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SUMMARY

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U.S. Carbon Dioxide Emissions in the Electricity Sector: Factors, Trends, and Projections

International negotiations and domestic policy developments continue to generate congressional interest in current and projected U.S. greenhouse gas (GHG) emission levels. In December 2015, delegations from 195 nations, including the United States, adopted an agreement in Paris that creates an international structure for nations to pledge to abate their GHG emissions, adapt to climate change, and cooperate to achieve these ends, including financial and other support. Pursuant to that agreement, the United States pledged (in 2015) to reduce GHG emissions by 26-28% by 2025 compared to 2005 levels. In 2017, President Trump announced his intention to withdraw from the Paris Agreement, but under the provisions of the agreement, this cannot be completed before November 4, 2020.

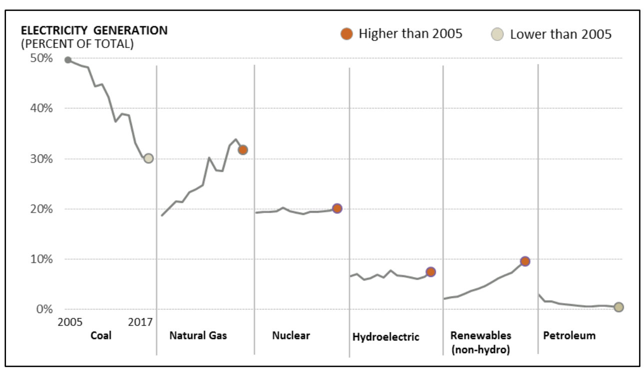
GHG emissions are generated throughout the United States from millions of discrete sources: vehicles, power plants, industrial facilities, households, commercial buildings, and agricultural activities (e.g., soils and livestock). Of the GHG source categories, carbon dioxide (CO_2) emissions from fossil fuel combustion account for the largest percentage (76%) of total U.S. GHG emissions. Among the sectors, transportation contributes the largest percentage (36%) of CO_2 emissions from fossil fuel combustion, with electric power second at 35%.

Recent changes in the U.S. electricity generation portfolio played a key role in the CO_2 emission decrease. The electricity portfolio affects CO_2 emission levels, because different sources of electricity generation produce different rates of CO_2 emissions per unit of electricity (zero in the case of some renewables). The **figure** below illustrates the changes in electricity portfolio between 2005 and 2017. Highlights include:

- Coal's contribution to total electricity generation decreased from 50% to 30%;
- Natural gas's contribution to total electricity generation increased from 19% to 32%; and
- Non-hydro renewable energy (wind and solar) generation increased from 2% to 10%.

In recent years, several groups have prepared projections of CO_2 emission levels in the electricity sector. The results generally indicate that the 2015 Clean Power Plan would have an impact on CO_2 emission levels from electricity generation. In addition, reference case scenarios in more recent studies (2018) project lower emissions by 2030 when compared to reference cases from earlier studies.

Percentage of Electricity Generation by Source: 2005-2017



Source: Prepared by CRS; data from EIA, Electric Power Monthly, Table 1.1, http://www.eia.gov/beta/epm/. Renewable sources include wind, utility scale solar, wood fuels, landfill gas, biogenic municipal solid waste, other biomass, and geothermal. Petroleum includes petroleum liquids and petroleum coke.

Multiple factors will likely impact electricity sector CO_2 emissions levels, including the electricity generation portfolio, the relative prices of fossil fuels, federal and/or state policy developments, economic impacts, and improvements in demand-side energy efficiency. Accurately forecasting future CO_2 emission levels is a complex and challenging endeavor. A comparison of actual CO_2 emissions between 1990 and 2017 with selected emission projections illustrates this difficulty. In general, actual emissions have remained well below projections.

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Introduction

The primary greenhouse gas (GHG)[1] emitted by human activities is carbon dioxide (CO_2). The majority of CO_2 emitted by human activities is generated through the combustion of fossil fuels. Although fossil fuels have facilitated economic growth in the United States and around the world, CO_2 emissions from fossil fuel combustion has contributed to an increase in the atmospheric concentration of CO_2 by about 40% over the past 150 years.[2] According to the Intergovernmental Panel on Climate Change's (IPCC) Fifth Assessment Report:

> Continued emission of greenhouse gases will cause further warming and long-lasting changes in all components of the climate system, increasing the likelihood of severe, pervasive and irreversible impacts for people and ecosystems.[3]

U.S. GHG emissions levels, particularly from CO_2, remain a topic of interest among policymakers and stakeholders. A variety of efforts that seek to reduce these emissions are currently underway or being developed on the international[4] and sub-national level (e.g., individual state actions or regional partnerships).[5]

Recent international negotiations and domestic policy developments have generated attention to current and projected U.S. GHG emission levels. In particular, delegations from 195 nations, including the United States, adopted the Paris Agreement in 2015, creating an international structure for nations to pledge to abate their GHG emissions, adapt to climate change, and cooperate to achieve these ends, including financial and other support.[6] Pursuant to the Paris Agreement, the United States pledged (in 2015) to reduce GHG emissions by 26%-28% by 2025

[1] GHGs in the atmosphere trap radiation as heat, warming the Earth's surface and oceans. The primary GHGs emitted by humans (and estimated by the Environmental Protection Agency in its annual inventories) include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), sulfur hexafluoride, chlorofluorocarbons, hydrofluorocarbons, and perfluorocarbons.

[2] For more information on climate change science, see CRS Report R43229, *Climate Change Science: Key Points*, by Jane A. Leggett.

[3] IPCC, Climate Change 2014: Synthesis Report. Summary for Policymakers, 2014, p. 8, https://www.ipcc.ch/report/ar5/syr/.

[4] Some countries have levied carbon taxes (or something similar) for over 20 years. For a review of carbon prices in other countries, see OECD, *Effective Carbon Rates: Pricing CO_2 Through Taxes and Emissions Trading Systems*, 2016, http://www.oecd-ilibrary.org/taxation/effective-carbon-rates_9789264260115-en; and the Carbon Tax Center website, http://www.carbontax.org/where-carbon-is-taxed.

[5] A number of U.S. states have taken action requiring GHG emission reductions. The most aggressive actions have come from the Regional Greenhouse Gas Initiative—a coalition of nine states from the Northeast and Mid-Atlantic regions—and California. The Regional Greenhouse Gas Initiative is a cap-and-trade system that took effect in 2009 and applies to CO_2 emissions from electric power plants (see CRS Report R41836, *The Regional Greenhouse Gas Initiative: Lessons Learned and Issues for Congress*, by Jonathan L. Ramseur). California established a cap-and-trade program that took effect in 2013. California's cap covers multiple GHGs, which account for approximately 85% of California's GHG emissions. For more details, see the California Air Resources Board website, https://www.carb.ca.gov/cc/capandtrade/capandtrade.htm.

[6] See CRS Insight IN10413, *Climate Change Paris Agreement Opens for Signature*, by Jane A. Leggett.

compared to 2005 levels.[7] In addition, pursuant to the Copenhagen Accord, the United States pledged (in 2009) to reduce GHG by 17% below 2005 levels by 2020.[8]

In 2017, President Trump announced his intention to withdraw from the Paris Agreement.[9] Under the provisions of the Paris Agreement, this cannot be completed before November 4, 2020.[10]

Whether the United States ultimately achieves the GHG emission targets will likely depend, to some degree, on CO_2 emissions from electric power plants—one of the largest sources of U.S. GHG emissions. During the Obama Administration, the U.S. Environmental Protection Agency (EPA) promulgated a final rule for CO_2 emissions from existing fossil-fuel-fired electric power plants.[11] The rule, known as the Clean Power Plan (CPP), appeared in the *Federal Register* on October 23, 2015.[12]

The CPP is the subject of ongoing litigation, and in 2016, the Supreme Court stayed the rule for the duration of the litigation.[13] In March 2017, President Trump issued an executive order that directed EPA to review the CPP (and other rulemakings) and "as soon as practicable, suspend, revise, or rescind the guidance, or publish for notice and comment proposed rules suspending, revising, or rescinding those rules."[14] Pursuant to that order, EPA proposed to *repeal* the CPP in October 2017.[15]

In a separate rulemaking, published in August 2018, EPA proposed to *replace* the CPP with the "Affordable Clean Energy" (ACE) rule.[16] In this proposal, EPA determined that the agency had exceeded its authority with the Obama Administration's CPP. In the ACE rulemaking, EPA proposed a more narrow interpretation of *best system of emission reduction*, directing states (in contrast to EPA under the CPP) to establish performance standards for existing coal-fired electric generating units based on EPA-identified technologies (i.e., heat rate improvements)[17] and other

[7] U.S. Government, "U.S. Cover Note, INDC and Accompanying Information," March 31, 2015, http://www4.unfccc.int/submissions/indc/Submission%20Pages/submissions.aspx. This pledge supplemented an Obama Administration commitment to reduce U.S. GHG emissions by 17% below 2005 levels by 2020. See Executive Office of the President, "The President's Climate Action Plan," June 2013, http://www.whitehouse.gov/sites/default/files/image/president27sclimateactionplan.pdf.

[8] For more information on the Copenhagen Accord, see CRS Report R44092, *Greenhouse Gas Pledges by Parties to the United Nations Framework Convention on Climate Change*, by Jane A. Leggett.

[9] The White House, "Statement by President Trump on the Paris Climate Accord," June 1, 2017, https://www.whitehouse.gov/the-press-office/2017/06/01/statement-president-trump-paris-climate-accord.

[10] For more information, see CRS Report R44609, *Climate Change: Frequently Asked Questions About the 2015 Paris Agreement*, by Jane A. Leggett and Richard K. Lattanzio.

[11] See CRS Report R44341, *EPA's Clean Power Plan for Existing Power Plants: Frequently Asked Questions*, by James E. McCarthy et al.

[12] EPA, "Carbon Pollution Emission Guidelines for Existing Stationary Sources: Electric Utility Generating Units," Final Rule, 80 *Federal Register* 64661, October 23, 2015. EPA cited Section 111(d) of the Clean Air Act as the authority to issue its final rule (42 U.S.C. §7411(d)).

[13] See CRS Report R44341, *EPA's Clean Power Plan for Existing Power Plants: Frequently Asked Questions*, by James E. McCarthy et al.

[14] Executive Order 13783, "Promoting Energy Independence and Economic Growth," 82 *Federal Register* 16093, March 31, 2017 (signed March 28, 2017).

[15] EPA, "Repeal of Carbon Pollution Emission Guidelines for Existing Stationary Sources: Electric Utility Generating Units," 82 *Federal Register* 48035, October 16, 2017.

[16] EPA, "Emission Guidelines for Greenhouse Gas Emissions from Existing Electric Utility Generating Units; Revisions to Emission Guideline Implementing Regulations; Revisions to New Source Review Program," 83 *Federal Register* 44746, August 31, 2018.

[17] The CPP's "building block 1" involved heat rate improvements (efficiency improvements) at coal-fired units.

considerations (e.g., useful life of the unit). Many of the legal questions raised in the CPP proceedings will likely be central to any future legal challenges to the repeal of the CPP or the ACE rule if finalized.[18]

An understanding of GHG emission source data and the underlying factors that affect emission levels might help inform the discussion among policymakers regarding GHG emission mitigation. A question for policymakers is whether U.S. GHG emissions will remain at current levels, decrease to meet 2025 targets, or increase toward former (or even higher) levels. Multiple factors—including economics, technology, and climate policies—will likely play a role in future GHG emission levels.

This report examines recent trends in CO_2 emissions from electricity generation and the factors that impact emission levels in that sector. The first section provides an overview of various sources of GHG emissions in the United States. The second section discusses CO_2 emissions from the electricity sector. The third section examines projections of CO_2 emissions in the electric power sector, with a particular focus on the role of the 2015 CPP final rule and other factors. The final section provides some concluding observations.

Emissions Data in This Report

This report uses GHG emissions data from two different sources: EPA and the Energy Information Administration (EIA). Estimates of total and net GHG emissions ("economy-wide") come from EPA's annual GHG emissions inventory. These estimates provide a big-picture view of U.S. GHG emission levels and GHG emission sources, particularly in the context of recent GHG emission reduction goals. EPA released the most recent version of its inventory in April 2018. This version includes GHG emissions data through 2016. In addition, the CO_2 data in EPA's CPP modeling results come from EPA. EPA released these results in 2015.

Although EPA's Inventory includes CO_2 emissions, this report uses CO_2 emissions data from EIA, because EIA's CO_2 emissions data are released on a monthly basis, including annual numbers for 2017. This allows for more recent comparisons of trends in emissions and related topics. A comparison of recent CO_2 emissions data from EPA and EIA reveals that their values vary by approximately 1%.

GHG emissions are typically measured in tons of CO_2-equivalent. This term of measure is used because GHGs vary by global warming potential (GWP). GWP is an index developed by the IPCC that allows comparisons of the heat-trapping ability of different gases over a period of time, typically 100 years. Consistent with international GHG reporting requirements, EPA's most recent GHG inventory uses the GWP values presented in the IPCC's 2007 Fourth Assessment Report. For example, based on these GWP values, a ton of methane is 25 times more potent than a ton of CO_2 when averaged over a 100-year time frame. The IPCC has since updated the 100-year GWP estimates, with some increasing and some decreasing. For example, the IPCC 2013 Fifth Assessment Report reported the 100-year GWP for methane as ranging from 28 to 36.

U.S. GHG Emissions

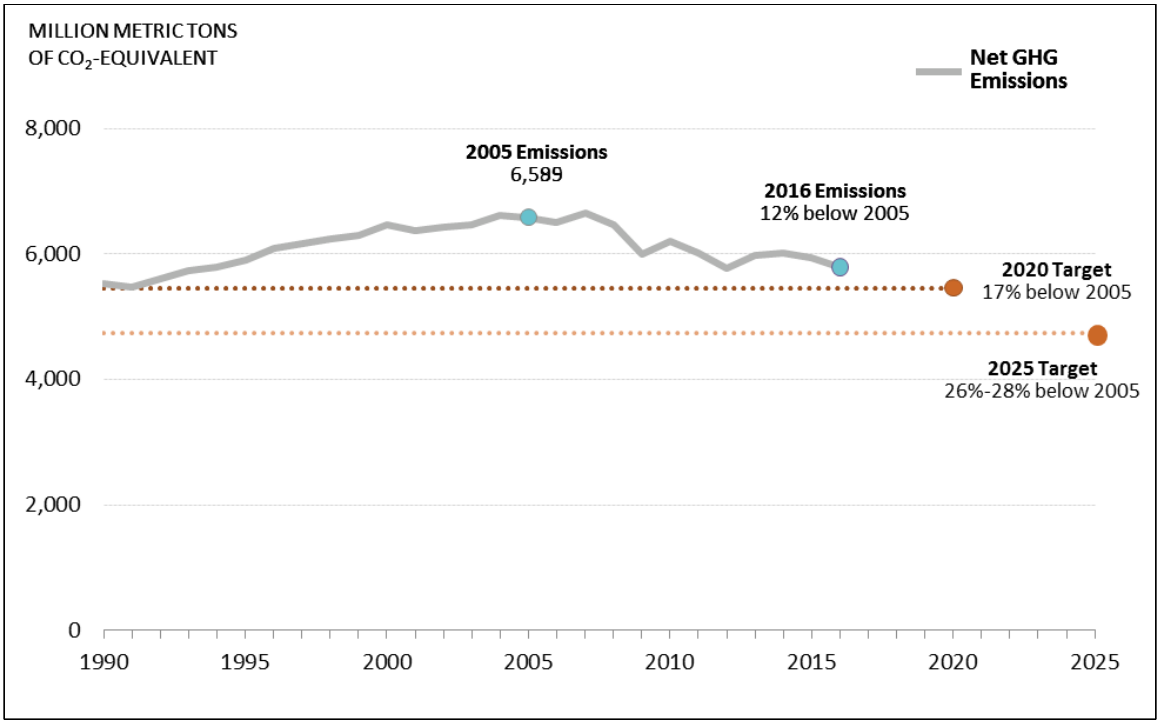
Figure 1 illustrates U.S. GHG between 1990 and 2016. As the figure indicates, U.S. GHG emissions increased 20% between 1990 and 2007 and then decreased by 10% over the next two years. Between 2010 and 2016, emissions decreased by 7%. Emissions in 2016 were roughly equivalent to 1994 emission levels.

In addition, **Figure 1** compares recent U.S. GHG emission levels to the 2020 and 2025 emissions goals made pursuant to the 2009 Copenhagen Accord and 2015 Paris Agreement, respectively. As the figure indicates, 2016 U.S. GHG emission levels were 12% less than 2005 emissions levels.

[18] For more information, see CRS Report R45393, *EPA's Affordable Clean Energy Proposal*, by Kate C. Shouse, Jonathan L. Ramseur, and Linda Tsang.

Figure 1. U.S. GHG Emissions (Net)

Compared to 2020 and 2025 Emission Targets



Source: Prepared by CRS; data from EPA, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2016*, April 2018, https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks.

Notes: Net GHG emissions includes net carbon sequestration from Land Use, Land Use Change, and Forestry. This involves carbon removals from the atmosphere by photosynthesis and storage in vegetation. See "Emissions Data in This Report" textbox for further details.

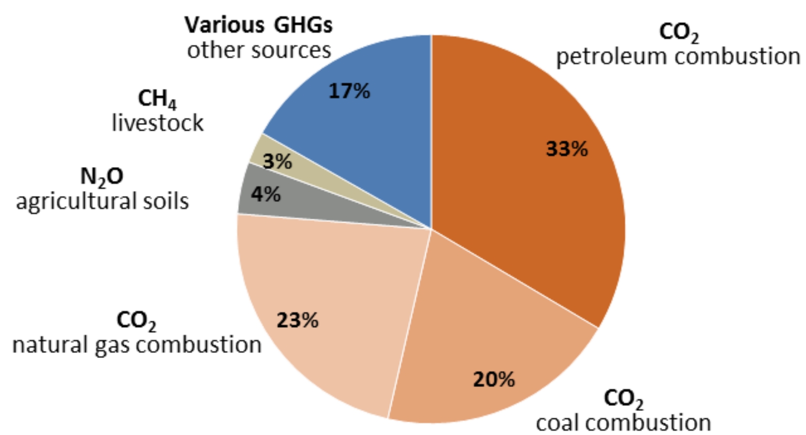
GHG Emission Sources

GHG emissions are generated throughout the United States from millions of discrete sources: power plants, industrial facilities, vehicles, households, commercial buildings, and agricultural activities (e.g., soils and livestock).[19] **Figure 2** illustrates the breakdown of U.S. GHG emissions by gas and type of source. The figure indicates that CO_2 from the combustion of fossil fuels—petroleum, coal, and natural gas—accounted for 76% of total U.S. GHG emissions in 2016. Recent legislative proposals that would address climate change have focused primarily on CO_2 emissions from fossil fuel combustion.

[19] GHG emissions are also released through a variety of natural processes such as methane emissions from wetlands. This report focuses on human-related (anthropogenic) GHG emissions.

Figure 2. U.S GHG Emissions by Source and Gas

2016 Data Measured in Metric Tons of CO_2-Equivalent



Source: Prepared by CRS; data from EPA, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2016*, April 2018, https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks. See "Emissions Data in This Report" textbox for further details.

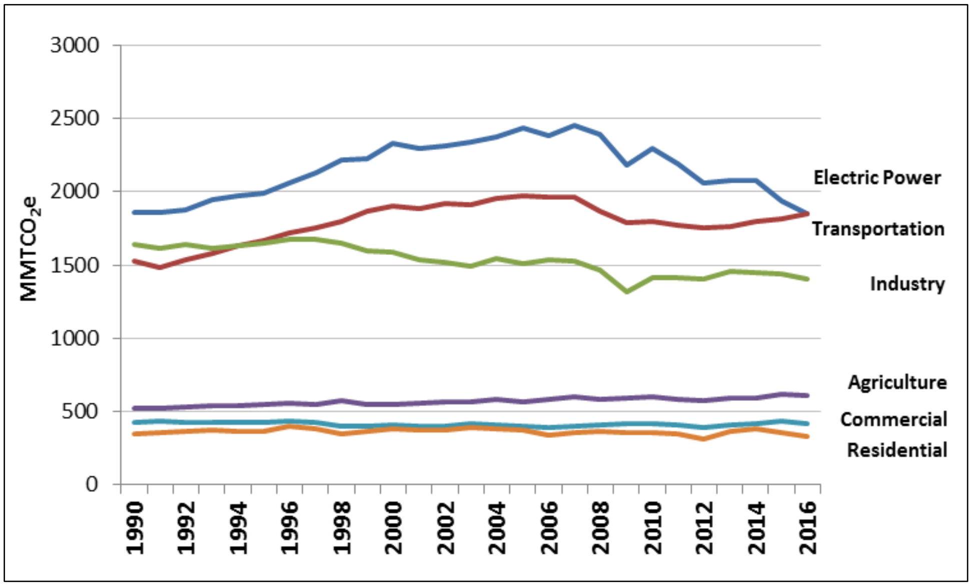
Notes: N_2O is nitrous oxide. The "Various GHGs—other sources" include the following:

Hydrofluorocarbons from the substitution of ozone-depleting substances (2%); CO_2 from non-energy fuel uses (2%); CH_4 from natural gas systems (2%), CH_4 from landfills (2%); CO_2 from iron and steel production (1%); CH_4 from coal mines (1%); and CH_4 from manure management (1%). Multiple smaller sources account for the remaining 6%. These percentages may not add up precisely due to rounding.

Another method of reporting GHG emissions is by sector. **Figure 3** illustrates the GHG emissions by sector between 1990 and 2016. As the figure indicates, GHG emissions in the electric power sector have historically accounted for the largest percentage of total U.S. GHG emissions. In the last decade, however, electric power emissions have decreased significantly (as discussed below). Whether that trend continues will likely play a large role in determining whether the United States meets its 2020 and 2025 emission targets.

Figure 3. U.S. GHG Emissions by Sector

1990-2016



Source: Prepared by CRS; data from EPA, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2016*, April 2018, https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks. See "Emissions Data in This Report" textbox for further details.

Regulations of GHG Emissions from Vehicles

On-road motor vehicles—which includes light-duty vehicles (cars, SUVs, vans, and pickup trucks) and medium- and heavy-duty vehicles (including buses, heavy trucks of all kinds, and on-road work vehicles)—are collectively the largest emitters of GHGs other than power plants. GHG emissions from on-road motor vehicles accounted for approximately 23% of total U.S. GHG emissions in 2016.[20]

EPA began to promulgate GHG emission standards for on-road vehicles in 2010 pursuant to authority under Section 202 of the Clean Air Act. EPA and the U.S. Department of Transportation's National Highway Traffic Safety Administration (NHTSA) finalized a joint rulemaking affecting fuel economy and GHG emissions from model year 2012-2016 light-duty motor vehicles on April 1, 2010 (Phase 1 standards). EPA and NHTSA promulgated a second phase of standards for vehicle model years 2017-2025 on October 15, 2012 (Phase 2 standards).

The Trump Administration proposed on August 24, 2018, amendments to the federal standards that regulate fuel economy and GHG emissions from new passenger cars and light trucks. For more information, see CRS In Focus IF10871, *Vehicle Fuel Economy and Greenhouse Gas Standards*, by Richard K. Lattanzio, Linda Tsang, and Bill Canis.

CO_2 Emissions from Fossil Fuel Combustion

Figure 4 illustrates the 2017 U.S. CO_2 emission contributions by sector from the combustion of fossil fuels. The electric power sector contributes the second-largest percentage (35%) of CO_2 emissions from fossil fuel combustion (2 percentage points behind the transportation sector). Within the electricity sector, the residential and commercial sectors each account for 13% of

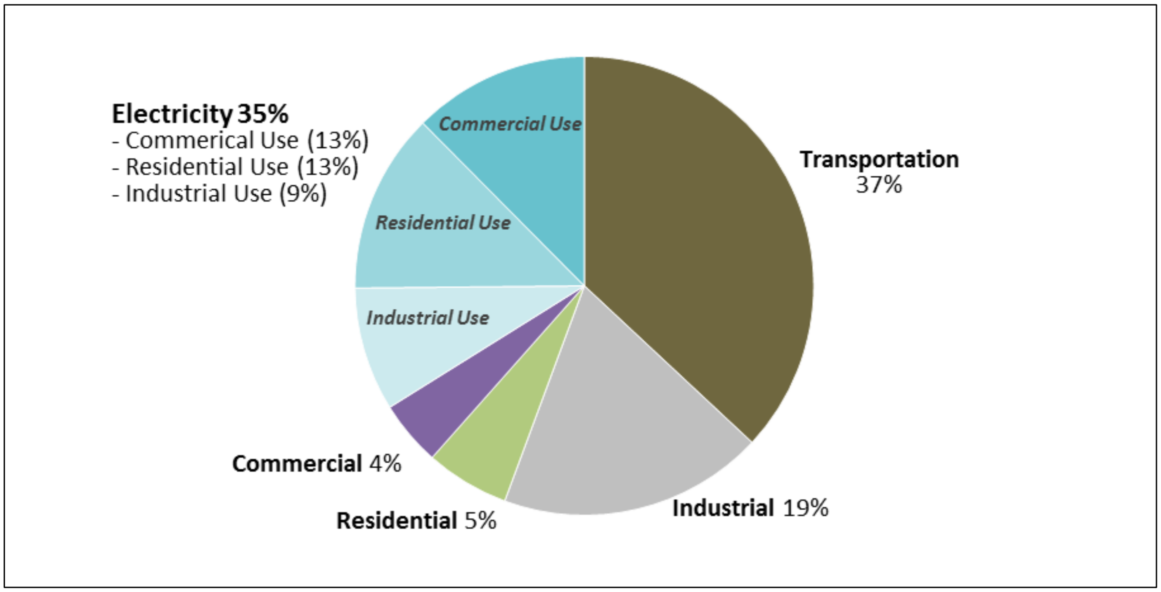
[20] Based on data from EPA, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2016*, April 2018, https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks.

fossil fuel combustion CO_2 emissions, and the industrial sector accounts for 9% of fossil fuel combustion CO_2 emissions (**Figure 4**).[21]

Many GHG emission reduction programs (e.g., the Regional Greenhouse Gas Initiative)[22] and legislative proposals have often focused on CO_2 emissions from the electricity generation sector due to the sector's GHG emission contribution and the relatively limited number of emission sources. In addition, electric power plants have been measuring and reporting CO_2 emissions to the EPA for multiple decades.

Figure 4. U.S. CO_2 Emissions from Energy Consumption by Sector

2017 Data



Source: Prepared by CRS; data from EIA, "Monthly Energy Review," Tables 12.2-12.6, https://www.eia.gov/totalenergy/data/monthly/.

Notes: CO_2 emissions related to electricity use in the transportation sector account for less than 1% of CO_2 emissions from total electricity generation. These emissions are not included in the above figure. In addition, the above chart does not include CO_2 emissions from the U.S. territories, which account for less than 1% of CO_2 emissions from energy consumption. The data in this figure do not include emissions associated with various processes that may be generated prior to combustion (e.g., fugitive CH_4 emissions from natural gas production). For more details on this issue, see CRS Report R44090, *Life-Cycle Greenhouse Gas Assessment of Coal and Natural Gas in the Power Sector*, by Richard K. Lattanzio.

CO_2 Emissions in the Electricity Sector

Figure 5 compares U.S. electricity generation with CO_2 emissions from the electricity sector between 1975 and 2017. As the figure illustrates, U.S. electricity generation generally increased between 1975 and 2007 and then decreased in 2008 and 2009. Historically, CO_2 emissions from electricity generation followed a similar course. However, in 2010, these trends decoupled. While electricity generation remained flat after 2010, CO_2 emissions continued a general trend of

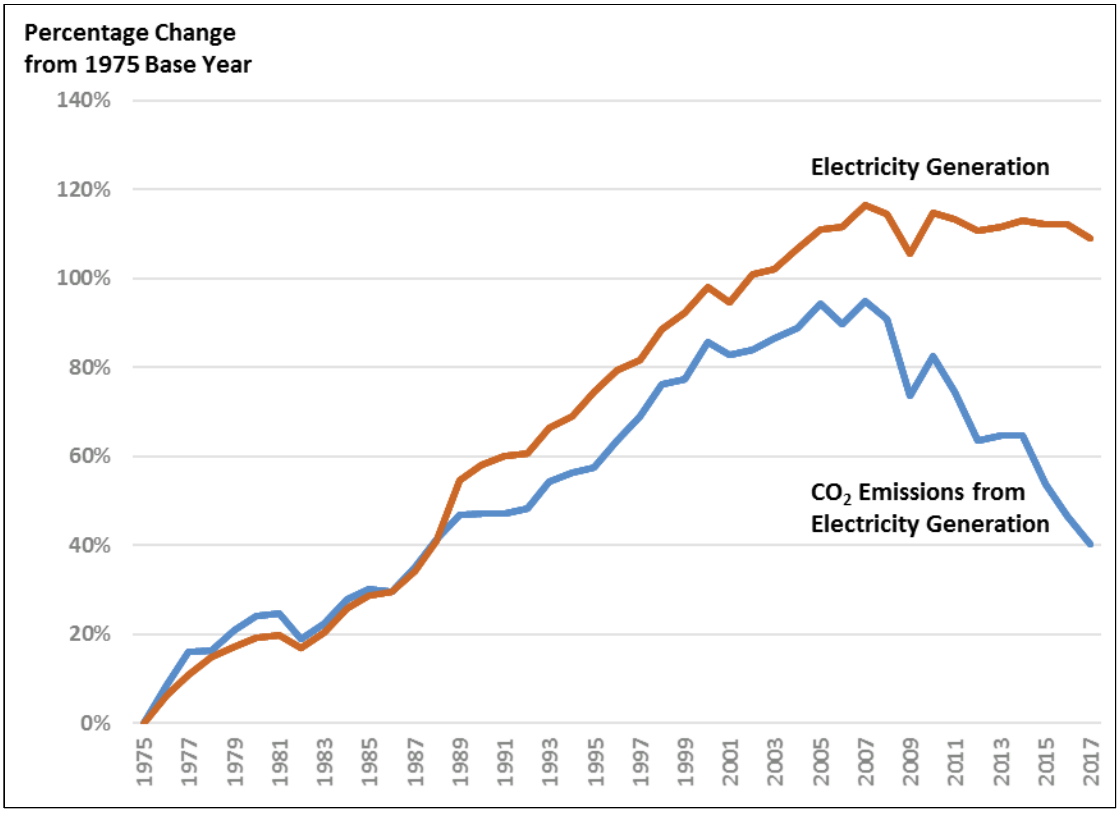
[21] CO_2 emissions related to electricity use in the transportation sector account for less than 1% of CO_2 emissions from total electricity generation.

[22] See CRS Report R41836, *The Regional Greenhouse Gas Initiative: Lessons Learned and Issues for Congress*, by Jonathan L. Ramseur.

reduction. Thus in 2017, electricity generation was essentially equivalent to generation in 2005, while CO_2 emissions were 27% below 2005 levels.

Figure 5. Electricity Generation and CO_2 Emissions from U.S. Electricity Sector

1975 - 2017



Source: Prepared by CRS; data from EIA, *Monthly Energy Review*, net electricity generation from Table 7.2 and emissions from Table 12.6, http://www.eia.gov/totalenergy/data/monthly/.

The decrease in CO_2 emissions in the electricity sector in recent years was likely a result of several factors, including overall economic conditions and electricity market developments. Historically, annual U.S. GDP decreases are a relatively uncommon occurrence: The United States has seen an annual decrease in GDP seven times over the past 50 years. The 2.9% GDP decrease in 2009 was the largest GDP decrease during that time frame.[23] The economic downturn in 2008 and 2009 resulted in a decrease of energy consumption (including electricity) across all economic sectors. The decline in electricity generation likely played a key role in the sharp decline in emission levels between 2007 and 2009.

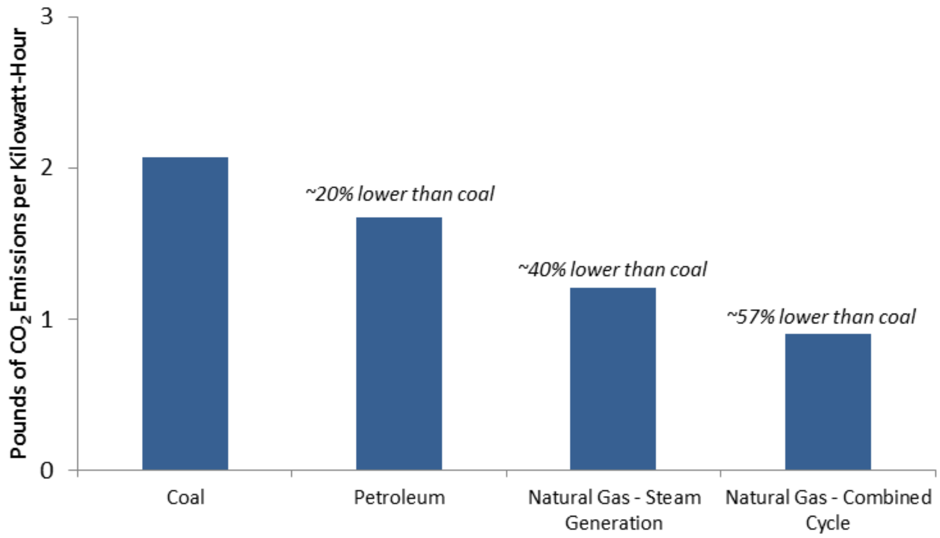
Another factor contributing to the recent decrease in CO_2 emissions from electricity generation was the change in the electricity generation portfolio. Electricity is generated from a variety of sources in the United States. Some sources—nuclear, hydropower, and some renewables—directly produce no CO_2 emissions with their electricity generation. Fossil fuels generate different amounts of CO_2 emissions per unit of electricity generated (often described as carbon intensity). **Figure 6** illustrates the relative comparison of CO_2 emissions between electricity produced from coal, petroleum, and natural gas. As the figure indicates, petroleum-fired electricity yields

[23] Bureau of Economic Analysis, gross domestic product data, http://www.bea.gov/national/index.htm.

approximately 80% of the CO_2 emission of coal-fired electricity per kilowatt-hour of electricity. Natural-gas-fired electricity from a steam generation unit yields approximately 60% of the CO_2 emissions of coal-fired electricity per kilowatt-hour of electricity. Natural-gas-fired electricity from a combined cycle unit yields approximately 43% of the CO_2 emissions of coal-fired electricity per kilowatt-hour of electricity.[24]

Therefore, a shift in the carbon intensity of the U.S. electricity generation portfolio would likely have (all else being equal) an impact on emissions from the electricity sector, which in turn, would have an impact on total U.S. GHG emissions.

Figure 6. Comparison of Fossil Fuels' Carbon Content in Electricity Generation



Source: Prepared by CRS; data from EIA, "How Much Carbon Dioxide Is Produced per Kilowatthour When Generating Electricity with Fossil Fuels?," https://www.eia.gov/tools/faqs/faq.cfm?id=74&t=11.

Notes: Carbon content values are derived by multiplying the fuel's CO_2 emission factor by the heat rate of a particular electric generating unit. In this figure, CRS used the coal emission factor for bituminous coal and the petroleum emission factor measure for distillate oil (number 2). Natural gas has only one factor. The heat rates of different electricity unit types can vary substantially. CRS used EIA's average steam generation value for coal, petroleum, and natural gas, as well as the average combined cycle value for natural gas. The above comparison does not account for the so-called life-cycle emissions associated with the energy supply chain. For more information, see CRS Report R44090, *Life-Cycle Greenhouse Gas Assessment of Coal and Natural Gas in the Power Sector*, by Richard K. Lattanzio.

Figure 7 illustrates the percentage of electricity generated by source between 2005 and 2017. As the figure indicates, the U.S. electricity generation portfolio has changed considerably in recent years. Highlights include the following:

- Coal: Between 2005 and 2017, coal-fired generation decreased by 40%. Its contribution to total electricity generation decreased from 50% to 30%.
- Natural gas: Between 2005 and 2017, natural-gas-fired generation increased by 67%. Its contribution to total electricity generation increased from 19% to 32%. *In 2016, natural gas surpassed coal in terms of percentage of total generation.*

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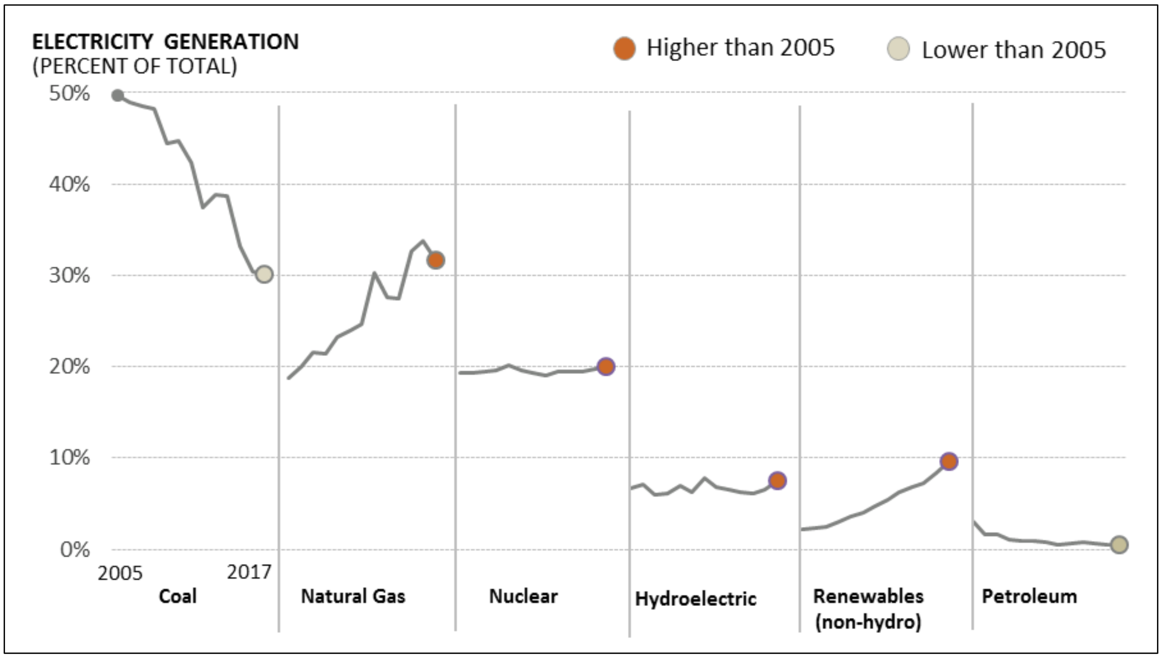
[24] For further discussion, see CRS Report R44090, *Life-Cycle Greenhouse Gas Assessment of Coal and Natural Gas in the Power Sector*, by Richard K. Lattanzio.

- Renewable energy: Between 2005 and 2017, non-hydro renewable energy generation increased by 343%. Its contribution to total electricity generation increased from 2% to 10%.

Figure 7. Percentage of Total Electricity Generation by Energy Source

2005-2017



Source: Prepared by CRS; data from EIA, *Electric Power Monthly*, Table 1.1, http://www.eia.gov/beta/epm/.

Notes: Renewable sources include wind, utility scale solar, wood fuels, landfill gas, biogenic municipal solid waste, other biomass, and geothermal. Petroleum includes petroleum liquids and petroleum coke.

Several factors likely played a role in these recent changes. Due in large part to technological advances—particularly directional drilling and hydraulic fracturing[25]—U.S. natural gas production increased dramatically (by 50%) between 2005 and 2015.[26] In 2016, production declined by 2% compared to 2015 levels but increased slightly in 2017 (about 1% higher than 2016). Relatedly, the weighted average annual price of natural gas dropped by about 60% between 2005 and 2015. By comparison, the weighted average annual coal price increased by about 40% during that time frame.[27] This change in relative fuel prices has played a key role in altering the economics of power generation (i.e., order of dispatch), leading to some natural gas displacement of coal in particular regions of the country.[28] These market forces have played a role

[25] Hydraulic fracturing is an industry technique that uses water, sand, and chemicals under pressure to enhance the recovering of natural gas and oil. It has taken on new prominence as it has been applied to tight oil and shale gas formation as an essential method for producing resources from those types of formations. See CRS Report R43148, *An Overview of Unconventional Oil and Natural Gas: Resources and Federal Actions*, by Michael Ratner and Mary Tiemann.

[26] EIA, "U.S. Dry Natural Gas Production," http://www.eia.gov/dnav/ng/hist/n9070us2a.htm.

[27] EIA, *Electric Power Annual*, Table 7.4, https://www.eia.gov/electricity/annual/html/epa_07_04.html.

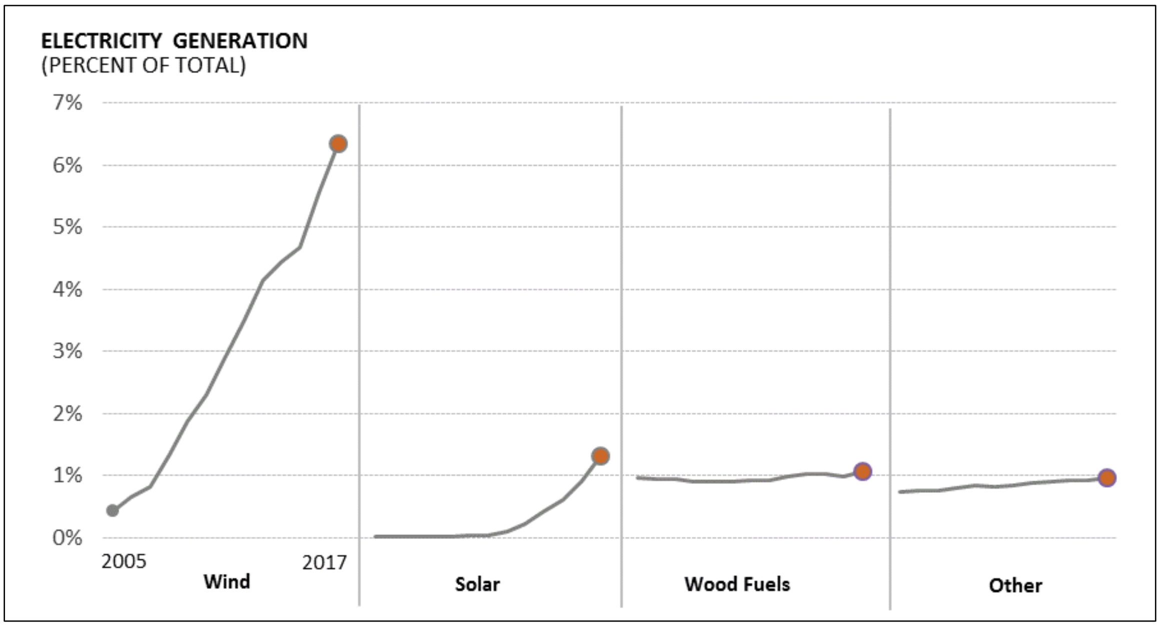
[28] See for example, EIA, *Fuel Competition in Power Generation and Elasticities of Substitution*, 2012, http://www.eia.gov/analysis/studies/fuelelasticities/.

in the retirement of coal-fired electric power plants: Between 2006 and 2016, the number of coal-fired power plants decreased from 353 to 230.[29]

Figure 8 provides a more detailed breakdown of the changes in generation from non-hydro renewable energy sources. The majority of the increased generation from renewable energy over the past 12 years is due to wind power, which increased 14-fold between 2005 and 2017. Although solar increased 96-fold over that time frame, the magnitude of wind generation exceeds solar generation: 254 Terawatt-hours of wind versus 53 Terawatt-hours of solar in 2017. Energy from wood fuels has remained relatively constant during this time frame. The increase in "other" renewable sources is due to increased use of landfill gas, which more than doubled between 2005 and 2017.

Figure 8. Percentage of Total Electricity Generation from Renewable Energy Sources (Not Including Hydroelectricity)

2005-2017



Source: Prepared by CRS; data from EIA, *Electric Power Monthly*, Table 1.1A, https://www.eia.gov/electricity/monthly/.

Notes: Solar generation does not include estimates of distributed solar generation, because EIA began to provide these estimates in 2014. Including these estimates would increase the percentage of solar generation in 2014 from 0.4% to 0.7%, in 2015 from 0.6% to 1.0%, in 2016 from 0.9% to 1.4%, and in 2017 from 1.3% to 1.9%. The "other" category includes landfill gas, biogenic municipal solid waste, other biomass, and geothermal sources.

CO_2 Emission Projections in the Electricity Sector

As the electricity sector contributes a large percentage (35%) of CO_2 emissions from fossil fuel combustion, policymakers and stakeholders are paying attention to both recent trends and future projections of CO_2 emissions in the electricity generation sector.

[29] EIA, *Electric Power Annual*, Table 4.1, 2017, https://www.eia.gov/electricity/data.php#gencapacity.

Multiple factors will likely impact CO_2 emission levels from the electricity sector. Some of these factors, which are identified below, are interrelated:

- Electricity generation portfolio (e.g., whether recent trends in coal, natural gas, and renewable energy use continue);
- Prices of fossil fuels—particularly natural gas—and renewable energy sources;
- Federal and/or state policy developments;
- Economic impacts (e.g., level of GDP growth); and
- Improvements in demand-side energy efficiency (e.g., commercial and residential electricity use).

In recent years, several groups, including EPA and EIA, have prepared projections of CO_2 emission levels in the electricity sector. The results of these emission projections are compared in **Table 1**. Many of the projections compare reference case scenarios with scenarios that assume implementation of the 2015 CPP final rule. All of the modeling scenarios below (except for EPA's 2015 projection) included the December 2015 renewable energy tax extensions.[30]

When comparing a reference case to a CPP scenario in the same model, the results generally indicate that the 2015 CPP final rule would have an impact on 2030 CO_2 emission levels from electricity generation. The difference between the two scenarios (CPP versus non-CPP) appears to be greater in the earlier studies, because the reference case scenarios in more recent studies project lower emissions by 2030 when compared to earlier studies. For example, the 2017 EIA reference case estimate was a 22% reduction below 2005 levels by 2030; the 2018 EIA reference case estimate was 28% below 2005 levels by 2030. The 2017 Rhodium Group reference case estimate was a 26% reduction below 2005 levels by 2030; the 2018 Rhodium Group estimate was 35% below 2005 levels by 2030.

In EPA's August 2018 ACE rulemaking,[31] the agency proposed, among other things, to replace the CPP. In the ACE rule, EPA proposed a more narrow interpretation of the "best system of emission reduction" than in the CPP, identifying a list of "candidate technologies" of heat rate improvement (HRI) measures at existing coal-fired units.[32] Based on this list and other unit-specific consideration, states would establish unit-specific performance standards, in contrast to the numeric performance standards (and state targets) EPA prepared for the CPP.

[30] On December 18, 2015, President Obama signed into law the Consolidated Appropriations Act, 2016 (P.L. 114-113). The act, among other provisions, extended and modified the production tax credit (PTC) and the investment tax credit (ITC) for specific renewable energy technologies. Prior to the December 2015 development, the PTC had expired, and the ITC was scheduled to expire at the end of 2016. The PTC will not be available to projects starting construction after December 31, 2019. However, PTC tax expenditures will continue after that date, because the PTC is available for the first 10 years of renewable electricity production. The ITC for solar is scheduled to decline from 30% to 26% in 2020 and 22% in 2021 before returning to the permanent rate of 10% after 2021. For further information, see CRS Report R44852, *The Value of Energy Tax Incentives for Different Types of Energy Resources: In Brief*, by Molly F. Sherlock. See also National Renewable Energy Laboratory, *Impacts of Federal Tax Credit Extensions on Renewable Deployment and Power Sector Emissions*, February 2016, http://www.nrel.gov/docs/fy16osti/65571.pdf.

[31] EPA, "Emission Guidelines for Greenhouse Gas Emissions from Existing Electric Utility Generating Units; Revisions to Emission Guideline Implementing Regulations; Revisions to New Source Review Program," 83 *Federal Register* 44746, August 31, 2018.

[32] EPA did not propose a best system of emission reduction for other types of electric generating units, such as natural gas combined cycle units.

Table 1 includes emission projections from the ACE proposal comparing CPP and non-CPP scenarios, as well as the HRI scenarios proposed in the rule.[33] In the projections from the 2018 ACE rule, the CPP and non-CPP scenarios differ by 2% (4% with the CPP demand-side efficiency scenario). The estimated percentage emission reductions between the ACE proposal HRI scenarios to replace the CPP and the non-CPP scenarios range between 0% and 1%.

Table 1. Comparison of Selected Modeling Projections: CPP and Non-CPP Scenarios

Million Metric Tons of CO_2 Emissions in Electricity Sector

Modeling Group (Year of Model)	Non-CPP Scenario: 2030 CO_2 Emissions	% Below 2005 Levels	CPP Scenario(s): 2030 CO_2 Emissions	% Below 2005 Levels
EPA (2015)	2,021	16%	1,644	32%
M. J. Bradley and Associates (2016)	1,780-1,876	22%-26%	1,577-1,729	28%-34%
National Renewable Energy Laboratory (2016)	Not included	Not included	1,448–1,556	32%-36%
Energy Information Administration (2017)	1,886	22%	1,537	36%
Rhodium Group (2017)	1,774	26%	1,524	37%
Rhodium Group (2018)	1,571	35%	Not included	Not included
EIA (2018)				
- *Reference Case*	1,739	28%	1,534	36%
- *Range from other scenarios*	1,778-1,605	26%-34%	1,534-1,448	36%-38%
EPA (2018)				
- Reference Case	1,643	32%	1,576-1,538	34%-36%
- ACE proposed rule scenarios to replace the CPP	1,619-1,631	32%-33%	NA	

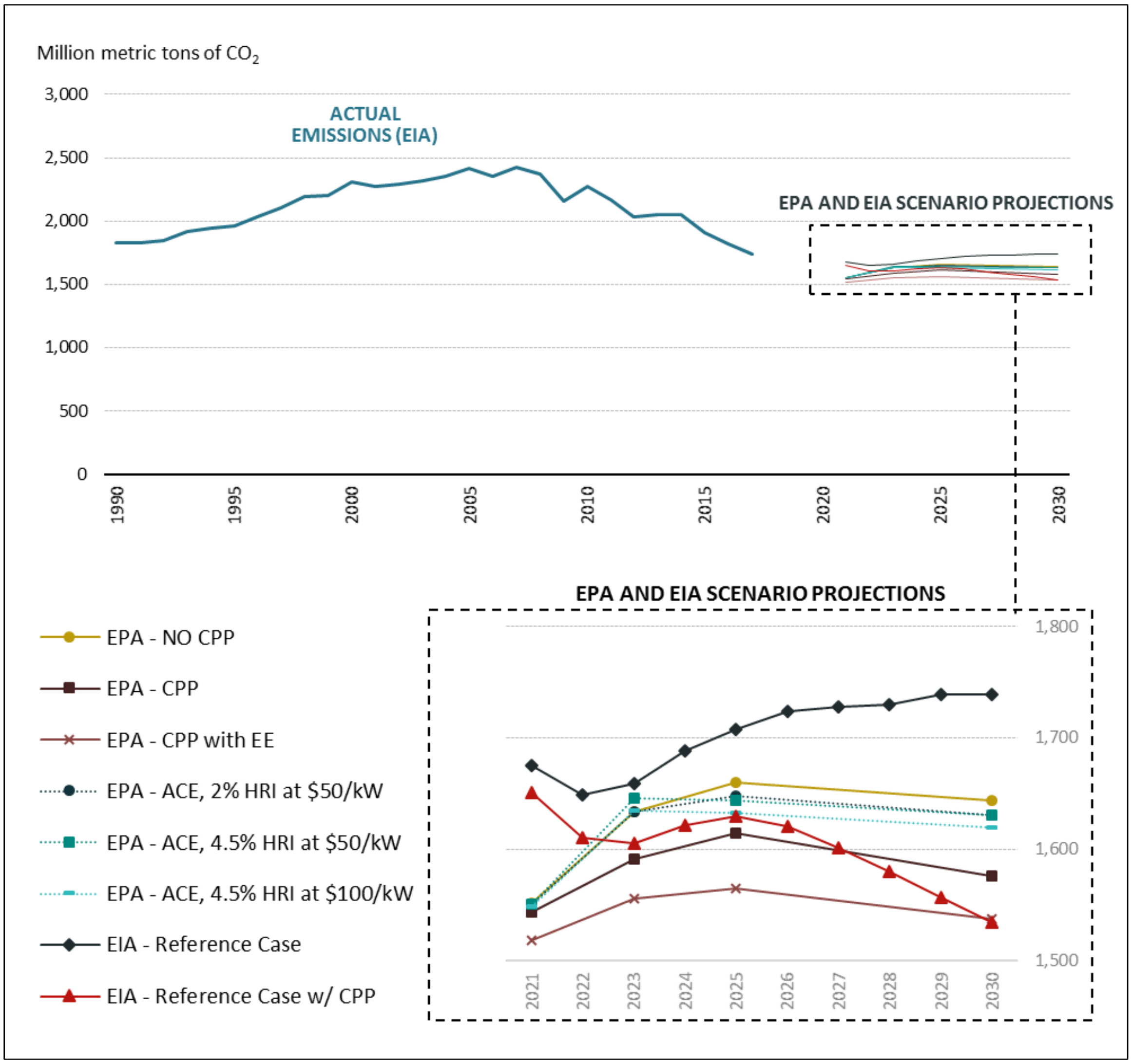
Source: EPA 2015 data from the agency's Power Sector Modeling, 2015, http://www.epa.gov/airmarkets/programs/ipm/cleanpowerplan.html; 2018 data from EPA, *Regulatory Impact Analysis for the Proposed Emission Guidelines for Greenhouse Gas Emissions from Existing Electric Utility Generating Units; Revisions to Emission Guideline Implementing Regulations; Revisions to New Source Review Program*, 2018; EIA data from *Annual Energy Outlook 2017*, 2017, https://www.eia.gov/outlooks/aeo/; *Annual Energy Outlook 2018*, 2018; Rhodium Group data from "Taking Stock 2017: Adjusting Expectations for US GHG Emissions," 2017, http://rhg.com/reports/taking-stock-2017-adjusting-expectations-for-us-ghg-emissions; and personal correspondence with authors to provide 2030 estimate for CPP scenario; and "Taking Stock 2018," 2018, https://rhg.com/research/taking-stock-2018; M. J. Bradley and Associates data from "EPA's Clean Power Plan Summary of IPM Modeling Results with ITC/PTC Extension," 2016, http://www.mjbradley.com/reports/updated-modeling-analysis-epas-clean-power-plan. National Renewable Energy Laboratory data from *Impacts of Federal Tax Credit Extensions on Renewable Deployment and Power Sector Emissions*, 2016, http://www.nrel.gov/docs/fy16osti/65571.pdf (and personal correspondence with report authors).

Notes: The groups in the table used different values for 2005 emission levels, but the differences were minimal. The percentage reductions in the table are based on the specific group's emission level in 2005.

[33] For more information on the ACE proposal, see CRS Legal Sidebar LSB10198, *EPA Proposes the Affordable Clean Energy Rule to Replace the Clean Power Plan*, by Linda Tsang.

Figure 9 provides a comparison between the actual CO_2 emissions in the electricity sector (1990-2017) and the CPP and non-CPP scenario projections from the 2018 analyses prepared by EIA and EPA. The figure also includes the ACE proposal scenarios that would replace the CPP.

Figure 9. Actual and Projected CO_2 Emissions in the Electricity Sector



Source: EPA, Analysis of the Proposed ACE Rule (modeling results), https://www.epa.gov/airmarkets/analysis-proposed-ace-rule; EIA, *Annual Energy Outlook 2018*, 2018, https://www.eia.gov/outlooks/aeo/.

Notes: In the ACE scenarios, EPA's model required each affected coal-fired unit to improve its heat rate by 2% or 4.5% at a capital cost of $50 or $100 per kilowatt. The model allowed a source to either adopt the improvement or retire, depending on the economics of either option. For more details regarding the assumptions in EPA's analysis see EPA, *Regulatory Impact Analysis for the Proposed Emission Guidelines for Greenhouse Gas Emissions from Existing Electric Utility Generating Units; Revisions to Emission Guideline Implementing Regulations; Revisions to New Source Review Program*, 2018, https://www.epa.gov/sites/production/files/2018-08/documents/utilities_ria_proposed_ace_2018-08.pdf.

Concluding Observations

International negotiations and domestic policy developments continue to generate congressional interest in current and projected U.S. GHG emission levels. U.S. GHG emission levels will likely depend, to some degree, on CO_2 emissions from power plants. Historically, CO_2 emissions from electricity generation have followed an upward course similar to electricity generation levels. However, in 2010, their courses diverged. While electricity generation has remained flat in recent years, CO_2 emissions have continued a trend of reduction. In 2017, electricity generation was essentially equivalent to generation in 2005, while CO_2 emissions were 27% below 2005 levels.

Multiple factors generally impact CO_2 emission levels from the electric power sector. Recent changes in the U.S. electricity generation portfolio between 2005 and 2017 played a key role:

- Coal's contribution to total electricity generation decreased from 50% to 30%;
- Natural gas's contribution to total electricity generation increased from 19% to 32%; and
- Non-hydro renewable energy (wind and solar) generation increased from 2% to 10%.

If these recent changes in the electricity generation portfolio continue, CO_2 emissions in the electricity sector will likely continue to decrease (assuming electricity consumption remains flat). Total U.S. GHG emissions should continue to decline as well, assuming the emission levels in other economic sectors remain flat.

Accurately forecasting future emission levels is a complex and challenging endeavor. Consequently, analysts often provide a range of emissions based on different scenarios or assumptions. The EIA provides annual forecasts of CO_2 emissions in its *Annual Energy Outlook* (AEO) publications. Regarding its various estimates, EIA states the following:

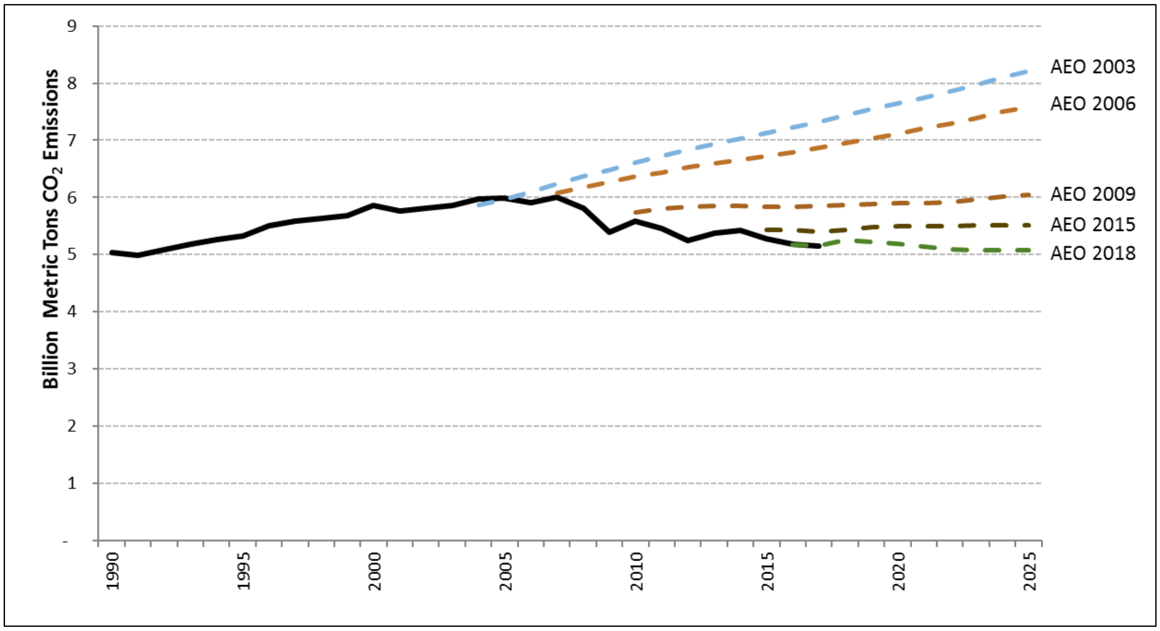
> Projections in the Annual Energy Outlook 2018 (AEO2018) are not predictions of what will happen, but rather modeled projections of what may happen given certain assumptions and methodologies.... Projections in the AEO should be interpreted with a clear understanding of the assumptions that inform them and the limitations inherent in any modeling effort.[34]

Figure 10 compares actual CO_2 emissions between 1990 and 2017 with selected EIA emission projections made in past years. In general, actual emissions have remained well below projections. For example, the AEO from 2006 projected that CO_2 emissions would be almost 6.9 billion metric tons in 2017, about 33% higher than observed emissions. By comparison, the more recent projections (AEO 2015 and AEO 2018) indicated that CO_2 emissions would remain relatively flat or experience modest declines through 2025.

[34] EIA, *Annual Energy Outlook 2018*, February 2018, https://www.eia.gov/outlooks/aeo/.

Figure 10. Actual CO_2 Emissions and Selected Past EIA CO_2 Emission Projections

CO_2 Emissions from Energy Use



Source: Prepared by CRS; data from EIA *Annual Energy Outlook* and *Monthly Energy Outlook* publications, http://www.eia.gov.

Notes: EIA publishes annual projections. The above figure includes projections from every third year since 2003. The projection from AEO 2012 is omitted because it is nearly identical to the AEO 2015 projection.

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