Executive Summary

Greenhouse Gases and the Kyoto Protocol

Over the past several decades, rising concentrations of greenhouse gases have been detected in the Earth's atmosphere. It has been hypothesized that the continued accumulation of greenhouse gases could lead to an increase in the average temperature of the Earth's surface and cause a variety of changes in the global climate, sea level, agricultural patterns, and ecosystems that could be, on net, detrimental.

The Intergovernmental Panel on Climate Change (IPCC) was established by the World Meteorological Organization and the United Nations Environment Programme in 1988 to assess the available scientific, technical, and socioeconomic information in the field of climate change. The most recent report of the IPCC concluded that: "Our ability to quantify the human influence on global climate is currently limited because the expected signal is still emerging from the noise of natural variability, and because there are uncertainties in key factors. These include the magnitudes and patterns of long-term variability and the time-evolving pattern of forcing by, and response to, changes in concentrations of greenhouse gases and aerosols, and land surface changes. Nevertheless, the balance of evidence suggests that there is a discernable human influence on global climate."[1]

The text of the Framework Convention on Climate Change was adopted at the United Nations on May 9, 1992, and opened for signature at Rio de Janeiro on June 4. The objective of the Framework Convention was to ". . . achieve . . . stabilization of the greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system." The signatories agreed to formulate programs to mitigate climate change, and the developed country signatories agreed to adopt national policies to return anthropogenic emissions of greenhouse gases to their 1990 levels.

The first and second Conference of the Parties in 1995 and 1996 agreed to address the issue of greenhouse gas emissions for the period beyond 2000, and to negotiate quantified emission limitations and reductions for the third Conference of the Parties. On December 1 through 11, 1997, representatives from more than 160 countries met in Kyoto, Japan, to negotiate binding limits on greenhouse gas emissions for developed nations. The resulting Kyoto Protocol established emissions targets for each of the participating developed countries—the Annex I countries[2]—relative to their 1990 emissions levels. The targets range from an 8-percent reduction for the European Union (or its individual member states) to a 10-percent increase allowed for Iceland. The target for the United States is 7 percent below 1990 levels.

Although atmospheric *concentrations* of greenhouse gases are thought to have the potential to affect the global climate, the Protocol establishes targets in terms of *annual emissions*. Non-Annex I countries have no targets under the Protocol, but the Protocol reaffirms the commitments of the Framework Convention by all parties to formulate and implement climate change mitigation and adaptation programs.

Should the Protocol enter into force, the emissions targets for the developed countries would have to be achieved on average over the commitment period 2008 to 2012. The greenhouse gases covered by the Protocol are carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride. The aggregate target is based on the carbon dioxide equivalent of each of the greenhouse gases. For the three synthetic greenhouse gases, countries have the option of using 1995 as the base year.

Several provisions of the Protocol allow for some flexibility in meeting the emissions targets. Net changes in emissions by direct anthropogenic land-use changes and forestry activities may be used to meet the commitment, but they are limited to afforestation, reforestation, and deforestation since 1990. Emissions trading among the Annex I countries is also allowed. No rules for trading were established, however, and the Conference of the Parties is required to establish principles, rules, and guidelines for trading at a future date. According to estimates presented by the Energy Information

[1] Intergovernmental Panel on Climate Change, *Climate Change 1995: The Science of Climate Change* (Cambridge, UK: Cambridge University Press, 1996).

[2] Australia, Austria, Belgium, Bulgaria, Canada, Croatia, Czech Republic, Denmark, Estonia, European Community, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Latvia, Liechtenstein, Lithuania, Luxembourg, Monaco, Netherlands, New Zealand, Norway, Poland, Portugal, Romania, Russian Federation, Slovakia, Slovenia, Spain, Sweden, Switzerland, Ukraine, United Kingdom of Great Britain and Northern Ireland, and United States of America. Turkey and Belarus are Annex I nations that have not ratified the Convention and did not commit to quantifiable emissions targets.

Administration (EIA) in its *International Energy Outlook 1998*,[3] there may be 165 million metric tons of carbon permits available from the Annex I countries of the former Soviet Union in 2010. Greenhouse gas emissions for those countries as a group are expected to be 165 million metric tons below 1990 levels in 2010 as a result of the economic decline that has occurred in the region during the 1990s. Additional carbon permits may also be available, depending on the "carbon price" that is established in international trading.

Joint implementation projects are permitted among the Annex I countries, allowing a nation to take emissions credits for projects that reduce emissions or enhance emissions-absorbing sinks, such as forests and other vegetation, in other Annex I countries. The Protocol also establishes a Clean Development Mechanism (CDM), under which Annex I countries can take credits for projects that reduce emissions in non-Annex I countries. In addition, any group of Annex I countries may create a bubble or umbrella to meet the total commitment of all the member nations. In a bubble, countries would agree to meet their total commitment jointly by allocating a share to each member. In an umbrella arrangement, the total reduction of all member nations would be met collectively through the trading of emissions rights. There is potential interest in the United States in entering into an umbrella trading arrangement with Annex I countries outside the European Union.

In 1990, total greenhouse gas emissions in the United States were 1,618 million metric tons carbon equivalent.[4] Of this total, 1,346 million metric tons, or 83 percent, consisted of carbon emissions from the combustion of energy fuels. By 1996, total U.S. greenhouse gas emissions had risen to 1,753 million metric tons carbon equivalent, including 1,463 million metric tons of carbon emissions from energy combustion. EIA's *Annual Energy Outlook 1998* (*AEO98*)[5] projects that energy-related carbon emissions will reach 1,803 million metric tons in 2010, 34 percent above the 1990 level. Because energy-related carbon emissions constitute such a large percentage of the Nation's total greenhouse gas emissions, any action or policy to reduce emissions will have significant implications for U.S. energy markets.

At the request of the U.S. House of Representatives Committee on Science, EIA performed an analysis of the Kyoto Protocol, focusing on the potential impacts of the Protocol on U.S. energy prices, energy use, and the economy in the 2008 to 2012 time frame. The request specified that the analysis use the same methodologies and assumptions employed in the *AEO98*, with no changes in assumptions about policy, regulatory actions, or funding for energy and environmental programs.

Methodology

The international provisions of the Kyoto Protocol, including international emissions trading between Annex I countries, joint implementation projects, and the CDM, may reduce the cost of compliance in the United States. Guidelines for those provisions, however, remain to be resolved at future negotiating meetings, and rules and guidelines for the accounting of emissions and sinks from activities related to agriculture, land use, and forestry activities must be developed. The specific guidelines may have a significant impact on the level of reductions from other sources that a country must undertake. Reductions in the other greenhouse gases may also offset the reductions required from carbon dioxide. A fact sheet issued by the U.S. Department of State on January 15, 1998, estimated that the method of accounting for sinks and the flexibility to use 1995 as the base year for the synthetic greenhouse gases may reduce the target to 3 percent below 1990 levels.[6] A similar estimate was cited by Dr. Janet Yellen, Chair, Council of Economic Advisers, in her testimony before the House Committee on Commerce, Energy and Power Subcommittee, on March 4, 1998.[7]

Because the exact rules that would govern the final implementation of the Protocol are not known with certainty, the specific reduction in energy-related emissions cannot be established. This analysis includes cases that assume a range of reductions in energy-related carbon emissions in the United States. Each case was analyzed to estimate the energy and economic impacts of achieving an assumed level of reductions.

A reference case and six carbon emissions reduction cases were examined in this report. The cases are defined as follows:

- **Reference Case (33 Percent Above 1990 Levels).** This case represents the reference projections of energy markets and carbon emissions without any enforced reductions and is presented as a baseline for comparisons of the energy market impacts in the reduction cases. Although this reference case is

[3]Energy Information Administration, *International Energy Outlook 1998*, DOE/EIA-0484(98) (Washington, DC, April 1998).

[4]Energy Information Administration, *Emissions of Greenhouse Gases in the United States 1996*, DOE/EIA-0573(96) (Washington, DC, October 1997).

[5]Energy Information Administration, *Annual Energy Outlook 1998*, DOE/EIA-0383(98) (Washington, DC, December 1997).

[6]See web site www.state.gov/www/global/oes/fs_kyoto_climate_980115.html.

[7]See web site www.house.gov/commerce/database.htm.

based on the reference case from *AEO98*, there are small differences between this case and *AEO98*, in order to permit additional flexibility in response to higher energy prices or to include certain analyses previously done offline directly within the modeling framework, such as nuclear plant life extension and generating plant retirements. Also, some assumptions were modified to reflect more recent assessments of technological improvements and costs. As a result of these modifications, the projection of energy-related carbon emissions in 2010 is slightly reduced from the *AEO98* reference case level of 1,803 million metric tons to 1,791 million metric tons.

- **24 Percent Above 1990 Levels (1990+24%).** This case assumes that carbon emissions can increase to an average of 1,670 million metric tons between 2008 and 2012, 24 percent above the 1990 levels. Compared to the average emissions in the reference case, carbon emissions are reduced by an average of 122 million metric tons each year during the commitment period.

- **14 Percent Above 1990 Levels (1990+14%).** This case assumes that carbon emissions average 1,539 between 2008 and 2012, approximately at the level estimated for 1998 in *AEO98*, 1,533 million metric tons. This target is 14 percent above 1990 levels and represents an average annual reduction of 253 million metric tons from the reference case.

- **9 Percent Above 1990 Levels (1990+9%).** This case assumes that energy-related carbon emissions can increase to an average of 1,467 million metric tons between 2008 and 2012, 9 percent above 1990 levels, an average annual reduction of 325 million metric tons from the reference case projections.

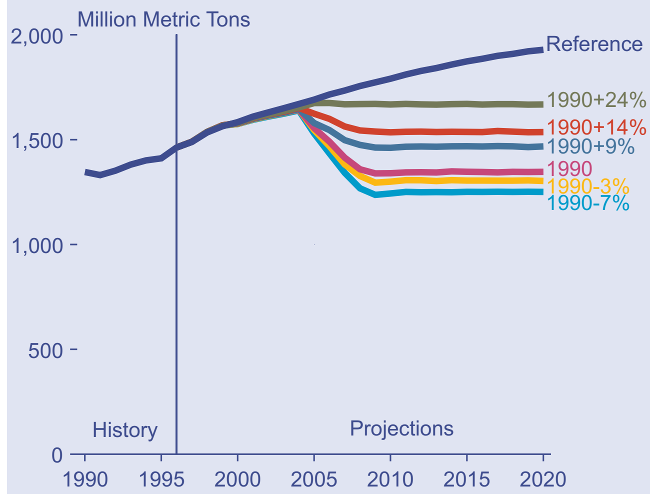
- **Stabilization at 1990 Levels (1990).** This case assumes that carbon emissions reach an average of 1,345 million metric tons during the commitment period of 2008 through 2012, stabilizing approximately at the 1990 level of 1,346 million metric tons. This is an average annual reduction of 447 million metric tons from the reference case.

- **3 Percent Below 1990 Levels (1990-3%).** This case assumes that energy-related carbon emissions are reduced to an average of 1,307 million metric tons between 2008 and 2012, an average annual reduction of 485 million metric tons from the reference case projections.

- **7 Percent Below 1990 Levels (1990-7%).** In this case, energy-related carbon emissions are reduced from the level of 1,346 million metric tons in 1990 to an average of 1,250 million metric tons in the commitment period, 2008 to 2012. Compared to the reference case, this is an average annual reduction of 542 million metric tons of energy-related carbon emissions during that period. This case essentially assumes that the 7-percent target in the Kyoto Protocol must be met entirely by reducing energy-related carbon emissions, with no net offsets from sinks, other greenhouse gases, or international activities.

In each of the carbon reduction cases, the target is achieved on average for each of the years in the first commitment period, 2008 through 2012 (Figure ES1). Because the Protocol does not specify any targets beyond the first commitment period, the target is assumed to hold constant from 2013 through 2020, the end of the forecast horizon (although more or less stringent requirements may be set by future Conferences of the Parties). The target is assumed to be phased in over a 3-year period, beginning in 2005, because the Protocol indicates that demonstrable progress toward reducing emissions must be shown by 2005. The phase-in allows energy markets to begin adjustments to meet the targets in the absence of complete foresight; however, a longer or more delayed phase-in could lower the adjustment costs—an option that is not considered here. In this analysis, some carbon reductions are expected to occur before 2005 as the result of capacity expansion decisions by electricity generators that incorporate their expectations of future increases in energy prices.

Figure ES1. Projections of Carbon Emissions, 1990-2020



Sources: **History:** Energy Information Administration, *Emissions of Greenhouse Gases in the United States 1996*, DOE/EIA-0573(96) (Washington, DC, October 1997). **Projections:** Office of Integrated Analysis and Forecasting, National Energy Modeling System runs KYBASE.D080398A, FD24ABV.D080398B, FD1998.D080398B, FD09ABV.D080398B, FD1990.D080398B, FD03BLW.D080398B, and FD07BLW.D080398B.

There are three ways to reduce energy-related carbon emissions: reducing the demand for energy services, adopting more energy-efficient equipment, and switching to less carbon-intensive or noncarbon fuels. To reduce emissions, a carbon price is applied to the cost of energy. The carbon price is applied to each of the energy fuels relative to its carbon content at its point of consumption. Electricity does not directly receive a carbon fee; however, the fossil fuels used for generation receive the fee, and this cost, as well as the increased cost of investment in generation plants, is reflected in the delivered price of electricity. In practice, these carbon prices could be imposed through a carbon emissions permit system.

In this analysis, the carbon prices represent the marginal cost of reducing carbon emissions to the specified level, reflecting the price the United States would be willing to pay in order to purchase carbon permits from other countries or to induce carbon reductions in other countries. In the absence of a complete analysis of trade and other flexible mechanisms to reduce carbon emissions internationally, the projected carbon prices do not necessarily represent the international market-clearing price of carbon permits or the price at which other countries would be willing to offer permits.

The projections in *AEO98* and in this analysis were developed using the National Energy Modeling System (NEMS), an energy-economy modeling system of U.S. energy markets, which is designed, implemented, and maintained by EIA.[8] The production, imports, conversion, consumption, and prices of energy are projected for each year through 2020, subject to assumptions on macroeconomic and financial factors, world energy markets, resource availability and costs, behavioral and technological choice criteria, costs and performance characteristics of energy technologies, and demographics. NEMS is a fully integrated framework, capturing the interactions of energy supply, demand, and prices across all fuels and all sectors of U.S. energy markets. NEMS provides annual projections, allowing the representation of the transitional effects of proposed energy policy and regulation.

NEMS includes a detailed representation of capital stock vintaging and technology characteristics, capturing the most significant factors that influence the turnover of energy-using and producing equipment and the choice of new technologies. The residential, commercial, transportation, electricity generation, and refining sectors of NEMS include explicit treatments of individual known technologies and their characteristics, such as initial cost, operating cost, date of commercial availability, efficiency, and other characteristics specific to the sector. Unknown technologies are not likely to be developed in time to achieve significant market penetration within the time frame of this analysis. Higher energy prices, as a result of carbon prices, for example, do not alter the characteristics or availability of energy-using technologies. However, higher prices induce more rapid adoption of more efficient or advanced technologies, because consumers would have more incentive to purchase them.

In addition, for new generating technologies, the electricity sector accounts for technological optimism in the capital costs of first-of-a-kind plants and for a decline in the costs as experience with the technologies is gained both domestically and internationally. In each of these sectors, equipment choices are made for individual technologies as new equipment is needed to meet growing demand for energy services or to replace retired equipment. In the other sectors—industrial, oil and gas supply, and coal supply—the treatment of technologies is somewhat more limited due to limitations on the availability of data for individual technologies; however, technology progress is represented by efficiency improvements in the industrial sector, technological progress in oil and gas exploration and production activities, and productivity improvements in coal production.

Carbon Reduction Cases

Carbon Prices

In 2010, the carbon prices projected to be necessary to achieve the carbon emissions reduction targets range from $67 per metric ton (1996 dollars) in the 1990+24% case to $348 per metric ton in the 1990-7% case (Table ES1 and Figure ES2). In the 1990+24% case, carbon prices generally increase from 2005 through 2020 (Table ES2 and Figure ES2). In the 1990+14% and 1990+9% cases, the carbon prices increase through 2013 and then essentially flatten.

In the three other carbon reduction cases, the carbon price escalates more rapidly in order to achieve the more stringent carbon reductions in the commitment period. The carbon price then declines as cumulative investments in more energy-efficient and lower-carbon equipment, particularly in the electricity generation sector, reduce the marginal cost of compliance in the later years of the forecast. These investments reduce the demand for carbon permits over an extended period of time, offsetting growth in energy demand and moderating the carbon prices. Figure ES3 shows the average carbon prices required to achieve the average carbon reductions.

Sectoral Impacts

As a result of the carbon prices and higher delivered energy prices, the overall intensity of energy use declines in the carbon reduction cases. Energy intensity, measured in energy consumed per dollar of gross

[8] Energy Information Administration, *The National Energy Modeling System: An Overview 1998*, DOE/EIA-0581(98) (Washington, DC, February 1998).

Table ES1. Selected Variables in the Carbon Reduction Cases, 1996 and 2010

Variable	1996	2010 Reference	2010 1990 +24%	2010 1990 +14%	2010 1990 +9%	2010 1990	2010 1990 -3%	2010 1990 -7%
U.S. Carbon Emissions								
(Million Metric Tons)	1,463	1,791	1,668	1,535	1,462	1,340	1,300	1,243
Emissions Reductions								
(Percent Change From Reference Case)	—	—	6.9	14.3	18.4	25.2	27.4	30.6
Total Energy Consumption								
(Quadrillion Btu)	93.8	111.2	106.5	101.9	99.6	95.2	93.9	91.7
(Percent Change From Reference Case)	—	—	-4.2	-8.4	-10.4	-14.4	-15.6	-17.5
Carbon Price								
(1996 Dollars per Metric Ton)	—	—	67	129	163	254	294	348
Carbon Revenue[a]								
(Billion 1996 Dollars)	—	—	110	195	233	333	374	424
Gasoline Price								
(1996 Dollars per Gallon)	1.23	1.25	1.39	1.50	1.55	1.72	1.80	1.91
(Percent Change From Reference Case)	—	—	11.2	20.0	24.0	37.6	44.0	52.8
Average Electricity Price								
(1996 Cents per Kilowatthour)	6.8	5.9	7.1	8.2	8.8	10.0	10.5	11.0
(Percent Change From Reference Case)	—	—	20.3	39.0	49.2	69.5	78.0	86.4
Actual Gross Domestic Product[b]								
(Billion 1992 Dollars)	6,928	9,429	9,333	9,268	9,241	9,137	9,102	9,032
(Percent Change From Reference Case)	—	—	-1.0	-1.7	-2.0	-3.1	-3.5	-4.2
(Annual Percentage Growth Rate, 2005-2010)	—	2.0	1.8	1.7	1.6	1.4	1.3	1.2
Potential Gross Domestic Product								
(Billion 1992 Dollars)	6,930	9,482	9,469	9,455	9,448	9,429	9,420	9,410
(Percent Change From Reference Case)	—	—	-0.1	-0.3	-0.4	-0.6	-0.7	-0.8
(Annual Percentage Growth Rate, 2005-2010)	—	2.0	2.0	1.9	1.9	1.9	1.9	1.9
Change in Energy Intensity								
(Annual Percent Change, 2005-2010)	—	-1.0	-1.6	-2.0	-2.1	-2.7	-2.8	-3.0
(Percent Change From Reference Case)	—	—	55.6	96.4	108.2	161.8	177.0	199.0

[a]The carbon revenues do not include fees on the nonsequestered portion of petrochemical feedstocks, nonpurchased refinery fuels, or industrial other petroleum.

[b]Carbon permit revenues are assumed to be returned to households through personal income tax rebates.

Source: Office of Integrated Analysis and Forecasting, National Energy Modeling System runs KYBASE.D080398A, FD24ABV.D080398B, FD1998.D080398B, FD09ABV.D080398B, FD1990.D080398B, FD03BLW.D080398B, FD07BLW. D080398B.

domestic product (GDP), declines (i.e., improves) at an average annual rate of 1 percent between 2005 and 2010 in the reference case due to the availability and adoption of more efficient equipment. In the carbon reduction cases, higher rates of improvement are projected—from 1.6 percent a year in the 1990+24% case to triple the reference case rate at 3.0 percent a year in the 1990-7% case.

In 2010, reductions in carbon emissions from electricity generation account for between 68 and 75 percent of the total carbon reductions across the cases. Electricity consumption is projected to be lower than in the reference case, with more efficient, less carbon-intensive technologies used for electricity generation. In all the carbon reduction cases except the 1990+24% case, carbon emissions from electricity generation in 2010 are lower than the actual 1990 level of 477 million metric tons of carbon emissions from the electricity supply sector. Electricity generators are expected to respond more strongly than end-use consumers to higher prices because this industry has traditionally been cost-minimizing, factoring future energy price increases into investment decisions. In contrast, the end-use consumers are assumed to consider only current prices in making their investment decisions and to consider additional factors, not only price, in their decisions. In addition, there are a number of more efficient and lower-carbon technologies for electricity generation that become economically available as the cost of generating electricity from fossil fuels increases.

Total electricity generation is lower in the carbon reduction cases because electricity sales range from 4 to 17 percent below the reference case in 2010 (Figure ES4). Reduction in electricity demand in response to higher electricity prices is somewhat mitigated by the change in relative prices. In 2010, electricity prices are between 20 and 86 percent above the reference case across the carbon reduction cases; however, delivered natural gas prices are higher by between 25 and 147 percent. With a smaller percentage price increase, electricity becomes more attractive in those end uses where it competes with natural gas, such as home heating.

Although reduced demand for electricity and efficiency improvements in the generation of electricity contribute to the total reductions in carbon emissions from electricity generation, fuel switching accounts for most

Table ES2. Selected Variables in the Carbon Reduction Cases, 1996 and 2020

Variable	1996	2020 Reference	2020 1990 +24%	2020 1990 +14%	2020 1990 +9%	2020 1990	2020 1990 -3%	2020 1990 -7%
U.S. Carbon Emissions								
(Million Metric Tons)	1,463	1,929	1,668	1,535	1,468	1,347	1,303	1,251
Emissions Reductions								
(Percent Change From Reference Case)	—	—	13.5	20.4	23.9	30.2	32.5	35.1
Total Energy Consumption								
(Quadrillion Btu)	93.8	117.0	108.6	105.6	103.8	100.9	99.9	98.8
(Percent Change From Reference Case)	—	—	-7.2	-9.7	-11.3	-13.8	-14.6	-15.6
Carbon Price								
(1996 Dollars per Metric Ton)	—	—	99	123	141	200	240	305
Carbon Revenue[a]								
(Billion 1996 Dollars)	—	—	162	184	202	263	306	372
Gasoline Price								
(1996 Dollars per Gallon)	1.23	1.24	1.42	1.45	1.49	1.60	1.67	1.80
(Percent Change From Reference Case)	—	—	14.5	16.9	20.2	29.0	34.7	45.2
Average Electricity Price								
(1996 Cents per Kilowatthour)	6.8	5.6	7.3	7.8	8.1	8.7	8.9	9.3
(Percent Change From Reference Case)	—	—	30.4	39.3	44.6	55.4	58.9	66.1
Actual Gross Domestic Product[b]								
(Billion 1992 Dollars)	6,928	10,865	10,815	10,808	10,796	10,799	10,793	10,782
(Percent Change From Reference Case)	—	—	-0.5	-0.5	-0.6	-0.6	-0.7	-0.8
(Annual Percentage Growth Rate, 2005-2020)	—	1.6	1.6	1.6	1.6	1.6	1.6	1.6
Potential Gross Domestic Product								
(Billion 1992 Dollars)	6,930	10,994	10,968	10,961	10,954	10,940	10,933	10.925
(Percent Change From Reference Case)	—	—	-0.2	-0.3	-0.4	-0.5	-0.6	-0.6
(Annual Percentage Growth Rate, 2005-2020)	—	1.7	1.6	1.6	1.6	1.6	1.6	1.6
Change in Energy Intensity								
(Annual Percent Change, 2005-2020)	—	-0.9	-1.4	-1.4	-1.5	-1.6	-1.7	-1.7
(Percent Change From Reference Case)	—	—	46.3	54.0	55.7	72.1	76.9	80.9

[a]The carbon revenues do not include fees on the nonsequestered portion of petrochemical feedstocks, nonpurchased refinery fuels, or industrial other petroleum.

[b]Carbon permit revenues are assumed to be returned to households through personal income tax rebates.

Source: Office of Integrated Analysis and Forecasting, National Energy Modeling System runs KYBASE.D080398A, FD24ABV.D080398B, FD1998.D080398B, FD09ABV.D080398B, FD1990.D080398B, FD03BLW.D080398B, FD07BLW. D080398B.

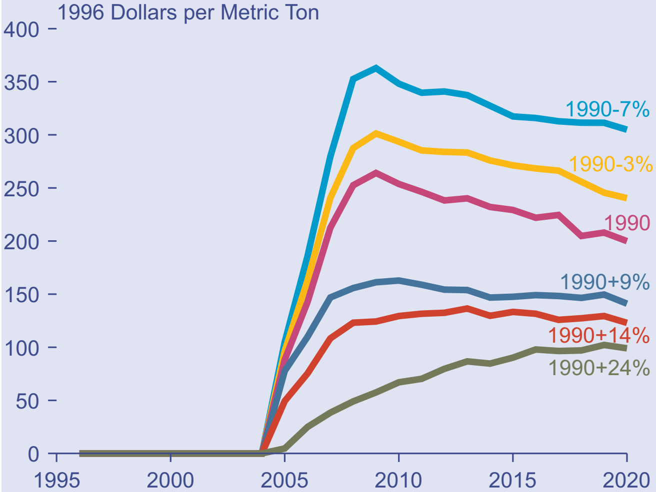
of the reductions (Figure ES5). The delivered price of coal to generators in 2010 is higher by between 153 and nearly 800 percent in the carbon reduction cases relative to the reference case. As a result, coal-fired generation, which accounts for about half of all generation in 2010 in the reference case, has a share between 42 percent and 12 percent in 2010 in the carbon reduction cases. To replace coal plants, generators build more natural gas plants, extend the life of existing nuclear plants, and dramatically increase the use of renewables in the more stringent reduction cases, particularly biomass and wind energy systems, which become more economical with higher carbon prices.

Assuming that carbon emissions from the generation of electricity are shared to each of the end-use demand sectors, based upon their consumption of electricity, the industrial and residential end-use demand sectors account for most of the carbon reductions, and the transportation sector accounts for the least (Figure ES6). In response to higher energy prices, consumers have an incentive to reduce demand for energy services, switch to lower-carbon energy sources, and invest in more energy-efficient technologies.

Because coal is the most carbon-intensive of the fossil fuels, delivered coal prices are most affected by the carbon prices (Figure ES7). Higher electricity prices reflect the increased costs of fossil fuels for generation and the incremental cost of additional investments, although the increase is mitigated by generation from renewables and nuclear power, because their fuel prices are not affected by carbon prices. Although the average carbon content of petroleum products is higher than that of natural gas, the percentage increase in the price of natural gas is higher than that of petroleum. Higher prices for petroleum are partially offset by lower world oil prices, and Federal and State taxes on gasoline also serve to mitigate the percentage increase.

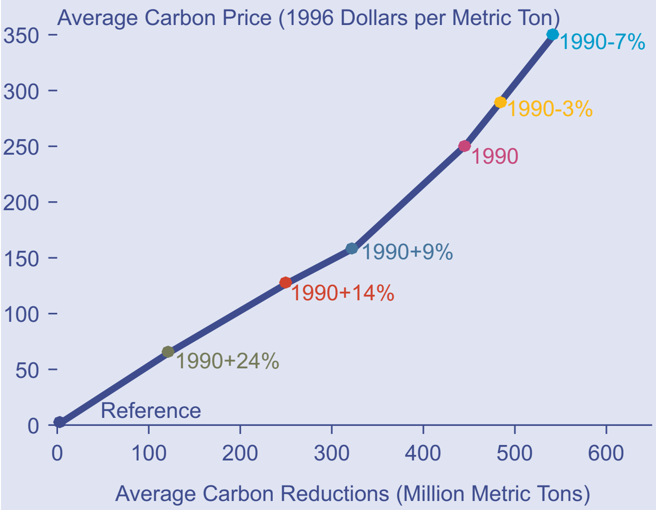
Total carbon emissions from the industrial sector are lower by between 7 and 28 percent in 2010 in the carbon reduction cases, relative to the reference case. Total industrial output is lower because of the impact of higher energy prices on the economy. As energy prices increase, industrial consumers accelerate the replacement of productive capacity, invest in more efficient technology, and switch to less carbon-intensive fuels. In 2010, industrial energy intensity is reduced from

Figure ES2. Projections of Carbon Prices, 1996-2020



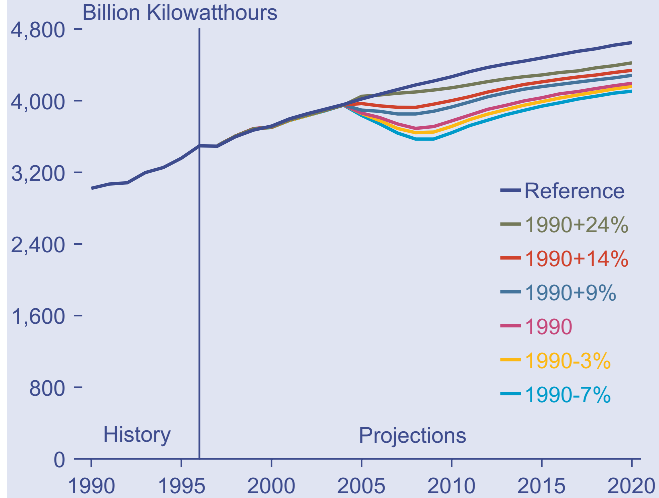
Source: Office of Integrated Analysis and Forecasting, National Energy Modeling System runs KYBASE.D080398A, FD24ABV.D080398B, FD1998.D080398B, FD09ABV.D080398B, FD1990.D080398B, FD03BLW.D080398B, and FD07BLW.D080398B.

Figure ES3. Average Projected Carbon Prices and Annual Carbon Emission Reductions, 2008-2010



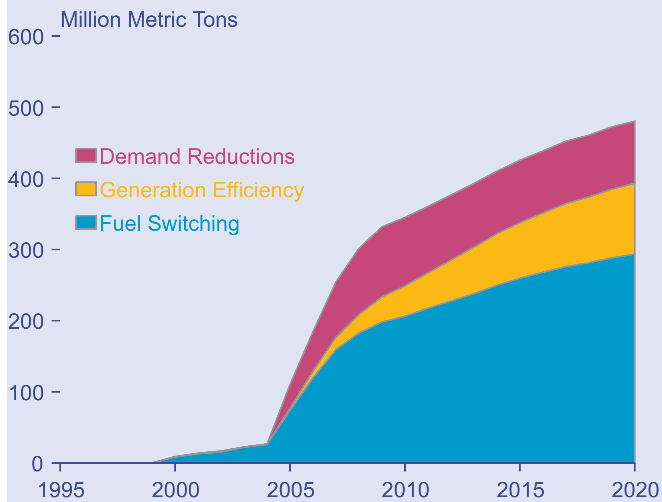
Source: Office of Integrated Analysis and Forecasting, National Energy Modeling System runs KYBASE.D080398A, FD24ABV.D080398B, FD1998.D080398B, FD09ABV.D080398B, FD1990.D080398B, FD03BLW.D080398B, and FD07BLW.D080398B.

Figure ES4. Projections of U.S. Electricity Generation, 1990-2020



Sources: **History:** Energy Information Administration, *Annual Energy Review 1997*, DOE/EIA-0384(97) (Washington, DC, July 1998). **Projections:** Office of Integrated Analysis and Forecasting, National Energy Modeling System runs KYBASE.D080398A, FD24ABV.D080398B, FD1998.D080398B, FD09ABV.D080398B, FD1990.D080398B, FD03BLW.D080398B, and FD07BLW.D080398B.

Figure ES5. Projected Reductions in Carbon Emissions From the Electricity Supply Sector, 1990-3% Case, 1996-2020



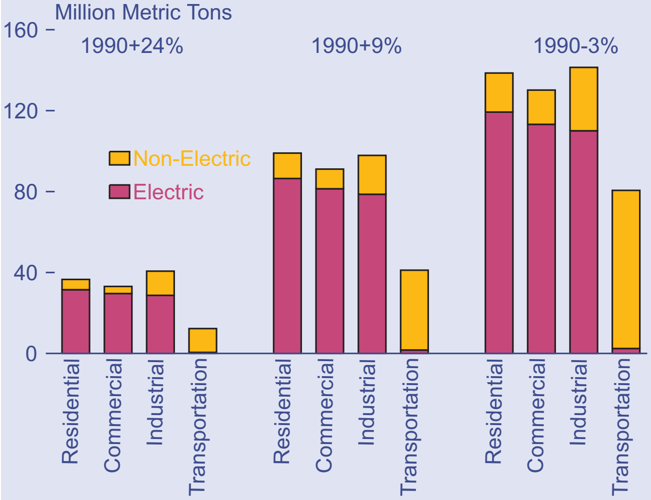
Source: Office of Integrated Analysis and Forecasting, National Energy Modeling System runs KYBASE.D080398A, FD03BLW.D080398B.

7.6 thousand British thermal units (Btu) per dollar of output in the reference case to between 7.4 and 7.1 thousand Btu in the carbon reduction cases.

In both the residential and commercial sectors, higher energy prices encourage investments in more efficient equipment and building shells and reduce the demand for energy services. Total carbon emissions in the residential sector are reduced by 11 percent in the 1990+24% case and by 45 percent in the 1990-7% case, relative to the reference case. Because of reduced demand for energy and improved end-use efficiencies, total energy use in 2010 ranges from 145 to 173 million Btu per household in the carbon reduction cases, compared with 184 million Btu per household in the reference case. Space heating and cooling account for the largest share of the change in energy demand; however, energy demand for a variety of miscellaneous appliances, such as computers, televisions, and VCRs, is also reduced.

In the commercial sector, total carbon emissions are lower by between 12 and 51 percent in the carbon reduction cases, compared to the reference case. Total energy use per square foot of commercial floorspace, which is 206 thousand Btu in 2010 in the reference case, is reduced to between 148 and 192 thousand Btu across the

Figure ES6. Projected Reductions in Carbon Emissions by End-Use Sector Relative to the Reference Case, 2010



Note: Electricity emissions are from the fuel used to generate electricity and are attributed to the sectors relative to their shares of electricity consumption.

Source: Office of Integrated Analysis and Forecasting, National Energy Modeling System runs KYBASE.D080398A, FD24ABV.D080398B, FD09ABV.D080398B, and FD03BLW. D080398B.

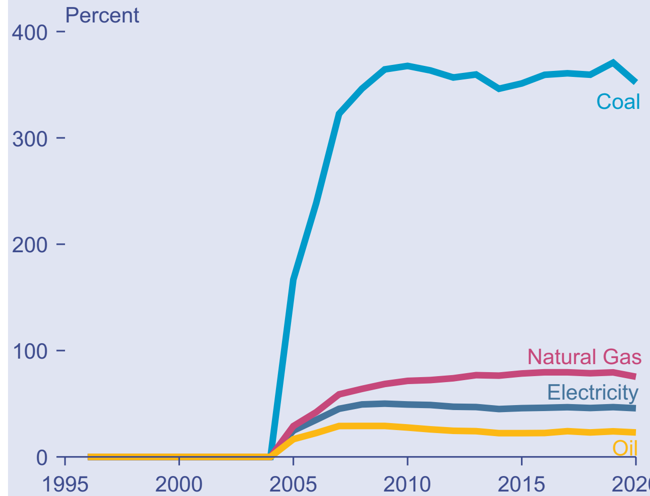
cases. Similar to the residential sector, most of the reduction occurs for space conditioning—heating, cooling, and ventilation; however, more efficient lighting and office equipment and reduced miscellaneous electricity use—for example, for vending machines and telecommunications equipment—also contribute to lower energy consumption.

The average price of gasoline in 2010 across the carbon reduction cases is between 11 and 53 percent higher than the projected reference case price. Carbon reductions in the transportation sector in 2010 range from 2 to 16 percent, primarily as the result of reduced travel and the purchase of more efficient vehicles. The relatively low carbon reductions for transportation result from the continued dominance of petroleum, although some increase in market share is projected for alternative-fuel vehicles. Improvements in average fuel efficiency are slowed by vehicle turnover rates. Although new car efficiency in 2010 improves from 30.6 miles per gallon in the reference case to between 32.0 and 36.4 miles per gallon in the carbon reduction cases, total light-duty fleet efficiency rises only from 20.5 miles per gallon to between 20.7 and 21.7 miles per gallon. The impact of carbon prices on the economy lowers light-duty vehicle and airline travel and freight requirements while inducing some efficiency improvements.

Impacts by Fuel

In order to achieve carbon emission reductions, the slate of energy fuels used in the United States is projected to change from that in the reference case (Figure ES8).

Figure ES7. Projected Changes in Average Delivered Prices for Energy Fuels in the 1990+9% Case Relative to the Reference Case, 1996-2020



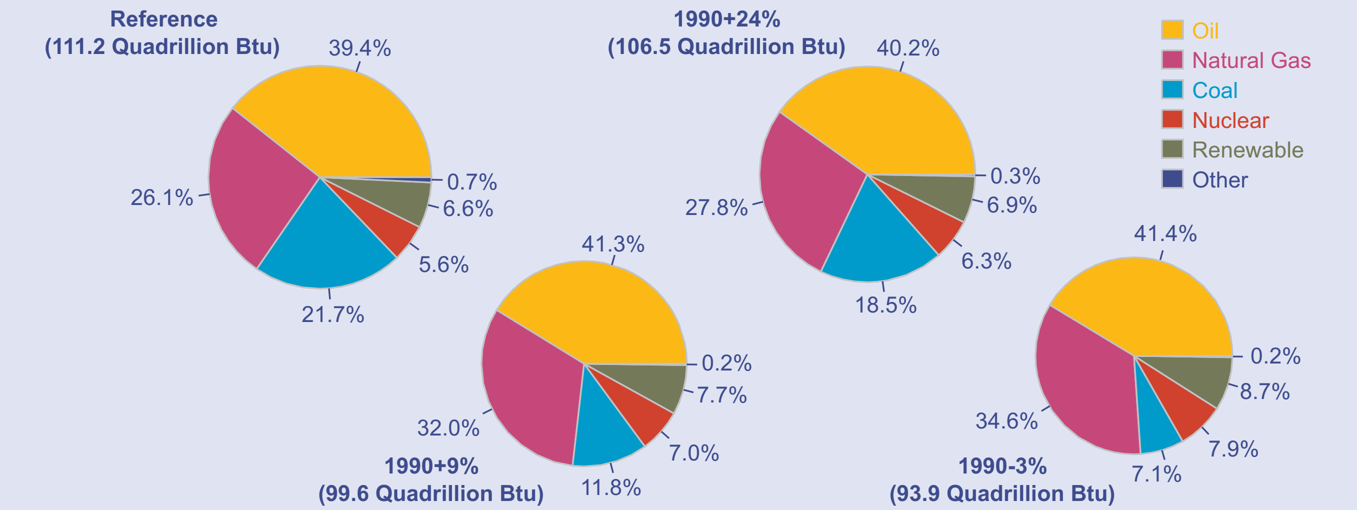
Source: Office of Integrated Analysis and Forecasting, National Energy Modeling System runs KYBASE.D080398A and FD09ABV.D080398B.

Because of the higher relative carbon content of coal and petroleum products, the use of both fuels is reduced, and there is a greater reliance on natural gas, renewable energy, and nuclear power. Although the use of petroleum declines relative to the reference case, it increases slightly as a share because most petroleum is used in the transportation sector, where fewer fuel substitutes are available.

Because of the high carbon content of coal, total domestic coal consumption is significantly reduced in the carbon reduction cases, by between 18 and 77 percent relative to the reference case in 2010 (Figure ES9). Most of the reductions are for electricity generation, where coal is replaced by natural gas, renewable fuels, and nuclear power; however, demand for industrial steam coal and metallurgical coal is also reduced because of a shift to natural gas in industrial boilers and a reduction in industrial output. Coal exports are also lower in the carbon reduction cases, by between 21 and 32 percent, due to lower demand for coal in the Annex I nations.

Although total U.S. coal production is reduced, the average minemouth coal price rises in the carbon reduction cases, by between 3 and 28 percent in 2010, because a larger share of production is from higher-cost eastern coal mines that tend to serve the remaining markets. Production of western coal is further discouraged by the higher cost of fuels used for rail transportation and by reduced incentive for investment in new mines, which are primarily in the West. Because of lower coal production, coal mine employment in 2010 is projected to be 15 to 63 percent lower than in the

Figure ES8. Projections of Fuel Shares of Total U.S. Energy Consumption, 2010



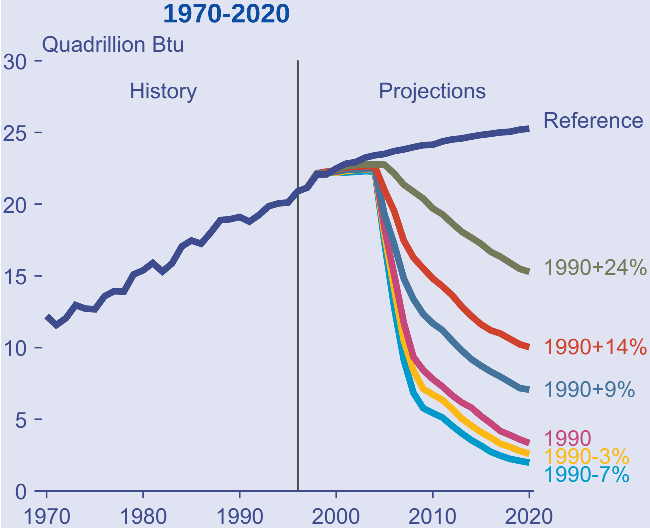
Note: "Other" includes net electricity imports, methanol, and liquid hydrogen.
Source: Office of Integrated Analysis and Forecasting, National Energy Modeling System runs KYBASE.D080398A, FD24ABV.D080398B, FD09ABV.D080398B, and FD03BLW.D080398B.

reference case; however, employment in the energy industry related to the production of natural gas and renewable fuels is likely to increase.

Petroleum consumption is lower in all the carbon reduction cases than in the reference case, by between 2 and 13 percent (Figure ES10). Because most of the petroleum is used for transportation, between 68 and 82 percent of the total reduction is in the transportation sector, as travel and freight requirements are reduced and higher-efficiency vehicles are used. Because of lower petroleum demand in the United States and in other developed countries that are committed to reducing emissions under the Kyoto Protocol, world oil prices are lower by between 4 and 16 percent in 2010, relative to the reference case price of $20.77 per barrel. In 2010, net crude oil and petroleum product imports are lower by a range of 3 to 22 percent relative to the reference case. Consequently, the dependency of the United States on imported petroleum is reduced from the reference case level of 59 percent to as little as 53 percent in 2010.

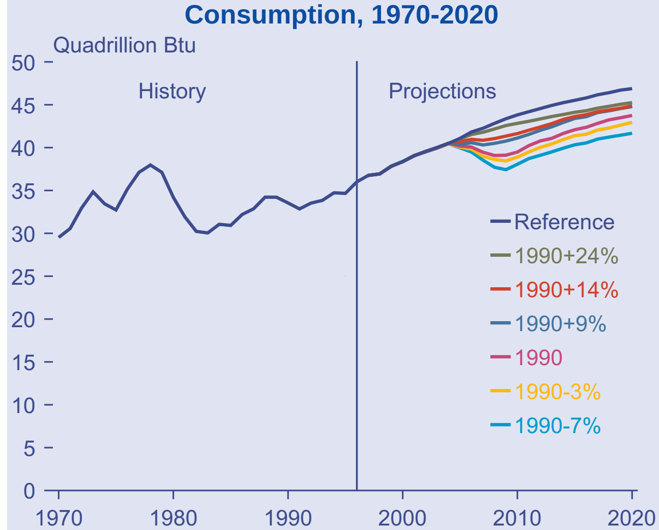
In 2010, natural gas consumption is higher than in the reference case, by a range of 2 to 12 percent across the carbon reduction cases (Figure ES11). Increased use of natural gas in the generation sector is only partially offset by reductions in the end-use sectors. Later in the forecast period, continued growth in natural gas

Figure ES9. Projections of U.S. Coal Consumption, 1970-2020



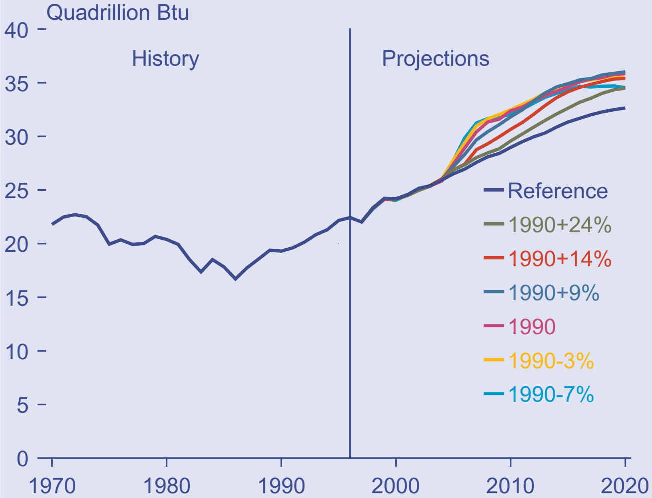
Sources: **History:** Energy Information Administration, *Annual Energy Review 1997*, DOE/EIA-0384(97) (Washington, DC, July 1998). **Projections:** Office of Integrated Analysis and Forecasting, National Energy Modeling System runs KYBASE.D080398A, FD24ABV.D080398B, FD1998.D080398B, FD09ABV.D080398B, FD1990.D080398B, FD03BLW.D080398B, and FD07BLW.D080398B.

Figure ES10. Projections of U.S. Petroleum Consumption, 1970-2020



Sources: **History:** Energy Information Administration, *Annual Energy Review 1997*, DOE/EIA-0384(97) (Washington, DC, July 1998). **Projections:** Office of Integrated Analysis and Forecasting, National Energy Modeling System runs KYBASE.D080398A, FD24ABV.D080398B, FD1998.D080398B, FD09ABV.D080398B, FD1990.D080398B, FD03BLW.D080398B, and FD07BLW.D080398B.

Figure ES11. Projections of U.S. Natural Gas Consumption, 1970-2020



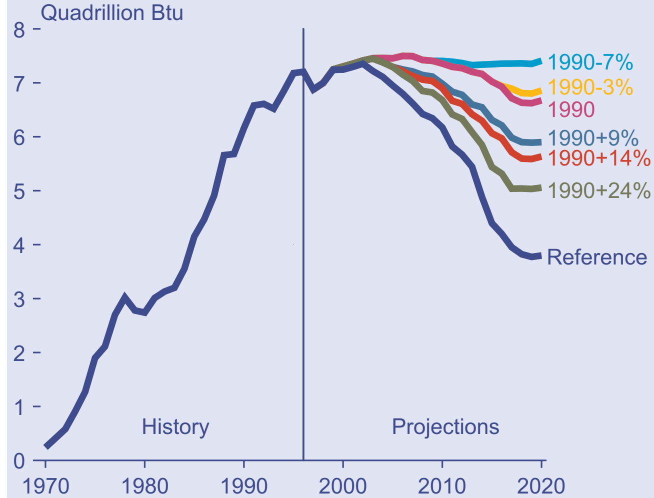
Sources: **History:** Energy Information Administration, *Annual Energy Review 1997*, DOE/EIA-0384(97) (Washington, DC, July 1998). **Projections:** Office of Integrated Analysis and Forecasting, National Energy Modeling System runs KYBASE.D080398A, FD24ABV.D080398B, FD1998.D080398B, FD09ABV.D080398B, FD1990.D080398B, FD03BLW.D080398B, and FD07BLW.D080398B.

consumption for electricity generation is mitigated by the increasing use of renewables and nuclear power, particularly in the more stringent carbon reduction cases. As a result, in 2020, natural gas use does not necessarily increase with higher levels of carbon reductions. As the result of higher demand, the average wellhead price of natural gas in 2010 is higher in all the carbon cases than in the reference case, by a range of 2 to 30 percent. Although meeting the levels of production that may be required will be a challenge for the industry, sufficient natural gas resources are available. The potential increases in both drilling and pipeline capacity are within levels achieved historically (or about to be achieved) and are not likely to be a constraint, given appropriate incentives and planning.

Nuclear power, which produces no carbon emissions, increases with carbon reduction targets by between 8 and 20 percent in 2010, relative to the reference case (Figure ES12). Although no new nuclear plants are assumed to be built in the carbon reduction cases, extending the lifetimes of existing plants is projected to become more economical with higher carbon prices. In the more stringent carbon reduction cases, most existing nuclear plants are life-extended through 2020, in contrast to the gradual retirement of approximately half of the nuclear plants projected in the reference case.

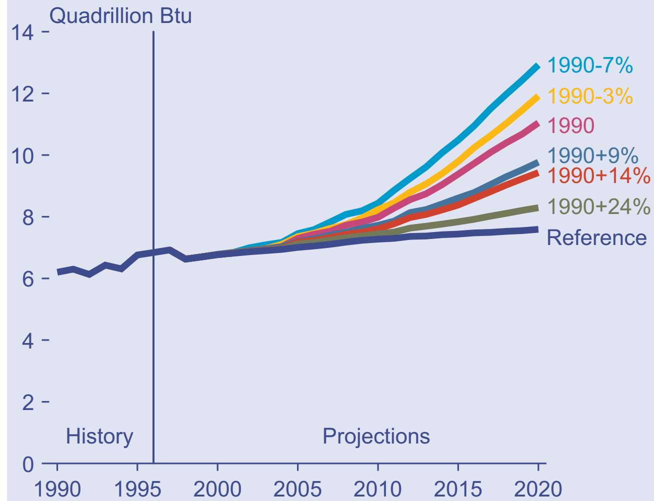
Consumption of renewable energy, which results in no net carbon emissions, is projected to be significantly higher with carbon reduction targets (Figure ES13). Across the carbon reduction cases, renewable energy consumption increases by between 2 and 16 percent in 2010 and by between 9 and 70 percent in 2020. Most of this increase occurs in electricity generation, primarily with additions to wind energy systems and an increase in the use of biomass (wood, switchgrass, and refuse). In the carbon reduction cases, the share of renewable generation is as much as 14 percent in 2010, compared with 10 percent in the reference case, increasing to as high as 22 percent in 2020, compared with 9 percent in the reference case. Because additional renewable technologies become available and economical later in the forecast period, the share of renewable generation continues to increase through 2020.

Figure ES12. Projections of U.S. Nuclear Energy Consumption, 1970-2020



Sources: **History:** Energy Information Administration, *Annual Energy Review 1997*, DOE/EIA-0384(97) (Washington, DC, July 1998). **Projections:** Office of Integrated Analysis and Forecasting, National Energy Modeling System runs KYBASE.D080398A, FD24ABV.D080398B, FD1998.D080398B, FD09ABV.D080398B, FD1990.D080398B, FD03BLW.D080398B, and FD07BLW.D080398B.

Figure ES13. Projections of U.S. Renewable Energy Consumption, 1990-2020



Sources: **History:** Energy Information Administration, *Annual Energy Review 1997*, DOE/EIA-0384(97) (Washington, DC, July 1998). **Projections:** Office of Integrated Analysis and Forecasting, National Energy Modeling System runs KYBASE.D080398A, FD24ABV.D080398B, FD1998.D080398B, FD09ABV.D080398B, FD1990.D080398B, FD03BLW.D080398B, and FD07BLW.D080398B.

Macroeconomic Impacts

In the energy market analyses, the projected carbon prices reflect the prices the United States would be willing to pay to achieve the Kyoto targets, without addressing the international trade in carbon permits. The macroeconomic analysis assumes that the carbon permit trading system would function as an auction run by the Federal Government, and that the United States would be free to purchase carbon permits in an international market at the marginal abatement cost in the United States. The U.S. State Department's assessment of the accounting of carbon-absorbing sinks and offsets from reductions in other greenhouse gases is assumed to reduce the U.S. emissions target to 3 percent below 1990 levels. The 3-percent target is then achieved through a combination of domestic actions and the purchase of permits on the international market. Thus, two flows of funds occur—domestic and international.

On the domestic side, U.S. permits are sold in a competitive auction run by the Federal Government, raising large sums of funds. In the 1990-3% case, where the revenues come entirely from the domestic market, the revenue collected in 2010 is projected to total $585 billion nominal dollars and $317 billion and $128 billion in the 1990+9% and 1990+24% cases, respectively. The collection of this money necessitates a careful consideration of appropriate fiscal policy to accompany the permit auction. Two approaches are considered: first, returning collected revenues to consumers through a personal income tax lump sum rebate and, second, lowering social security tax rates as they apply to both employers and employees. The two policies are meant only to be representative of a set of possible fiscal policies that might accompany an initial carbon mitigation policy.

The second flow of funds is associated with U.S. purchases of international carbon permits and assumes that the carbon price determined in the U.S. energy market analysis is the international price at which permits would be traded. The differences between the reduction level in the 1990-3% case and those in the other cases are assumed to be met by purchases of permits in international markets. Table ES3 shows average carbon reductions, purchases of international permits, and the carbon price for the three cases considered in the macroeconomic assessment for the 2008-2012 period.

The energy market analysis in this report does not address the international implications of achieving a particular target at the projected carbon price. For the macroeconomic assessment, the simplifying assumption is made that in each case the domestic carbon price is the same as the international permit price when different levels of trading are used to achieve the Kyoto target, implying that different international supplies of permits would be available in the alternative cases considered. This is an important simplifying assumption, and the value placed on the overseas transfer of funds to purchase international permits is subject to considerable uncertainty. However, this element must be considered a key factor in performing any assessment of the impacts on the economy, and therefore it is explicitly factored into the analysis.

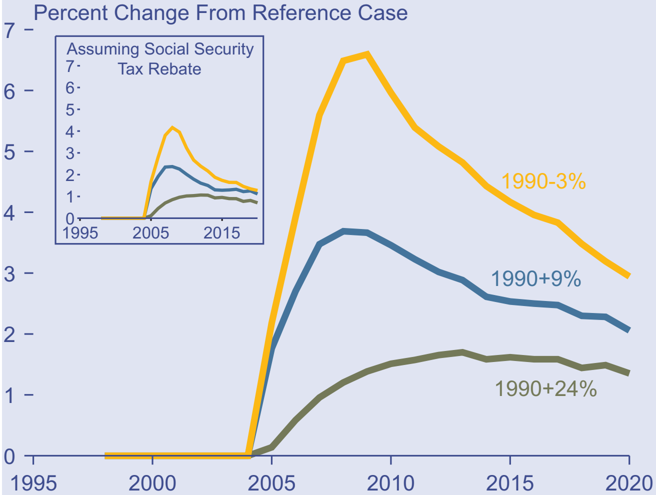
As a direct consequence of the carbon price, aggregate energy prices in the U.S. economy are expected to rise. One way to measure this effect is to look at the percentage change in prices in the economy. For example, in the 1990+9% case, energy prices are 56 percent higher than the reference case projection in 2010 and remain more than 50 percent above the reference case over the rest of the forecast period. The projected energy price increases would also affect downstream prices for all goods and services in the economy as measured by the producer price index. The projected increase in producer prices relative to the reference case in 2010 is 9 percent in the 1990+9% case. Final prices for goods and services in 2009, as shown by the consumer price index (CPI) series, are about 4 percent higher in the 1990+9% case (Figure ES14). Expressed as a rate of change, CPI inflation rises by 0.7 percentage points between 2005 and 2010, as the reference case CPI rises by 3.6 percent a year and the 1990+9% case rises by 4.3 percent a year. These figures suggest the following rule of thumb for the year 2010: each 10-percent increase in aggregate prices for energy may lead to a 1.5-percent increase in producer prices and a 0.7-percent increase in consumer prices.

Table ES3. Energy Market Assumptions for the Macroeconomic Analysis of Three Carbon Reduction Cases, Average Annual Values, 2008 through 2012

Analysis Case	Binding Carbon Emissions Reduction Target (Million Metric Tons)	Average U.S. Carbon Emissions Reductions (Million Metric Tons)	U.S. Purchases of International Permits (Million Metric Tons)	Carbon Price: 1996 Dollars per Metric Ton	Carbon Price: 1992 Dollars per Metric Ton	Value of Purchased International Permits (Billion 1992 Dollars)
1990-3%.	485	485	0	290	263	0
1990+9%	485	325	160	159	144	23
1990+24%	485	122	363	65	59	21

Source: Office of Integrated Analysis and Forecasting, National Energy Modeling System.

Figure ES14. Projected Changes in Consumer Price Index Relative to the Reference Case, 1998-2020



Note: Carbon permit revenues are assumed to be returned to households through reductions in personal income taxes.

Source: Simulations of the Data Resources, Inc. (DRI) Macroeconomic Model of the U.S. Economy.

One aspect of the CPI is particularly noteworthy. The CPI measures the prices that consumers face, regardless of the country of origin of the product. Import prices, to the extent that they do not rise at the rate of domestic prices because non-Annex I countries do not face carbon constraints, would dampen the price effects as lower-priced imports find their way into U.S. markets.

Because energy resources are used to produce most goods and services, higher energy prices can affect the economy's production potential. Long-run equilibrium costs are associated with reducing reliance on energy in favor of other factors of production—including labor and capital, which become relatively cheaper as energy costs rise. Short-run adjustment costs, or business cycle costs, can arise when price increases disrupt capital or employment markets. Long-run costs are considered unavoidable. Short-run costs might be avoidable if price changes can be accurately anticipated or if appropriate compensatory monetary and fiscal policies can be implemented. The economic assessment in this analysis considers both the short-run and long-run costs to the economy and focuses on the 1990-3%, 1990+9%, and 1990+24% carbon reduction cases.

The possible impacts on the economy are summarized in Table ES4, which shows average changes from the reference case projections over the period from 2008 through 2012 in the three carbon reduction analysis cases. The *loss of potential GDP* measures the loss in productive capacity of the economy directly attributable to the reduction in energy resources available to the economy. The *macroeconomic adjustment cost* reflects frictions in the economy that may result from the higher prices of the carbon mitigation policy. It recognizes the possibility that cyclical adjustments may occur in the short run. The *loss in actual GDP* for the economy is the sum of the loss in potential and the adjustment cost. The *purchase of international permits* represents a claim on the productive capacity of domestic U.S. resources. Essentially, as funds flow abroad, other countries have an increased claim on U.S. goods and services.

The loss of potential GDP plus the purchase of international permits represent the long-run, unavoidable impact on the economy. The *total cost to the economy* is represented by the loss in actual GDP plus the purchase of international permits (Figure ES15). These costs need to be put in perspective relative to the size of the ecomomy, which averages $9,425 billion between 2008 and 2012. Tables ES5 and ES6 summarize the macroeconomic impacts projected for the years 2010 and 2020.

In the long run, higher energy costs would reduce the use of energy by shifting production toward less energy-intensive sectors, by replacing energy with labor and capital in specific production processes, and by encouraging energy conservation. Although reflecting a more efficient use of higher-cost energy, the gradual

Table ES4. Macroeconomic Impacts in Three Carbon Reduction Cases, Average Annual Values, 2008-2012
(Billion 1992 Dollars)

Analysis Case	Loss in Potential GDP	Macroeconomic Adjustment Cost	Loss in Actual GDP	Purchases of International Permits	Total Cost to the Economy
1990-3%					
Personal Income Tax Rebate	58	225	283	0	**283**
Social Security Tax Rebate	58	70	128	0	**128**
1990+9%					
Personal Income Tax Rebate	32	137	169	23	**192**
Social Security Tax Rebate	32	59	91	23	**114**
1990+24%					
Personal Income Tax Rebate	12	76	88	21	**109**
Social Security Tax Rebate	12	44	56	21	**77**

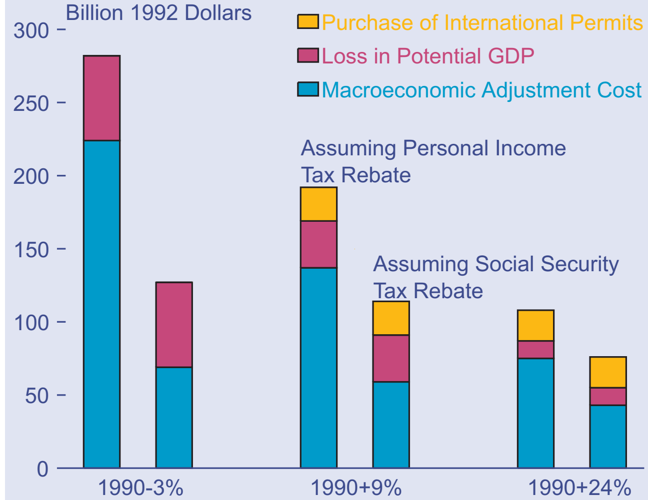
Note: Loss in potential GDP plus the macroeconomimc adjustment cost equals the loss in actual GDP. The actual GDP loss plus purchases of international permits equals the total cost to the economy.

Source: Simulations of the Data Resources, Inc. (DRI) Macroeconomic Model of the U.S. Economy.

reduction in energy use would tend to lower the productivity of other factors in the production process. The derivation of the long-run equilibrium path of the economy can be characterized as representing the "potential" output of the economy when all resources—labor, capital, and energy—are fully employed. As such, potential GDP is equivalent to the full employment concept in other analyses that focus on long-run growth while abstracting from business cycle behavior. Figure ES16 shows the losses in the potential economic output, as measured by potential GDP, for the three carbon reduction cases. The shapes of the three trajectories mirror the carbon price trajectories.

The ultimate impacts of carbon mitigation policies on the economy will be determined by complex interactions between elements of aggregate supply and demand, in conjunction with monetary and fiscal policy decisions. As such, cyclical impacts on the economy are bound to be characterized by uncertainty and controversy. However, raising the price of energy and

Figure ES15. Projected Annual Costs of Carbon Reductions to the U.S. Economy, 2008-2012



Source: Simulations of the Data Resources, Inc. (DRI) Macroeconomic Model of the U.S. Economy.

Table ES5. Projected Impacts on Gross Domestic Product, 2005 and 2010

Variable	1996	2005 Reference	2010						
			Reference	1990 +24%	1990 +14%	1990 +9%	1990	1990 -3%	1990 -7%
Potential GDP									
(Billion 1992 Dollars)	6,930	8,585	9,482	9,469	9,455	9,448	9,429	9,420	9,410
(Percent Change From Reference Case)	—	—	—	-0.1	-0.3	-0.4	-0.6	-0.7	-0.8
(Annual Growth Rate, 2005-2010, Percent)	—	—	2.0	2.0	1.9	1.9	1.9	1.9	1.9
Actual GDP, Assuming Personal Income Tax Rebate									
(Billion 1992 Dollars)	6,928	8,525	9,429	9,333	9,268	9,241	9,137	9,102	9,032
(Percent Change From Reference Case)	—	—	—	-1.0	-1.7	-2.0	-3.1	-3.5	-4.2
(Annual Growth Rate, 2005-2010, Percent)	—	—	2.0	1.8	1.7	1.6	1.4	1.3	1.2
Actual GDP, Assuming Social Security Tax Rebate									
(Billion 1992 Dollars)	6,928	8,525	9,429	9,369	9,337	9,326	9,291	9,281	9,247
(Percent Change From Reference Case)	—	—	—	-0.6	-1.0	-1.1	-1.5	-1.6	-1.9
(Annual Growth Rate, 2005-2010, Percent)	—	—	2.0	1.9	1.8	1.8	1.7	1.7	1.6

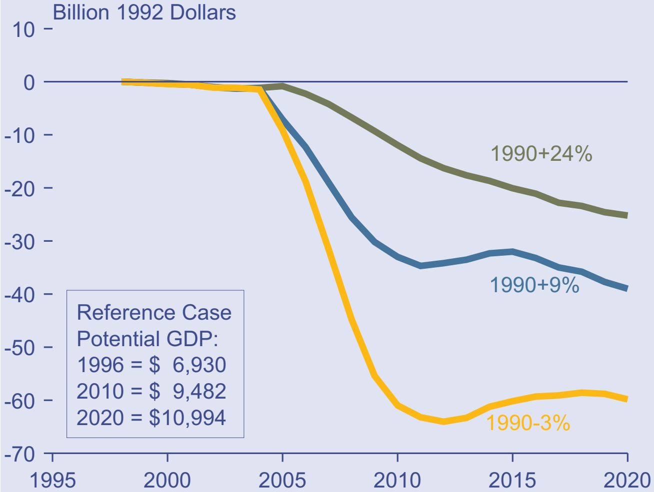
Source: Simulations of the Data Resources, Inc. (DRI) Macroeconomic Model of the U.S. Economy.

Table ES6. Projected Impacts on Gross Domestic Product, 2005 and 2020

Variable	1996	2005 Reference	2020						
			Reference	1990 +24%	1990 +14%	1990 +9%	1990	1990 -3%	1990 -7%
Potential GDP									
(Billion 1992 Dollars)	6,930	8,585	10,994	10,968	10,961	10,954	10,940	10,933	10,925
(Percent Change From Reference Case)	—	—	—	-0.2	-0.3	-0.4	-0.5	-0.6	-0.6
(Annual Growth Rate, 2005-2020, Percent)	—	—	1.7	1.6	1.6	1.6	1.6	1.6	1.6
Actual GDP, Assuming Personal Income Tax Rebate									
(Billion 1992 Dollars)	6,928	8,525	10,865	10,815	10,808	10,796	10,799	10,793	10,782
(Percent Change From Reference Case)	—	—	—	-0.5	-0.5	-0.6	-0.6	-0.7	-0.8
(Annual Growth Rate, 2005-2020, Percent)	—	—	1.6	1.6	1.6	1.6	1.6	1.6	1.6
Actual GDP, Assuming Social Security Tax Rebate									
(Billion 1992 Dollars)	6,928	8,525	10,865	10,840	10,832	10,828	10,833	10,835	10,842
(Percent Change From Reference Case)	—	—	—	-0.2	-0.3	-0.3	-0.3	-0.3	-0.2
(Annual Growth Rate, 2005-2020, Percent)	—	—	1.6	1.6	1.6	1.6	1.6	1.6	1.6

Source: Simulations of the Data Resources, Inc. (DRI) Macroeconomic Model of the U.S. Economy.

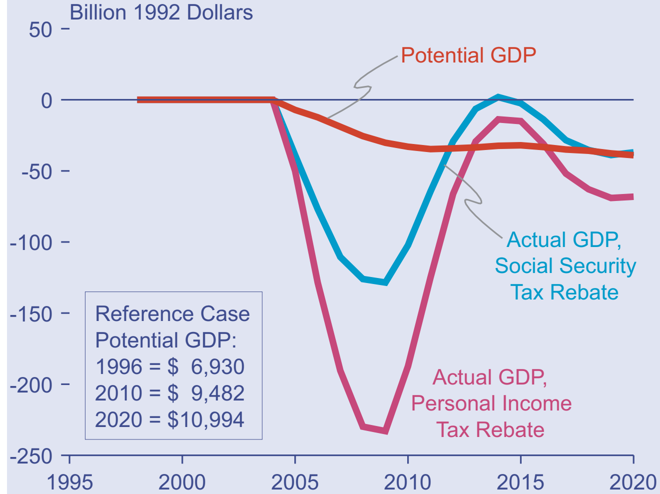
Figure ES16. Projected Dollar Losses in Potential GDP Relative to the Reference Case, 1998-2020



Note: Carbon permit revenues are assumed to be returned to households through reductions in personal income taxes.

Source: Simulations of the Data Resources, Inc. (DRI) Macroeconomic Model of the U.S. Economy.

Figure ES17. Projected Changes in Potential and Actual GDP in the 1990+9% Case Relative to the Reference Case Under Different Fiscal Policies, 1998-2020



Source: Simulations of the Data Resources, Inc. (DRI) Macroeconomic Model of the U.S. Economy.

downstream prices in the rest of the economy could introduce cyclical behavior in the economy, resulting in employment and output losses in the short run. The measurement of losses in actual output for the economy, or actual GDP, represents the transitional cost to the aggregate economy as it adjusts to its long-run path. Resources may be less than fully employed, and the economy may move in a cyclical fashion as the initial cause of the disturbance—the increase in energy prices—plays out over time.

Collection of money from a permit auction system necessitates a careful consideration of appropriate fiscal policy to accompany the carbon reduction policy. Two alternative fiscal policies are analyzed, both returning collected revenue back to agents in the economy: a cut in personal income taxes and a cut in social security taxes as they apply to both employers and employees. In both cases, the Federal deficit is maintained at reference case levels. The personal income tax cut essentially returns collected revenues to consumers, helping to maintain personal disposable income. Like the personal income tax cut, the social security tax cut returns collected funds to the private sector of the economy, ameliorating the near-term impacts of higher energy prices. Although consumers and businesses still would face much higher relative prices for energy than for other goods and services, disposable income is maintained near reference case values to the extent that funds flow back to consumers.

In the fiscal policy settings, higher prices in the economy place upward pressure on interest rates. The Federal Reserve Board seeks to balance the consequences of higher energy prices on the economy and possible adverse effects on output and employment by making adjustments to the Federal funds rate. The adjustments would be designed to moderate the possible impacts on both inflation and unemployment, and to return the economy to its long-run growth path.

Figure ES17 shows the projected impacts on both actual and potential GDP for the two hypothetical fiscal policies (income tax and social security tax cuts) in the 1990+9% case. The figure indicates that, in the 2008 to 2012 period, the short-run cyclical impact on actual GDP is larger than the long-run impact on potential GDP; however, the two output concepts begin to converge by 2015, and by 2020 they have merged into a steady-state path reflected by potential GDP. Monetary policy is instrumental in balancing inflation and unemployment impacts through the adjustment period, acting in a manner to bring the economy back to its long-run growth path.

The choice of the accommodating fiscal policy is also key to the assessment of the ultimate impacts on the economy. While the personal income tax option moderates the impacts through a return of funds to consumers, the social security tax option has cost-cutting aspects of lowering the employer portion of the tax, which serves to reduce inflationary pressures in the aggregate economy. On the employer side, the reduction in employer contributions to the social security system would lower costs to the firm and, thereby, moderate the near-term price consequences to the economy. Since it is the price effect that produces the predominately negative effect on the economy, any steps to reduce inflationary pressures would serve to moderate adverse impacts on the aggregate economy.

Another way to view the macroeconomic effects is by looking at the effects of the carbon reduction cases on the growth rate of the economy, both during the period of implementation from 2005 through 2010 and then over the entire period from 2005 through 2020 (Figures ES18 and ES19). In the reference case, potential and actual GDP grow at 2.0 percent per year from 2005 through 2010. In the 1990+9% case, the growth rate in potential GDP slows to 1.9 percent per year, and the growth rate in actual GDP slows to 1.6 percent per year when the personal income tax rebate is assumed or 1.8 percent per year when the social security tax rebate is assumed. However, through 2020, with the economy rebounding back to the reference case path, there is no appreciable change in the projected long-term growth rate. The results for the 1990+24% and 1990-3% cases are similar.

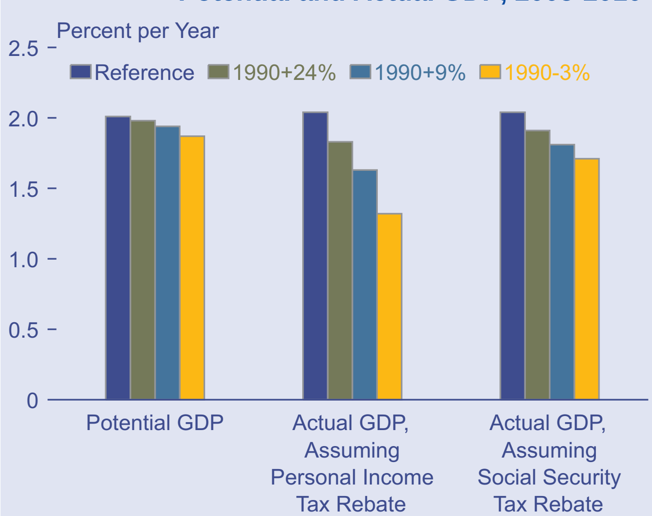
Aggregate impacts on the economy, as measured by potential and actual GDP, are shown in Table ES7 in terms of losses in GDP per capita. In the 1990+9% case, the loss in potential GDP per capita is $106; however, the loss in actual GDP for in the 1990+9% case is $567 assuming the personal income tax rebate and $305 assuming the social security tax rebate. Again, the lower value (loss in potential GDP) represents an unavoidable loss per person, and the higher values (loss in actual GDP) reflect the highly uncertain, but significant, impacts that individuals could experience as the result of frictions within the economy. To provide perspective, actual GDP per capita averages $31,528 in the reference case between 2008 and 2012.

Sensitivity Cases

This analysis includes several sensitivity cases designed to examine alternative assumptions that may have significant impacts on energy demand and carbon emissions over the next 20 years, including higher and lower economic growth, faster and slower availability and rates of improvement in technology, and the construction of new nuclear power plants. The sensitivity cases illustrate how such factors influence the results of the carbon reduction cases. With the exception of the nuclear power case, the sensitivity cases are analyzed relative to the 1990+9% case.

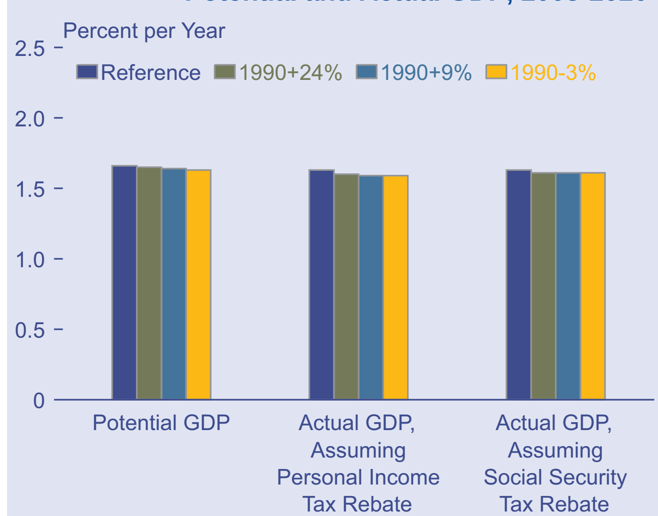
Because each sensitivity case is constrained to the same level of carbon emissions as the case to which it is compared, the primary impact is not on the carbon emissions levels, or even on aggregate energy consumption, but rather on the carbon price required to meet the emissions target. For example, in the high technology case, projected carbon emissions during the

Figure ES18. Projected Annual Growth Rates in Potential and Actual GDP, 2005-2010



Source: Simulations of the Data Resources, Inc. (DRI) Macroeconomic Model of the U.S. Economy.

Figure ES19. Projected Annual Growth Rates in Potential and Actual GDP, 2005-2020



Source: Simulations of the Data Resources, Inc. (DRI) Macroeconomic Model of the U.S. Economy.

Table ES7. Projected Losses in Potential and Actual GDP per Capita, Average Annual Values, 2008-2012 (1992 Dollars per Person)

Analysis Case	Loss in Potential GDP per Capita	Loss in Actual GDP per Capita, Personal Income Tax Rebate	Loss in Actual GDP per Capita, Social Security Tax Rebate
1990-3%	193	947	428
1990+9%	106	567	305
1990+24	40	294	187

Source: Simulations of the Data Resources, Inc. (DRI) Macroeconomic Model of the U.S. Economy.

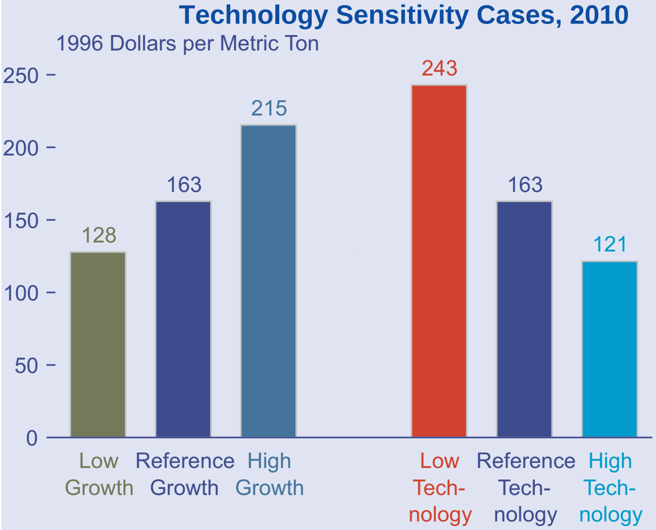
compliance period are the same as in the corresponding reference technology case. What differs is the cost of meeting the target, as reflected in the required carbon price.

Macroeconomic Growth

The assumed rate of economic growth has a strong impact on the projection of energy consumption and, therefore, on the projected levels of carbon emissions. Two sensitivity cases explore the effects of higher and lower economic growth on the cost of reducing carbon emissions to the 1990+9% level. Higher economic growth results from higher assumed growth in population, the labor force, and labor productivity, resulting in higher industrial output, lower inflation, and lower interest rates. As a result, GDP increases at an average rate of 2.4 percent a year through 2020, compared with a growth rate of 1.9 percent a year in the reference case. With higher macroeconomic growth, energy demand grows faster, as higher manufacturing output and higher income increase the demand for energy services, resulting in higher carbon emissions. Assumptions of lower growth in population, the labor force, and labor productivity result in an average annual growth rate of 1.3 percent in the low economic growth case, resulting in lower carbon emissions.

With higher economic growth, both industrial output and energy service demand are higher. As a result, carbon prices must be correspondingly higher to attain a given carbon emissions target. In the high macroeconomic growth case, the carbon price in 2010 is $215 per metric ton, $52 per metric ton higher than the carbon price of $163 per metric ton in the 1990+9% case with reference growth assumptions (Figure ES20). In the low macroeconomic growth case, the carbon price in 2010 is $128 per metric ton. The higher carbon prices necessary to achieve the carbon reductions with higher economic growth have a negative impact on the economy and the energy system. Nevertheless, total energy consumption in 2010 is higher with higher economic growth, by 2.2 quadrillion Btu relative to the 1990+9% case, which assumes the same economic growth rate as the reference case. In the low economic growth case, total energy consumption is lower by 2.2 quadrillion Btu in 2010.

Figure ES20. Projected Carbon Prices in the 1990+9% High and Low Economic Growth and High and Low Technology Sensitivity Cases, 2010



Source: Office of Integrated Analysis and Forecasting, National Energy Modeling System runs FD09ABV.D080398B, LMAC09.D080698A, HMAC09.D080598A, FREEZE09. D080798A, and HITECH09.D080698A.

In order to meet the carbon reduction targets with higher economic growth, there is a shift to less carbon-intensive fuels and higher energy efficiency. On a sectoral basis, higher economic growth affects total energy consumption in the industrial and transportation sectors more significantly than in the other end-use sectors. Total consumption of both renewables and natural gas is higher, primarily for electricity generation but also in the industrial sector. Coal use for generation is lower, and the use of nuclear power is higher as a result of the higher carbon prices. Petroleum consumption is also higher with higher economic growth, both in the transportation and industrial sectors.

Total energy intensity is lower in the high economic growth case, partially offsetting the increases in the demand for energy services caused by the higher growth assumption. With higher economic growth, there is greater opportunity to turn over and improve the stock of energy-using technologies. In addition, the higher carbon price induces more efficiency improvements and some offsetting reductions in energy service demand, moderating the impacts of higher economic growth. With higher economic growth, aggregate energy intensity declines at an average annual rate of 1.9 percent through 2010, compared to 1.6 percent with reference economic growth. The opposite effects on energy intensity occur with lower economic growth, with the decline in energy intensity slowing from 1.6 percent to 1.3 percent between 1996 and 2010.

Technological Progress

The rates of development and market penetration of energy-using technologies have a significant impact on projected energy consumption and energy-related carbon emissions. Faster development of more energy-efficient or lower-carbon-emitting technologies than assumed in the reference case could reduce both consumption and emissions; however, because the reference case already assumes continued improvement in both energy consumption and production technologies, slower technological development is also possible.

To analyze the impacts of technology improvement, high technology assumptions were developed by experts in technology engineering for each of the energy-consuming sectors, considering the potential impacts of increased research and development for more advanced technologies. The revised assumptions included earlier years of introduction, lower costs, higher maximum market potential, and higher efficiencies than assumed in the reference case.[9] Also, this sensitivity case assumed the availability of carbon sequestration technology for coal- and natural-gas-fired power plants, which would remove carbon dioxide and store it in underground aquifers; however, the technology is uneconomical relative to other technologies because of its high operating and storage costs.

These technological improvements were developed under the assumption of increased research and development, and they are distinct from the more rapid adoption of advanced technologies that occurs with higher energy prices in the carbon reduction cases. It is possible that further technology improvements could occur beyond those in the high technology sensitivity case if a very aggressive research and development effort were established. The low technology sensitivity case assumes that all future equipment choices are made from the end-use and generation equipment available in 1998, with new building shell and industrial plant efficiencies frozen at 1998 levels. Comparing this sensitivity case to a case with reference technology assumptions demonstrates the importance of technology improvement in the reference case.

Because faster technology development makes advanced energy-efficient and low-carbon technologies more economically attractive, the carbon prices required to meet carbon reduction levels are significantly reduced. Conversely, slower technology improvement requires higher carbon prices (Figure ES20). With high technology assumptions, the carbon price in 2010 is $121 per metric ton, $42 per metric ton lower than the carbon price of $163 per metric ton in the 1990+9% case with the reference technology assumptions. With the low technology assumptions, the carbon price increases to $243 per metric ton in 2010.

In the high technology sensitivity case, total energy consumption in 2010 is lower by 2.1 quadrillion Btu, or about 2 percent, than in the 1990+9% case with reference technology. Delivered energy consumption in both the industrial and transportation sectors is lower as efficiency improvements in industrial processes and most transportation modes outweigh the countervailing effects of lower energy prices. In the residential and commercial sectors, the effect of lower energy prices balances the effect of advanced technology, and consumption levels are at or near those in the reference technology (1990+9%) case. In the generation sector, coal use for generation is 40 percent higher than with reference technology assumptions, due to efficiency improvements and the lower carbon price.

In the low technology sensitivity case, the converse trends prevail. In 2010, total energy consumption is higher by 1.5 quadrillion Btu than in the 1990+9% case with reference technology assumptions. Delivered energy consumption is higher in the industrial and transportation sectors and lower in the residential and commercial sectors, suggesting that industry and transportation are more sensitive to technology changes than to price changes, and the residential and commercial sectors are more sensitive to price changes. With the higher carbon prices in the low technology case, coal use is further reduced in the generation sector, and more natural gas, nuclear power, and renewables are used to meet the carbon reduction targets.

Nuclear Power

In the reference case, nuclear electricity generation declines significantly because 52 percent of the total nuclear capacity available in 1996 is assumed to be retired by 2020. A number of units are retired before the end of their 40-year operating licenses, as suggested by industry announcements and analysis of the age and operating costs of the units. In the carbon reduction cases, life extension of the plants can occur if it is economical; and there is an increasing incentive to invest in nuclear plant refurbishment with higher carbon prices. However, these cases do not allow the construction of new nuclear power plants, given continuing high capital investment costs and institutional constraints associated with nuclear power. A nuclear power sensitivity case examines the impact of allowing new plants to be constructed. Because nuclear plants still are not economically competitive with fossil and renewable plants in the 1990+9% case, the nuclear power sensitivity case was analyzed against the 1990-3% case. In addition to allowing new nuclear plants, the higher costs assumed in the reference case for the first few advanced nuclear plants were reduced in this sensitivity.

Relative to the 1990-3% case, 1 gigawatt of new nuclear capacity is added by 2010 in the nuclear power sensitivity case, and 41 gigawatts, representing about 68 new plants of 600 megawatts each, are added by 2020. With most of the impact from the new nuclear plants coming after the commitment period of 2008 through 2012, there is little impact on carbon prices in 2010. By 2020, however, carbon prices are $199 per metric ton with the assumption of new nuclear plants, as compared with $240 per metric ton in the 1990-3% case with the reference nuclear assumptions. In 2010, total energy consumption is about the same in this sensitivity case as in

[9]The design of the high technology sensitivity case differs from the high technology cases in *AEO98*, which generally did not include an analysis of improvements for specific technologies.

the 1990-3% case, but in 2020 it is about 1.8 quadrillion Btu higher. Somewhat lower energy prices induce higher consumption in all sectors, and the availability of more carbon-free nuclear generation allows the carbon reduction target to be met with higher end-use consumption.

Uncertainties in the Analysis

The reference case projections in both *AEO98* and this analysis represent business-as-usual forecasts, given known trends in technology and demographics, current laws and regulations, and the specific methodologies and assumptions used by EIA. Because EIA does not include future legislative and regulatory changes in its reference case projections, the projections provide a policy-neutral baseline against which the impacts of policy initiatives can be analyzed.

Results from any model or analysis are highly uncertain. By their nature, energy models are simplified representations of complex energy markets. The results of any analysis are highly dependent on the specific data, assumptions, behavioral characteristics, methodologies, and model structures included. In addition, many of the factors that influence the future development of energy markets are highly uncertain, including weather, political and economic disruptions, technology development, and policy initiatives. Recognizing these uncertainties, EIA has attempted in this study to isolate and analyze the most important factors affecting future carbon emissions and carbon prices. The results of the various cases and sensitivities should be considered as relative changes to the comparative baseline cases.

In addition to the uncertainties concerning the final interpretation and implementation of the Kyoto Protocol, specific actions that might be taken to reduce greenhouse gas emissions in the United States have not been formulated. Actions taken by other Annex I countries to reduce emissions, future growth in worldwide energy consumption and emissions, and the opportunities for reducing emissions through joint implementation and the CDM are unknown, and they are likely to have important impacts on the international trade of carbon permits and the carbon permit price. This analysis assumes that auctioned permits will constrain carbon emissions and raise the price of fossil fuels, with revenues from the auction recycled to consumers either through personal income tax or social security tax rebates. Alternative carbon reduction programs and fiscal policies would be likely to change the cost of carbon reduction from the costs in this analysis. The timing of carbon reduction programs and the amount of adjustment time allowed could also be important in determining costs.

Future technology development also cannot be known with certainty and may have a significant effect on the cost of achieving carbon reductions. The technology sensitivity cases in this analysis explore some of the potential impacts, but even the high technology sensitivity does not include possible breakthrough or speculative technologies. On the other hand, even the reference case technology assumptions include continued development of more energy-efficient and renewable technologies, which serve to mitigate the costs of carbon reduction. Those technology improvements are likely, but not certain.

Finally, consumer response to carbon initiatives is uncertain. Because energy price changes that have occurred in the past may not provide sufficient evidence about the reaction of consumers to sustained high energy prices, changes in demand as a result of the higher carbon fees cannot be projected with confidence. In addition to price-induced changes, consumers might also respond to climate change initiatives and a national commitment to reduce emissions by adopting more energy-efficient or renewable technologies sooner than expected. Finally, public acceptance of large-scale renewable technologies or the continuation of nuclear power—both of which make important contributions to the achievement of the carbon emissions reductions at the costs projected in this analysis—cannot be known with certainty.