CHAPTER 7

ADDRESSING CLIMATE CHANGE

Introduction

Addressing climate change and transitioning to a clean energy system is one of the greatest and most urgent challenges of our time. If left unchecked, greenhouse gas (GHG) emissions threaten future national and global welfare and economic output. The impacts of climate change are real and being felt today. Fifteen of the sixteen warmest years on record globally have occurred between 2000 and 2015, and 2015 was the warmest year on record. Although it is difficult to link specific weather events to climate change, some extreme weather events have become more frequent and intense, consistent with climate model predictions. The number of weather events that have led to damages in excess of $1 billion has been increasing in recent years due to both climate change and economic development in vulnerable areas.

Without proactive steps to reduce greenhouse gas emissions and slow the climate warming already being observed, future generations will be left with—at a minimum—the costly burden of facing the impacts of a changed climate on our planet, and potentially with catastrophic climate impacts. From an economic perspective, the causes of global climate change involve a classic negative environmental externality. The prices of goods and services in our economy do not reflect their full costs because they do not incorporate the costs of the impacts of greenhouse gas emissions associated with their production and consumption. Policies that internalize these costs will improve social welfare while reducing the odds of catastrophic climate events. In addition to the costs incurred to date, delaying policy action can increase both future climate change damages and the cost of future mitigation.

Addressing the environmental externalities from climate change involves changing the long-run trajectory of our economy toward a more energy efficient and lower greenhouse gas-emitting path. Since President Obama took office, substantial strides have been made toward achieving this goal. Between 2008 and 2015, the U.S. energy system has shifted considerably toward cleaner energy resources. Energy intensity, which refers to energy consumed per dollar of real gross domestic product (GDP), declined by 11 percent from 2008 to 2015, following a pattern of steady decline over the past four decades. Carbon intensity, the amount of carbon dioxide emitted per unit of energy consumed, has declined by 8 percent from 2008 to 2015, and carbon dioxide emitted per dollar of GDP has declined by 18 percent over this period. In fact, U.S. carbon dioxide emissions from the energy sector fell by 9.5 percent from 2008 to 2015, and in the first 6 months of 2016 they were at the lowest level in 25 years. These trends, in combination, are favorable for climate change mitigation, and all have occurred while the economy recovered from the Great Recession. The economy has grown by more than 10 percent since 2008, and by more than 13 percent from its recession low point in 2009.

Since mitigating climate change serves a public good benefiting all countries, it also involves working with other countries to reduce greenhouse gas emissions worldwide. In addition to mitigation, addressing climate change involves building resilience to current and future impacts, developing adaptation plans and preparing for the changing frequency and severity of extreme events. Steps taken by the United States, along with extensive outreach to other countries, subsequently helped pave the way for the 2015 Paris Agreement in which more than 190 countries committed to take concrete steps to reduce greenhouse gas emissions. The Paris Agreement establishes a long-term, durable global framework with the aim of keeping climate warming to well below 2 degrees Celsius.

Given that the impacts of climate change are already being felt today and, that even with aggressive mitigation, impacts will continue into the future, the optimal response to climate change includes not only mitigation, but also adaptation. Building resilience to the current and future impacts of climate change is akin to insuring against the uncertain future damages from climate change. In parallel with domestic mitigation and global cooperation, Administration policies have also promoted resilience.

This chapter reviews the economic rationale for the Administration's efforts on climate change and the transformation of the energy system. It provides an overview of a selection of the most important policy efforts and then examines the key economic trends related to climate change and energy, many of which have already been influenced, and will be increasingly influenced going forward by policy measures under the Administration's 2013 Climate Action Plan. These trends include increases in electricity generation from natural gas and renewable energy resources, improvements in energy efficiency, and shifts in transportation energy use. The chapter also analyzes the sources of these trends, by decomposing emissions reductions in the power sector as attributable to lower-carbon fossil-fuel resources and renewable energy generation, as well as by decomposing emissions reductions in the entire economy as attributable to lower energy intensity, lower carbon intensity, and a lower than expected level of GDP due to economic shocks, primarily the Great Recession. Understanding the driving forces behind these trends allows for an assessment of how the multitude of policy mechanisms utilized in this Administration have helped the United States pursue a more economically efficient path that addresses environmental and other important externalities.

Consistent with long-standing policy, the Administration has worked to ensure that regulations that affect carbon emissions and other climate-related policies are undertaken in an efficient and cost effective manner. Rigorous regulatory impact analyses demonstrate that economically efficient mechanisms were used to achieve climate goals. Policies put in place since 2008 will generate substantial net benefits. The first-ever carbon pollution standards for power plants would reduce greenhouse gas emissions significantly and, depending on the methods states use to comply, could generate net benefits of $15 billion to $27 billion just in 2025. Greenhouse gas standards for light-duty cars and trucks are also estimated to have sizable net benefits. The first-ever national greenhouse gas and fuel economy standards for commercial trucks, buses, and vans should generate hundreds of billions of dollars in net benefits over the life of the vehicles affected by the rule.

Other policies will either make energy cleaner or reduce energy use. The Administration extended tax credits for wind and solar projects, first in the 2009 American Recovery and Reinvestment Act (the Recovery Act) and again in 2015. The Recovery Act included substantial funding for both energy efficiency and renewables development (CEA 2016c). In addition, stronger energy efficiency standards for residential and commercial appliances, and many others, are projected to generate substantial net economic benefits to the U.S. economy.

The long time horizons for these policies, reinforced by the Administration's substantial investments in research and development for clean energy technologies, will continue to spur innovation and ensure that recent energy-sector shifts will have a durable impact on the economy and the climate.

The Administration's climate policies go well beyond what is discussed in this chapter. Rather than provide a comprehensive review of implemented and planned policies, this chapter focuses on the economics of domestic actions to reduce greenhouse gas emissions and transition to cleaner sources of energy. Additional Federal policies and programs are assessed in other Administration documents.[1] The chapter also draws on analyses from energy and climate chapters in prior *Economic Reports of the President* (CEA 2013, 2015a).

The Economic Rationale for Climate Action

Climate change is not just a future problem—the costly impacts of changing weather patterns and a warming planet are being felt now (U.S. Global Change Research Program 2014). Fifteen of the sixteen warmest years on record globally have occurred between 2000 and 2015, and the 2015 average temperature was the highest on record (NOAA 2016a). Each of the first 8 months in 2016 set a record as the warmest respective month globally in the modern temperature record, dating to 1880; in fact, August 2016 marked the 16th consecutive month that the monthly global temperature record was broken, the longest such streak in 137 years of recordkeeping (NOAA 2016b). Not only are temperatures rising on average, but heat waves—which have detrimental human health impacts—have also been on the rise in Europe, Australia, and across much of Asia since 1960 (IPCC 2013). Among extreme weather events, heat waves are a phenomenon for which the scientific link with climate change is fairly robust. For example, studies suggest that climate change doubled the likelihood of heat waves like the one that occurred in Europe in 2003, which is estimated to have killed between 25,000 and 70,000 people, and that deadly heat in Europe is 10 times more likely today than it was in 2003 (Christidis et al. 2015; Stott 2004; Robine et al. 2008; D'Ippoliti et al. 2010).

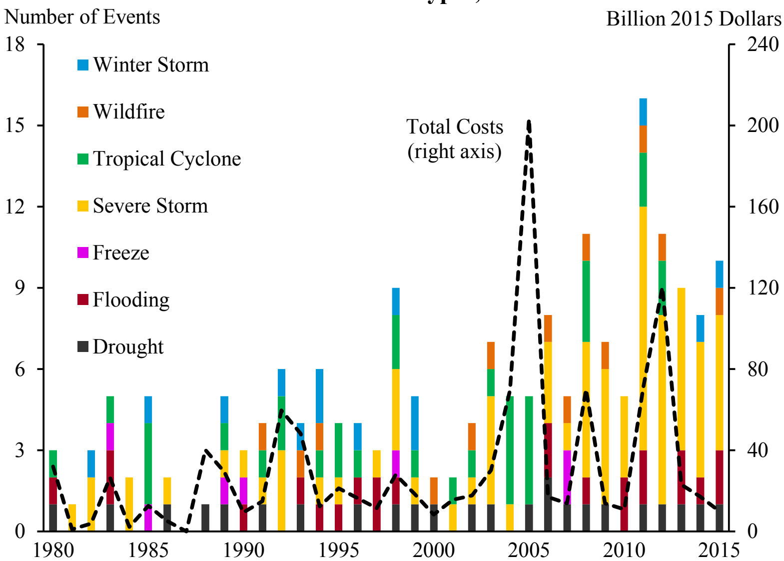
Wildfires and certain types of extreme weather events such as heavy rainfall, floods, and droughts with links to climate change have also become more frequent and/or intense in recent years (Department of State 2016b; U.S. Global Change Research Program 2014). As illustrated in Figure 7-1, the annual number of U.S. weather events that cause damages exceeding $1 billion has risen dramatically since 1980, due both to climate change and to increasing economic development in vulnerable areas (NOAA 2016c).[2] An intense drought that has plagued the West Coast of the United States since 2013 led to California's first-ever statewide mandatory urban water restrictions (California Executive Department 2014).

---

[1] For discussion of clean energy investments under the American Recovery and Reinvestment Act, see CEA (2016c). For additional reviews of the Administration's climate policies, see DOE (2015), EPA (2015a), and Department of State (2016b).

[2] Regional economic development can increase the magnitude of damages from weather-related events because economic growth increases the assets (and population) at risk.

Figure 7-1
Billion-Dollar Event Types, 1980–2015



Source: National Oceanic and Atmospheric Administration.

As atmospheric levels of carbon dioxide have increased, the amount of carbon dioxide dissolved in the ocean has risen all over the world, increasing ocean acidification and threatening marine life. Further, over the past 100 years, the average global sea level has risen by more than 8 inches, leading to greater risk of erosion, flooding, and destructive storm surges in coastal areas (U.S. Global Change Research Program 2014).

Growing research also links climate change with diminished health and labor productivity in the United States, due to both temperature and pollution increases (EPA 2015a; Crimmins 2016). For example, recent research finds that when daily maximum temperatures exceed 85 degrees Fahrenheit, U.S. labor supply is reduced by as much as one hour a day (relative to the 76- to 80-degree range) for outdoor industries such as construction and farming (Graff Zivin and Neidell 2014). Studies also suggest strong links between warming and mortality—an additional day of extreme heat (above 90 degrees Fahrenheit) can lead to an increase in annual age-adjusted U.S. mortality rates of around 0.11 percent relative to a day in the 50- to 60-degree range (Deschênes and Greenstone 2011).[3] Warmer temperatures can also lead to higher urban levels of ozone, an air pollutant that affects

[3]This study and the others cited here analyze inter-annual weather variation to estimate climate impacts. As such, they may overstate climate impacts, because less-costly adaptation activities may be available over longer time horizons in response to permanent climate changes than are available in response to short-term weather shocks.

people and vegetation (U.S. Global Change Research Program 2014). For example, in the California agricultural sector, a decrease in ozone concentration by 10 parts per billion can lead to a more than 5-percent increase in worker productivity (Graff Zivin and Neidell 2012). These studies represent just a small selection of the growing body of evidence on the economic costs of climate change.

Based on the current trajectory and the results of climate science research, the economic costs from warmer temperatures and changing weather patterns are expected to grow in the coming years. Increased temperatures due to climate change could lead to a 3-percent increase in age-adjusted mortality rates and an 11-percent increase in annual residential energy consumption (as demand for air conditioning increases) in the United States by the end of the century (Deschênes and Greenstone 2011). Average U.S. corn, soybean, and cotton yields may decrease by 30 to 46 percent by 2100, assuming no change in the location and extent of growing areas, and assuming that climate warming is relatively slow (Schlenker and Roberts 2009).[4] Extreme heat is also expected to affect labor productivity and health: by 2050, the average American will likely see the number of 95-degree Fahrenheit days more than double relative to the last 30 years, and labor productivity for outdoor workers may fall by as much as 3 percent by the end of the century (Risky Business Project 2014). Within the next 15 years, assuming no additional adaptation, higher sea levels and storm surges will increase the estimated damage costs from coastal storms by $2 billion to $3.5 billion annually in the United States, and these costs are projected to increase to $42 billion annually by the end of the century (Risky Business Project 2014). Based on emissions trajectories in 2014, by 2050 existing U.S. coastal property worth between $66 billion and $106 billion could be at risk of being inundated, with the Eastern and Gulf coasts particularly affected (again, assuming no additional adaptation) (Risky Business Project 2014).

The impacts of climate change will also affect the U.S. Federal Budget. For example, an increase in the frequency of catastrophic storms, along with rising seas, will require more disaster relief spending, flood insurance payments, and investments to protect, repair, and relocate Federal facilities. Changing weather patterns and extreme weather events will affect American farmers and thus expenditures on Federal crop insurance and disaster payments. Health impacts of climate change will increase Federal health care expenditures. An increase in wild-land fire frequency and intensity

[4] Like the studies on human health, economic estimates of the agricultural impacts of climate change are based on inter-annual weather variation and may overstate climate impacts, if less costly adaptation activities are available over long time horizons in response to permanent climate change.

will strain Federal fire suppression resources. In addition to these likely increases in expenditures, climate change is expected to reduce economic output and diminish Federal revenue. A recent report by the U.S. Office of Management and Budget projects that the combined detrimental impacts of climate change on Federal revenues and expenditures by 2100 could easily exceed $100 billion annually, when the estimates are expressed in terms of their equivalent percentage of current U.S. GDP (OMB 2016).

Addressing Externalities

The impacts of climate change present a clear economic rationale for policy as a means to both correct market failures and as a form of insurance against the increased risk of catastrophic events. Climate change reflects a classic environmental externality. When consumers or producers emit greenhouse gases, they enjoy the benefits from the services provided by the use of the fuels, while not paying the full costs of the damages from climate change. Since the price of goods and services that emit greenhouse gases during production does not reflect the economic damages associated with those gases, market forces result in a level of emissions that is too high from society's perspective. Such a market failure can be addressed by policy. The most efficient policy would respond to this market failure by putting an economy-wide price on the right to emit greenhouse gases. In the absence of a uniform carbon price to regulate emissions, however, other climate policy mechanisms can improve social welfare by pricing emissions indirectly. For example, putting in place emission limits and incentivizing low-carbon alternatives can make carbon-intensive technology relatively more expensive, shifting demand toward less carbon-intensive products, and thus reducing emissions. Energy efficiency standards can reduce energy use, implicitly addressing the external costs of emissions and resulting over-consumption of energy. Gasoline or oil taxes help to directly address the external costs due to emissions from the combustion of oil.

Correcting Other Market Failures

Some policies to address the climate change externality have an additional economic benefit from addressing other market failures. For example, reducing carbon dioxide emissions through lower carbon electricity generation often also reduces the emissions of local and regional air pollutants that cause damage to human health, a second environmental externality.

There are also innovation market failures where some of the returns from investment in innovation and new product development spill over to other firms from the firm engaged in innovation. For example, there is substantial evidence that the social returns from research and development investment are much higher than the private returns due to some of the knowledge spilling over to other firms.[5] Though in principle these positive spillovers can be good for society, they prevent the innovating firms from capturing the full returns to their investments in technological innovation, resulting in less than the efficient level of investment. While not specific to the energy area, the failure to internalize the positive spillovers to research into technologies that would reduce carbon emissions is compounded by the failure to take into account the external cost of carbon emissions.

Other market failures that may be partly addressed by climate-oriented policies include information market failures due to inadequate or poor information about new clean energy or energy-efficient consumer technologies, and network effects (such as, a situation where the value of a product is greater when there is a larger network of users of that product) that consumers do not consider in their decisions on the purchase of new clean energy technologies. While not market failures, per se, vulnerability to supply disruptions and the potential macroeconomic effects of oil price shocks provide additional reasons to invest in clean transportation technologies. These factors, taken together, can lead to an underinvestment in research, as well as underinvestment in energy efficiency and deployment of clean energy, and can provide additional economic motivations for policy. For example, energy efficiency standards may help address information market failures that hamper consumers' ability to understand the energy costs of different product choices, and policies promoting clean transportation infrastructure may reduce vulnerability to oil supply disruptions.

Insurance against Catastrophe

Despite a large body of research on how human activities are changing the climate, substantial uncertainty remains around the amount and location of damages that climate change will cause. This is because there are cascading uncertainties from the interplay of key physical parameters (such as the exact magnitude of the global temperature response to the atmospheric buildup in greenhouse gases), the local and regional manifestations of global climate change, the vulnerabilities of different economic sectors, and the adaptation measures that could decrease impacts. For example, climate scientists have developed probability distributions of the sensitivity of the climate to increases in the concentration of greenhouse gases in the atmosphere, and there is some small, but non-zero probability of very high

[5] See Jaffe and Stavins (1994) or Gillingham and Sweeney (2012) for more on innovation market failures in the context of clean energy.

climate sensitivity.[6] With the possibility of significant climate sensitivity, coupled with the possibility of high future greenhouse gas emissions, the risk of irreversible, large-scale changes that have wide-ranging and potentially catastrophic consequences greatly increases. The term "tipping point" is commonly used to refer to a "critical threshold at which a tiny perturbation can qualitatively alter the state of development of a system" (Lenton et al. 2008). When it comes to climate, at a tipping point, a marginal increase in emissions could make a non-marginal—and potentially irreversible—impact on damages. Hypothetical climate tipping points could lead to catastrophic events like the disappearance of Greenland ice sheets and associated sea level rise, or the destabilization of Indian summer monsoon circulation.

It is impossible to know precisely how likely or how costly these low-probability, high-impact events, or "tail risks" are, but we do know that the associated costs and impacts on human society would be very substantial and that their likelihood increases with higher atmospheric concentrations of greenhouse gases. Economists have been increasingly interested in understanding how these tail risks should be incorporated into policy choices. A series of papers by Martin Weitzman lay out an analytical framework for understanding policy under conditions with catastrophic fat tail risks (such as the risk of a catastrophe that has more probability weight than it would in a normal distribution).[7] Weitzman's analysis points out that, under certain conditions, the expected costs of climate change become infinitely large.[8] While there has been an active debate in the literature on the conditions under which Weitzman's findings may apply, his work both underscores the importance of understanding tail risks, and provides an economic rationale for taking early action to avoid future, potentially very large risks.[9] Just as individuals and businesses routinely purchase insurance to guard against risks in everyday life, like fire, theft, or a car accident, and just as conservative safety standards guard against catastrophic failures at major infrastructure like nuclear plants and highway bridges, climate policy can be seen as protection against the economic risks—small and large—associated with climate change.

---

[6] According to the IPCC, equilibrium climate sensitivity is likely in the range 1.5°C to 4.5°C (high confidence), extremely unlikely less than 1°C (high confidence), and very unlikely greater than 6°C (medium confidence) (IPCC 2013).
[7] For example, a Student's t-distribution is a fat-tailed distribution.
[8] Weitzman's "Dismal Theorem" is presented and discussed in several papers: Weitzman (2009), Weitzman (2011), and Weitzman (2014). Further analyses of the "theorem" include Newbold and Daigneault (2009), Nordhaus (2009), and Millner (2013).
[9] In fact, Weitzman's conditions are not necessary for there to be an economic motivation: there is a broader economic motivation for a precautionary policy with a sufficiently risk averse or loss averse decision-maker.

Delaying Action on Climate Change Increases Costs

When considering climate change policy from an economic perspective, it is critical to consider not just the cost of action but also the cost of inaction. Delaying climate policies may avoid or reduce expenditures in the near term, but delaying would likely increase costs substantially in the longer run. The economic literature discusses two primary mechanisms underlying the substantial increase in costs from delayed action.

First, if delay leads to an increase in the ultimate steady-state concentration of greenhouse gases, then there will be additional warming and subsequent economic damages in the long run. Using the results of a leading climate model, CEA (2014) estimates that if a delay causes the mean global temperature to stabilize at 3 degrees Celsius above preindustrial levels instead of 2 degrees, that delay will induce annual additional damages of approximately 0.9 percent of global output. (To put that percentage in perspective, 0.9 percent of output in the United States in 2015 alone was over $160 billion.) The next degree increase, from 3 degrees to 4 degrees, would incur even greater *additional* costs of approximately 1.2 percent of global output. It is critical to note that these costs would be incurred year after year.

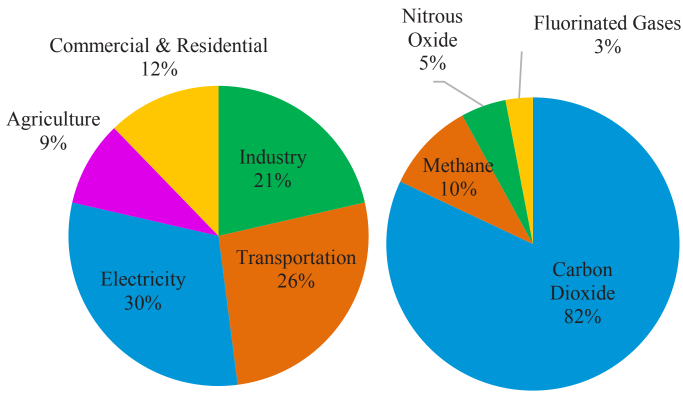
Second, if the delayed policy aims to achieve the same carbon target as a non-delayed policy, then the delayed policy will require more stringent actions given the shorter timeframe. More stringent actions will generally be more costly, though technological innovation can make future mitigation cheaper than it is today, lowering the future cost of low-carbon technologies needed to meet the target. In addition, since investment in innovation responds to policy, taking meaningful steps now sends a long-term signal to markets that the development of low-carbon technologies will be rewarded. At the same time, this signal creates a disincentive for investing in new high-carbon infrastructure that would be expensive to replace later on. CEA (2014) estimates the costs of delaying the achievement of a specific target—by these calculations, if the world tries to hit the goal stated in Paris of less than a 2-degree increase in the global mean surface temperature relative to pre-industrial levels, but waits a decade to do so, the cost of limiting the temperature change would increase by roughly 40 percent relative to meeting the goal without the decade delay.[10]

Administration Climate Policies

Since President Obama took office in 2009, the Administration has undertaken numerous steps toward both mitigating climate change and

[10] These estimates, as further described in CEA (2014), are developed from a meta-analysis of research on the cost of delay for hitting a specific climate target.

Figure 7-2
Greenhouse Gas Emissions by Type and Sector in 2014



Source: Environmental Protection Agency.

responding to its effects. Greenhouse gas emissions in the United States amounted to 6,870 million metric tons of carbon dioxide equivalents in 2014 (the most recent inventory), and these emissions are spread over several sectors, as shown in the left chart of Figure 7-2.[11] In 2014, carbon dioxide emissions made up 82 percent of total greenhouse gas emissions; methane, 10 percent; nitrous oxides, 5 percent; and fluorinated gases, 3 percent (right chart of Figure 7-2) (EPA 2016a). The electricity sector in 2014 generated the largest share of emissions—nearly a third—which together with the fact that some of the least-expensive marginal emissions reductions opportunities are in the power sector (Kaufman, Obeiter and Krause 2016) motivate the Clean Power Plan and clean energy investments (discussed below). Transportation follows with 26 percent of emissions, motivating a variety of efficiency and innovation policies in the transportation sector.[12]

The Administration's steps to address greenhouse gases cover nearly all sectors and gases. These steps help reduce emissions both now and in the longer term by promoting low-carbon electricity generation, dramatically improving energy efficiency for many products, facilitating the transition to a cleaner transportation system, reducing emissions of high-potency greenhouse gases, and bolstering our land-sector sink (the capacity of land

[11] These are gross greenhouse gas emissions. Note that the Administration's multi-year GHG reduction targets are based on GHG emissions, net of carbon sinks.
[12] The most recent EPA GHG annual inventory is from 2014. In March 2016, the rolling 12-month average emissions estimates from the U.S. Energy Information Administration suggested that transportation emissions had exceeded those from electric power generation for the first time since 1979.

uses and land management activities to remove carbon dioxide from the atmosphere). In parallel, they have also promoted resilience, with a variety of programs focused on adapting to a changing climate. This section highlights just a few of the Administration's many climate and energy initiatives. The next section discusses outcomes.

Supporting Growth of Renewable Energy

President Obama has made substantial investments in renewable energy supported by Federal policies that promote research, development, and deployment of renewable energy. These policies help address the underinvestment in renewable energy due to environmental externalities as well as the underinvestment in R&D due to knowledge spillovers. The Administration signaled its strong support for clean energy from the beginning by making a historic $90 billion investment in clean energy in the American Recovery and Reinvestment Act. The macroeconomic demand shock of the Great Recession required a bold policy response that included stimulus spending along with tax cuts and aid to affected individuals and communities. The Administration's decision to focus an important part of that spending (about an eighth of the total) on clean energy was a vital step in pushing the economy toward a cleaner energy future, and a foundational step for supporting continued progress throughout the President's eight years in office.

The Recovery Act extended and expanded the Production Tax Credit (PTC) and the Investment Tax Credit (ITC), critical policies directly focused on renewable energy. These policies provide subsidies for renewable energy production and installation to help address the unpriced externalities that place renewable energy at a disadvantage. In December 2015, the Administration secured a five-year extension of the PTC and ITC, signaling to developers that renewable energy continues to be an area worthy of greater investment (Bailey 2015).

The Recovery Act also created two new programs to support renewable energy generation: a set of loan guarantees for renewable energy project financing (the 1705 Loan Guarantee Program) and cash grants for renewable energy projects (the 1603 Cash Grant Program). The 1705 program supported construction of the first five solar PV projects over 100 MW in the United States. The 1603 program provided $25 billion to support total installed renewable energy capacity of 33.3 GW (CEA 2016c). The Act also included funding for energy efficiency projects, clean transportation, grid modernization, advanced vehicles and fuels, carbon capture and storage, and clean energy manufacturing.[13]

Since its actions to mitigate the Great Recession, the Administration has undertaken a set of efforts to help ensure that renewable energy is accessible to all Americans and underserved communities, in particular. Launched in July 2015, the National Community Solar Partnership, part of the Administration's SunShot initiative, is fostering innovation in financing and business models and spreading best practices to facilitate adoption of solar systems in low- and moderate-income (LMI) communities.[14] The U.S. Department of Housing and Urban Development is facilitating Property Assessed Clean Energy (PACE) financing to make it easier and more affordable for households to finance investments in solar energy and energy efficiency. The Administration has set a goal to bring 1 gigawatt (GW) of solar to low- and moderate-income families by 2020, and the U.S. Department of Agriculture has awarded almost $800 million to guarantee loan financing and grant funding to agricultural producers and rural small businesses (USDA 2016). USDA programs focusing on renewable energy have resulted in support for the construction of six advanced biofuel production facilities, more than 4,000 wind and solar renewable electricity generation facilities, and more than 100 anaerobic digesters to help farm operations capture methane to product electricity (Vilsack 2016). The Administration has also set a goal for the U.S. Department of the Interior to approve 20,000 MW of renewable energy capacity on public lands by 2020, and has set ambitious annual goals for the U.S. General Services Administration to purchase minimum percentages of its electricity from renewable sources, reaching 100 percent in 2025; both of these update and expand on earlier such goals in the Energy Policy Act of 2005 (EOP 2013, EOP 2015). The Administration has also expanded opportunities to join the solar workforce with programs like the Solar Instructor Training Network, AmeriCorps funding, and Solar Ready Vets to help reach the goal of training 75,000 workers to enter the solar industry by 2020.

---

[13] See CEA (2016c) for more on the impacts of these policies and more detail on clean energy support provided by ARRA. Some funded programs were extended or had greater take-up than anticipated, so the total allocation of ARRA-related clean energy programs will be more than $90 billion; CEA calculations indicate that just under $90 billion of ARRA clean energy-related dollars had been spent by the end of 2015.

[14] The SunShot initiative in the U.S. Department of Energy, launched in 2011, has the goal of making solar electricity cost competitive with conventional forms of electricity generation by 2020.

Carbon Pollution Standards for Power Plants

In August 2015, the President and the EPA announced the finalization of the Clean Power Plan (CPP)—the first-ever national carbon pollution standards for existing power plants. This historic action by the United States to address environmental externalities from carbon dioxide emissions focuses on the power sector, the source of just under a third of all greenhouse gas emissions and the largest source of U.S. carbon dioxide emissions in 2014 (EPA 2015c).

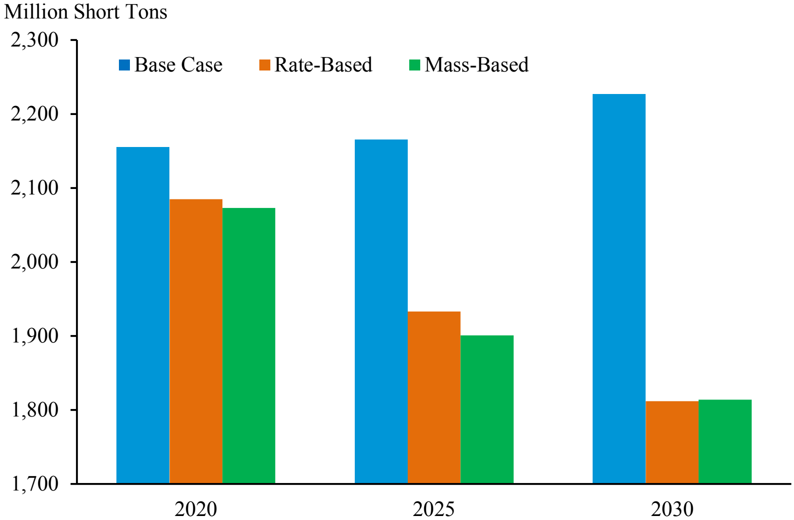
Consistent with the framework set out in the Clean Air Act, the CPP sets emission performance rates for fossil fuel-fired power plants based on the best system of emission reduction the EPA found was available, considering cost, energy impacts, and health and environmental impacts. The CPP translates those rates into state-specific goals and provides states with broad flexibility to reach the goals. For example, a state can choose a mass-based standard, which limits the total number of tons of carbon dioxide from regulated plants and can be achieved with a cap-and-trade system or another policy approach of the state's choice. As an alternative, the state can comply with a rate-based standard, whereby the state requires regulated sources to meet a specified emissions rate (the amount of emissions generated per unit of electricity produced) through a number of policy approaches. This flexibility allows states to choose cost-effective approaches to reducing emissions that are tailored to meet the state's own policy priorities.[15] Further, for greater economic efficiency gains, the CPP permits emissions trading across states; affected electric generation units (EGUs) can trade emissions credits with EGUs in other states with compatible implementation plans (EPA 2015c).

When the CPP is fully in place,[16] CO_2 emissions from the electric power sector are projected to be 32 percent below 2005 levels by 2030, resulting in 870 million tons less carbon pollution in 2030, equivalent to the annual emissions of 166 million cars (EPA 2015b, 2015c). Not only will the CPP help mitigate climate change, but it will also protect the health of American families by reducing asthma attacks in children and preventing premature deaths and non-fatal heart attacks by reducing emissions of other harmful air pollutants, and will help to provide an incentive for further

[15] From an economic perspective, the mass-based approach may be preferable because it does not create incentives to expand electricity production to facilitate compliance and does not require verification of demand reductions due to energy efficiency policies and investments (Fowlie et al. 2014).

[16] Implementation of the CPP has been stayed by the Supreme Court. The Administration is confident that it will be upheld in court as it is consistent with Supreme Court decisions, EPA's statutory authority, and air pollution standards that EPA has put in place to address other air pollution problems.

Figure 7-3
Clean Power Plan Projected Carbon Dioxide Emissions



Source: Environmental Protection Agency.

innovation to lower the costs of low-carbon energy (EPA 2015b). Given the combined effects of changes in average retail electricity rates and lower electricity demand, EPA projects that average electricity bills will decline by 3-4 percent in 2025, and by 7-8 percent in 2030, due to the CPP (EPA 2015c). Figure 7-3 shows the projected emissions reductions under the CPP. The base case bars refer to a world with all other current policies, while the rate-based and mass-based bars indicate what carbon dioxide emissions from the power sector are projected to be under the CPP if all states opt for each type of plan.

The rigorous benefit-cost analysis performed for the CPP projects that it would generate substantial net benefits to the U.S. economy. Given the flexibility afforded states in compliance with the CPP's emissions guidelines, estimates of benefits and costs are not definitive—both benefits and costs will depend on the compliance approaches states actually choose. Using Federal estimates of the social cost of carbon dioxide (SC-CO2), discussed further below, along with estimates of the co-benefits from the CPP's reductions in health damages from fine particulate matter and ozone, the CPP's regulatory impact analysis projects net benefits to the U.S. economy in 2020 of $1.0 billion to $6.7 billion, depending on the compliance approaches states choose. Net benefit estimates increase significantly in later years, with a projected range of $16 billion to $27 billion in 2025, and $25 billion to $45 billion in 2030 (EPA 2015c).[17]

Improving Energy Efficiency and Conservation

Improved energy efficiency reduces emissions and, by correcting environmental externalities or information market failures, can also improve economic efficiency. Administration initiatives have already succeeded in improving energy efficiency in millions of homes around the country, reducing energy costs, and cutting energy use by the Federal Government, with greater improvements expected in future years. Technological shifts have aided greatly in efficiency improvements. For example, LED lighting has seen a nearly 90 percent decrease in cost per kilolumen since 2008. The costs of lithium-ion battery packs for electric vehicles have fallen from above $1,000/kWh in 2007 to under $410/kWh in 2014, with estimates for leading manufacturers coming in as low as $300/kWh (Nykvist and Nilsoon 2015; DOE 2015).

In the President's first term, the departments of Energy and Housing and Urban Development completed energy efficiency upgrades in over 1 million homes, saving families on average more than $400 each on their heating and cooling bills in the first year alone (EOP 2016). The President also launched the Better Buildings Challenge in 2011, a broad, multi-strategy initiative to improve energy use in commercial, industrial, residential, and public buildings by 20 percent by 2020 (DOE 2016b). More than 310 organizations have committed to the Better Buildings Challenge, and the partners have saved over 160 trillion Btus of energy from 2011 to 2015, leading to $1.3 billion in reduced energy costs (DOE 2016d).

Since 2009, the Department of Energy's Building Technologies Office has issued 42 new or updated energy efficiency standards for home appliances, which are projected to save consumers more than $540 billion on their utility bills through 2030, and to cut carbon dioxide emissions by 2.3 billion metric tons (DOE 2016a). The products covered by standards represent about 90 percent of home energy use, 60 percent of commercial

[17] The regulatory impact analysis for the CPP reports estimates in constant 2011 dollars. In 2015 dollars, the net benefits to the U.S. economy would be $1.1 to $7.1 billion in 2020, $17 to $27 billion in 2025, and $26 to $47 billion in 2030. The CPP applies to existing power plants. In October 2015, the EPA issued final carbon pollution standards for newly constructed, modified, or reconstructed fossil-fuel-fired power plants. Due to projected market conditions (particularly the expectation of continued low natural gas prices, which make it likely that any new plants would comply with the rule's requirements even if it were not in place), analyses performed by the EPA and the U.S. Energy Information Administration (EIA) indicate that the new source standards will have negligible impacts on emissions, as well as negligible economic benefits and costs. Should gas prices rise significantly, the rule is projected to generate significant net benefits (EPA 2015d).

Box 7-1: Quantifying the Benefits of Avoided Carbon Emissions

Benefit-cost analysis is the well-known approach to determining whether any given policy will provide net benefits to society. Benefit-cost analysis of a policy that yields reductions of greenhouse gas emissions requires an estimate of the benefits of those reductions. The question is non-trivial, as estimating the impact of marginal increases in emissions requires calculations over long time spans and distributions of climate sensitivities and socioeconomic outcomes. To take on this task, the Obama Administration established a Federal Interagency Working Group (IWG) in 2009 to develop estimates of the value of damages per ton of carbon dioxide emissions (or, conversely, the benefits per ton of emissions reductions). The resulting social cost of carbon dioxide (SC-CO2) estimates, developed in 2009-10, provide consistent values based on the best available climate science and economic modeling, so that agencies across the Federal Government could estimate the global benefits of emissions reductions. Before these estimates were available, impacts of rules on greenhouse gas emissions had been considered qualitatively, or had been monetized using values that varied across agencies and rules. Creating a single SC-CO2 was an important step in ensuring that regulatory impact analysis of Federal actions reflects the best available estimates of the benefits of reducing greenhouse gas emissions.

The IWG updated the original 2010 SC-CO2 estimates in May 2013 to incorporate refinements that researchers had made to the underlying peer-reviewed models. Since then, minor technical revisions have been issued twice—in November 2013 and in July 2015. Both of

Table 7-i

Social Cost of CO_2, 2010–2050 (in 2007 Dollars Per Metric Ton of CO_2)

Discount Rate Year	5% Average	3% Average	2.5% Average	High Impact (95th Pct at 3%)
2010	10	31	50	86
2015	11	36	56	105
2020	12	42	62	123
2025	14	46	68	138
2030	16	50	73	152
2035	18	55	78	168
2040	21	60	84	183
2045	23	64	89	197
2050	26	69	95	212

Source: Interagency Working Group (2016).

these resulted in insignificant changes to the overall estimates released in May 2013. The IWG also sought independent expert advice from the National Academies of Sciences, Engineering, and Medicine (NAS) to inform future updates of the SC-CO2 estimates. In August 2016, the IWG updated its technical support document to incorporate January 2016 feedback from the NAS by enhancing the presentation and discussion of quantified uncertainty around the current SC-CO2 estimates. The NAS Committee recommended against a near-term update of the estimates. Also in August 2016, the IWG issued new estimates of the social costs of two additional GHGs, methane (CH_4) and nitrous oxide (N_2O), applying the same methodology as that used to estimate the SC-CO2 (IWG 2016a).

To estimate the SC-CO2, SC-CH4, and SC-N2O, three integrated assessment models (IAMs) are employed. IAMs couple models of atmospheric gas cycles and climate systems with aggregate models of the global economy and human behavior to represent the impacts of GHG emissions on the climate and human welfare. Within IAMs, the equations that represent the influence of emissions on the climate are based on scientific assessments, while the equations that map climate impacts to human welfare ("damage functions") are based on economic research evaluating the effects of climate on various market and non-market sectors, including its effects on sea level rise, agricultural productivity, human health, energy-system costs, and coastal resources. Estimating the social cost of emissions for a given GHG at the margin involves perturbing the emissions of that gas in a given year and forecasting the increase in monetized climate damages relative to the baseline. These incremental damages are then discounted back to the perturbation year to represent the marginal social cost of emissions of the specific GHG in that year.

The estimates of the cost of emissions released in a given year represent the present value of the additional damages that occur from those emissions between the year in which they are emitted and the year 2300. The choice of discount rate over such a long time horizon implicates philosophical and ethical perspectives about tradeoffs in consumption across generations, and debates about the appropriate discount rate in climate change analysis persist (Goulder and Williams 2012; Arrow, et al. 2013; Arrow, et al. 2014). Thus, the IWG presents the SC-CO2 under three alternative discount rate scenarios, and, given the potential for lower-probability, but higher-impact outcomes from climate change, a fourth value is presented to represent the estimated marginal damages associated with these "tail" outcomes (IWG 2015, IWG 2016b). All four current estimates of the SC-CO2, from 2010 to 2050, are below.

Sources: IWG (2013, 2015, 2016a, 2016b), Goulder and Williams (2012), Arrow et al (2013, 2014).

building use, and 30 percent of industrial energy use, which taken cumulatively, represented around 40 percent of total primary energy use in 2015.[18] By 2030, the cumulative operating cost savings from all standards in effect since 1987 will reach nearly $2 trillion, with a cumulative reduction of about 7.3 billion tons of CO_2 emissions (DOE 2016a).

Pricing the external costs from greenhouse gas emissions would increase the likelihood of consumers adopting these options on their own, but when the greenhouse gas-emitting energy is underpriced, then programs to help move consumers toward a more energy-efficient outcome can improve economic efficiency. Each of these standards has been subject to rigorous benefit-cost analysis, and each has economic benefits in excess of costs. This demonstrates that such standards not only reduce GHG emissions, but do so in an economically efficient way. For example, new rules for commercial air conditioning and heating equipment sold between 2018 and 2048 are projected to have net economic benefits of $42 billion to $79 billion (DOE 2016c).[19]

Addressing Transportation Sector Emissions

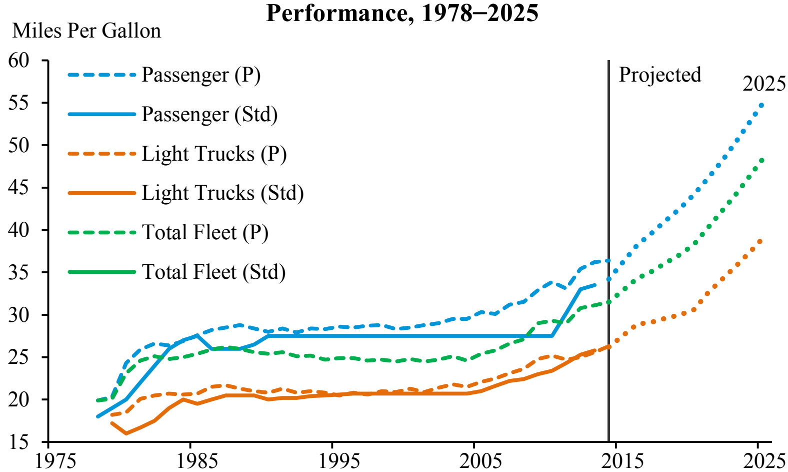
Since 2009, President Obama has implemented policies that reduce emissions from the transportation sector—one of the largest sources of U.S. greenhouse gas emissions (EPA 2016a). Again, these policies can help internalize environmental externalities and address information market failures. Through improvements to the fuel economy of gasoline- and diesel-powered cars and trucks, and the technological progress that has been made on hybrid and electric drivetrains, the transportation sector has made substantial improvements to date, and the Administration has put policies in place to increase the likelihood that these improvements will continue for years to come. In addition, the Administration has continued to implement rules on Renewable Fuel Standards in ways that reduce the carbon intensity of our transportation sector.

Under this Administration, the EPA and the National Highway Traffic Safety Administration have issued GHG emission and fuel economy standards for light-duty passenger vehicles and the first-ever GHG and fuel economy standards for medium- and heavy-duty trucks. The latest set of standards for passenger vehicles will reduce new vehicle GHG emissions by nearly a half and approximately double the average new vehicle fuel economy

[18] Calculation based on total energy use by sector from the EIA's Monthly Energy Review (MER), Table 2.1.

[19] The net benefits of these new rules are represented in 2014 dollars. In 2015 dollars, these rules are expected to have slightly higher net benefits that round to the same figures ($42 to $79 billion).

Figure 7-4
Corporate Average Fuel Economy Standards and Performance, 1978–2025



Note: Dotted lines represent actual performance (P) and solid lines represent the relevant fuel economy standard (Std). Projections are based on the CAFE MY 2017–2025 standards and assume that fuel economy performance meets the standards.
Source: National Highway Traffic Safety Administration.

(NHTSA 2012). Combined, the Phase 1 and Phase 2 GHG and fuel economy standards for light-duty vehicles are projected to reduce GHG emissions by 6 billion metric tons over the lifetime of vehicles sold from 2012 to 2025 (EPA 2012). Building on the first-ever GHG and fuel economy standards for new medium- and heavy-duty vehicles built between 2014 and 2020, issued in 2011, EPA and NHTSA finalized "Phase 2" standards in 2016 that will further raise fuel economy for these vehicles through 2027. Combined, the Phase 1 and Phase 2 heavy-duty vehicle standards are expected to reduce GHG emissions by 2.5 billion metric tons over the lifetime of vehicles sold from 2014 to 2029 (EPA and NHTSA 2016).

Achieving these goals will require a variety of innovations and investments by automobile firms that have been challenging thus far because emissions carry no price, consumers often undervalue fuel efficiency, and vehicle purchasers are not always the entities paying for the fuel.[20] These investments may unlock new technologies to further reduce transportation emissions. For example, firms with innovative low-emissions technologies may sell compliance credits or license technology to other firms, given the flexibility provisions in the vehicle emissions standards, providing an

[20] The lack of investment may be due to multiple market failures including from the unpriced positive externalities from innovation (Bergek, Jacobsson, and Sandén 2008).

Box 7-2: Investing in Clean Energy Research and Development

Research and development in clean energy is essential to climate change mitigation because improved technologies will reduce the cost of producing and distributing clean energy. The research and development (R&D) market failure from imperfect appropriability of innovations—in which innovations spill over to other firms and the innovative firm cannot fully capture the returns—is particularly important in early stage R&D because the private return to basic innovation is relatively low and the social return is high. The gap between social and private returns to clean energy innovations is magnified by the additional environmental externalities that private firms do not internalize (Nordhaus 2011). Since many clean energy technologies are in fledgling stages and require foundational developments, the R&D market failure leads to significant underinvestment in R&D for those technologies, suggesting a role for policy.

The Obama Administration has made significant investments in clean energy R&D. The American Recovery and Reinvestment Act directed a substantial amount of its $90 billion in clean energy funding to research and development. This included funding for the Advanced Research Projects Agency – Energy (ARPA-E) program, which funds clean energy projects that are in early innovation stages and have high potential societal value. ARPA-E's first projects were funded by the Recovery Act, and it has since sponsored over 400 energy technology projects. The Recovery Act set a precedent for continued investment in clean energy R&D; subsequent fiscal budget proposals have included significant funding to continue such programs.

The 2013 Climate Action Plan structured the Administration's continuing commitment to investment in clean energy R&D. Consistent with the goals of the Plan, the DOE's Office of Energy Efficiency and Renewable Energy (EERE) launched the SunShot Initiative, which funds solar energy R&D. The EERE Wind Program funds R&D activity in wind energy technologies, including offshore and distributed wind. EERE's Geothermal Technologies Office conducts research on geothermal systems in order to lower the risks and costs of geothermal development and exploration. Additionally, EERE supports R&D in cleaner transportation technologies through a variety of programs: the Hydrogen and Fuel Cells Program funds basic and applied research to overcome the technical barriers of hydrogen production, delivery and storage technologies as well as fuel cell technologies. The Bioenergy program supports R&D in sustainable biofuels, with a focus on advanced biofuels that are in earlier stages of development but can take advantage of existing transportation infrastructure by providing functional substitutes for crude oil, gasoline, diesel fuel and jet fuel. The Vehicles Technologies Office funds R&D to encourage deployment of electric cars by developing advanced batteries, electric drive systems and lightweight vehicles. These efforts combined represent billions of dollars invested in clean energy R&D.

Public investment in R&D helps correct for private underinvestment due to market failures and moves investment toward efficient levels, allowing for cost reductions in clean energy use. Clean energy technology costs have declined significantly since 2008, and the Administration's R&D investments supported this trend. More importantly, these investments will help to ensure that positive trends in clean energy penetration and greenhouse gas emissions reductions continue into the future, since the economic benefits of R&D—particularly in early stage innovations—accrue over a very long time horizon.

Source: Nordhaus (2011).

incentive for innovation.[21] Figure 7-4 shows fuel economy standards over time, including the major increase since 2008, and further increases projected through 2025.

In March 2012, the Administration launched "EV Everywhere," an electric vehicle Grand Challenge that seeks to make electric vehicles as affordable and convenient to own as gasoline-powered vehicles within the next decade (DOE 2012). Much of the focus of this initiative is to foster early-stage innovation, an endeavor that helps to address innovation market failures since the social return from such innovation is greater than the private return. EV Everywhere has already spurred dramatic technological and cost improvements in EV technology. In addition, since 2010, DOE investments through the Grand Challenge have contributed to a 50-percent reduction in the modeled high-volume cost of electric vehicle batteries, and DOE has invested in industry, national laboratory, and university projects that explore how to make EV batteries even more efficient and cost-effective (Brescher Shea 2014). Since the program's launch, hundreds of employers have joined the Workplace Charging Challenge pledging to provide charging access for their employees (DOE 2016f). These policies are examples of some of the incentives the Administration has implemented to support EVs; others include tax credits for purchase of electric vehicles, support for domestic electric vehicle battery manufacturing, and more than $6 billion in Recovery Act funds for programs to promote research and development of

[21] Economic theory and empirical evidence suggest that trading and other market-based approaches provide greater incentives for technological innovation than do prescriptive regulations that would achieve the same level of emissions reduction (Keohane 2003; Popp 2003).

advanced vehicle technologies (CEA 2016c). Much like owning a car was difficult until enough people had cars that gas stations were plentiful, the network effects of electric vehicles provide an economic case for a policy push supporting the necessary services to move the industry toward critical mass.

Reducing Emissions from High Potency Greenhouse Gases

To further help address the environmental externality from greenhouse gas emissions, the Administration has also developed policies to reduce the emissions of other potent greenhouse gases, such as hydro-fluorocarbons (HFCs) and methane. When the President launched his Climate Action Plan in June 2013, he pledged to reduce emissions of HFCs through both domestic and international leadership (EPA 2016b). Through actions like leader-level joint statements with China in 2013 and with India in 2016, the United States has led global efforts to secure an ambitious amendment to the Montreal Protocol to phase down HFCs. In October 2016, the 197 Parties to the Montreal Protocol agreed to amend the Protocol to phase down HFC use in developed countries beginning in 2019, and to freeze HFC use in developing countries in 2024, though some will wait until 2028 (UNEP 2016).

At the same time, the Administration has taken important steps to reduce HFC consumption domestically under EPA's Significant New Alternatives Policy, a Clean Air Act program under which EPA identifies and evaluates substitutes for industrial chemicals and publishes lists of acceptable and unacceptable substitutes. The Administration has also announced a suite of private-sector commitments and executive actions that are projected to reduce HFCs equivalent to more than 1 billion metric tons of carbon dioxide emissions globally through 2025.

The President has also taken steps to reduce methane emissions, which accounted for 10 percent of U.S. greenhouse gas emissions in 2014.[22] In January 2015, the Administration set a goal of reducing methane emissions from the oil and gas sector by 40 to 45 percent from 2012 levels by 2025, which would save up to 180 billion cubic feet of natural gas in 2025—enough to heat more than 2 million homes for a year. The Administration's commitment to this goal was reaffirmed and strengthened in March 2016 in a joint statement with Prime Minister Justin Trudeau of Canada, in which both countries pledged to reduce methane emissions from the oil and gas sector and to explore new opportunities for additional reductions. In May 2016, EPA finalized methane pollution standards for new and modified

[22] This is based on the U.S. EPA's emissions inventory, for which the most recent data are from 2014. More recent research suggests that U.S. methane emissions may be much higher than the estimates underlying EPA's 2014 inventory (Turner et al. 2016; Schwietzke et al. 2016).

Box 7-3: Building Resilience to Current and Future Climate Change Impacts

The Obama Administration has implemented many policies and actions to support and enhance climate resilience. For example, in 2013, the President signed an Executive Order that established an interagency Council on Climate Preparedness and Resilience and a State, Local, and Tribal Leaders Task Force made up of governors, mayors, county officials, and Tribal leaders from across the country. The Task Force developed recommendations on how to modernize Federal Government programs to incorporate climate change and support community resilience to its impacts. The Administration has responded to a number of these recommendations, for example, by implementing the National Disaster Resilience Competition that made nearly $1 billion available for resilient housing and infrastructure projects to states and communities that had been impacted by major disasters between 2011 and 2013. Government agencies have also provided additional support for Federal-Tribal Climate Resilience and support for reliable rural electric infrastructure. In addition, the Administration developed and launched a Climate Data Initiative and Climate Resilience Toolkit to improve access to climate data, information, and tools. A new Resilience AmeriCorps program was also established; through this program, AmeriCorps VISTA members are recruited and trained to serve low-income communities across the country by developing plans and implementing projects that increase resilience-building capacity.

The Department of Transportation (DOT) now includes improving resilience to the impacts of climate change as a primary selection criteria for its Transportation Investment Generating Economic Recovery (TIGER) grants, which provide $500 million in Federal funds to improve transportation infrastructure while generating economic recovery and enhancing resilience in communities (DOT 2016). Similarly, the newly created FASTLANE grant program includes improving resilience to climate impacts as a primary selection criterion. In 2014, USDA created Climate Hubs in partnership with universities, the private sector, and all levels of government to deliver science-based information and program support to farmers, ranchers, forest landowners, and resource managers to support decision-making in light of the increased risks and vulnerabilities associated with a changing climate.

President Obama has also used executive action to establish a clear, government-wide framework for advancing climate preparedness, adaptation, and resilience, and directed Federal agencies to integrate climate-risk considerations into their missions, operations, and cultures. As of 2016, 38 Federal agencies have developed and published climate adaptation plans, establishing a strong foundation for action (Leggett 2015). These plans will improve over time, as new data, information, and tools become available, and as lessons are learned and actions are taken to effectively adapt to climate change through agencies' missions and operations.

The Administration is developing government-wide policies to address shared challenges where a unified Federal approach is needed. For example, the Federal Government is modernizing its approach to floodplain management through the establishment of the Federal Flood Risk Management Standard (pursuant to E.O. 13690, Establishing a Federal Flood Risk Management Standard and a Process for Further Soliciting and Considering Stakeholder Input), in part to ensure that Federally funded projects remain effective even as the climate changes and flood risk increases. To promote resilience to wildfire risks, E.O. 13728, Wildland-Urban Interface Federal Risk Mitigation, directs Federal agencies to take proactive steps to enhance the resilience of Federal buildings to wildfire through the use of resilient building codes. E.O. 13677, Climate Resilient International Development, promotes sound decision making and risk management in the international development work of Federal agencies. Pursuant to E.O. 13677, the Department of the Treasury, the U.S. Agency for International Development, the Millennium Challenge Corporation, the State Department, the U.S. Department of Agriculture, and other Federal agencies with international development responsibilities have established guidelines and criteria to screen projects and investments against potential climate impacts, with a goal of making these investments more climate resilient.

In March 2016, the President signed a Presidential Memorandum: Building National Capabilities for Long-Term Drought Resilience with an accompanying Action Plan. Drought routinely affects millions of Americans and poses a serious and growing threat to the security of communities nationwide. The Memorandum lays out six drought-resilience goals and corresponding actions, and permanently establishes the National Drought Resilience Partnership (NDRP) as an interagency task force responsible for coordinating execution of these actions. These actions build on previous efforts of the Administration in responding to drought and are responsive to input received during engagement with drought stakeholders, which called for shifting focus from responding to the effects of drought toward supporting coordinated, community-level resilience and preparedness.

Sources: DOT 2016, Leggett 2015.

sources in the oil and gas sector, and the agency has taken the first steps toward addressing existing sources under forthcoming standards. EPA regulations promulgated in July 2016 will substantially reduce emissions of methane-rich gases from municipal solid waste landfills.

Promoting Climate Resilience

Even with all of the efforts to reduce emissions, the impacts of climate change are already occurring and will continue into the future. From an economic perspective, optimal responses to climate change would balance the costs of mitigation, the costs of adaptation, and the residual damages of climate change. Moreover, ideally, policies to encourage climate resilience would be informed by research on the degree of anticipated private investment in adaptation, and any anticipated gaps in such investment based on market failures or other factors. Relative to research on climate change damages and the impacts of mitigation, economic research on resilience is less developed, however, making it difficult to quantify the impacts of specific policies.

The economic literature suggests that some impacts of climate change, particularly the rise in extreme temperatures, will likely be partly offset by increased private investment in air conditioning (Deschênes 2014; Deschênes and Greenstone 2011; Barreca et al. 2016), and that movement to avoid temperature extremes, either spending more time indoors in the short run, or relocating in the long run, could also reduce climate impacts on health (Deschênes and Moretti 2009; Graff Zivin and Neidell 2014). Similarly, in the agricultural sector, farmers may switch crops, install or intensify irrigation, move cultivated areas, or make other private investments to adapt to a changing climate. Farmers are likely to make at least some investments that yield net benefits in the long run, though existing evidence is mixed regarding the likely extent and impact of private adaptive responses in agriculture (Auffhammer and Schlenker 2014; Schlenker and Roberts 2009; Fishman 2012). In terms of extreme events, countries that experience tropical cyclones more frequently appear to have slightly lower marginal damages from a storm (Hsiang and Narita 2012), suggesting some adaptive response. Recent work finds no evidence of adaptation to hurricane frequency in the United States, but significant evidence exists of adaptation for other Organization for Economic Cooperation and Development (OECD) countries (Bakkensen and Mendelsohn 2016).

Private adaptation measures are costly, and the extent to which they will mitigate climate impacts is uncertain. The costs of not enhancing resilience to climate impacts, though also uncertain, may be higher. From an economic perspective, building resilience to the current and future impacts of climate change—a critical component of the President's Climate Action Plan—is prudent planning and akin to buying insurance against the future damages from climate change and their uncertain impacts.

Progress To-Date in Transitioning to A Clean Energy Economy

In recent years, the U.S. energy landscape has witnessed several large-scale shifts, with technological advances greatly increasing domestic production of petroleum and natural gas while renewable energy sources, particularly wind and solar energy, have concurrently seen a sharp rise in production. These shifts provide important context for the progress on decreasing greenhouse gas emissions, energy intensity, and carbon intensity. For example, renewable production provides zero carbon energy, while the rise in natural gas electricity generation, a relatively lower-carbon fossil fuel, has displaced some coal-based energy generation that had higher carbon content.

In the past decade, the United States has become the largest producer of petroleum and natural gas in the world (EIA 2016). U.S. oil production increased from 5 million barrels a day (b/d) in 2008 to a peak of 9.4 million b/d in 2015, which sizably reduced U.S. oil imports. More importantly for climate outcomes, U.S. natural gas production increased from 20 trillion cubic feet (Tcf) in 2008 to 27 Tcf in 2015. Both increases were largely due to technological advances combining horizontal drilling, hydraulic fracturing, and seismic imaging.

The U.S. energy sector has simultaneously undergone a transformation toward lower-carbon energy resources. The United States has both reduced the energy intensity of its economic activity and shifted toward cleaner energy sources, both of which have reduced emissions. This section documents the progress made to date in the transition to a clean energy economy and analyzes the contribution of different factors to that transition. The analysis considers the role of increased renewable energy production that provided additional zero carbon energy; increased energy efficiency that reduced energy consumption for a given amount of economic output; domestic natural gas production that reduced gas prices relative to coal; and shocks to the economy that affected the level of GDP, most notably the Great Recession.

Reduced Growth in Greenhouse Gas Emissions

Greenhouse gas emissions, dominated by carbon dioxide emissions, grew fairly steadily until 2008 (EPA 2016a). Since 2008, both carbon dioxide emissions and total greenhouse gas emissions have been declining (Figure 7-5). Although the economic downturn in 2008-09 certainly contributed, Figure 7-5 shows that emissions have declined since 2008, while GDP has risen after a drop in the beginning of the period. Figure 7-6 shows that the decline since 2008 in carbon dioxide emissions from the electric power sector, which made up roughly 30 percent of total emissions in 2014, has been particularly noticeable (EPA 2016a). In fact, carbon dioxide emissions from electricity generation in 2015 were the lowest since 1992, after peaking in 2007; and in the first half of 2016, carbon dioxide emissions from the U.S. energy sector were at the lowest level in 25 years (EIA 2016b).

The decline in emissions, which has continued even as the economy has recovered, largely stemmed from two major shifts in U.S. energy consumption patterns over the past decade: a decline in the amount of energy that is consumed per dollar of GDP and a shift toward cleaner energy. The amount of energy used to produce one dollar of real GDP in the United States, or the energy intensity of real GDP, has declined steadily over the past four decades and, in 2015, stood at less than half of what it was in the early 1970s (Figure 7-7). Since 2008, the energy intensity of real GDP has fallen by almost 11 percent (Figure 7-8).[23] Meanwhile, cleaner energy sources like natural gas and zero-emitting sources like renewables have increasingly displaced the use of dirtier fossil fuel sources. This shift has led to an even larger decline in carbon emissions per dollar of real GDP, which was more than 18-percent lower in 2015 than it was in 2008 (Figure 7-8).

The next subsections discuss these trends, followed by an analysis of how each trend contributed to the decline in carbon dioxide emissions.

Declining Energy Intensity

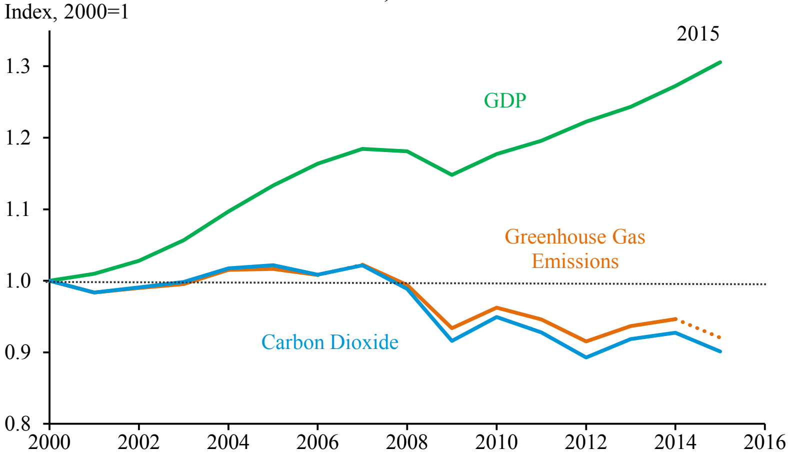
Total U.S. energy consumption has been falling—with consumption in 2015 down 1.5 percent relative to 2008. The fact that the U.S. economy is using less energy while continuing to grow reflects a decline in overall energy intensity that is due to both more efficient use of energy resources to complete the same or similar tasks and to structural shifts in the economy that have led to changes in the types of tasks that are undertaken. The continuation of these changes, which have been occurring for decades (Figure 7-7), is spurred by market forces, and the increasing efficiency in the use of energy resources is supported by energy efficiency policies.

This continual trend of declining economy-wide energy intensity was also predictable based on historical projections from the U.S. Energy

[23] The uptick in 2012 in Figure 7-8 is due to a number of early nuclear plant closures.

Figure 7-5

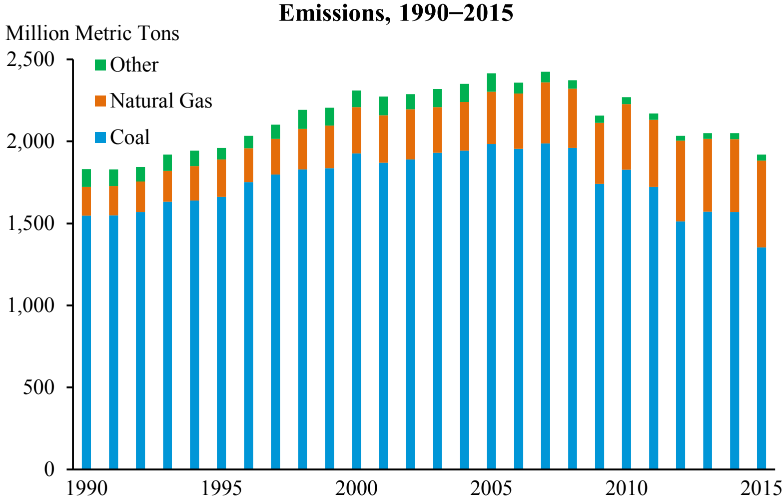
GDP and Greenhouse Gas and Carbon Dioxide Emissions, 2000–2015



Note: Total emissions from EPA is available through 2014; 2014–2015 trend is estimated using change in CO_2 emissions from the energy sector from the EIA.
Source: Environmental Protection Agency, Energy Information Administration, and Bureau of Economic Analysis.

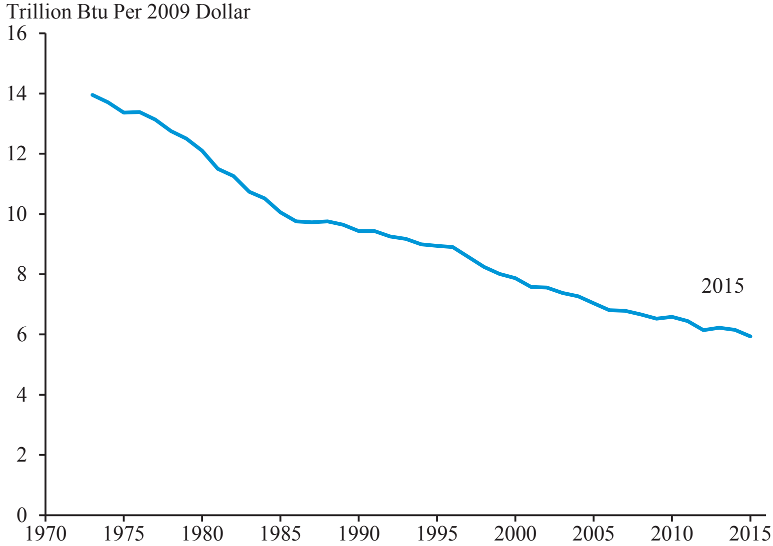
Figure 7-6

Electric Power Sector Carbon Dioxide Emissions, 1990–2015



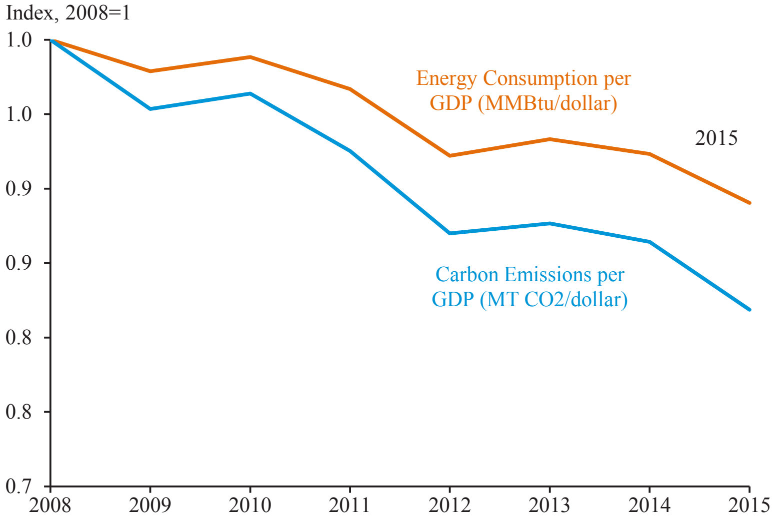
Note: Other includes emissions from the petroleum, geothermal, and non-biomass waste electric sectors.
Source: Energy Information Administration.

Figure 7-7
Energy Intensity of Real U.S. GDP, 1973–2015



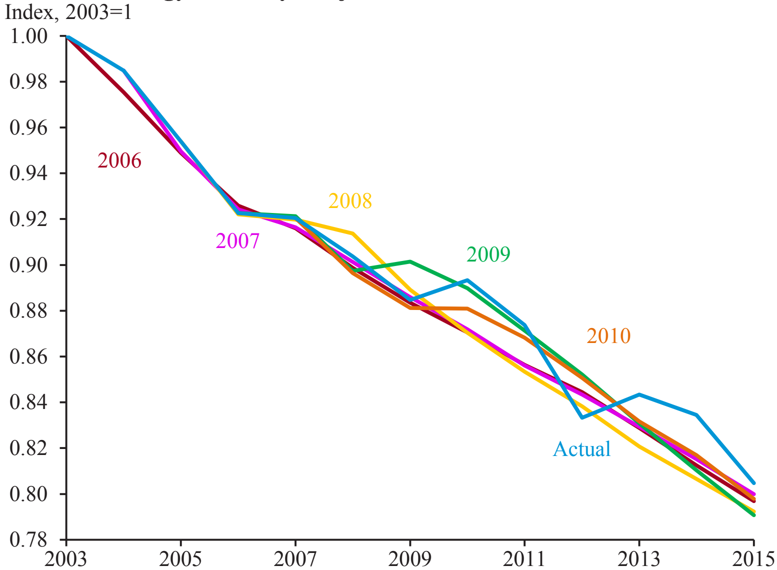
Source: Energy Information Administration.

Figure 7-8
Carbon Emissions and Energy Consumption per Real U.S. GDP, 2008–2015



Source: Energy Information Administration.

Figure 7-9
Energy Intensity Projections and Actual, 2003–2015



Source: Energy Information Administration; CEA calculations.

Information Administration (EIA).[24] Figure 7-9 plots both the observed decline in energy intensity in the U.S. economy, as well as EIA projections of the decline in energy intensity going back to 2003.[25] Not only has the decline in energy intensity been relatively steady, but it has tracked closely with predictions. Changes in energy intensity come from policy as well as technological and behavioral shifts. The fact that it has been predicted to decrease over time comes from assumptions that technology will continue to develop and policies will continue to encourage efficiency. With the extensive energy efficiency policies implemented by the Administration since 2009, EIA projects energy intensity to decline another 17 percent by 2025 (EIA 2016a).[26]

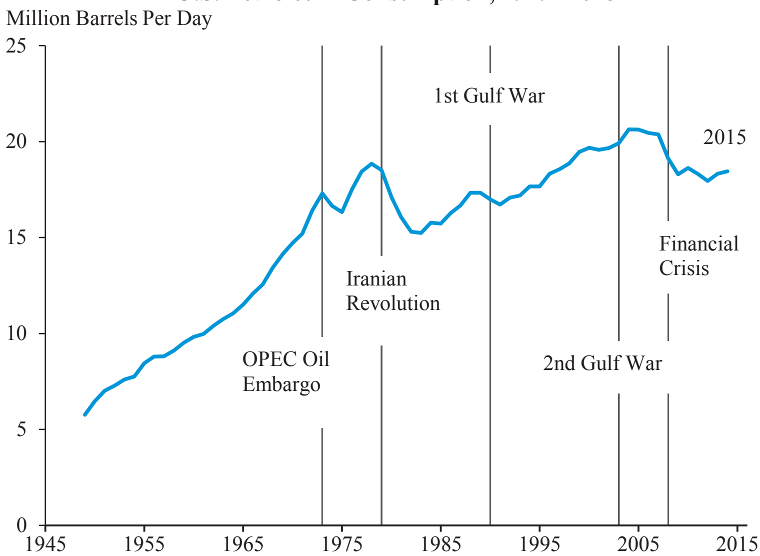
Although the aggregate energy intensity has been steadily and predictably moving downward, aggregation masks differences across sectors of the economy. One notable example is the transportation sector, which has driven a decline in U.S. petroleum consumption relative to both recent levels and past projections.

[24] EIA forecasts do include existing policies, as well as finalized policies with impacts in the future that have been projected at the time of the forecast.

[25] Figures 7-9, 7-12, 7-13, and 7-14a to 7-14c use an index, with actual U.S. energy intensity in 2003 set equal to 1.0, and actual and projected energy intensity since 2003 expressed relative to that baseline. Projections use annual (negative) growth rates for energy intensity from the 2006, 2007, 2008, 2009, and 2010 EIA Annual Energy Outlook.

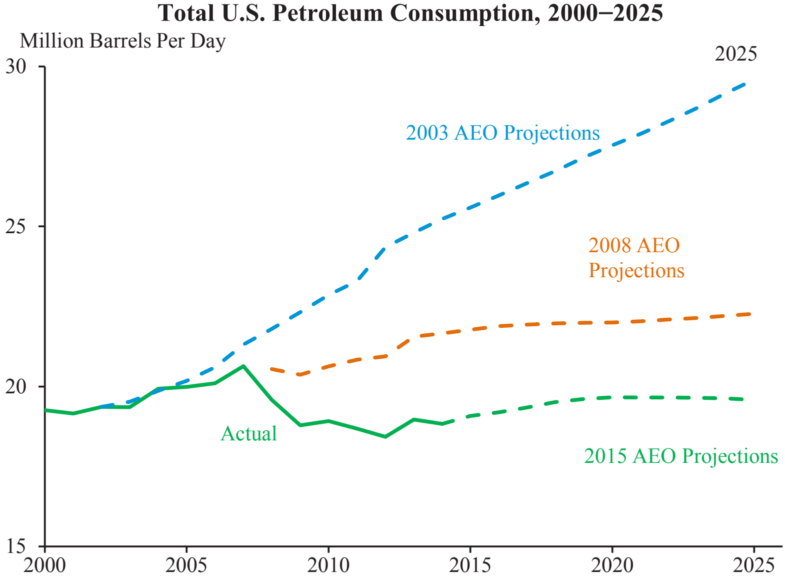
[26] Energy intensity (QBtu / GDP) metric is calculated from AEO 2016 reference case projections of annual energy use and GDP (EIA 2016a).

Figure 7-10
U.S. Petroleum Consumption, 1949–2015



Source: Energy Information Administration.

Figure 7-11
Total U.S. Petroleum Consumption, 2000–2025



Source: Energy Information Administration.

Petroleum consumption was 2 percent lower in 2015 than it was in 2008 (EIA 2016b), while the economy grew more than 10 percent over this same period. In fact, petroleum consumption peaked in 2004, and the subsequent decline over the next several years surprised many analysts (Figure 7-10). The actual consumption of oil in 2015 was more than 25 percent below EIA projections made in 2003 for consumption that year. Moreover, the surprising decline in consumption relative to past projections is expected to grow over the next decade to 34 percent in 2025 (Figure 7-11). This trend through 2014 was primarily attributed to a population that was driving less and to rising fuel economy in the light-duty fleet.[27]

With this petroleum consumption surprise, the energy intensity in the transportation sector has declined beyond that which was projected by EIA in 2003, as seen in Figure 7-12.

In contrast, the residential sector showed less of a decline in energy intensity than was projected by EIA in 2003, and even than in some later projections (Figure 7-13). The actual residential energy intensity did decline substantially—likely due in part to energy efficiency standards—but sits above the level that was projected in most prior years for 2015. This greater-than-expected energy intensity in the residential sector may be due to factors such as new electronic appliances being plugged in, a slow-down of replacement of older appliances after the economic recession began in 2008, or a shift in preference for house size or energy consumption at home.

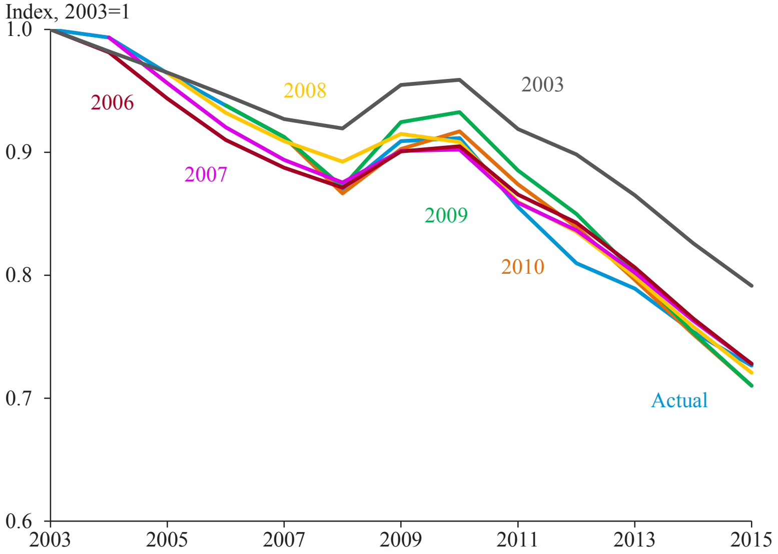
Energy intensity in the electric power and commercial sectors (Figures 14a and 14c, respectively) in 2015 tracked quite closely to prior projections. Actual 2015 energy intensity in the industrial sector (Figure 7-14b) was below what would have been predicted in 2003, though closer to later predictions.

Declining Carbon Intensity

While the energy intensity of the economy has continued a relatively steady downward trend, carbon intensity—carbon emissions per unit of energy consumed—has had a much more dramatic shift, relative to projections, in the past decade. Projections made in 2008 and in prior years showed carbon intensity holding relatively steady. However, since 2008, carbon intensity has fallen substantially and continues to fall—leading to revised projections nearly every single year. Figure 7-15a shows the observed carbon

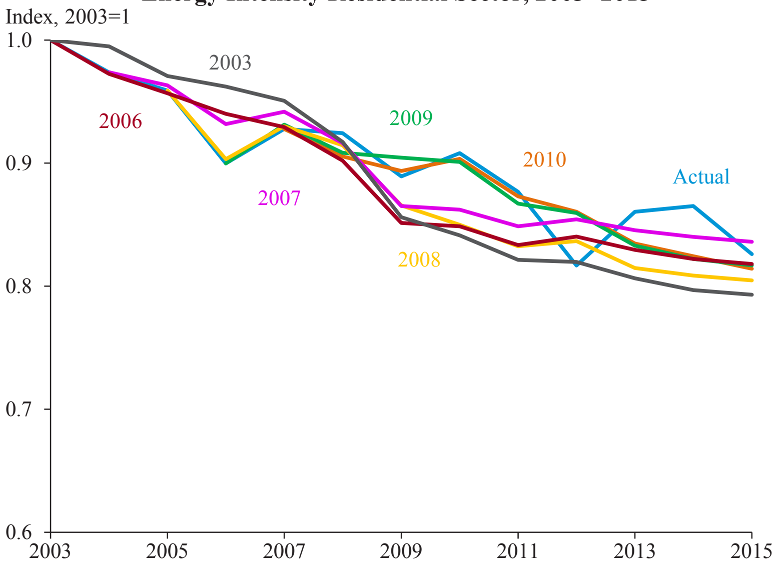
[27] See CEA (2015b) for a more detailed analysis. In 2015-16, low gasoline prices have led to significant increases in vehicle miles travelled (VMT); VMT reached a 6-month record high in the first half of 2016. Since low oil (and thus low gasoline) prices are expected to continue at least through the end of 2016 (EIA 2016), the upward trend observed in 2015 may continue in 2016.

Figure 7-12
Energy Intensity Transportation Sector, 2003–2015



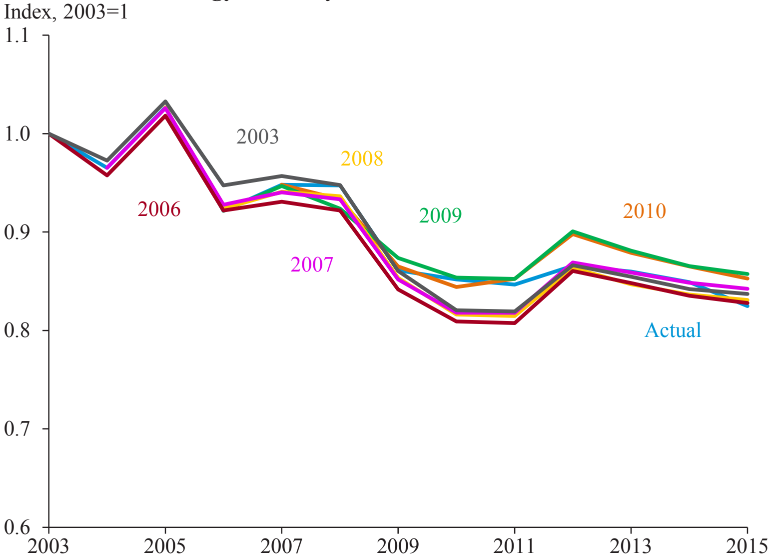
Source: Energy Information Administration; CEA Calculations.

Figure 7-13
Energy Intensity Residential Sector, 2003–2015



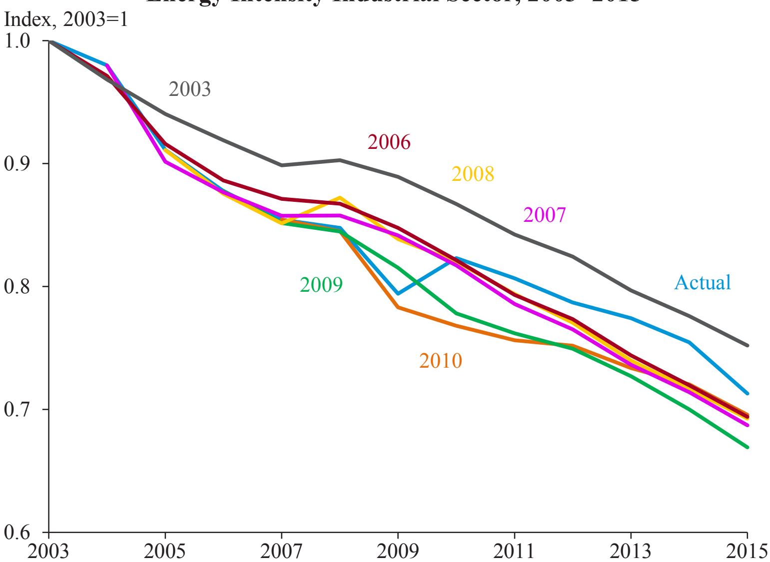
Source: Energy Information Administration; CEA Calculations.

Figure 7-14a
Energy Intensity Electric Sector, 2003–2015



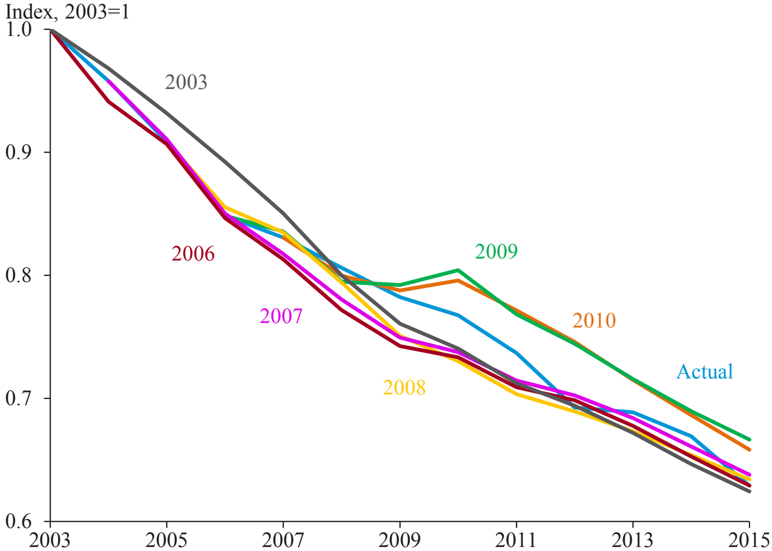
Source: Energy Information Administration; CEA Calculations.

Figure 7-14b
Energy Intensity Industrial Sector, 2003–2015



Source: Energy Information Administration; CEA Calculations.

Figure 7-14c
Energy Intensity Commercial Sector, 2003–2015



Source: Energy Information Administration; CEA Calculations.

emissions intensity of energy use in the U.S. economy, as well as several EIA projections. Beginning in 2008, these projections are all noticeably above the observed carbon intensity. Figure 7-15b shows that carbon emitted per dollar of GDP has also declined over this period, and that declines exceed predictions.

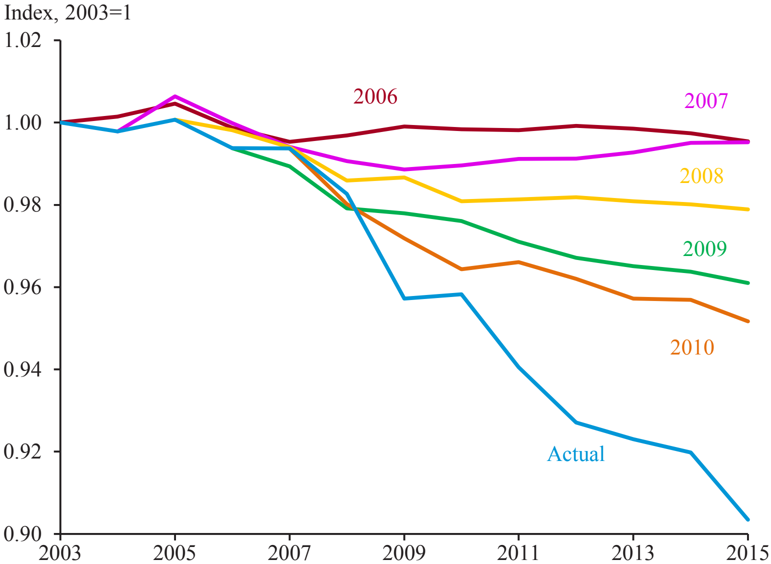
There are two primary reasons for the declining carbon intensity: a considerable shift to natural gas (a lower-carbon fossil fuel) and a remarkable growth in renewable energy, especially wind and solar.

The shift to lower carbon fossil fuels can be seen in Figure 7-16. Since 2008, coal and petroleum consumption have fallen 30 and 4 percent, respectively. Meanwhile, natural gas consumption has risen by almost 19 percent, with much of this increase displacing coal for electricity generation. This is due, in large part, to the surge in U.S. natural gas production discussed earlier. In fact, the share of electricity generation using natural gas surpassed the share produced from coal in 2015 for the first time on record (Figure 7-17). As natural gas is a much lower-carbon fuel than coal for electricity generation, this shift has contributed to lower carbon intensity.

Clean energy has undergone notable trends since 2008: electricity generation from renewable energy has increased, and costs of key clean energy technologies have fallen as there have been sizable efficiency gains in renewable energy. As seen in Figure 7-18, the share of non-hydropower renewables in U.S. electricity generation has increased from 3 percent in

Figure 7-15a

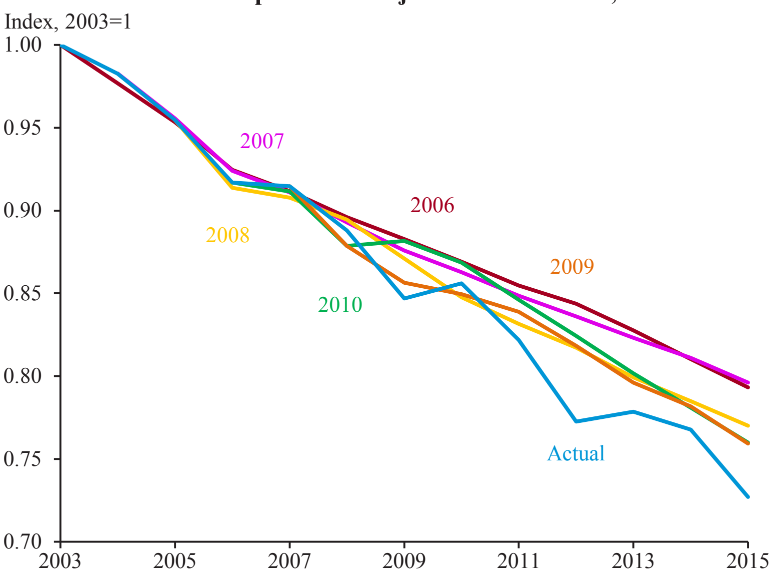
Carbon Intensity Projections and Actual, 2003–2015



Source: Energy Information Administration; CEA calculations.

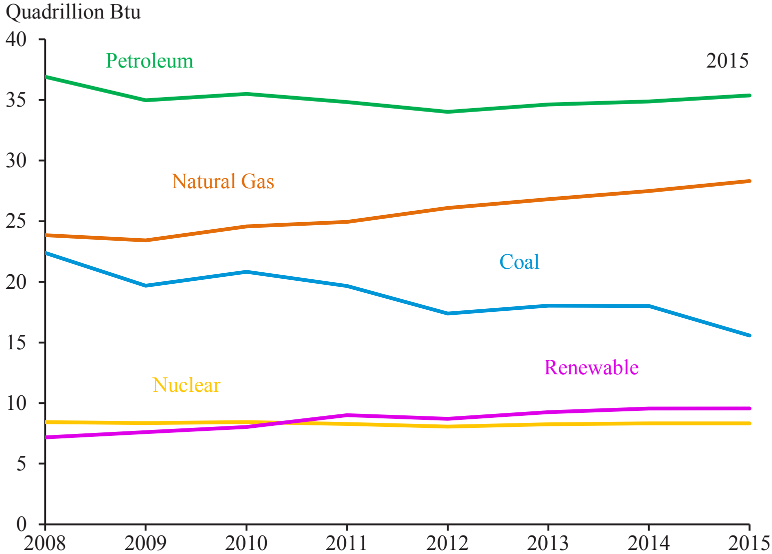
Figure 7-15b

Carbon Emissions per GDP Projections and Actual, 2003–2015



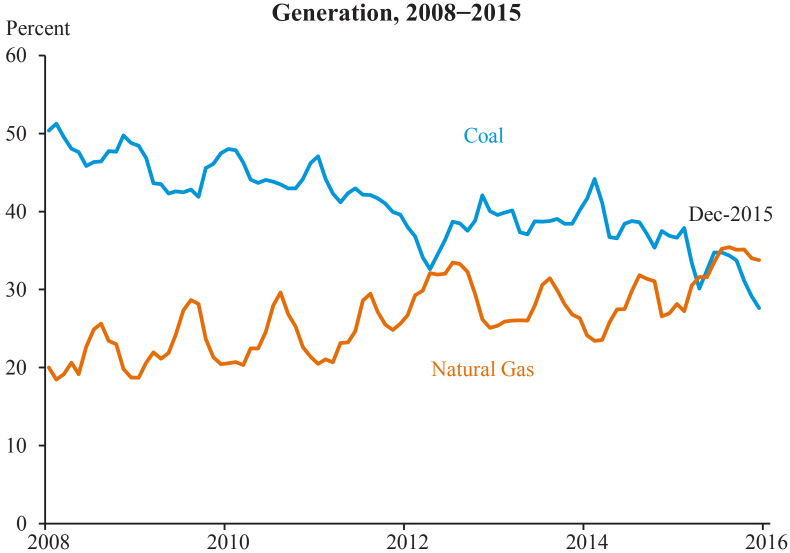
Source: Energy Information Administration; CEA calculations.

Figure 7-16
U.S. Energy Consumption by Source, 2008–2015



Source: Energy Information Administration.

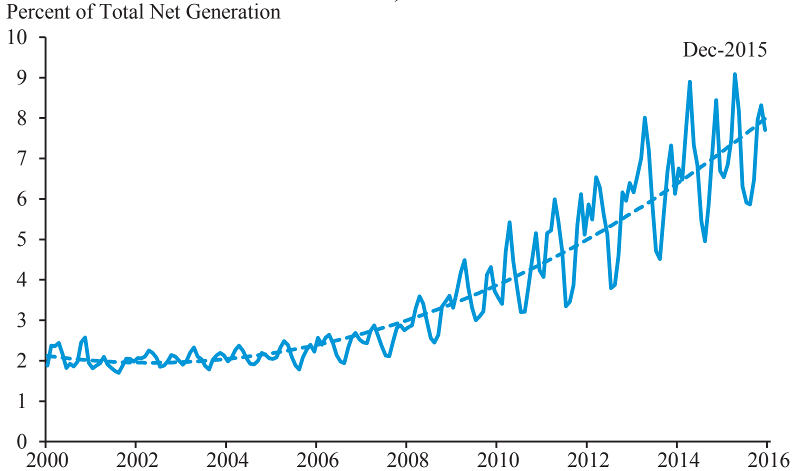
Figure 7-17
Coal and Natural Gas Share of Total U.S. Electricity Generation, 2008–2015



Source: Energy Information Administration.

Figure 7-18

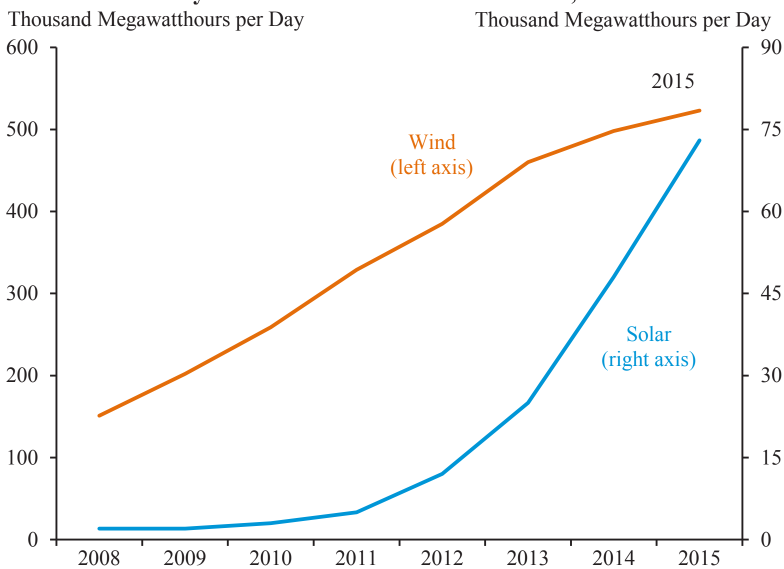
Monthly Share of Non-Hydro Renewables in Net Electric Power Generation, 2000–2015



Note: Dotted line is a smoothed trend, shown to dampen the strong seasonal patterns (the share of non-hydro renewables drops during the winter and summer-both seasons of high power generation demand).
Source: Energy Information Administration.

Figure 7-19

Electricity Generation from Wind and Solar, 2008–2015



Source: Energy Information Administration.

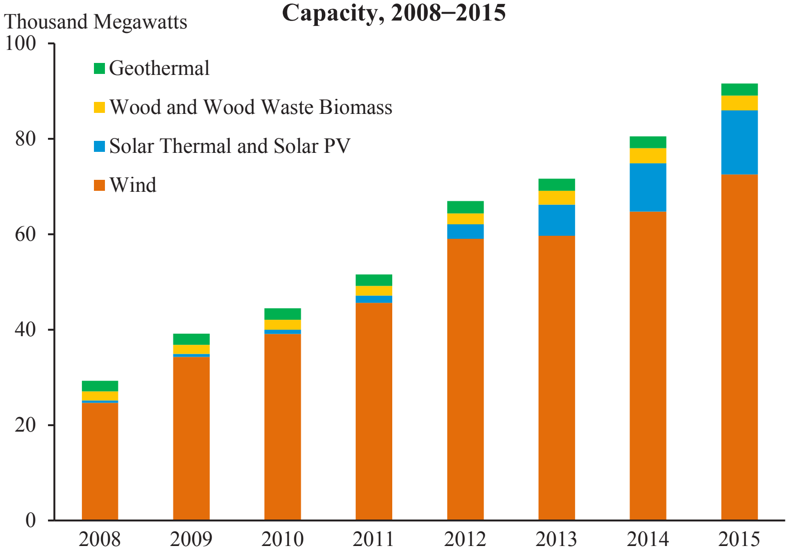
2008 to 7 percent in 2015. Figure 7-19 shows that at the end of 2015, the United States generated more than three times as much electricity from wind and 30 times as much from solar as it did in 2008. Many factors have contributed to this growth, including improved technologies and falling costs, state renewable portfolio standards, other State and local policies, and the major Federal initiatives discussed earlier.

This rapid growth in new electricity generation from renewable sources comes from rapid growth in renewable energy capacity. Electric generation capacity refers to the maximum output that a generator can produce, while electricity generation refers to the actual electricity produced. As illustrated in Figure 7-20, non-hydro renewable energy capacity in the United States more than tripled between 2008 and 2015, from less than 30 gigawatts to almost 100 gigawatts. Most of the increase was driven by growth in wind and solar capacity, and deployments in the first half of 2016 suggest a continuing trend. From January through June 2016, no new coal capacity was installed; solar, wind and natural gas added 1,883 MW, 2,199 MW, and 6,598 MW of new installed capacity, respectively, over the same period (Federal Energy Regulatory Commission 2016).

One reason for increases in renewable electricity generation and capacity is the decline in the cost of renewable energy and other notable clean energy technologies. A common metric for comparing cost competitiveness between renewable and conventional technologies is the "levelized cost of electricity" (LCOE). The LCOE can be interpreted as the per-kilowatt-hour cost (in real dollars) of building and operating a generating plant over an assumed financial life and duty cycle. Several key inputs are taken into account when calculating LCOE, including capital costs, fuel costs, fixed and variable operations and maintenance costs, financing costs, and an assumed utilization rate for each plant type (EIA 2015). Because solar and wind technologies have no fuel costs, their LCOEs are highly dependent on estimated capital costs of generation capacity and can vary substantially by region. While using the LCOE as a measure of technology cost has drawbacks, and energy project developers may not always rely on this metric when assessing project costs, it provides a helpful benchmark for understanding changes in technology costs over time.

Wind and solar LCOEs have fallen substantially since 2008. Figure 7-21 shows that the LCOE for onshore wind technologies has decreased on average by almost 40 percent from 2008 to 2014, based on unsubsidized LCOE; that is, the cost of wind electricity without considering the benefits

Figure 7-20
U.S. Non-Hydro Renewable Energy Electric Power Sector Installed Capacity, 2008–2015



Source: Energy Information Administration.

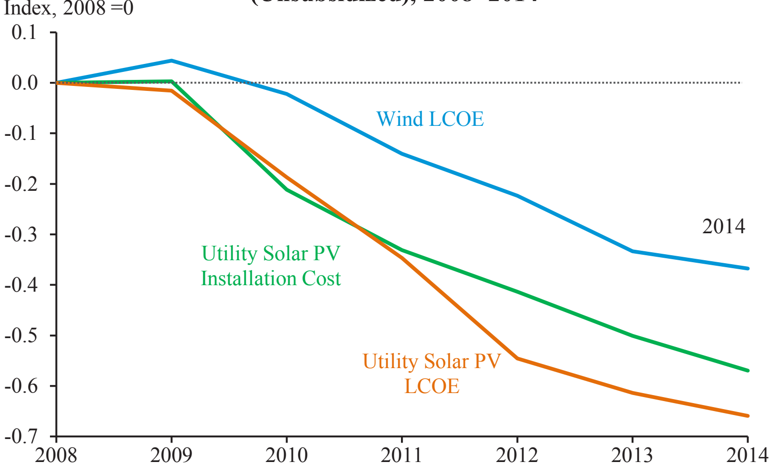
from Federal tax incentives. Installation costs for solar PV have decreased by 60 percent, and LCOE for solar has fallen by almost 70 percent. [28]

In Figures 7-21 and 7-22, the measure of LCOE does not include local, State and Federal tax credits or other incentives for renewable energy. When these incentives are also considered, the cost declines described above mean that in many locations renewable energy costs are at or below the cost of fossil fuels. Renewables are truly reaching "grid parity," which means that the cost of renewables is on par with the cost of new fossil-generated electricity on the grid. Although wind and solar have been considered more expensive forms of new generation, current ranges of unsubsidized costs are showing some wind and solar projects coming in at lower costs than some coal generation. Further, forecasts show a trend toward increasing grid parity in the future. For example, forecasts for wind and solar PV costs from the EIA and the International Energy Agency (IEA) suggest that the unsubsidized technology cost of new wind and solar will be on par with or below that of new coal plants by 2020 (Figure 7-22).[29] Moreover, there are already places

[28] LCOE for wind is estimated by average power-purchase agreement (PPA) prices plus estimated value of production tax credits available for wind, and average PPA prices for solar PV.

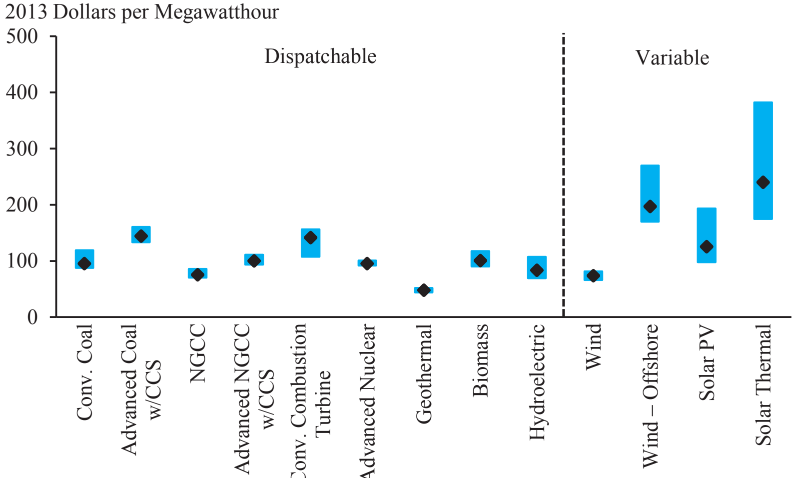
[29] The larger bounds in costs for some renewable technologies, such as solar and off-shore wind, reflect a range of potential technology options that are being considering for future commercial deployment of these developing technologies.

Figure 7-21
Change in Costs for Onshore Wind and Solar (Unsubsidized), 2008–2014



Sources: Wind: National Renewable Energy Lab, DOE (2015), Lawrence Berkeley National Laboratory (2014); Solar: Lawrence Berkeley National Laboratory (2015a), Lawrence Berkeley National Laboratory (2015b).

Figure 7-22
Total System LCOE Comparison Across Generation Technologies (Unsubsidized), 2020 Forecast



Note: Shaded region reflects minimum and maximum of range. NGCC is natural gas combined cycle. CCS is carbon capture and storage. PV is photovoltaics.
Source: Energy Information Administration.

in the United States where new wind and solar can come online at a similar or lower cost than new coal.[30] Note that EIA projections suggest that the unsubsidized LCOE for wind and solar will continue to be above that for natural gas (conventional combined cycle), on average across the United States, in 2018 and 2022 (EIA 2016a).

To better understand what is driving the declining carbon intensity, CEA estimates the portion of carbon intensity in electricity generation decline due to two factors: a reduced carbon intensity of fossil-fuel generation driven by a shift toward natural gas resources, and an increase in electric generation from renewable resources. To do so, CEA uses an analytical approach that develops estimates of counterfactual emissions holding constant the carbon intensities of the electric generating portfolio in 2008.

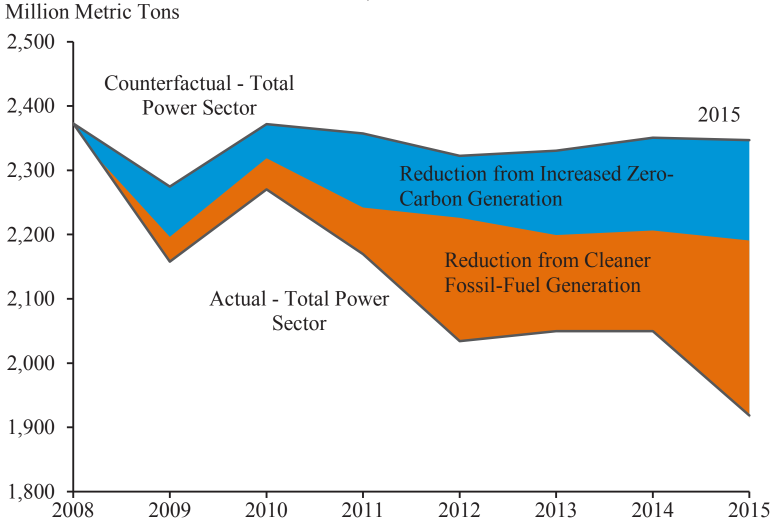
In particular, CEA first considers the case where the emissions factor associated with the portfolio of fossil-fuel electric generation; that is, the emissions per unit of energy generated from a fossil-fuel resource, in 2008 is held constant through 2015. As the emissions factor reflects the mix of resources in the fossil-fuel electric generating portfolio in 2008, this factor reflects the composition and efficiency of coal, natural gas, and petroleum generation resources in 2008. Applying this factor to the total electricity generated from fossil-fuel resources from 2009 to 2015 develops a counterfactual level of emissions had the portfolio of fossil-fuel resources remained constant in mix and efficiency over this time. Then, the difference between the quantity of emissions in the counterfactual and the observed emissions from electricity generated by fossil fuels during this time provides an estimate of emissions saved as a result of the reduction in carbon intensity of fossil-fuel electricity generation.[31] This reduction in carbon intensity is expected to stem primarily from increased natural gas generation, though would also include improvements in technical efficiency from fossil fuel resources. Much of the shift toward natural gas comes from rising supplies and falling prices of natural gas in the United States, though some may stem from policies that have aimed to account for and internalize some of the externalities of coal combustion.

Next, in a similar fashion, the analysis considers the emissions outcomes if the emissions factor from the entire portfolio of electricity generating resources in 2008 were held constant through 2015. The difference between these counterfactual emissions and total actual emissions from

[30] Wind: DOE (2015), Wiser and Bolinger (2014); Solar: Galen and Darghouth (2015), Bolinger and Seel (2015).

[31] This analytical approach holds fixed the observed kWh demand from fossil fuels and total power when estimating counterfactual emissions. To the extent that the shift to natural gas led to an increase in electricity demand, this approach would overstate the impact of coal-to-gas switching on reducing emissions.

Figure 7-23
Decomposition of Emission Reductions from Power Sector, 2008–2015



Source: Energy Information Administration; CEA Calculations.

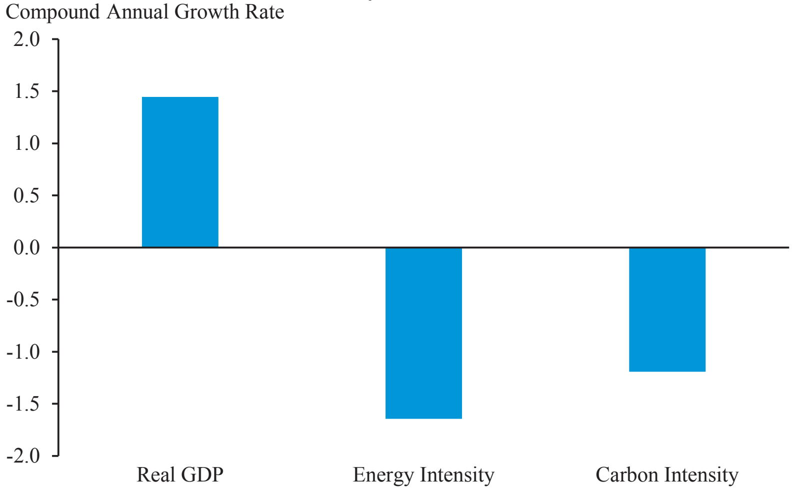
electricity generation would then represent the total avoided emissions from changes in the carbon intensity of the entire electricity portfolio. By subtracting total avoided emissions attributed to reduced carbon intensity from fossil fuel resources calculated as described above, the remaining difference between actual and counterfactual emissions can be attributed to an increase in resources with zero-carbon footprints; that is, an increase in the share of renewable energy resources.[32] For 2015, 284 million metric tons (MMT) (66 percent) of 428 MMT total avoided emissions was due to reduced carbon intensity from lower-carbon fossil resources, leaving 144 MMT (34 percent) attributable to increased generation from renewables. Figure 7-23 shows this decomposition from 2008 to 2015.

Decomposition of the Unexpected and Total Declines in Emissions

This section summarizes overall contributions to the observed emissions decline by decomposing reductions into those attributable to lower energy intensity, lower carbon intensity, and the difference from projections

[32] While this could include increased generation from nuclear power, the EIA shows that net generation from nuclear power remained fairly constant over the period, with an overall reduction in 2015 compared to 2008. Year-to-year fluctuations in nuclear or hydro power can affect annual changes in the contribution of non-carbon energy, but the overall result of significant contribution from non-hydro renewables over time is not altered by these sources, as both hydro and nuclear power saw small declines over the 2008-15 window.

Figure 7-24
Growth Rates of GDP, Energy Intensity and Carbon Intensity, 2008–2015



Source: Bureau of Economic Analysis, National Income and Product Accounts; Energy Information Administration.

on the size of the economy in 2015. The decomposition analysis follows the methodology in CEA (2013), but with the added component of considering emissions from both "expected" and "unexpected" trends. The emissions considered in the analysis are energy-related carbon dioxide emissions, which comprised 97 percent of U.S. carbon dioxide emissions and 83.6 percent of U.S. greenhouse gas emissions in 2014 (EPA 2016a).

As an initial step, one could simply look at GDP growth, energy intensity, and the carbon intensity of energy production to see what has influenced changes in emissions (Figure 7-24). Rising GDP, all else equal, causes an increase in emissions, but the declining energy intensity of output (energy usage per dollar of GDP) and the declining carbon intensity of energy (carbon emissions per energy usage) both pushed down on this tendency of emissions to rise as the economy grows.

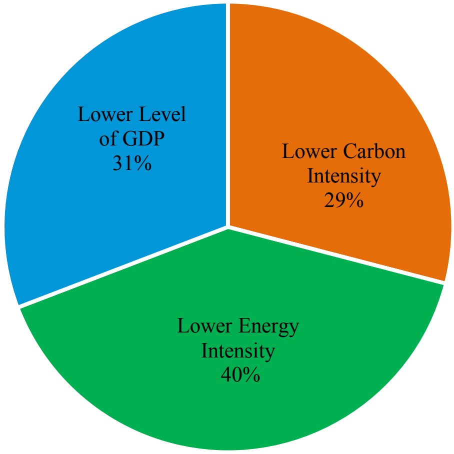
Alternatively, one can use expectations for the paths of these three variables to understand what drove emissions relative to a reasonable expectation in 2008. The general approach of this decomposition is to ask the following: starting in a given base year, what were actual or plausible projections of the values of GDP, energy intensity, and the carbon intensity of energy out to the current year. These three values imply a projected value for the current level of carbon emissions. Then, relative to this forecast, what were the actual emissions, and what were the actual values of these three determinants of emissions? If, hypothetically, the forecasts of energy and carbon intensity were on track, but the GDP forecast differed from projections because of the (unexpected) recession, this would suggest that the unexpected decline in carbon emissions was a consequence of the recession. In general, the forecasts of all the components will not match the realized outcomes, and the extent to which they vary—that is, the contribution of the forecast error of each component to the forecast error in carbon emissions—allows analysts to attribute shares of the unexpected decline in carbon emissions to unexpected movements in GDP, unexpected shifts in energy intensity, and unexpected shifts in carbon intensity.[33]

In the 2013 *Economic Report of the President*, this approach was performed to decompose emissions reductions from 2005 to 2012 (CEA 2013). The analysis found that actual 2012 carbon emissions were approximately 17 percent below the "business as usual" baseline projections made in 2005, with 52 percent due to the lower-than-expected level of GDP, 40 percent from cleaner energy resources, and 8 percent from increased energy efficiency improvements above the predicted trend.

CEA has completed this new decomposition approach in a similar fashion as in the 2013 *Economic Report of the President*, but over a different time frame: from 2008 to 2015 instead of from 2005 to 2012. In this decomposition, emissions in 2015 are compared to projections of emissions in 2015 made in 2008, based on the EIA's *Annual Energy Outlook* from 2008. Then, emissions reductions here can be seen as reductions above and beyond projections, or "unexpected" emissions reductions. As discussed above, energy intensity was projected to decline significantly over this time frame, and emissions reductions from energy intensity occurred largely as predicted. Thus, in this decomposition, energy intensity does not account for any of the "unexpected" emissions reductions, though it fell notably over the relevant time frame and contributed to realized declines in emissions. CEA's analysis suggests that 46 percent of unexpected emissions reductions in 2015 are attributable to a lower-than-predicted carbon intensity of energy, with the remaining 54 percent due to a lower level of GDP than projected in 2008. The role GDP plays in the decomposition largely reflects the fact that the major financial crisis and recession were not anticipated in early 2008, when EIA's projections were made. However, a larger-than-expected decline in carbon intensity also contributes substantially and reflects other

[33] Specifically, CO2 emissions are the product of (CO2/Btu)×(Btu/GDP)×GDP, where CO2 represents U.S. CO2 emissions in a given year, Btu represents energy consumption in that year, and GDP is that year's GDP. Taking logarithms of this expression, and then subtracting the baseline from the actual values, gives a decomposition of the CO2 reduction into contributions from each factor.

Figure 7-25
Decomposition of Total CO_2 Emission Reductions, 2008–2015



Source: Bureau of Economic Analysis, National Income and Product Accounts; Energy Information Administration, August 2016 Monthly Energy Review and 2008 Annual Energy Outlook; CEA Calculations.

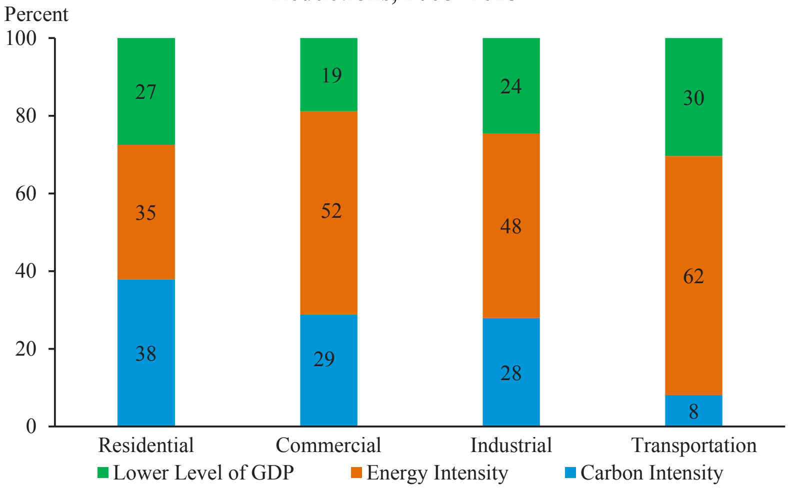
developments in recent years (for example, the shifts toward natural gas and renewables discussed earlier).

Figure 7-25 takes the same decomposition approach using the forecast of 2015 GDP to determine a "GDP surprise" but considers emissions reductions in 2015 compared with observed emissions in 2008, rather than projections for 2015. That is, the projections hold energy intensity and carbon intensity in 2008 constant over the period from 2009 to 2015. In this manner, Figure 7-25 decomposes *total* emissions reductions since 2008 in a way that includes expected, as well as unexpected, movements in either energy intensity or carbon intensity.

Considering total emissions reductions compared with 2008, Figure 7-25 shows that 40 percent of total emissions reductions can be attributed to lower energy intensity, 29 percent to lower carbon intensity, and 31 percent to a lower level of GDP. The impact of lower energy intensity, while expected, was substantial.

To further understand the decline in emissions since 2008, CEA considers emission declines separately by sector—residential, commercial, industrial, and transportation—and decomposes total emission impacts from reduced energy intensity, reduced carbon intensity, and a lower level of GDP (due to unanticipated shocks, most notably the Great Recession) separately by sector. To perform the sector-by-sector analysis, CEA estimates

Figure 7-26
Sectoral Decompostion of Total CO_2 Emission Reductions, 2008–2015



Source: Bureau of Economic Analysis, National Income and Product Accounts; Energy Information Administration, August 2016 Monthly Energy Review; CEA Calculations.

the GDP contributions from each sector using data from the U.S. Bureau of Economic Analysis.[34] Then, CEA performs the same decomposition of total emissions reductions that was done for the economy as a whole in Figure 7-25.

Results of the sectoral decomposition analysis are reported in Figure 7-26. In the residential sector, a lower level of GDP, lower energy intensity, and lower carbon intensity each played a similar role in reducing emissions from 2008 to 2015. For the transportation sector, a majority of emissions reductions (more than 60 percent) were due to a decrease in energy intensity. This finding could reflect the impact of increased fuel efficiency from light-duty vehicle fuel efficiency standards implemented by the Administration over this time, though the analysis cannot establish a causal link.[35] Reductions in energy intensity also played important roles (48 to 52 percent) in emissions reductions from the commercial and industrial sectors, possibly reflecting shifts toward less energy-intensive industries. Any influence of Administration energy efficiency policies (such as, appliance standards) could also be captured here, though no causal link is established in this analysis.

[34] See the Appendix for more detail.
[35] Phase 1 of the first-ever medium- and heavy-duty vehicle standards, finalized in 2011, affected model years 2014-2018, so fuel economy standards for these larger vehicles could only have contributed to the energy intensity share at the very end of the period.

Lower carbon intensity also played a role in emissions reductions in the residential, commercial, and industrial sectors, responsible for 38, 29, and 28 percent of emissions reductions, respectively. In the residential sector, lower carbon intensity in regional electricity supply portfolios from shifts toward natural gas and zero-carbon energy resources would translate to reduced emissions from end-use electricity consumption. This impact would occur similarly for electricity-intensive commercial and industrial activities. Lower carbon intensity in the industrial sector could also result from substitution of lower-carbon natural gas for coal or oil in industrial processes.

How Administration Policies Meet Future Emissions Reductions Targets

In 2009, the President set a goal to cut emissions in the range of 17 percent below 2005 levels by 2020, a goal that was re-affirmed by the U.S. pledge at the 2009 United Nations Framework Convention on Climate Change (UNFCCC) Conference of the Parties in Copenhagen. Subsequently, in 2015 the United States submitted its target to the UNFCCC to reduce emissions 26 to 28 percent below 2005 levels by 2025. In the *2016 Second Biennial Report of the United States of America*, the U.S. presented results from an interagency effort to project the trajectory of GHG emissions through 2030, including the impact of U.S. policies and measures that have either been implemented or planned consistent with the Climate Action Plan. The report found that the implementation of all finalized, and planned, additional policies, including measures that at the time had been proposed but not yet finalized, would lay the foundation to meet those targets.

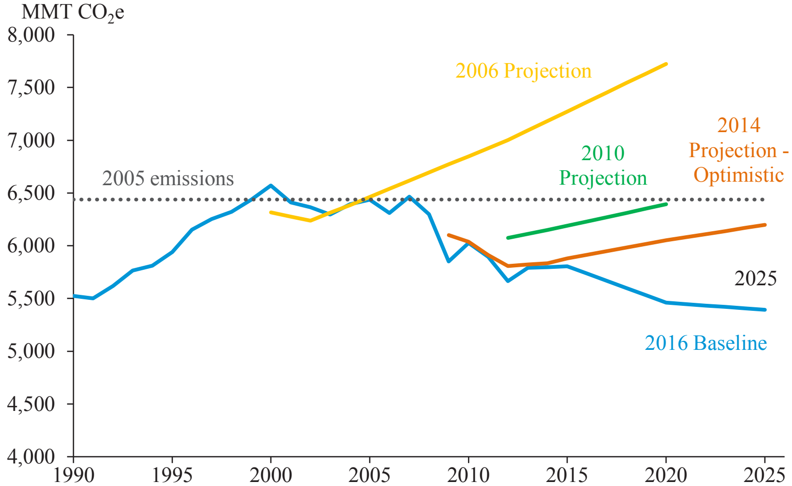
The estimates of U.S. GHG emissions take into account factors such as population growth, long-term economic growth, historic rates of technological change, and usual weather patterns. Projections for future emissions are modeled based on anticipated trends in technology adoption, demand-side efficiency gains, fuel switching, and implemented policies and measures. The report's estimates synthesize projected CO_2 emissions, non-CO_2 emissions, and CO_2 sequestration based on data from the Department of Energy, the Energy Information Administration, the Environmental Protection Agency, and the Department of Agriculture. The main source of uncertainty in emission projections is the range of land use, land-use change, and forestry projections, which approximate the ability of the land sector to remove CO_2 emissions from the atmosphere. The report therefore produces a range of projections using a set of modeling techniques from various agencies, which reflect differing perspectives on macroeconomic outlook, forest characteristics, and management trends. However, in part due to actions undertaken by the United States to bolster the forest carbon sink, the authors of the 2016 report believe that the United States is trending toward a more high-sequestration ("optimistic") pathway.

The report estimates two emissions projection scenarios. The first, the *Current Measures* scenario, reflects the impact of those policies and measures that have been established up to mid-2015. This includes, most notably, the Clean Power Plan, more stringent light-duty vehicle economy standards, recent appliance and equipment efficiency standards, and actions to reduce agricultural emissions and bolster our forest carbon sink. However, the *Current Measures* scenario does not include measures that were not final at the time of the publication, such as then-draft standards for oil and gas methane, phase two heavy-duty vehicle standards, and the five-year extension of tax credits for wind and solar. Therefore, the *Current Measures* scenario underestimates the full impact of policies undertaken under the President's Climate Action Plan. Under the *Current Measures* scenario, GHG emissions are projected to decline 15 percent below the 2005 level in 2020 with an optimistic land sector sink (Figure 7-27). The effects of policies implemented under the Obama Administration are clear when comparing the 2015 projections to the 2006 projections, in which emissions were expected to increase by about 20 percent above 2005 levels by 2020. Clear progress in driving down projected GHG emissions can be seen since 2010 and even since 2014. The 2016 projections mark the first time a U.S. Climate Action Report has projected GHG emissions to fall based on existing policies. This reflects the large number of policies implemented in the prior two years.

Also in the *2016 Second Biennial Report* is an *Additional Measures* scenario that includes measures consistent with the Climate Action Plan that were planned, but not implemented, when the Report was completed, such as policies to cut methane and volatile organic compound emissions from oil and gas systems, and a proposed amendment to the Montreal Protocol to phase down production and consumption of hydrofluorocarbons. The report estimates the impact of planned policies separately on emissions of carbon dioxide, hydrofluorocarbons, methane, and nitrous oxide. These estimates are synthesized and presented as a range due to uncertainty in policy implementation. The report projects that the *Additional Measures* scenario with an optimistic land sector sink will lead to emission reductions of at least 17 percent from 2005 levels in 2020, and 22 to 27 percent below 2005 levels in 2025 (Figure 7-28). Note that some of the policies included in the report as "additional measures" (for example, new GHG emissions standards for heavy-duty vehicles, and methane standards for new sources in the

Figure 7-27

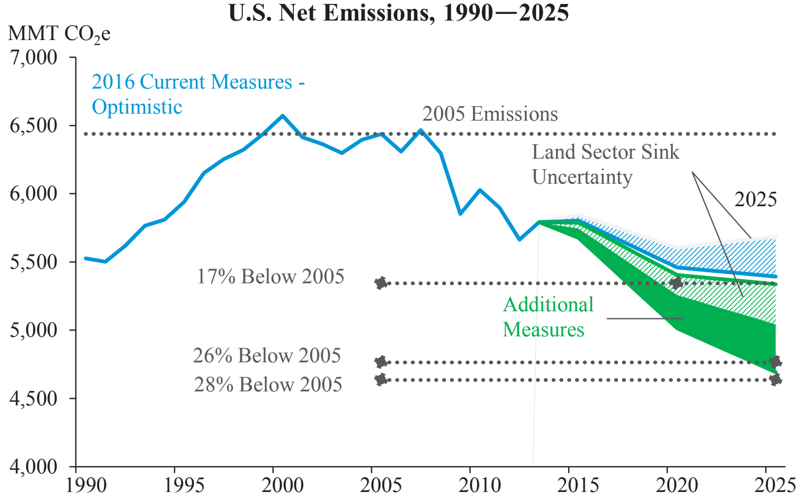
U.S. Net Emissions based on Current Measures, 1990–2025



Note: The 2016 Baseline only includes policies finalized by mid-2015, so it underestimates the full impact of U.S. climate policies finalized under the Adminstration's Climate Action Plan through 2016.
Source: Department of State (2016).

Figure 7-28

U.S. Net Emissions, 1990—2025



Note: Major policies included in this figure as "additional measures" such as heavy-duty vehicle standards and methane rules for oil, gas and landfills have been finalized in 2016, and would further decrease the 2016 "current measures" projection if included.
Source: U.S. Department of State (2016).

oil and gas sector) were subsequently finalized in 2016, as was an agreement by the Parties to the Montreal Protocol to phase down global hydrofluorocarbon use (UNEP 2016). If included, these would move the 2016 projection below its current position in Figure 7-28.

These projections show that recent Administration actions on emission-reduction policies are already moving the United States toward its targets. The additional implementation of policies planned as of 2016 will put the economy on track to meet the 2020 target and will build a foundation for meeting the 2025 target. Under this scenario, this level of emission reduction will occur even while the economy is projected to grow by 50 percent.

American Leadership in International Cooperation

As climate change mitigation is a global public good, international cooperation is essential for an effective and economically efficient solution. The President's ambition and dedication to addressing climate change have helped accentuate the United States' position as a global leader on this issue. On December 12, 2015, more than 190 countries agreed to the most ambitious climate change mitigation goals in history. The Paris Agreement entered into force in November 2016, 30 days after the date on which the required threshold (at least 55 Parties, accounting for at least 55 percent of global greenhouse gas emissions) was officially met. The Agreement establishes a long-term, durable global framework to reduce global greenhouse gas emissions where, for the first time ever, all participating countries commit to putting forward nationally determined contributions. The Agreement lays the foundation for countries to work together to put the world on a path to keeping climate warming well below 2 degrees Celsius, while pursuing efforts to limit the increase even more. The nationally determined contributions agreed to in Paris, though historic, will not halt climate change on their own, but the Paris Agreement provides a framework for progress toward that goal.[36]

In the lead up to the Paris Agreement in 2015, the United States worked bilaterally with many countries to build support for an ambitious agreement. Most notably, starting in 2013, the United States and China intensified their climate cooperation and, in November 2014, President

[36] Building on the historic Paris Agreement, in October 2016, 191 members of the International Civil Aviation Organization (ICAO) meeting in Montreal, Canada adopted a market-based measure to reduce carbon dioxide emissions from international aviation – aviation comprises two percent of global carbon emissions, but was not covered by the Paris Agreement. Like other aspects of climate change mitigation, reducing aviation emissions requires international cooperation.

Obama and President Xi made a surprise announcement of their countries' respective post-2020 climate targets. President Obama announced the ambitious U.S. goal to reduce emissions by 26 to 28 percent below 2005 levels by 2025, and China committed for the first time to implement policies leading to a peak in its carbon dioxide emissions around 2030 and an increase in the share of non-fossil fuels in primary energy consumption. Further, in September 2015, President Obama and President Xi reaffirmed their commitment to a successful outcome in Paris, a shared determination to move ahead decisively in implementing domestic climate policies, strengthening bilateral coordination and cooperation on climate change and promoting sustainable development. In addition to working closely with China, the United States worked hand-in-hand with a broad range of countries to increase support for international climate action and an ambitious agreement in Paris, including with Brazil, Canada, India, Indonesia, Mexico, small islands, and many others.

The United States has remained a leader in the global effort to mobilize public and private finance for mitigation and adaptation. Since the 15th Conference of the Parties (COP-15) to the United Nations Framework Convention on Climate Change in December 2009, the United States has increased its climate financing by fourfold for developing countries (Department of State 2016a). In November 2014, President Obama pledged that the United States would contribute $3 billion to the Green Climate Fund to reduce carbon pollution and strengthen resilience in developing countries, the largest pledge of any country. This strong U.S. pledge helped increase the number and ambition of other countries' contributions, and U.S. leadership helped propel initial capitalization of the fund to over $10 billion, a threshold seen by stakeholders as demonstrating serious donor commitment.

At the Paris Conference, Secretary of State John Kerry announced that the United States would double its grant-based public climate finance for adaptation by 2020. As of 2014, the United States had invested more than $400 million a year of grant-based resources for climate adaptation in developing countries, providing support to vulnerable countries to reduce climate risks in key areas including infrastructure, agriculture, health, and water services. The commitment that the United States and other countries have shown to mobilizing climate finance will help to support developing countries' transitions to low-carbon growth paths.

One of the most important components of the landmark Paris Agreement is that, by sending a strong signal to the private sector that the global economy is transitioning toward clean energy, the Agreement will foster innovation to allow the United States to achieve its climate objectives while creating new jobs and raising standards of living. The submission of ambitious national contributions in five-year cycles gives investors and technology innovators a clear indicator that the world will demand clean power plants, energy efficient factories and buildings, and low carbon transportation both in the short term and in the decades to come.

Another example of U.S. diplomatic leadership to drive global action on climate change mitigation is the Administration's work over several years toward an amendment to the 1987 Montreal Protocol to phase down the global production and consumption of hydrofluorocarbons, potent greenhouse gases. This work included the development of leader-level joint statements with China in 2013 and with India in 2015. In October 2016, the 197 Parties to the Montreal Protocol agreed to amend the Protocol to phase down HFC use in developed countries beginning in 2019, and to freeze and subsequently phase down HFC use in the vast majority of developing countries in 2024 (UNEP 2016). The agreement could avoid up to 0.5 degrees Celsius of warming by the end of the century, and it also provides financing to developing countries to help them transition to new air conditioning and refrigeration technologies that do not use HFCs.

The United States helped found the Clean Energy Ministerial, an ambitious effort among 25 governments representing around 75 percent of global greenhouse gas emissions and 90 percent of global clean energy investments. Through annual ministerial meetings (the United States hosted in 2010 and 2016), collaborative initiatives, and high-profile campaigns, the CEM is bringing together the world's largest countries, the private sector, and other stakeholders for real-world collaboration to accelerate the global clean energy transition. Twenty-one countries, the European Union, nearly 60 companies and organizations, and 10 subnational governments, made more than $1.5 billion in commitments to accelerate the deployment of clean energy and increase energy access at the June 2016 Clean Energy Ministerial.

On the first day of the Paris Conference, President Obama joined 19 other world leaders to launch Mission Innovation—a commitment to accelerate public and private global clean energy innovation. Twenty-two governments, representing well over 80 percent of the global clean energy research and development (R&D) funding base, have now agreed under Mission Innovation to seek to double their R&D investments over five years (Mission Innovation 2016). In addition, a coalition of 28 global investors committed to supporting early-stage breakthrough energy technologies in countries that have joined Mission Innovation (Bodnar and Turk 2015). The combination of ambitious commitments and broad support for innovation and technology will help ratchet up energy investments over the coming years, accelerate cost reductions for low-carbon solutions, and spur increasing greenhouse gas emissions reductions.

Plans for the Future

Building on the progress discussed in this chapter in decreasing emissions and shifting toward a clean energy economy will require concerted effort over the coming years. Many of the policies and commitments begun by the President will have growing impacts over time, including several recently enacted policies mentioned above, as well as ongoing initiatives discussed below that form some of the next steps to continuing progress on climate issues. Also discussed below are some of the President's proposals for furthering clean energy goals that Congress has not yet acted upon, as well as potentially promising directions for longer-term climate policy.

On June 29, 2016 at the North American Leaders Summit in Ottawa, Canada, the President was joined by Canadian Prime Minister Justin Trudeau and Mexican President Enrique Peña Nieto in announcing the North American Climate, Energy, and Environment Partnership. The Partnership outlines several goals the three countries aim to achieve. Notably, a primary tenant of the Partnership is for North America to attain 50 percent clean power generation by 2025, including renewable, nuclear, and carbon capture, utilization and storage technologies, as well as demand reduction through energy efficiency. Each country will pursue these actions individually by establishing specific legal frameworks and clean energy national goals, tailored to each country's unique conditions. Additionally, the three countries aim to drive down short-lived climate pollutants, such as reducing methane emissions from the oil and gas sector by 40 to 45 percent by 2025. Other elements of the national methane emissions-reducing strategies could target key sectors such as waste management. To improve energy efficiency, the Partnership intends to better align and further improve appliance and equipment efficiency standards: North American neighbors plan to align six energy efficiency standards or test procedures for equipment by the end of 2017, and to align 10 standards or test procedures by the end of 2019. In order to advance integration of all clean energy sources, including renewables, the Partnership also strives to support the development of cross-border transmission projects that can play a key role in cleaning and increasing the reliability and flexibility of North America's electricity grid. At least six transmission lines currently proposed, or in permitting review, would add approximately 5,000 MW of new cross-border transmission capacity. The three economies will align approaches for evaluating the impact of direct and indirect greenhouse gas emissions of major projects, such as using similar methodologies to estimate the social cost of carbon and other greenhouse gases. In summary, the North American Climate, Clean Energy, and Environment Partnership Action Plan aims to advance clean and secure energy, drive down short-lived climate pollutants, promote clean and efficient transportation, protect nature and advance science, and show global leadership in addressing climate change.

In 2015, about 41 percent of U.S. coal was produced on Federally managed land, and this coal was responsible for about 10 percent of U.S. greenhouse gas emissions (BLM 2016a). The President's 2016 State of the Union address called to "change the way we manage our oil and coal resources, so that they better reflect the costs they impose on taxpayers and our planet." Three days later, Department of the Interior Secretary Sally Jewell announced the first comprehensive review of the Federal coal leasing program in over 30 years (DOI 2016). This announcement followed a series of listening sessions across the country in 2015, initiated by Secretary Jewell, to consider if taxpayers and local communities were getting fair returns on public resources, how the coal leasing structure could improve in transparency and competitiveness, and how the federal coal program could be managed consistently with national climate change mitigation objectives (BLM 2016b). The Department of the Interior has yet to complete its analysis of these issues. However, the current structure of the coal leasing program does not price externalities from coal combustion, and independent analysis by CEA concludes that it does not provide a fair return to taxpayers, making this review a crucial policy step from an economic perspective (CEA 2016a).

Through a Programmatic Environmental Impact Statement (PEIS) expected to be prepared over three years, the review will examine the Interior Department's current process to determine when, where, and how to provide leases and respond to feedback and concerns raised during the listening sessions as well as by the Government Accountability Office (GAO 2013). The review will inform how the Federal coal program can be reformed to ensure a fair return to American taxpayers for public resources while considering the environmental and public health impact of Federal coal production.

While the review is underway, mining will continue under existing leases, but the Department of the Interior will pause new leases, with some limited exceptions. This is consistent with practices under the previous two programmatic reviews in the 1970s and 1980s. The Department of the Interior also announced a series of reforms to improve the transparency of the Federal coal program, including the establishment of a publicly available database to monitor carbon emissions from fossil fuels on public lands and to increase transparency from Bureau of Land Management (BLM) offices regarding requests to lease coal or reduce royalties (BLM 2016b).

A transition to a clean energy economy means removing subsidies that encourage fossil fuel consumption and production, including the $4 billion in annual subsidies oil companies receive from taxpayers. The President called on Congress to end these subsidies (Slack 2012), and proposed eliminating inefficient fossil fuel subsidies in every budget he has submitted, with the Fiscal Year 2017 Federal Budget proposing to repeal $4 billion in subsidies to oil, gas, and other fossil fuel producers, as well as to expand the tax that supports the Oil Spill Liability Trust Fund to apply to oil sand crude oil. Following through on these proposals is a step toward avoiding a policy bias toward fossil fuel energy consumption and giving clean energy production a more level playing field. Given the climate externalities associated with fossil fuel use, subsidizing fossil fuel consumption or production means that not only are the externalities unpriced, but more fossil fuels are consumed than a pure market outcome even without considering the externalities. Removing the subsidies moves the incentives toward the efficient outcome.

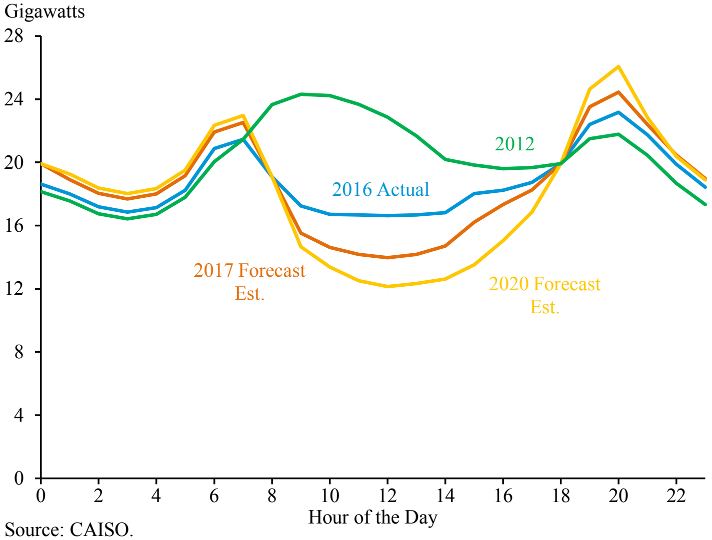
Announced in 2016, the President's 21st Century Clean Transportation Plan seeks to improve America's transportation accessibility and convenience, while reducing the emissions intensity of travel. The President's plan includes $20 billion in additional annual investments to reduce traffic and improve accessibility for work and school trips by expanding transit systems, adding high-speed rail in major corridors, modernizing freight systems, and supporting the TIGER program, which provides grants for innovative transportation projects. The Plan also directs an additional $10 billion a year to support planning efforts by State and local governments to maximize the benefits of public investments. The funds will encourage land use planning and investments in infrastructure to support low-carbon transit options as well as the development of livable cities with resilient transit options. In addition, the Plan directs just over $2 billion a year toward the deployment of smart and clean vehicles and aircraft, supporting pilot deployments of autonomous vehicles, expanding the Diesel Emissions Reduction Act Grant Program, and investing in the safe integration of new technologies.

To fund these investments, the President proposed a $10 a barrel fee on oil, phased in gradually over five years. Revenues from the fee would provide long-term solvency for the Highway Trust Fund to maintain infrastructure, in addition to supporting new investments under the Plan. By placing a fee on oil, this policy would take a step toward ameliorating the current market failure that allows parties involved in emissions-generating activities to bear less than the full costs of that activity. Further, by directing revenues from the fee toward investments in a resilient and low-carbon transportation

Box 7-4: Supporting Increased Penetration of Variable Energy with Smart Markets and Storage

The two most rapidly growing renewable energy technologies, wind and solar, come with unique operating characteristics. The variable nature of their production profile creates new challenges for management of the electric grid, as compared to traditional generating resources with a more dispatchable output profile. For example, when considering the timing of output from wind and solar, the net electricity load, which is the demand for electricity less wind and solar generation, can exhibit a "duck curve"—where the low net load in the middle of the day ramps up quickly as the sun sets before trailing off as demand ebbs later at night—looking much like the neck, head, and bill of a duck. The figure below plots this curve for an illustrative spring day in California. We see that current levels of variable energy resource (VER) penetration begin to create this duck shape, increasingly so for future years, when VERs are projected to increase.

Figure 7-i
Net Load for March 31



Source: CAISO.

In addition to the unique net load profile created by variable renewable resources, wind and solar output exhibits more idiosyncratic variation as compared to traditional resources, a feature that also creates additional grid management needs.

As penetration of variable energy resources has increased across the country and the world, so too has the development of technologies and operational changes to increase the flexibility of the electricity grid. In addition to increasing transmission, larger balancing areas, and system operational changes, smarter markets and energy storage and management systems can also support the flexibility requirements created by increased use of VERs. Smart markets, which refers to communications technologies and approaches that facilitate end-user responses in the demand for electricity, can be leveraged to allow demand to adjust to the true current cost of electricity. Dynamic electricity pricing structures, as well as technology that facilitates end-user adjustment of demand such as smart appliances, support integration of VERs by increasing the incentives and ability of consumers to modify their own electricity demand. Further, the recent proliferation of smart markets infrastructure with the deployment of 16 million smart meters since 2010 (DOE 2016e), lays the necessary foundation for these resources to support grid integration.

Opportunities for energy storage to support integration are also rapidly expanding as the storage industry has seen dramatic cost reductions in the last decade from over $1,000 per KWh in 2007 to under $410 per kWh today (Nykvist and Nilsoon 2015). Storage technologies support grid integration by temporarily storing electricity for later use during times of grid stress, as well as storing variable energy produced for use later that might otherwise be discarded due to low demand.

Although analysts had previously claimed that variable energy penetration beyond 15 to 20 percent was not technically feasible (Farmer, Newman, and Ashmole 1980; Cavallo, Hock, and Smith 1993), instantaneous VER penetrations have already achieved high levels, with Texas hitting a record 45 percent of total penetration in March 2016 and Portugal running for four days straight on 100 percent renewables (wind, solar, and hydropower) (Electricity Reliability Council of Texas 2016, ZERO 2016). As more VERs increase the need and the value of grid flexibility, supporting the ability of smart markets and energy storage to provide grid integration services by ensuring that regulatory and electricity markets allow for the monetization of these resources will be critical to transition to an increasingly low-carbon grid (CEA 2016b).

Sources: CEA (2016b), DOE (2016e), Nykvist and Nilsoon (2015), Electricity Reliability Council of Texas (2016), ZERO (2016), Farmer et al. (1980), Cavallo (1993).

sector, the fee would incentivize private-sector innovation and investment in clean transportation technologies. A portion of the fee would also be directed to provide relief to vulnerable households.

In 2009, the President urged Congress to pass an energy bill that would have used market-based mechanisms to incentivize a clean energy transformation (Obama 2009). A bill with a proposed national cap-and-trade system passed in the House but was not voted on in the Senate (Walsh 2010). While over the President's terms the Administration has pursued a number of policies that indirectly price carbon-emitting activities, going forward, a widely held view across a broad spectrum of economists is that policies that put a direct, uniform price on carbon are the most efficient and comprehensive way to both meet the goals set forth in the Paris Agreement and to efficiently transition to a clean energy economy. Even with a comprehensive national carbon price, some additional Federal climate policies (such as investments in clean energy research and development) would likely still be efficient.

Conclusion

As discussed in this report, the costs of climate change are large, the impacts are being felt now, and they will intensify in the future. Further, delaying policy action designed to halt climate change will likely increase its costs. There is strong economic rationale for policies to address climate change based on both correcting a market failure from the negative externality produced by greenhouse gas emissions, and as a form of insurance against catastrophes caused by global warming. Since the President took office in 2009, the United States has taken numerous steps to both mitigate climate change and respond to its effects. The Administration leveraged a diverse set of policy mechanisms, from tax credits for renewable energy technologies to the first-ever greenhouse gas emission standards for vehicles and power plants, to pivot the nation toward a greener and stronger economy while recovering from the Great Recession. With the implementation of these policies, renewable energy technology costs have declined, and deployment of clean energy technologies has increased. With the implementation of Administration policies, and with a concurrent increase in supply and decrease in the cost of natural gas, the carbon intensity of our electric portfolio has decreased, and the overall energy and carbon intensity of the economy has declined. All of these changes in the U.S. energy system, favorable to climate change mitigation, have occurred while the economy has grown.

Although the progress made to date in transitioning toward a clean-energy economy since 2009 presents only a portion of the Administration's accomplishments in the clean energy and climate change space, the forward-looking policies established by this Administration, as well as proposals for further action, provide a pathway for the Nation to continue this transformation to a low-carbon economy that achieves future emissions reductions goals. Some of the progress made during the Administration's eight years is due to policy and some from technological breakthroughs and changes in natural gas production. To meet U.S. climate goals, it will be essential to build on this progress by achieving the emissions reductions projected from a number of policies that are just beginning to be implemented, and by taking further actions. The Administration's significant investments in clean energy research and development also help to ensure that the decreases in carbon intensity and energy intensity analyzed here will continue over the long run.

Finally, as climate change is global in nature, the 2015 Paris Agreement provides a critical missing link between domestic and international climate actions. Adopted by over 190 countries in December 2015, and officially entering into force in November 2016, the Agreement is the most ambitious climate change agreement in history, laying the foundation for a path to keep the global temperature rise well below 2 degrees while pursuing efforts to limit the increase even more. The United States set a goal of a 2025 emissions level in the range of 26 to 28 percent below 2005 emissions levels, and the goals set forth in the President's Climate Action Plan provide a path for the United States to uphold this commitment. However, the work is not finished. Continued efforts in upcoming years are critical to achieving these goals and transitioning to an energy system that incorporates externalities into energy production and consumption decisions, moving toward economically efficient outcomes that support the goal of global climate change mitigation.

Appendix: Detail on Sectoral Emissions Decomposition Analysis

In order to do the decomposition on a sector-by-sector basis, consider that each of the four sectors contributes to a portion of GDP. To approximate a sector's GDP contribution, each sector is matched to category in the National Income Product Accounts (NIPA), with matchings below. Then, the percent of GDP is calculated for each sector. To calculate 2008 baseline projections, this observed contribution percent is multiplied by forecasts of GDP made in 2008. This way, the difference between the actual versus the baseline of sector GDP mirrors the difference between actual and projected GDP. Performing this mapping for each sector allows for the same identity to be used to decompose emissions in the total economy as for the sector by sector decomposition.

The energy consumption and emissions included for each sector can be found in EIA glossary and documentation materials for the Monthly Energy Review (MER) Tables 2.1 and Tables 12.2 – 12.5.

Residential Sector

The account category used to approximate GDP contribution is the category for "Housing and Utilities", within Personal Consumption Expenditure - Services - Household Consumption Expenditures.

Transportation Sector

The account category used to approximate GDP contribution is the category "Transportation", within Personal Consumption Expenditures - Services - Household Consumption Expenditures.

Industrial Sector

The account category used to approximate GDP contribution is the category "Goods", within Personal Consumption Expenditures.

Commercial Sector

The account category used to approximate GDP contribution is the category "Services" within Personal Consumption Expenditures.