTTI_State_Research_Guide.pdf.

[275] U.S. Department of Energy (2015). "Energy Efficiency Standards for New Federal Commercial and Multi-Family High-Rise Residential Buildings' Baseline Standards Update." *Federal Register*, Vol. 80, No. 215. 10 CFR Part 433, Docket No. EERE–2014–BT–STD–0047, RIN 1904–AD39. Pages 68750-68751.

[276] President Barack Obama (2015). "Executive Order 13693 of March 19, 2015: Planning for Federal Sustainability in the Next Decade." *Federal Register*, Vol. 80, No. 57, Pages 15871-15884.

[277] U.S. Department of Energy, Office of Energy Efficiency & Renewable Energy. "Federal Energy Management Program." http://energy.gov/eere/femp/federal-energy-management-program. Accessed April 28, 2016.

[278] The White House (2012). "Fact Sheet: Obama Administration Announces Additional Steps to Increase Energy Security." www.whitehouse.gov/the-press-office/2012/04/11/fact-sheet-obama-administration-announces-additional-steps-increase-ener. Accessed June 28, 2016.

[279] U.S. Air Force (2013). "U.S. Air Force Energy Strategic Plan." Priority 3 Goals and Objectives, page 15. www.safie.hq.af.mil/shared/media/document/AFD-130325-132.pdf.

[280] American Council on Renewable Energy. "Selected U.S. Department of Defense Goals, Priorities and Requirements for Renewable Energy." www.acore.org/dod-energy-goals. Accessed June 28, 2016.

[281] U.S. Department of the Navy (2016). "Renewable Energy Program Office." www.greenfleet.dodlive.mil/energy/repo-3/. Accessed June 28, 2016.

[282] U.S. Department of State (2016). Second Biennial Report of the United States of America. Pages 26-27. http://unfccc.int/national_reports/biennial_reports_and_iar/submitted_biennial_reports/items/7550.php. Accessed April 28, 2016.

[283] Database of State Incentives for Renewables & Efficiency (2015). "Rhode Island's Green Power Purchasing for

State Facilities." http://programs.dsireusa.org/system/program/detail/5845. Accessed April 28, 2016.
[284] National Association of State Energy Officials. "Tennessee Office of Energy Programs." http://www.naseo.org/members-state?State=TN. Accessed April 28, 2016.
[285] Tennessee State Government (2015). "EmPowerTN." http://www.tn.gov/main/section/empower-tn. Accessed April 25, 2016.
[286] Arlington County Board (2013). Memorandum: Achieving the AIRE 2012 goal. https://arlingtonva.s3.amazonaws.com/wp-content/uploads/sites/13/2015/08/052113-CMO-AIRE-2012-goal-report-Final.pdf. Pages 1–3. Accessed April 28, 2016.
[287] Arlington County, Virginia (2013). Community Energy Plan: An Element of Arlington County's Comprehensive Plan. http://arlingtonva.s3.amazonaws.com/wp-content/uploads/sites/13/2015/08/Arlingtons-Community-Energy-Plan.pdf. Page 3. Accessed April 28, 2016.
[288] City of Minneapolis (2015). 2013 Energy Benchmarking Report. Accessed April 28, 2016. http://www.minneapolismn.gov/www/groups/public/@health/documents/images/wcms1p-141979.pdf. Page 4.
[289] Raupach et al. "Global and regional drivers of accelerating CO_2 emissions." Equation 4. http://www.pnas.org/content/104/24/10288.full.pdf. Accessed January 31, 2016.
[290] U.S. Census Bureau. International Data Base. July 2015. http://www.census.gov/population/international/data/idb/informationGateway.php. Accessed February 1, 2016.
[291] Bureau of Economic Analysis. Gross Domestic Product. January 2016. http://www.bea.gov/national/index.htm#gdp. Accessed February 1, 2016.
[292] U.S. Energy Information Administration. "Monthly Energy Review." Table 12.6 and Table 7.2b. http://www.eia.gov/totalenergy/data/monthly/. Accessed December 28, 2015.
[293] U.S. Energy Information Administration. "State Carbon Dioxide Emissions." October 26, 2015. http://www.eia.gov/environment/emissions/state/. Accessed March 24, 2016.
[294] U.S. Energy Information Administration. Electricity Data Browser. http://www.eia.gov/electricity/data/browser/. Accessed March 24, 2016.
[295] U.S. Energy Information Administration. Electricity Data Browser. http://www.eia.gov/electricity/data/browser/. Accessed March 24, 2016.