CHAPTER 6

CLIMATE CHANGE AND THE PATH TOWARD SUSTAINABLE ENERGY SOURCES

The Administration is committed to a comprehensive energy strategy that supports economic and job growth, bolsters energy security, positions the United States to lead the world in clean energy, and addresses the global challenge of climate change. Finding a responsible path that balances the economic benefits of low-cost energy, the social and environmental costs associated with energy production, and our duty to future generations is a central challenge of energy and environmental policy.

The most significant long-term pollution challenge facing America and the world is the anthropogenic emissions of greenhouse gases. The scientific consensus, as reflected in the 2009 assessment by the U.S. Global Change Research Program (USGCRP) on behalf of the National Science and Technology Council, is that anthropogenic emissions of greenhouse gases are causing changes in the climate that include rising average national and global temperatures, warming oceans, rising average sea levels, more extreme heat waves and storms, and extinctions of species and loss of biodiversity. A multitude of other impacts have been observed in every region of the country and virtually all economic sectors.

As part of the United Nations Climate Change Conferences in Copenhagen and Cancún, the United States pledged to cut its carbon dioxide (CO_2) and other human-induced greenhouse gas emissions in the range of 17 percent below 2005 levels by 2020, and to meet its long-term goal of reducing emissions by 83 percent by 2050. Approximately 87 percent of U.S. anthropogenic emissions of all greenhouse gases (primarily CO_2 and methane) are energy-related, and fossil-fuel combustion accounts for approximately 94 percent of U.S. CO_2 emissions (EPA 2010a).

Climate change is often described in terms of changes in background conditions that unfold over decades, but extreme events superimposed on, and possibly amplified by, those background changes can cause severe damage. For example, storm surges superimposed on higher sea levels will cause greater flooding, heat waves superimposed on already warmer temperatures will cause greater damage to crops, and a warmer atmosphere amplifies the potential for both droughts and floods.

From an economist's perspective, greenhouse gas emissions impose costs on others who are not involved in the transaction resulting in the emissions; that is, greenhouse gas emissions generate a negative externality. Appropriate policies to address this negative externality would internalize the externality, so that the price of emissions reflects their true cost, or would seek technological solutions that would similarly reduce the externality. Such policies encourage energy efficiency and clean energy production. In addition, prudence mandates that the Nation prepare now for the consequences of climate change.

Consequences and Costs of Climate Change

The clear scientific consensus is that anthropogenic greenhouse gas emissions are causing our climate to change. These changes include increasing temperatures, rising sea levels, changing weather patterns, and increasingly severe heat waves, with negative consequences for human health, property, and ecosystems.[1]

The Changing Climate

Projections using a wide variety of climate models paint a broadly similar picture of how global temperatures can be expected to rise in response to emissions—a picture that is also consistent with observed temperature changes (Rohling et al. 2012). Likely temperature paths, from a comparison of models by the USGCRP (2009), predict that the average global temperature under a low-emissions scenario will increase by approximately 4°F by the end of this century; under the medium and high emissions scenarios, end-of-century increases are 7°F and 8°F, respectively. Some regions are projected to experience greater temperature increases than others. The Arctic has warmed by almost twice the global average in recent decades, in part because warming melts snow and ice, leading to less reflected sunlight, which causes yet more warming (Arctic Monitoring and Assessment Programme 2011).

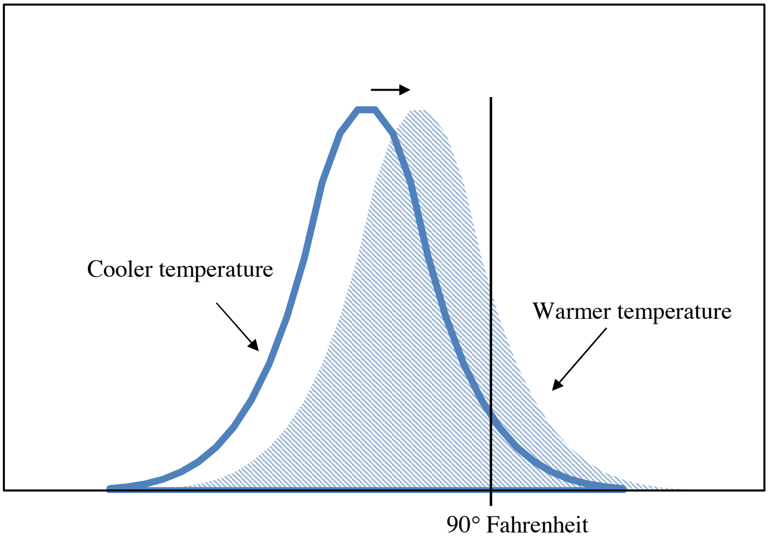
[1] The scientific consensus on the effects of greenhouse gas emissions on climate is summarized in reports by the USGCRP (2009) and the International Panel on Climate Change (IPCC 2012). The draft Third National Climate Assessment report, prepared by the National Climate Assessment Development Advisory Committee, was issued for public comment in January 2013.

Warming temperatures raise sea levels because of expanding ocean water, melting mountain glaciers and ice caps, and partial melting of the Greenland and continental Antarctic ice sheets. Since 1880, the global sea level has risen about 20 centimeters, more than half of which has occurred since 1950. Projections by the National Oceanographic and Atmospheric Administration show sea levels rising over the 21st century by 19 to 200 centimeters (NOAA 2012).

Increasingly common extreme events, such as heat waves, droughts, floods, and storms, pose some of the most significant risks of climate change. In its assessment of the current scientific literature, the IPCC (2012) concluded that increases in greenhouse gases will almost certainly increase the frequency and magnitude of hot daily temperature extremes during the 21st century, while episodes of cold extremes will decrease. In addition, the length, frequency, and intensity of heat waves are very likely to increase over most land areas, and droughts may intensify (Hansen, Sato, and Ruedy 2012; Rhines and Huybers 2013). In fact, an increase in the mean temperature implies more very hot days and fewer very cold days, even if the variability of daily temperatures around the mean remains unchanged. This phenomenon—a disproportionate increase in previously extreme temperatures as the mean temperature increases—is illustrated in Figure 6-1, which displays a shift in a hypothetical distribution of possible daily temperatures. The implications of Figure 6-1 accord with observed changes over the past decades and centuries as well as with climate model simulations. For example, according to the USGCRP estimates, under a high-emissions scenario, areas of the Southeast and Southwest that currently experience an average of 60 days a year with a high temperature above 90°F will experience 150 or more such days by the end of the century.

Patterns of precipitation and storms are also likely to change, although the nature of these changes currently is more uncertain than those for temperature. Northern areas of the United States are projected to become wetter, especially in the winter and spring; southern areas, especially the Southwest, are projected to become drier. Moreover, heavy precipitation events will likely be more frequent: downpours that currently occur about once every 20 years are projected to occur every 4 to 15 years by 2100, depending on location. The strongest cold-season storms are projected to become stronger, more frequent, and more costly. For more on the costs of storms, see Box 6-1.

Figure 6 - 1
Illustrative Average Temperature Distribution



Source: CEA illustration.

Estimating the Economic Cost of Climate Change: The Social Cost of Carbon

Because greenhouse gas emissions cause climate change, policies to reduce climate change must focus on reducing anthropogenic greenhouse gas emissions. An important step in informing a policy response is knowing precisely where carbon emissions are coming from, and that is the purpose of the Environmental Protection Agency (EPA) Greenhouse Gas Reporting Program discussed in Data Watch 6-1.

Another critical step in formulating policy responses to climate change is to estimate the economic costs induced by emitting an additional, or marginal, ton of CO_2. This cost—which covers health, property damage, agricultural impacts, the value of ecosystem services, and other welfare costs of climate change—is often referred to as the "social cost of carbon" (SCC). Having a range for the SCC provides a benchmark that policymakers and the public can use to assess the net benefits of emissions reductions stemming from a proposed policy. Although various studies, notably Stern (2006), have estimated the cost of climate change, until recently the Federal Government did not generate its own unique set of estimates of the SCC.

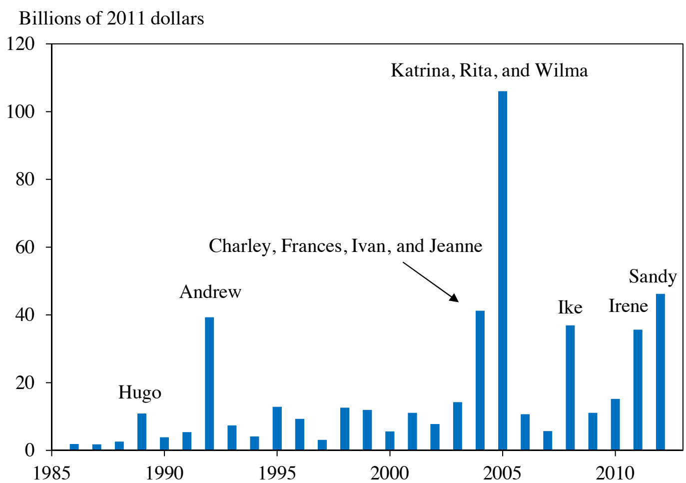
In 2010, a Federal interagency working group, led by the Council of Economic Advisers and the Office of Management and Budget, produced a white paper that outlined a methodology for estimating the SCC and

Box 6-1: The Cost of Hurricanes

Hurricanes draw energy from the temperature difference between the surface ocean and mid-level atmosphere. Although no one hurricane or storm can be attributed to global warming, there is some expectation that warming surface waters will increase the maximum intensity of hurricanes, and a trend toward increasing hurricane intensity has been observed in the North Atlantic over the past three decades (Kossin et al. 2007). As the figure shows, insured losses from storms have also been increasing over the past 20 years, a trend that is driven by losses from recent large hurricanes. Because many of the losses from hurricanes are uninsured, total costs can substantially exceed insured costs.

Development near vulnerable coasts, increasing intensity of storms, and rising sea levels point toward hurricane winds, precipitation, and storm surges that are increasingly destructive. In fact, several studies project substantial increases in hurricane-related costs because of climate change.[1] It is difficult to isolate the contribution of climate change to the historical increase in hurricane costs. Nonetheless, from the perspective of social cost, the relevant facts are that the total cost is increasing, and that storm costs will increase with coastal development and could well also increase in response to greater storm severity.

Total Insured Market Losses Caused by All Storm Types, 1985–2012



Note: Years with the 12 costliest hurricanes in U.S. history are labeled.
Source: Munich Reinsurance Company (2012).

[1] Mendelsohn et al. (2012); Nordhaus (2010); Pielke (2007); Narita et al. (2009).

Data Watch 6-1: Tracking Sources of Emissions: The Greenhouse Gas Reporting Program

In October 2009, the Environmental Protection Agency (EPA) launched its Greenhouse Gas Reporting Program, an ambitious effort to collect and make publicly available facility-level data on greenhouse gas emissions across the United States. Today, experts and non-experts alike can view, explore, and download comprehensive information on greenhouse gas emissions using the EPA's convenient online data tool. The program is a leap forward for greenhouse gas data collection and the first of its kind in its scale and "bottom-up" approach. It will be an important piece of administrative infrastructure for any future effort to regulate or price greenhouse gas emissions.

Since 1990, the EPA has reported estimates of greenhouse gas emissions in its annual Inventory of U.S. Greenhouse Gas Emissions and Sinks, in compliance with the U.S. commitment under the United Nations Framework Convention on Climate Change. These estimates, however, are mostly "top-down," in that the EPA estimates national emissions using aggregate data on fuel production, imports and exports, and inventories. In 2008, Congress instructed the agency to begin to collect facility-level data, and the EPA developed the Greenhouse Gas Reporting Program to augment the data collected through the National Greenhouse Gas Inventory. The first wave of data, which covers emissions in 2010, was made publicly available in January 2012. More than 6,000 facilities—refineries, power plants, chemical plants, landfills, and more—were required to report their emissions, which amounted to 3.2 billion tons of carbon dioxide equivalent (CO_2e) that year alone.[1] The EPA will release data on 2011 emissions in early 2013.

The EPA provides its database of facility-level greenhouse gas emissions online (http://ghgdata.epa.gov), and visitors can view data by sector or geography or both. The site's rich interface and powerful maps software permits easy spatial analysis of emissions, and built-in charts help users glean useful information from what might otherwise be an unwieldy dataset. Although the Greenhouse Gas Reporting Program is an important step forward for greenhouse gas data collection, there are a few limitations: only facilities that emit more than 25,000 tons of greenhouse gases (measured in CO_2e) a year are required to report (although some sectors are "all in," meaning even emitters below the 25,000-ton threshold report for the first three to five years), and the program does not cover emissions from agriculture or land use.

[1] http://www.epa.gov/ghgreporting/ghgdata/reported/index.html

provided numeric estimates (White House 2010). The SCC calculation estimates the cost of a small, or marginal, increase in global emissions. This process was the first Federal Government effort to consistently calculate the social benefits of reducing CO_2 emissions for use in policy assessment. To date, the 2010 interagency SCC values have been used to evaluate at least 17 rules at various stages in the rulemaking process by the EPA, the Department of Transportation (DOT), and the Department of Energy (DOE).

To estimate the SCC, the working group used three different peer-reviewed models from the academic literature of the economic costs of climate change and tackled some key issues in computing those costs. One issue is the choice of the discount rate used to compute the present value of future costs: because many of the costs occur in the distant future, the SCC is sensitive to the weight placed on the welfare of future generations. Another issue is how to handle some of the uncertainty surrounding climate projections. Box 6-2 explains how the working group dealt with uncertainty about the equilibrium climate sensitivity, which serves as a proxy for the climate system's response to greenhouse gas emissions.

The working group report provided four values for the social cost of emitting a ton of CO_2 in 2011: $5, $22, $36, and $67, in 2007 dollars. The first three estimates, which average the cost of carbon across various models and scenarios, differ depending on the rate at which future costs and benefits are discounted (5, 3, and 2.5 percent, respectively). The fourth value, $67, comes from focusing on the worst 5 percent of modeled outcomes, discounted at 3 percent. All four values rise over time because the marginal damages increase as atmospheric CO_2 concentrations rise.

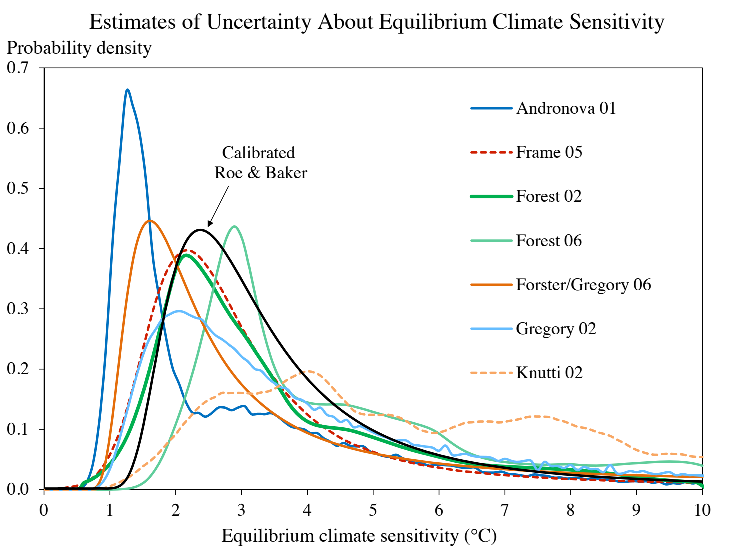
The SCC study acknowledged that these estimates, while a substantial step forward, need refinement, for example by a more complete treatment of some damage categories. A detailed discussion of the methodology can be found in Greenstone, Kopits, and Wolverton (2013). The interagency working group has committed to update its estimates of the SCC as the literature evolves and as new scientific and economic evidence become available.

Policy Implications of Scientific and Economic Uncertainty

As a general matter, policy decisions must commonly be made in the presence of uncertainty. A standard approach for cost estimation or policy evaluation in the presence of uncertainty is to consider different scenarios and to compute a weighted average (expected value) over those scenarios. But in some cases it is difficult to quantify this uncertainty. In particular, some of the unknowns about climate change concern extreme scenarios that are far outside recorded human experience. Although such events are

Box 6-2: Handling Uncertainty About Equilibrium Climate Sensitivity

The 2010 Federal study on the social cost of carbon (SCC) used three integrated economic-geophysical models to estimate the cost of climate change: the DICE model, the PAGE5 model, and the FUND model.[1] The costs estimated by each model are sensitive to climatic, economic, and emissions parameters. A key input parameter for each model is the equilibrium climate sensitivity, defined as the increase in the long-term annual global-average surface temperature increase associated with a doubling of atmospheric carbon dioxide (CO_2) concentration relative to pre-industrial levels.



Source: IPCC (2007); Roe and Baker (2007).

The Intergovernmental Panel on Climate Change (IPCC 2012) suggests a range for the equilibrium climate sensitivity of 2–4.5°C (3.2–7.2°F), but the scientific uncertainty extends outside this range. The figure shows distributions of possible values of this parameter arising from different studies; each line in the figure corresponds to a given study, and the higher the line, the greater the chances (according to that study) of the corresponding value of the equilibrium climate sensitivity.

[1] The DICE model was developed by William Nordhaus, David Popp, Zili Yang, Joseph Boyer, and colleagues. The PAGE model was developed by Chris Hope with John Anderson, Paul Wenman, and Erica Plambeck. The FUND model was developed by David Anthoff and Richard Tol.

Although the distributions from different studies differ, each holds open the possibility that the value of this parameter might be very large.

This range of uncertainty over the equilibrium climate sensitivity matters for estimating the economic costs of carbon emissions: a higher value implies a more amplified response of temperature to carbon emissions, which would be associated with greater human consequences. To handle this uncertainty, the task force adopted a standard approach used by economists, which is to compute a weighted average—technically, an expected value—where the weighting reflects the uncertainty in the scientific literature. Specifically, simulations were run for many values of the equilibrium climate sensitivity drawn randomly from an assumed probability distribution and the results were averaged, producing the expected value for the SCC. The resulting SCC estimate incorporates the uncertainty in the equilibrium climate sensitivity.

therefore difficult to quantify, the possibility of very severe outcomes can and should inform policy.

One principle of policy design under uncertainty is that the policy should be able to adapt as more is learned and the uncertainty is resolved; another is that a policy should be robust to uncertainty.[2] A robust policy aims to give acceptable outcomes no matter what happens, within a given range of possible outcomes. As applied to climate change, this idea of robust policy in the face of uncertainty leads to policies that avoid worst-case outcomes. Such an approach has been advocated by Weitzman (2009, 2011), who argues that, when considering the expected damages of unmitigated global climate change, it is important to consider low probability but potentially catastrophic impacts that could occur. By focusing on avoiding the most costly climate outcomes, a climate change policy that is robust to scientific uncertainty would be more aggressive than a policy that simply focuses on quantifiable uncertainty or a consensus temperature path. If future scientific knowledge were to determine that the worst outcomes could be ruled out, then a robust policy could be adjusted. Thus, although uncertainty complicates the task of computing costs, it is not in itself a reason for inaction or delay.

[2] An important early paper on policymaking under uncertainty is Brainard (1967). Recent work in economics on robust policy in the face of model uncertainty includes Hansen and Sargent (2001, 2007), Giannoni (2002), Onatski and Stock (2002), and Funke and Paetz (2011).

Carbon Emissions: Progress and Projections

The past five years have seen a remarkable turnaround in U.S. emissions of carbon dioxide. As can be seen in Figure 6-2, from the early 1980s through the mid-2000s, energy-related CO_2 emissions increased from approximately 4,500 million metric tons (MMT) to a peak of just over 6,000 MMT in 2007. Since 2007, however, emissions have fallen sharply to approximately 5,500 MMT in 2011, the most recent year for which there is complete data. Indeed, as shown in the figure, this reduction in emissions makes significant progress toward achieving the Copenhagen Accord target of a 17 percent reduction in greenhouse gas emissions below 2005 levels by 2020.[3]

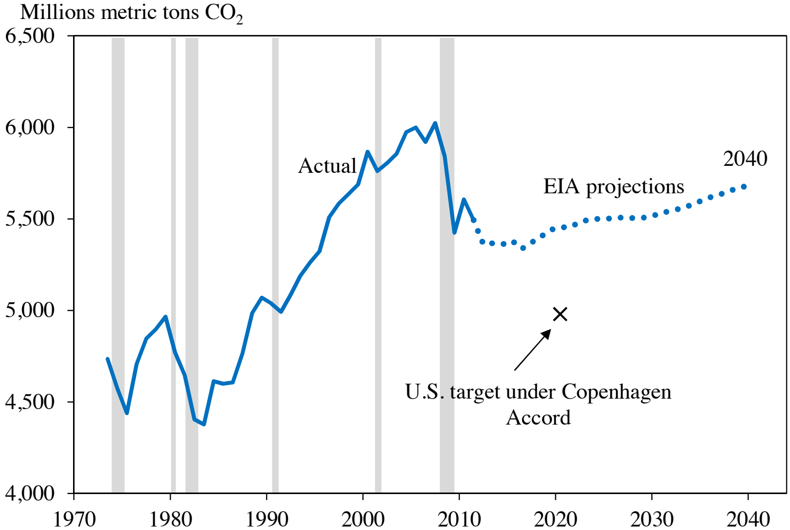
A natural question is what set of new events or initiatives led to the sharp reduction in emissions. There are a number of candidate explanations: reductions in the carbon content of energy, most notably the substitution of natural gas and renewables for coal; improvements in economy-wide energy efficiency; and unexpectedly low energy demand because of the recession. To estimate the contribution of these factors to the decline in emissions, one needs to posit a counterfactual path for these three variables, that is, for the carbon content of energy (CO_2 per British thermal unit, or Btu), energy use per dollar of gross domestic product (Btu/GDP), and GDP. Given a counterfactual, or baseline, path for these variables, one can decompose the decline in carbon emissions to a decline in the carbon content of energy, an accelerated improvement in energy efficiency, or a shortfall of GDP, relative to the baseline path.[4] Because the question focuses on the role of new developments, a natural approach is for the baseline to be a business-as-usual projection from a given starting point. For the purpose of this exercise, the starting point is taken to be the 2005 values of the carbon content of energy, energy efficiency, and GDP; the business-as-usual projections are made either by using historical published forecasts or by extrapolating historical trends.

The results of this decomposition estimate that actual 2012 carbon emissions are approximately 17 percent below the "business as usual" baseline. As shown in Figure 6-3, of this reduction, 52 percent was due to the recession (the shortfall of GDP, relative to trend growth), 40 percent came

[3] United Nations Framework Convention on Climate Change, Appendix I, http://unfccc.int/meetings/copenhagen_dec_2009/items/5264.php.

[4] Specifically, CO_2 emissions are the product of (CO_2/Btu)×(Btu/GDP)×GDP, where CO_2 represents U.S. CO_2 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 CO_2 reduction into contributions from clean energy, energy efficiency, and the recession.

Figure 6-2
U.S. Energy-Related Carbon Dioxide Emissions, 1973–2040



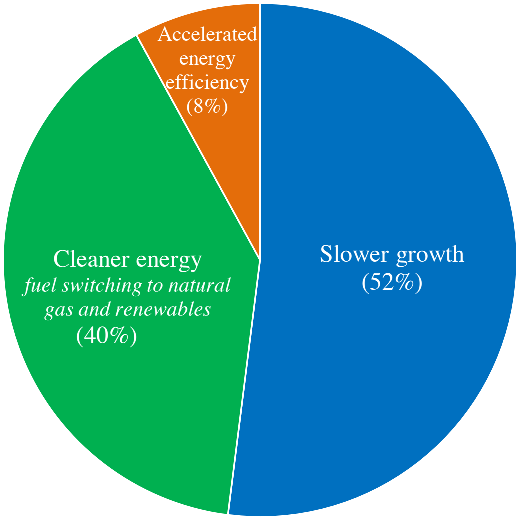
Note: Shading denotes recession.
Source: EIA (2012b).

from cleaner energy (fuel switching), and 8 percent came from accelerated improvements in energy efficiency, relative to trend. Of the cleaner energy improvements, most (approximately two-thirds) came from reductions in emissions from burning coal. Reductions in emissions from petroleum combustion also made important contributions (approximately one-third), as these high-carbon content fuels were replaced by lower carbon-content natural gas and clean renewable energy sources, notably wind and biofuels. The contribution from energy efficiency stems from efficiency improvements over the 2005–12 period that were faster than projected; in particular, the Energy Information Administration (EIA 2005) forecast a reduction in the energy content of GDP of 1.6 percent per year, but energy efficiency improved by more than this forecast.[5]

As the economy improves, GDP will rise, and the weakness of the economy in 2007–09 will no longer restrain energy consumption. Thus if the recent reductions in emissions are to be continued, a greater share will need to be borne by fuel switching into natural gas and into zero-emissions renewables, and by accelerating improvement in economy-wide energy efficiency.

[5] Houser and Mohan (forthcoming) undertake a similar decomposition. They use different assumptions for the baseline, including somewhat stronger post-2005 GDP growth in the "business as usual" case than is assumed here, and as a result attribute slightly more of the post-2005 reduction in CO_2 emissions to slower economic growth.

Figure 6-3
Decomposition of CO_2 Emission Reductions, 2005–2012



Source: Bureau of Economic Analysis, National Income and Product Accounts; EIA (2013); CEA calculations.

Policy Responses to the Challenge of Climate Change

As a general matter, government intervention may be warranted if an individual's action produces a negative externality; that is, if the action imposes costs on another person and those costs are not borne by the person taking the action. As with many environmental problems, the impacts of pollution are broadly shared by society, and individuals emitting pollution do not bear the full, direct costs of their individual action (or reap the full benefits individually of reducing pollution). In the case of anthropogenic emissions of greenhouse gases, the costs of climate change are borne by others, including future generations, and those costs are not reflected in the price of greenhouse gas emissions. This market failure is also present in reverse: an entrepreneur with a clever idea for reducing greenhouse gas emissions, such as a novel energy conservation technology, cannot recoup the full benefit of her innovation because there is no way she can charge those who will benefit from the abatement of those emissions.

This diagnosis of the market failure underlying climate change clarifies the need for government to protect future generations that will be affected by today's emissions. Responding to the challenge of climate change leads to a multipronged approach to policy. Four such responses are implementing market-based solutions; technology-based regulation of greenhouse gas emissions; supporting the transition of the U.S. energy sector to technologies, such as renewables and energy efficiency, that reduce our overall carbon footprint; and taking actions now to prepare for those impacts that are by now unavoidable.

Market-Based Solutions

In his 2013 State of the Union Address, President Obama urged Congress to pursue a bipartisan, market-based solution to climate change. Market-based solutions to greenhouse gas emissions provide economic incentives so that the cost of polluting reflects the economic harm caused to others by that pollution. In this sense, market-based solutions are said to "internalize" the externality caused by the pollution. Under the standard assumptions of economic theory, market-based solutions to pollution are economically efficient because those who create the externality can choose the least costly and disruptive way to reduce their emissions. Under market-based solutions, the effective price of the activity producing the negative externality is adjusted so that it reflects the cost of that externality. There are various ways that market-based solutions can be implemented, one of which is a cap-and-trade system like the one Senators McCain and Lieberman worked on.[6]

Another example of a market-based solution is a Clean Energy Standard that would require electric utilities to obtain an increasing share of delivered electricity from clean sources but would allow them to meet the standard by trading clean-energy credits. By allowing trading in credits, electric utilities that produce renewable energy at relatively low cost can sell credits to those for which renewable production would be high-cost. Thus the total cost across all utilities of meeting the standard is reduced, relative to the cost were each utility required to meet the standard without tradable credits. In this way, a market for clean energy credits harnesses private-sector incentives to minimize the cost of generating electricity from clean energy sources.[7]

Direct Regulation of Carbon Emissions and the Vehicle Greenhouse Gas / Corporate Average Fuel Economy (CAFE) Standards

Another way to address the externality of carbon emissions is by direct regulation. In 2007, the Supreme Court ruled in *Massachusetts v. EPA* that it is incumbent upon the EPA to determine whether greenhouse gases

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[6] For a more detailed discussion of cap-and-trade, see the *2010 Economic Report of the President,* chapter 9.

[7] For further discussion of a Clean Energy Standard, see the *2012 Economic Report of the President,* chapter 6.

pose a risk to public health or welfare and, if so, to regulate greenhouse gas emissions under the Clean Air Act. In 2012, the U.S. Court of Appeals for the District of Columbia Circuit upheld the EPA's authority to regulate greenhouse gas emissions.

The Administration's corporate average fuel economy (CAFE) and greenhouse gas regulations, released in 2012 jointly by the EPA and the DOT, require automakers to increase the fuel economy of passenger cars and light trucks so that they are estimated to achieve 54.5 miles per gallon by 2025, approximately doubling the previous mileage standards.[8] The new fuel economy standards are expected to save more than 2 million barrels of oil a day by 2025—more than we import from any country other than Canada—and to reduce consumer expenditures on gasoline. The standards are projected to reduce annual CO_2 emissions by over 6 billion metric tons over the life of the program, roughly equivalent to the emissions from the United States in 2010 (White House 2011a).

The new fuel economy standards help to correct the externality that the cost of carbon emissions is not accounted for in the price of gasoline. The standards also provide a clear signal to the thousands of firms in the auto supply chain that investments in fuel-saving innovation will pay off. These innovations range from large (batteries for electric cars) to small (lighter-weight bolts), and often require suppliers to coordinate with each other. For example, use of innovative high-strength steels can reduce the overall weight of a vehicle, but only if firms making automotive parts and those making tooling for the parts each invest in new production processes (Helper, Krueger, and Wial 2012). The new standards ensure demand for fuel-saving innovations and thus provide an incentive for such investments.

Energy Efficiency

An important way to reduce greenhouse gas emissions is to use energy more efficiently, that is, to use less energy to provide a given service outcome. For example, weatherizing a home improves efficiency by requiring less energy to maintain a given inside temperature. Using less energy, in turn, reduces greenhouse gas emissions.

The Administration has made energy efficiency initiatives an important component of its energy plan.[9] These initiatives include major research

[8] Because the standards regulate greenhouse gas emissions, they can be met in part in ways that do not improve fuel economy. In particular, if improvements are made by reducing leakage of greenhouse gases in auto air conditioners, or by replacing refrigerants with non-greenhouse gases, then the goal of reducing greenhouse gas emissions is achieved without improving fleet fuel economy.

[9] http://www.whitehouse.gov/sites/default/files/email-files/the_blueprint_for_a_secure_energy_future_oneyear_progress_report.pdf

investments to improve the efficiency of building designs and components such as lighting, heating, and air conditioning, along with smart building controls. Other important initiatives include the weatherization of more than 1 million homes across the country, the President's Better Buildings Challenge with $2 billion in private-sector commitments to energy efficiency retrofits, new standards for residential and commercial appliances, and the Rural Energy for America Program. The Administration has also introduced a variety of programs to help consumers learn about developments in energy efficiency; one such example is the Home Energy Score, a new voluntary program from the DOE to help homeowners make cost-effective decisions about energy improvements. Additionally, as part of a broader manufacturing strategy, the Administration has partnered with manufacturing companies representing more than 1,400 plants that plan to make investments that will improve energy efficiency by 25 percent over 10 years.

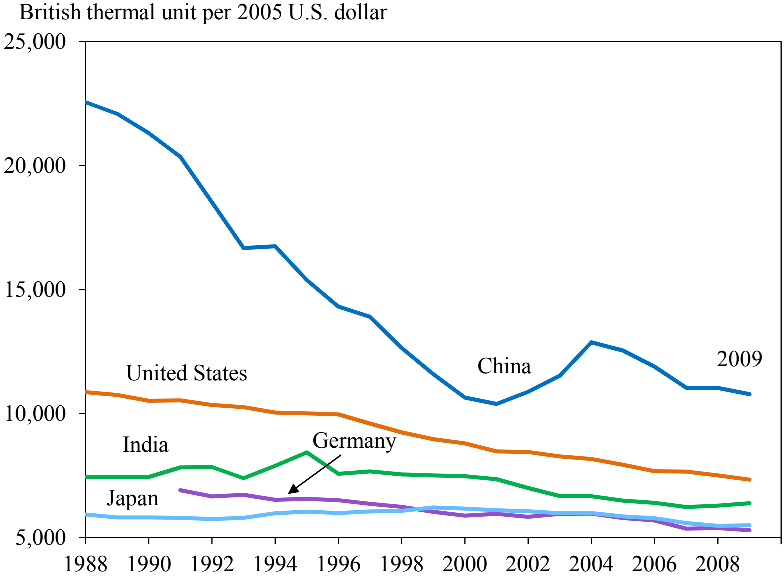
An overall measure of economy-wide energy use is the amount of energy needed to generate a dollar's worth of goods and services ("energy intensity"). As is shown in Figure 6-4, the energy intensity of the U.S. economy has fallen steadily over the past quarter century, with an annual average rate of decline of 1.7 percent from 1990 through 2011. However, U.S. energy intensity is still one-third higher than that of Germany and Japan, in part because Germany and Japan have automobiles and building codes that are more energy efficient, as well as smaller homes set more densely.[10]

One reason for the decline in the energy intensity of the U.S. economy is the increasing importance of services as a share of U.S. GDP. Manufacturing is more energy-intensive than is the production of services, and for decades the share of U.S. GDP derived from services has been growing while the share derived from manufacturing has been declining. This shift from manufacturing to services therefore has reduced the energy intensity of the U.S. economy.

To control for changes in the energy-GDP ratio driven by changes in the sectoral composition of output, the DOE developed an "Economy-wide Energy Intensity Index." This index estimates the amount of energy needed to produce a basket of goods in one year, relative to the previous year. As indicated in Figure 6-5, between 1985 and 2010, the DOE Energy Intensity Index fell by 14 percent. In contrast, the energy-GDP ratio fell by 33 percent. Thus, while much of the decline in energy usage per dollar of GDP has come from improvements in energy efficiency, much of it has also come from

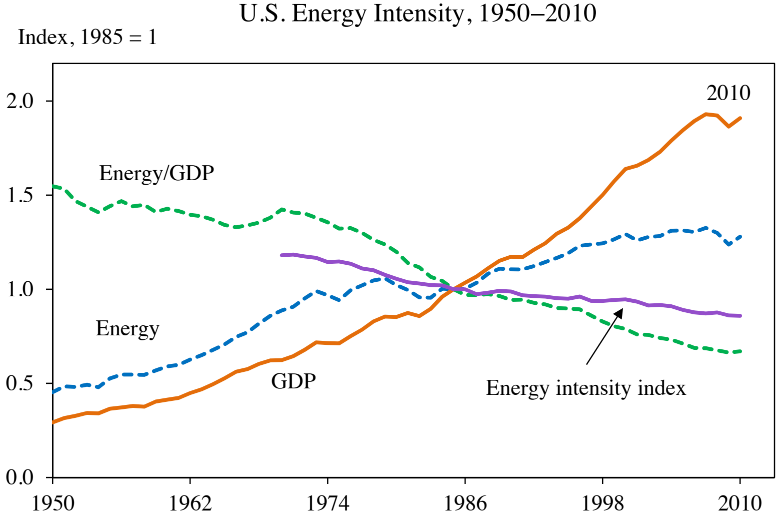
[10] In neither Germany nor Japan is the lower energy intensity due to having less manufacturing than the United States. In fact, manufacturing (an energy-intensive sector) is almost twice as high as a share of GDP in Germany as it is in the United States.

Figure 6-4
Energy Use per Dollar of GDP, Selected Countries, 1988−2009



Source: Energy Information Administration, International Energy Statistics.

Figure 6-5
U.S. Energy Intensity, 1950–2010



Note: "Energy" is the amount of energy consumed (measured in Btu) compared to 1985 levels. "Energy/GDP" is energy consumed divided by GDP, compared to 1985 levels. The energy intensity index is available starting in 1970.
Source: Department of Energy, Office of Energy Efficiency and Renewable Energy, Energy Intensity Indicators: Trend Data.

factors other than improved efficiency such as shifts in the composition of output.

The energy intensity index measures the energy footprint of U.S. production, not of U.S. consumption. This distinction arises because energy intensity includes energy used to produce exported goods and services (which are not consumed domestically) and excludes energy used to produce imports. To estimate the CO_2 intensity of consumption, as opposed to the CO_2 intensity of production, one needs to adjust U.S. CO_2 emissions for the difference of foreign emissions in the production of imports less domestic emissions in the production of exports.

Technical developments that use less energy to provide a service, such as maintaining a room at a comfortable temperature, can both reduce energy consumption and improve consumer welfare. Because technical improvements in energy efficiency reduce the energy cost of the service, consumers are better off, and because the price of the service declines, they might use more of it. For example, weatherizing a home might tempt the homeowner to bump up the thermostat a couple of degrees. This consumer response of using more of the newly efficient service is known as the rebound effect. The magnitude of the rebound effect depends on the particular service, more specifically on the elasticity of demand for the service. Viewed solely through the lens of CO_2 reduction—a lens that is appropriate because CO_2 emissions are underpriced—the rebound effect suggests that government efforts on energy efficiency should emphasize services with inelastic demand, so that price changes do not substantially alter service consumption and actual energy savings approach the technically feasible energy savings.

One such example is the services derived from automobiles. In the context of the vehicle greenhouse gas–CAFE standard discussed earlier, the EPA assumes a rebound effect of about 10 percent[11], that is, consumers will drive about 10 percent more than if the efficiency of their vehicles had not increased (EPA 2010b). In their reviews of the rebound effect, Greening, Greene, and Difiglio (2000) and Gillingham et al. (2013) suggest more generally that the rebound effect tends to range between 10 percent and 30 percent. Although much has been written on the rebound effect, the base of original research is limited, and more research is needed concerning the rebound effect (and the associated price elasticities) empirically, both in the short and long run.

[11] The EPA rebound estimate draws on the literature, for example, Small and Van Dender (2007).

Energy Production in Transition

The United States is in a period of swift and profound change in the way that energy is produced and consumed. Thanks to recent advances in technology, more of the country's domestic oil and gas resources are now accessible. As a result, U.S. oil production has climbed to the highest level in 15 years and natural gas production reached an all-time high. This increase in domestic oil production enhances energy security, and increased natural gas production has substituted for coal, which reduces CO_2 emissions per unit of energy produced. At the same time, the Obama Administration has taken historic steps to promote greater energy efficiency and the deployment of renewable energy across the U.S. economy. In the past five years, the United States has more than doubled non-hydroelectric renewable electricity generation. The Administration is working to continue these trends through a comprehensive "all of the above" approach to energy policy that takes advantage of all domestic energy resources, while also igniting the innovation needed to lead the world in clean energy.

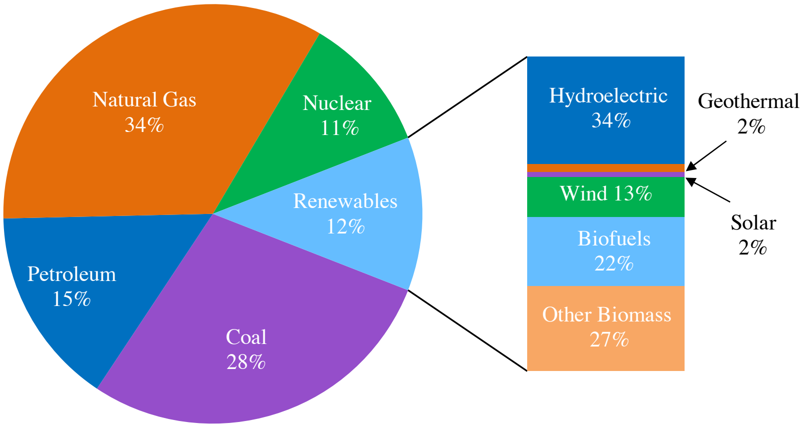
The transformation of the U.S. energy sector to one with a smaller carbon footprint is central to climate change policy. As Figure 6-6 shows, approximately 77 percent of U.S. energy production in 2011 came from burning fossil fuels, and the remaining 23 percent was approximately evenly split between nuclear and renewables. In broad terms, the share of natural gas (the fossil fuel with the lowest carbon content) and the share of renewables have been expanding, displacing the share of coal (the fossil fuel with the highest carbon content).

Oil and Natural Gas

New developments in exploration and production techniques and technology have made the extraction of new sources of oil and natural gas economically viable, resulting in a U.S. production boom. Figure 6-7 shows the changing consumption and production trends of natural gas in the United States, along with the U.S. share of global production since 2000. As a result of the developments in shale gas production, total U.S. natural gas production rose 27 percent, from 18.1 trillion cubic feet in 2005 to 23.0 trillion cubic feet in 2011, and wellhead prices fell 46 percent, from $7.33 per thousand cubic feet to $3.95 per thousand cubic feet. In 2011, for the first time in 30 years, energy production from dry natural gas exceeded energy production from coal.

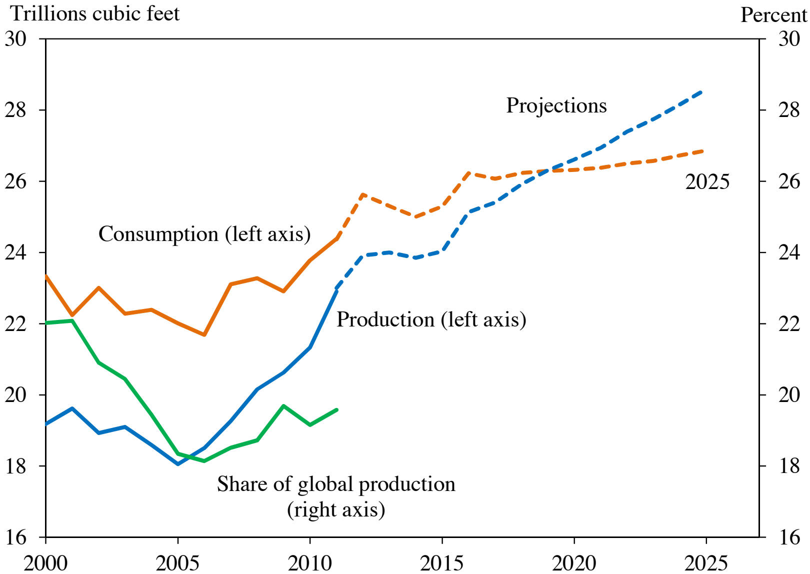
The benefits of increased production of natural gas are observed throughout the U.S. economy. In recent years, low energy costs have become a competitive advantage to the U.S. industrial sector. Additionally, low

Figure 6-6
Total U.S. Primary Energy Production, 2011



Note: Natural gas includes natural gas plant liquids.
Source: EIA (2012a).

Figure 6-7
U.S. Natural Gas Consumption and Production, 2000–2025



Source: EIA (2012b).

prices for byproducts of natural gas such as methane, ethane, and propane spur growth in agriculture, petrochemical manufacturing, and other industries that use these byproducts.

In the power sector, burning natural gas produces nitrogen oxides, carbon dioxide, and other pollutants, but in lower quantities than burning coal or oil. The life-cycle emissions of greenhouse gases from a combined-cycle natural gas plant is roughly half that of a typical coal-fired power plant per kilowatt hour (Logan et al. 2012). On the other hand, methane, a primary component of natural gas and a greenhouse gas, can be emitted from natural gas systems into the atmosphere through production processes, component leaks, losses in transportation, or incomplete combustion. Measuring fugitive methane emissions from the U.S. natural gas supply chain and, more generally, understanding the potential impacts of natural gas development on water quality, air quality, ecosystems, and induced seismicity, are critical to understanding the impact on the environment of the increasing use of natural gas.

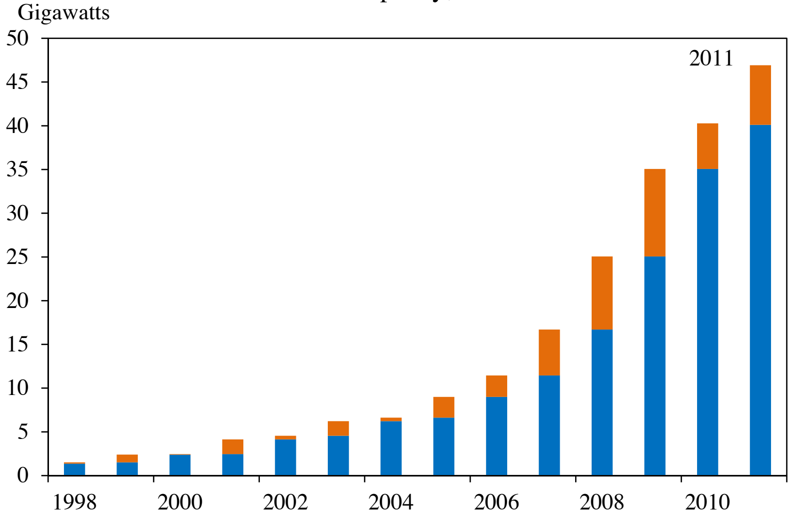
Renewable Energy

In the long run, large reductions in carbon emissions require large increases in energy production from zero-emissions sources, especially renewable energy. In the beginning of his Administration, President Obama set a goal of doubling U.S. renewable energy generation capacity from wind, solar, and geothermal sources by 2012. This ambitious goal has been achieved, thanks both to the Administration's historic investments in clean energy technologies and to decades of government-funded research and development (R&D) aimed at driving costs down to the point where renewable energy is competitive with traditional fossil-fuel energy.

Since 2008, the most significant increase in renewable energy production has been in wind energy. The dramatic increase in wind generating capacity is shown in Figure 6-8. In 2011, wind power constituted more than 30 percent of new additions to U.S. electric generating capacity: close to 6.8 gigawatts of new wind generating capacity was installed in the United States, representing an investment of $14 billion. Wind energy supplies 20 percent of electricity consumption in some states, including Iowa and South Dakota. As a nation, the United States accounts for 20 percent of total global wind power generation and 16 percent of global installed capacity. In 2012, wind power provided more than 3 percent of the nation's electricity generation (EIA 2013b).

The Administration also continues a strong commitment to the development and promotion of solar energy. An important aim is bringing the cost of solar photovoltaics down closer to grid parity with traditional,

Figure 6-8
Annual and Cumulative Growth in U.S.Wind Power Capacity, 1998–2011



Note: Orange bars are annual additions to capacity and blue bars are total installed capacity at the outset of the year.
Source: DOE (2012b).

fossil sources of energy, including natural gas. The Administration's support for solar energy has included more than $13 billion since September 2009 through DOE programs for solar-related projects, including applied R&D, demonstrations, and the DOE clean energy loan guarantee program. In 2011, the DOE launched an ambitious new effort, the Sunshot Initiative, aimed at reducing the installed costs of solar energy systems of all sizes (residential, commercial, and utility) by an additional 75 percent by the end of the decade.

Solar photovoltaic capacity is growing rapidly, with current installed capacity estimated to be approximately 4 gigawatts.[12] The Interstate Renewable Energy Council estimates that grid-connected photovoltaic capacity increased more than tenfold between 2007 and 2011.

President Obama has set a goal of once again doubling generation from wind, solar, and geothermal sources by 2020, and has called on Congress to make the renewable energy Production Tax Credit permanent and refundable, as part of comprehensive corporate tax reform, providing incentives and certainty for investments in clean energy.[13]

[12] The Interstate Renewable Energy Council (IREC), the Solar Energy Industries Association (SEIA), and the National Renewable Energy Lab (NREL).
[13] http://www.whitehouse.gov/sites/default/files/uploads/sotu_2013_blueprint_embargo.pdf.

Advanced Technologies and R&D

The Federal Government also has an important role to play in R&D involving frontier fossil-fuel technologies. Notably, the Administration has invested nearly $6 billion in clean coal technology R&D—the largest such investment in U.S. history—and this strategy has attracted more than $10 billion in additional private sector capital investment. Clean coal technology involves removing CO_2 from flue gases released from burning coal, then preventing its escape into the atmosphere by injecting it underground, a process known as carbon capture and sequestration. The recovered CO_2 can potentially be used to recover hard-to-reach oil reserves, partially offsetting the carbon capture costs. Another clean coal technology in the R&D stage is hydrogen production from coal, in which the highly concentrated CO_2 stream is captured and sequestered. Advanced technologies also have the potential to make natural gas burn even cleaner by capturing and storing CO_2 emissions, and the government has a role to play in encouraging research into these technologies.

Federal research efforts on zero- and reduced-emissions energy sources extend into other domains as well, including research toward shifting cars and trucks to nonpetroleum fuels.

Preparing for Climate Change

The policies discussed so far aim to reduce emissions of greenhouse gases and thereby to stem future costs of climate change. But the climate has not yet fully adjusted to current levels of greenhouse gases, and ongoing anthropogenic emissions will continue to increase greenhouse gas concentrations because CO_2 remains in the atmosphere for centuries. Thus, while it is important for all countries to sharply reduce CO_2 emissions to limit the extent of further climate change, even with the most concerted international efforts additional climate change is inevitable. We therefore face a world with an unavoidably changing climate for which we need to prepare.

Policies to prepare for climate change occur at many scales. At the local level, preparing for climate change can entail changing building codes to make structures more storm- and flood-resistant and investing in stronger community planning and response. More substantially, destructive effects of coastal storms can be partially dissipated by restoring natural storm barriers such as tidal wetlands, sand dunes, and coastal barrier landforms.

National policies to prepare for climate change range from providing information about likely changes in local climates and weather patterns, to supporting further research on and monitoring of climate change and its consequences, to providing proper incentives for individuals to prepare for climate change. For example, federal insurance programs, such as the Agriculture Department's crop insurance program and the Federal Emergency Management Agency's flood insurance program, provide insurance either with a subsidy or where there is no private market (that is, the price a private insurer would charge would exceed what a purchaser would be willing to pay). Revisiting federal insurance subsidies could encourage practices that could be increasingly important in the face of accelerating climate changes, such as farmers planting drought-resistant varietals or homeowners building or renovating away from flood plains.

Preparing for climate change will also entail larger-scale infrastructure investments. Some of these investments involve maintaining existing infrastructure. For example, a 2007 investigation by the American Society of Civil Engineers reported that chronic underfunding of the New Orleans hurricane protection system was one of the principal causes of the levee failures after Hurricane Katrina, a storm that inflicted over $110 billion of damages.

Other investments involve enhancing or extending existing infrastructure. For example, the electric power grid can be made more resilient to increasingly severe storms and rising sea levels by using smart grid technology, which pinpoints outage locations and helps to isolate outages, reducing the risk of widespread power shutdowns. The Recovery Act provided the single largest smart grid investment in U.S. history ($4.5 billion matched by an additional $5.5 billion from the private sector), funding both the Smart Grid Investment Grant and Smart Grid Demonstration programs, among others, to spur the Nation's transition to a smarter, stronger, more efficient, and more reliable electricity system (White House 2011b).

Conclusion

The scientific consensus is that the anthropogenic emission of greenhouse gases is causing climate change. The results can be seen already in higher temperatures and extreme weather, and these are but precursors of what lies ahead. Although greenhouse gas emissions and climate change are global problems, the United States is in a unique position to tackle these challenges and to provide global leadership.

The Nation has made substantial progress toward the Administration's ambitious short-term Copenhagen targets for reducing emissions of carbon dioxide, but much difficult work lies ahead. Undertaking this work, which reflects the Administration's commitment to future generations, entails many policy steps that are economically justified by the negative externalities imposed by greenhouse gas emissions. Policies to reduce emissions of greenhouse gases include market-based policies; encouraging energy efficiency; direct regulation; encouraging fuel switching to reduced-emissions fuels; and supporting the development and widespread adoption of zero-emissions energy sources such as wind and solar. And, as the country reduces emissions along this path, it also needs to prepare for the climate change that is occurring and will continue to occur. Together these policies pave the way toward a sustainable energy future.