1. Scope and Methodology of the Study

Background

The Greenhouse Gas Effect

The greenhouse effect is a natural process by which some of the radiant heat from the Sun is captured in the lower atmosphere of the Earth, thus maintaining the temperature of the Earth's surface. The gases that help capture the heat, called "greenhouse gases," include water vapor, carbon dioxide, methane, nitrous oxide, and a variety of manufactured chemicals. Some are emitted from natural sources; others are anthropogenic, resulting from human activities.

Over the past several decades, rising concentrations of greenhouse gases have been detected in the Earth's atmosphere. Although there is not universal agreement within the scientific community on the impacts of increasing concentrations of greenhouse gases, it has been theorized that they may lead to an increase in the average temperature of the Earth's surface. To date, it has been difficult to note such an increase conclusively because of the differences in temperature around the Earth and throughout the year, and because of the difficulty of distinguishing permanent temperature changes from the normal fluctuations of the Earth's climate. In addition, there is not universal agreement among scientists and climatologists on the potential impacts of an increase in the average temperature of the Earth, although it has been hypothesized that it could lead to a variety of changes in the global climate, sea level, agricultural patterns, and ecosystems that could be, on net, detrimental.

The most recent report of the Intergovernmental Panel on Climate Change (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]

U.S. Greenhouse Gas Emissions

In 1990, total greenhouse gas emissions in the United States were 1,618 million metric tons carbon equivalent,[2] according to 1997 estimates published by the Energy Information Administration (EIA).[3] Of this total, 1,346 million metric tons, or 83 percent, was due to carbon emissions from the combustion of energy fuels—the focus of this report. 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*)[4] projects that energy-related carbon emissions will reach 1,577 million metric tons in 2000, 17 percent above the 1990 level. Projected emissions continue to rise at an average annual rate of 1.5 percent a year from 1996 to 2010, reaching 1,803 million metric tons of carbon emissions in 2010, 34 percent above the 1990 level. Because energy-related carbon emissions are a large portion of total greenhouse gas emissions, any efforts to reduce greenhouse gas emissions will likely have a significant impact on the energy sector; however, as discussed later, there are a number of factors outside the domestic energy market that also affect emissions levels.

To put U.S. emissions in a global perspective, the United States produced about 24 percent of the worldwide energy-related carbon emissions in 1996, which totaled 6.6 billion metric tons, as noted in EIA's *International Energy Outlook 1998* (*IEO98*).[5] Although continued increases in carbon emissions are expected for the United States and other industrialized countries, much

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

[2] Greenhouse gases differ in their impacts on global temperatures. For comparison of emissions from the various gases, they are often weighted by global warming potential (GWP), established by the Intergovernmental Panel on Climate Change, which is a measure of the impact of each gas on global warming relative to that of carbon dioxide, which is defined as having a GWP equal to 1.

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

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

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

more rapid increases are projected for the developing countries of Asia, the Middle East, Africa, and Central and South America. As a result, global carbon emissions from energy use are expected to increase at an average annual rate of 2.4 percent from 1996 through 2010, reaching 8.3 billion metric tons, to which the United States would contribute about 22 percent.

The Framework Convention on Climate Change

As a result of increasing warnings by members of the climatological and scientific community about the possible harmful effects of rising greenhouse gas concentrations, the 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. A series of international conferences followed, and in 1990 the United Nations established the Intergovernmental Negotiating Committee for a Framework Convention on Climate Change. After a series of negotiating sessions, 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, implement, . . . and . . . update . . . programmes containing measures to mitigate climate change by addressing anthropogenic emissions by sources and removals by sinks" and to prepare periodic emissions inventories, promote development and diffusion of technologies for emissions control, and cooperate in adaptation. In addition, the developed country signatories agreed to "adopt national policies and take corresponding measures on the mitigation of climate change" and to "communicate . . . detailed information on its policies and measures . . . with the aim of returning individually or jointly to their 1990 levels these anthropogenic emissions of carbon dioxide and other greenhouse gases." The Convention excludes chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs), greenhouse gases that are deemed to cause damage to the Earth's stratospheric ozone and are controlled by the 1987 Montreal Protocol on Substances that Deplete the Ozone Layer.

The Framework Convention established the Conference of the Parties to "review the implementation of the Convention and . . . make, within its mandate, the decisions necessary to promote the effective implementation." In 1995, the first Conference of the Parties met in Berlin and issued the Berlin mandate, an agreement to "begin a process to enable it to take appropriate action for the period beyond 2000." The second Conference of the Parties, held in Geneva in July 1996, called for negotiations on quantified limitations and reductions of greenhouse gas emissions and policies and measures for the third Conference of the Parties in Kyoto, Japan, in December 1997.

The Climate Change Action Plan

Responding to the Framework Convention, on April 21, 1993, President Clinton called upon the United States to stabilize greenhouse gas emissions by 2000 at 1990 levels. Specific steps to achieve U.S. stabilization were enumerated in the Climate Change Action Plan (CCAP),[6] published in October 1993, which consists of a series of 44 actions to reduce greenhouse gas emissions. The actions include voluntary programs, industry partnerships, government incentives, research and development, regulatory programs including energy efficiency standards, and forestry actions. Greenhouse gases affected by these actions include carbon dioxide, methane, nitrous oxide, hydrofluorocarbons (HFCs), and perfluorocarbons (PFCs). At the time CCAP was developed, the Administration estimated that the actions it enumerated would reduce total net emissions[7] of these greenhouse gases in the United States to 1990 levels by 2000.

In addition to the climate-related actions of CCAP, the Energy Policy Act of 1992 (EPACT), Section 1605(a), provided for an annual inventory of U.S. greenhouse gas emissions, which is contained in the EIA publication series, *Emissions of Greenhouse Gases in the United States*.[8] Also, Section 1605(b) of EPACT established the Voluntary Reporting Program, permitting corporations, government agencies, households, and voluntary organizations to report to EIA on actions that have reduced or avoided emissions of greenhouse gases. The results of the Voluntary Reporting Program are reported annually by EIA, most recently in *Mitigating Greenhouse Gas Emissions: Voluntary Reporting*,[9] which reports 1995 activities. Entities providing data to the Voluntary Reporting Program include some participants in government-sponsored voluntary programs, such as the

[6]President William J. Clinton and Vice President Albert Gore, Jr., *The Climate Change Action Plan* (Washington, DC, October 1993).

[7]Carbon dioxide is absorbed by growing vegetation and soils. Defining the total impacts of CCAP as net reductions accounts for the increased sequestration of carbon dioxide as a result of the forestry and land-use actions in the program.

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

[9]Energy Information Administration, *Mitigating Greenhouse Gas Emissions: Voluntary Reporting*, DOE/EIA-0608(96) (Washington, DC, October 1997).

Climate Wise and Climate Challenge programs, which are cosponsored by the U.S. Environmental Protection Agency and the U.S. Department of Energy to foster reductions in greenhouse gas emissions by industry and electricity generators. Voluntary activities for 1996 and 1997 will be available in the fall of 1998.

The Kyoto Protocol

Prior to the third Conference of the Parties, at the June 26, 1997, Earth Summit+5 Conference at the United Nations, President Clinton pledged U.S. support for binding emissions targets and announced three initiatives: a pledge of $1 billion over 5 years by the United States for the development of more energy-efficient and alternative energy technologies in developing countries; the strengthening of environmental guidelines for U.S. companies investing overseas; and a partnership with private industry to install solar panels on 1 million rooftops in the United States by 2010.

On October 22, 1997, President Clinton proposed that developed countries should stabilize emissions at 1990 levels between 2008 and 2012, with reductions below 1990 levels in the following 5-year period. He also indicated his support for joint implementation projects and international emissions trading and declared that participation by developing countries was necessary for the United States to assume binding obligations. At the same time, the President announced additional initiatives to address greenhouse gas emissions: a $5 billion program of tax incentives and research and development spending for energy-efficient and lower-carbon technologies; the establishment of an emissions trading system with credit for early reductions; the restructuring of the electricity industry; and reductions of emissions from Federal sources. Funding for the program was increased to $6.3 billion in the Administration's 1999 budget request.

Representatives from more than 160 countries met in Kyoto on December 1 through 11, 1997. The resulting Kyoto Protocol established binding emissions targets for developed nations, relative to their emissions levels in 1990, for an overall reduction of about 5 percent.[10] The individual targets for the Annex I countries[11] range from an 8-percent reduction for the European Union (EU) (or its individual member states) to a 10-percent increase allowed for Iceland. Australia and Norway also are allowed increases of 8 and 1 percent, respectively, while New Zealand, the Russian Federation, and the Ukraine are held to their 1990 levels. Other Eastern European countries undergoing transition to market economies have reduction targets of between 5 and 8 percent. The reduction targets for Canada and Japan are 6 percent and, for the United States, 7 percent. Although atmospheric *concentrations* of greenhouse gases ultimately have the potential to affect the global climate, the Protocol establishes targets in terms of *annual emissions*.

The greenhouse gases included in the targets are carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride.[12] For the latter three gases, individual nations have the option of using 1995 as the base year from which to achieve reductions, instead of 1990. The aggregate target is established using the carbon dioxide equivalent of each of the greenhouse gases. Other greenhouse gases are not limited by the Protocol, although CFCs and HCFCs are controlled by the Montreal Protocol. This analysis focuses on carbon emissions from the combustion of energy fuels, which constituted 83 percent of all U.S. greenhouse gas emissions in 1990. Carbon dioxide emissions from sources other than energy use are not included in the analysis, nor are emissions of the five other gases covered by the Kyoto Protocol; however, reductions in those gases may lessen the required reductions in energy-related carbon emissions, as discussed below.

The established targets must be achieved over the period 2008 to 2012, the first commitment period. Essentially, each country can average its emissions over that 5-year period to establish compliance, smoothing out short-term fluctuations that might result from economic cycles or extreme weather patterns. Each country must have made demonstrable progress by 2005. No targets are established for the period after 2012, although lower targets may be set by future Conferences of the Parties.

Sources of emissions include fuel combustion, fugitive emissions from fuels, industrial processes, solvents, agriculture, and waste management and disposal. The Protocol does not prescribe specific actions to be taken but lists a number of potential actions, including energy efficiency improvements, enhancement of carbon-absorbing sinks, such as forests and other vegetation, research and development of sequestration technologies, phasing out of fiscal incentives and subsidies that

[10]The text of the Kyoto Protocol is available at web site www.unfccc.de.

[11]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.

[12]Hydrofluorocarbons are a non-ozone-depleting substitute for CFCs; perfluorocarbons are byproducts of aluminum production and are also used in semiconductor manufacturing; and sulfur hexafluoride is used as an insulator in electrical equipment and in semiconductor manufacturing.

may inhibit the goal of emissions reductions, and reduction of methane emissions in waste management and in energy production, distribution, and transportation.

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 will also be used in meeting the commitment; however, these are limited to afforestation, reforestation, and deforestation since 1990. Emissions trading among the Annex I countries is permitted. No rules for trading are established, however, and the Conference of the Parties is required to establish principles, rules, and guidelines for trading at a future date. Joint implementation projects are also allowed among the Annex I countries, whereby a nation could take emissions credits for projects that reduce emissions or enhance sinks in other countries. It is specifically indicated that trading and joint implementation are supplemental to domestic actions.

The Protocol also establishes a Clean Development Mechanism (CDM), under which Annex I countries can take emissions credits for projects that reduce emissions in non-Annex I countries, provided that the projects lead to measurable, long-term benefits. Reductions from such projects undertaken from 2000 until the first commitment period can be used to assist compliance in the commitment period. This provision calls for the establishment of an executive board to oversee the projects. In addition, an unspecified share of the proceeds from the project activities must be used to cover administrative expenses and to assist with adaptation those countries that are particularly vulnerable to climate change.

Banking—the carrying over of unused allowances from one commitment period to the next—is allowed; however, the borrowing of emissions allowances from a future commitment period is not permitted. Under the Protocol, Annex I countries, such as the nations of the European Union (EU), may create a bubble or umbrella to meet the total commitment of all the member nations. In a bubble, countries agree to meet the total commitment jointly by allocating a share to each member. In an umbrella arrangement, the total reduction of all member nations is met collectively through the trading of emissions rights. There is potential interest in the United States in entering into an umbrella trading arrangement.

Non-Annex I countries have no targets under the Protocol, although it reaffirms the commitments of the Framework Convention by all parties to formulate and implement climate change mitigation and adaptation programs and to promote the development and diffusion of environmentally sound technologies and processes. Developing countries can voluntarily enter into the Protocol by full amendment of the Protocol.

The Protocol became open for signature on March 16, 1998, for a 1-year period. Under its provisions, it enters into force 90 days following acceptance of at least 55 Parties, including Annex I countries accounting for at least 55 percent of the total 1990 carbon dioxide emissions from Annex I nations. Signature by the United States would need to be followed by Senate advise and consent to ratification.

There are a number of uncertainties and issues to be resolved at future Conferences of the Parties. As indicated in the Protocol, 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. This issue was directed to the IPCC by subsequent climate change talks in Bonn in June 1998. In addition, rules and guidelines must be established for emissions trading, joint implementation projects, and the CDM.

Other issues covered in the Protocol but deferred to subsequent sessions include flexibility for Annex I countries undergoing transition to market economies, commitments for subsequent periods, climate change adaptation actions, sanctions for failure to meet commitments, guidelines for the reporting and review of emissions and sinks, and international cooperation in education, research and development, and technology transfer.

Emissions Trading

Even before the Kyoto Protocol, many analyses of the impacts of greenhouse gas emissions reductions have favored emissions trading programs, including joint implementation programs, as a means of achieving emissions reductions. In the United States, the Clean Air Act Amendments of 1990 (CAAA90) established a trading program for emissions of sulfur dioxide (SO_2) by electricity generators in order to reduce emissions to fixed specified levels. Permits issued to electricity generators allow them to emit up to a specified level of SO_2, with the total number of issued permits equal to the national limit on emissions. Generators may reduce emissions by using lower-sulfur coals, installing scrubbers, or increasing the utilization of cleaner-generating plants. Generators that reduce emissions below their allowed levels can sell excess emissions permits, which can be purchased by other generators for whom it is more cost-effective to purchase permits at the prevailing market price than to reduce emissions. Emissions permits can also be banked for future use. Compared with traditional control programs that mandate specific compliance options or require uniform reductions, this SO_2 trading program is credited with reducing the overall cost of compliance by allowing reductions to be made in the most cost-effective manner.

Unlike SO_2, carbon emissions are primarily an international, rather than domestic, issue. In theory, a similar trading scheme for carbon emissions could be formulated either internationally or within individual countries to achieve fixed emissions levels. Indeed, the Kyoto Protocol provides for international emissions trading but defers the determination of specific guidelines and rules for establishing an open trading market and managing the international flow of funds for the purchase of permits. Additional complexities may arise in establishing baseline projections against which to monitor and verify net emissions reductions, particularly with regard to the CDM.

Even within the United States, carbon emissions trading may be more complicated than the current SO_2 trading plan for several reasons. The largest sources of SO_2 are a small number of large coal-burning generation plants. This makes it relatively easy to monitor their fuel use and emissions and to build and maintain an allowance trading system to ensure compliance. In contrast, there are a large number of entities that emit carbon, including households, commercial establishments, industrial facilities, automobiles, trucks, airplanes, ships, and fossil-fired generating stations. The development and operation of a monitoring and trading system for carbon emissions would thus be much more complicated. In addition, there were technologies available to reduce SO_2 emissions at generation plants at the time the allowance trading program was initiated, and switching to low-sulfur coal was an option. Although research is ongoing, there are no readily available pre- or post-combustion technologies for removing carbon from fossil fuels (although the high technology sensitivity case included in this analysis assumes that carbon sequestration technologies will become available for electricity generators). Therefore, the options for carbon reduction are limited to fuel switching to lower-carbon or carbon-free fuels, efficiency improvements, and reductions in energy demand.

Methodology of the Analysis

In March 1998, the U.S. House of Representatives Committee on Science requested that the EIA perform an analysis of the Kyoto Protocol, focusing on the impacts of the Protocol on U.S. energy prices, energy use, and the economy in the 2008 to 2012 time frame for a number of emissions targets. (See letters of request in Appendix D.) The request specified that the analysis use the same reference case assumptions as in *AEO98* unless changes in the assumptions could be justified on the basis of the Protocol—that is, there should be no changes in assumptions regarding policy, regulatory actions, or funding of energy or environmental programs, including the energy-related provisions of the Administration's revenue proposals of February 1998.

Each target in the analysis was to be achieved on average between 2008 and 2012, phasing in beginning in 2005 and stabilizing at the target level after 2012, although targets beyond 2012 have not yet been established and may in fact be more stringent. The Committee indicated that no new nuclear plants should be allowed, although economical life extensions of nuclear plants should be permitted. Construction of new nuclear plants, variations in economic growth, and different assumptions concerning technology characteristics were all to be analyzed as sensitivities to the target cases.

Numerous studies have been conducted on the topic of reducing greenhouse gas emissions. They can be clustered into several broad categories. One group of studies are cost-benefit analyses, which seek to establish an optimal level of either emissions reductions or emissions prices with a goal of balancing the costs and benefits of emissions reductions, explicitly accounting for the mitigation of damage as a result of emissions controls. A second category of studies address the cost-effectiveness of alternative paths for emissions reductions. Assuming a level of global concentrations of greenhouse gases, these analyses derive an optimal timing strategy for the imposition of emissions controls.

Other studies are more narrowly focused on the costs of achieving specific emissions reductions or on the impacts of policies and technology on emissions levels. Before the Conference of the Parties in Kyoto, analyses examined the costs of emissions targets under a variety of assumptions about the possible level and timing of the targets. Since the Conference, analyses have focused on the levels and timing specified in the Kyoto Protocol and studied the costs of achieving those levels under a range of assumptions about the international provisions and other flexibility measures in the Protocol. Some of those analyses are included in the comparison of results in Chapter 7. This EIA analysis is among this final category of studies, with more detail on U.S. energy markets and the economy than other analyses but not addressing the potential benefits of emissions reductions, optimal timing, or international trade.

The Protocol includes a number of international provisions—including international emissions trading, joint implementation projects, and the CDM—that may reduce the cost of compliance. Because EIA cannot fully address these aspects of the Protocol at this time, the analysis focuses on domestic impacts and includes a range of cases with different levels of energy-related carbon emissions. Although any impact on the global climate will likely be caused by atmospheric concentrations of greenhouse gases, the targets in the Kyoto Protocol are in terms of annual emissions. This analysis addresses the annual emissions targets as specified in the Protocol.

The National Energy Modeling System

At the request of the Committee, this analysis uses the same basic assumptions and methodologies that were used for *AEO98*. The projections in *AEO98* 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.[13] 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.

Reference case projections are developed annually using NEMS and published in the *Annual Energy Outlook* (*AEO*). NEMS is also used to analyze the effects of existing and proposed laws, regulations, and standards related to energy production and use; the impacts of new and advanced energy technologies; the savings from higher energy efficiency; the impacts of energy tax policy on the U.S. economy and energy system; and the impacts of environmental policies, such as the CAAA90 and regulations on alternative and reformulated fuels. Special analyses of these and other topics are performed at the request of the U.S. Congress, other offices in the U.S. Department of Energy, and other government agencies. Because NEMS provides annual projections, it is well suited to represent the transitional effects of proposed energy policy and regulation.

Within NEMS, four end-use demand modules represent energy consumption in the residential, commercial, industrial, and transportation sectors, subject to fuel prices, macroeconomic factors, and the characteristics of energy-using technologies in those sectors. The fuel supply and conversion modules represent the domestic production, imports, transportation, and conversion processes to meet the domestic and export demand for coal, petroleum products, natural gas, and electricity, accounting for resource base characteristics, industry infrastructure and technology, and world market conditions. The modules of NEMS interact to solve for the economic supply and demand balance for each fuel.

In order to capture regional differences in energy consumption patterns and resource availability, NEMS is a regional model. The end-use demand for energy is represented for each of the nine Census divisions. The supply and conversion modules use the North American Electric Reliability Council regions and subregions for electricity generation; aggregations of the Petroleum Administration for Defense Districts for refineries; and production regions specific to oil, natural gas, and coal supply and distribution.

NEMS incorporates interactions between the energy system and the economy and between domestic and world oil markets. Key macroeconomic variables, including the gross domestic product (GDP), disposable personal income, industrial output, housing starts, employment, and interest rates, drive energy consumption and investment decisions. In turn, changes in energy prices and energy activity affect economic activity, a feedback captured within NEMS. Also, an international energy module in NEMS represents world oil prices, production, and demand and the interactions between the domestic and world oil markets. Within this module, world oil prices and supplies respond to changes in U.S. demand and production.

Technology Representation in NEMS

A key feature of NEMS is the representation of technology and technology improvement over time. The residential, commercial, transportation, electricity generation, and refining sectors of NEMS include explicit treatments of individual technologies and their characteristics, such as initial cost, operating cost, date of commercial availability, efficiency, and other characteristics specific to the sector. 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 addition, in the electricity generation sector, fossil-fired and nuclear generating units can be retired before the end of their useful lives if it is more economical to bring on a replacement unit than to continue to operate the existing unit.

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. In the industrial sector, technology improvement for the major processing steps of the energy-intensive industries is represented by technology possibility curves of efficiency improvements over time. In the oil and gas supply sector, technology progress for exploration and production activities is represented by trend-based improvement in

[13] See Energy Information Administration, *The National Energy Modeling System: An Overview 1998*, DOE/EIA-0581(98) (Washington, DC, February 1998), for a summary description. Detailed documentation is available through the National Energy Information Center at 202/586-8800 or on the EIA web site at www.eia.doe.gov.

finding rates, success rates, costs, and the size of the resource base. Productivity improvements over time represent technological progress in coal production.

Because of the detailed representation of capital stock vintaging and technology characteristics, NEMS captures the most significant factors that influence the turnover of energy-using and producing equipment and the choice of new technologies. New, more advanced technologies for buildings and equipment are generally characterized by the technology costs, performance, and availability, existing standards, and energy prices. Equipment that does not meet efficiency standards is not available as a choice.

The relative costs of purchasing and operating different types of equipment are factored into consumer choices, which are represented by elasticities and discount rates derived from the analysis of available data. Within the residential sector, for example, housing stocks are calculated by region and housing type, using aggregate housing starts from the macroeconomic forecast and assumed retirement rates. Stocks of energy-using equipment are also tracked, reflecting equipment retirement, replacements, and new housing starts. Choices for new equipment and efficiency levels for new houses are influenced by the characteristics of available technology, existing standards, energy prices, and consumer preferences as reflected in past decisions. In the end-use sectors, all technology choices are based on the assumption that future energy prices will remain at the same level as the prices for the year in which the decision is being made, this being the most likely representation of how customer decisions are made. However, in the generation and refining sectors, which are cost minimizers, capacity expansion decisions include foresight of future energy prices and demand.

In all sectors, technology improvement occurs even in a reference case because new, more efficient technology will be adopted as demand for energy services increases and existing buildings and equipment are retired. The characteristics of the technologies include initial dates of commercial availability of more advanced technologies as well as changes in efficiency and cost that are assumed to occur in the future. Higher energy prices may accelerate the adoption of more efficient technologies. Past improvements in energy efficiency have resulted in part from efficiency standards that are included in the analysis; future efficiency standards assumed are those approved standards with specified efficiency levels.

The detailed characterization of energy consumption patterns and technology decisions in NEMS allows for an explicit representation of the introduction of new energy-using equipment and the improvement of the capital stock. Because longer-term forecasting models typically are not annual models, they tend not to capture the gradual transition of energy markets, including the capital stock vintaging and turnover, as NEMS does. In addition, because of the longer time horizon, longer-term models tend to have less detailed representations of energy markets.

Although prices play a role in consumers' decisions on energy-consuming equipment, there are other factors that come into play. Consumers tend to make decisions based on a number of personal preferences and lifestyle choices, in which energy prices may be only a part of the decisionmaking process. Preferences for larger televisions or higher horsepower vehicles are examples of factors that may outweigh energy costs. As another example, in the residential sector, home rental instead of purchase and frequent moving tend to lower the incentive to invest in more energy-efficient equipment. Information also has a major role in consumer decisions and will likely continue to do so in the adoption of new, more advanced technologies. Particularly when a more efficient or alternatively fueled technology carries a significantly higher cost or has different operational characteristics than more conventional technologies, information on the benefits of the new technology will be key to its adoption and penetration. Ultimately, the success of a given technology will depend not on the behavior of the marginal consumer, who may be particularly cost-conscious or innovative, but on the behavior of the average consumer, whose decision rests on a number of considerations.

Technology improvements, even when adopted in the market, may not necessarily lead to reductions in energy demand. In the transportation sector, for example, the use of more advanced technologies that could improve vehicle efficiency has been offset by increasing demand for larger and higher horsepower vehicles. To the extent that energy prices are a factor in consumer decisions, efficiency improvements may also increase energy demand. Efficiency gains may lower the cost of driving or operating other equipment, perhaps encouraging more travel, larger homes, and purchases of more equipment and increasing the demand for energy services.

New or tightened efficiency standards could also reduce the demand for energy, but stock turnover would still limit the speed of penetration. Standards have also been suggested to encourage the use of renewable fuels for electricity generation, such as those in the proposed Electric System Public Benefits Protection Act of 1997, the proposed Electric Consumers Protection Act of 1997, and the Administration's proposed Comprehensive Electricity Competition Act; however, proposed and possible future standards, legislation, and programs are not included in the analysis.

The *Annual Energy Outlook 1998*

At the request of the Committee on Science, this study of the impacts of the Kyoto Protocol is based on the reference case assumptions of *AEO98*. In accordance with the requirement that the reference case EIA projections be policy-neutral, the *AEO98* projections assume that all Federal, State, and local law, regulations, policies, and standards in effect as of July 1, 1997, remain unchanged through 2020. Potential impacts of pending or proposed legislation, proposed standards, or sections of existing legislation for which funds had not been appropriated are not included in the projections. In general, the *AEO98* projections were prepared using the most current data available as of July 31, 1997.

The *AEO98* projections assume continued growth in the U.S. economy, with GDP growing at an average annual rate of 1.9 percent through 2020. Additional key factors underlying the projections are the assumptions concerning world oil markets. Continued technological improvement in the production of oil and the expansion of production capability worldwide hold the increase in the real, inflation-adjusted world oil price to an average growth rate of 0.4 percent a year. Domestically, with technological advances in the exploration and production of natural gas, the average annual growth in the average wellhead price is projected to be 0.5 percent even with rapid growth in the demand for natural gas. The average price of coal declines throughout the projection period due to increasing productivity in coal production and the expansion of production from lower-cost western sources.

AEO98 represents the ongoing restructuring of the electricity industry by assuming lower operating, maintenance, and administrative costs, as noted in the trends of recent data; early retirements of higher-cost coal-fired and nuclear power plants; and lower capital costs and efficiency improvements for coal- and natural-gas-fired generation technologies. Additional assumptions include a revised financial structure that features a higher cost of capital in competitive markets. Specific restructuring plans are included for those regions that have announced plans. California, New York, and New England are assumed to begin competitive pricing in 1998 with stranded cost recovery phased out by 2008. The provisions of the California legislation for stranded cost recovery and price caps are incorporated. With these assumptions and declining coal prices, electricity prices decline at an average annual rate of 1 percent in the *AEO98* projections.

Electricity generation from nuclear power declines significantly in the projections. About 20 percent of the nuclear capacity available in 1996 is assumed to be retired by 2010, with no new plants constructed. It is assumed that nuclear units would be retired as early as 10 years before the expiration of their operating licenses, based on utility announcements and on analysis of the age and operating costs of the units. To offset the decline of nuclear power and to meet the growth of electricity demand, coal and natural gas generation expand in the projections, particularly the gas technologies. The financial assumptions for restructuring weigh against more capital-intensive projects, such as coal and baseload renewable technologies.

With decreases or moderate increases in the prices of energy and continued economic growth, total energy consumption in *AEO98* increases by 1 percent a year on average through 2020. Consumption in all end-use sectors grows in the projections; however, demand in the transportation sector increases most rapidly, reflecting increased travel and slow improvement in the efficiency of vehicles. Total energy intensity, measured as energy use per dollar of GDP, declines in the projections at an average annual rate of 0.9 percent. This rate is considerably less than the 2.3-percent decline in energy intensity experienced between 1970 and 1986 when rapid price increases and a shift to less energy-intensive industries led to rapid energy intensity improvements. On average, energy intensity has been flat between 1986 and 1996. The projected improvement still reflects continued improvements in energy efficiency that partially offset increases in the demand for energy services.

As noted earlier, projected carbon emissions from energy combustion in *AEO98* reach 1,803 million metric tons in 2010, 34 percent above the 1990 level of 1,346 million metric tons, rising to 1,956 million metric tons in 2020. Total emissions are projected to increase at an average annual rate of 1.5 percent between 1996 and 2010 in the reference case, and per capita emissions also increase at an average annual rate of 0.7 percent during that period, as continued economic growth and moderate price increases encourage growth in energy services and energy consumption. Between 2010 and 2020, efficiency improvements tend to offset continued growth in the demand for energy services, and per capita emissions nearly flatten. During that period, total emissions increase at an average rate of 0.8 percent a year. Over the entire projection period, the slow growth of renewable technologies and the decline of electricity generation from nuclear power plants also contribute to the growth of emissions.

Projections of carbon emissions in *AEO98* include EIA's analysis of the impacts of CCAP for the 31 of the 44 CCAP actions that relate to carbon dioxide emissions from energy combustion. The analysis does not account for the remaining actions related to non-energy programs, gases other than carbon dioxide, or forestry and land use. The analysis of CCAP represents EIA's estimate of the effects of incorporating assumptions concerning behavioral change as a result of CCAP and does not result in the reductions estimated by the developers of CCAP. The initial estimates of the impacts of the CCAP actions by the Administration projected stabilization of net greenhouse gas emissions in 2000 at 1990 levels; however, a more recent review and update of CCAP significantly reduces the expected impact.[14] In *AEO98*, carbon emissions in 2010 are reduced by about 36 million metric tons as a result of CCAP, compared with the more recent estimate by the sponsors of about 95 million metric tons for the energy-related actions in CCAP. Differences between the CCAP impacts estimated by EIA and by the program sponsors are due primarily to differences in the estimated impacts of voluntary programs; some estimates by the sponsors that include ongoing trends that would occur even in the absence of CCAP; and regulatory actions included by the sponsors but not included by EIA because they are not yet enacted or finalized.

The *Annual Energy Outlook 1995* (*AEO95*)[15] was the first *AEO* to include the impacts of CCAP in the projections. Even then, the goal of stabilizing carbon emissions in 2000 at 1990 levels seemed unlikely. *AEO95* projected that energy-related carbon emissions would reach 1,471 million metric tons in 2000, a level nearly reached in 1996 when emissions were 1,463 million metric tons. Each subsequent *AEO* has raised the estimate of carbon emissions, primarily because of lower price projections that encourage energy use and reduce the penetration of renewable sources of energy.

There are several reasons that the target specified by CCAP for 2000 is unlikely to be realized. First, U.S. economic growth has been slightly higher than assumed at the time the CCAP programs were formulated. Second, energy prices have increased at a more moderate rate than initially assumed in the early 1990s. Both these factors have contributed to higher growth in energy consumption than earlier assumed, leading to higher emissions levels. Third, the funding for a number of the CCAP programs is lower than initially requested. Finally, some voluntary programs have proven less effective than initially estimated by the Administration.

Carbon Reduction Cases

The Kyoto Protocol specifies that the U.S. target for total greenhouse gas emissions in the first commitment period will be 7 percent below the level of emissions in 1990. This analysis focuses on the carbon dioxide emissions from the use of energy, which constituted 83 percent of total U.S. greenhouse emissions in 1996 (1,463 million metric tons of energy-related carbon emissions in the total greenhouse gas emissions of 1,753 million metric tons carbon equivalent).

The specific reduction in energy-related carbon emissions that will be required is highly dependent on a number of factors outside the domestic energy sector. Programs to reduce emissions of the other five greenhouse gases covered by the Protocol may decrease the requirement for reductions in carbon dioxide emissions. Similarly, forestry, agriculture, and land use programs may also offset some carbon dioxide emissions; however, the rules to account for agriculture and forestry emissions and sinks have yet to be developed and are subject to considerable uncertainty. According to a fact sheet prepared by the U.S. Department of State on January 15, 1998, discussing the Kyoto negotiations, the method of accounting for sinks and the flexibility to use 1995 as the base year for the synthetic greenhouse gasses may mean that the reduction would be no more than 3 percent below 1990 levels, based on the Administration's estimates.[16] Similar estimates were 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.[17] Finally, because this analysis does not fully represent international energy markets and other activities, the potential role of international emissions trading and the CDM in alleviating U.S. reductions of carbon dioxide is not directly represented in the analysis. Even those analyses that do include international trade must make assumptions about the activities, because the development of guidelines and mechanisms has been deferred.

The success of programs to reduce greenhouse gases at relatively low costs may depend on the success of international trade of carbon permits, joint implementation projects, and the CDM. Some analyses of greenhouse gas reductions that have low costs of compliance assume that a number of relatively low-cost carbon permits will be available from Annex I countries with less expensive opportunities to reduce emissions. Based on EIA's analysis in *IEO98*, there may be 165 million metric tons of carbon permits available from the Annex I countries in the former Soviet Union in 2010, because of the economic decline of those countries in the 1990s, and additional permits may be available as a result of carbon reduction projects. The total estimate of such opportunities is highly uncertain, however, and it is also unclear whether those countries would choose to sell available permits immediately or bank them for later use as their economies and populations grow. The potential transaction costs of international trading are also unknown.

[14]U.S. Department of State, Office of Global Change, *Climate Action Report*, Department of State Publication 10496 (Washington, DC, July 1997).

[15]Energy Information Administration, *Annual Energy Outlook 1995*, DOE/EIA-0383(95) (Washington, DC, January 1995).

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

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

The role of developing countries is another area of uncertainty for international activities. In July 1997, the Senate unanimously passed the Byrd-Hagel resolution, sponsored by Senators Robert Byrd of West Virginia and Chuck Hagel of Nebraska, resolving “that the United States should not be a signatory to any protocol to, or other agreement regarding, the United Nations Framework Convention on Climate Change . . . which would mandate new commitments to limit or reduce greenhouse gas emissions for the Annex I Parties, unless the protocol or other agreement also mandates new specific scheduled commitments . . . for Developing Country Parties within the same compliance period or would result in serious harm to the economy of the United States.”[18] President Clinton has declared on several occasions that he will not submit the Protocol for ratification without pledges of meaningful participation by developing countries. While participation by developing countries may be key to the acceptance of the Protocol, development of specific guidelines and rules for the international programs has been deferred, including the means to establish baseline projections and to monitor and verify emissions reductions.

There is also a possibility that investments to reduce carbon emissions in developing countries could be limited. First, such bilateral ventures may be viewed as substitutes for or additions to foreign aid, a political concern to both the United States and developing countries. Also, it is possible that the continuing discussions about the implementation of the Protocol will raise the topic of trade limits—restrictions on the amount of reductions that any one country can satisfy through international programs. The Protocol states that such activities are to be supplemental to domestic actions. In the views of some countries, there is a potential problem with certain nations undertaking little internal action.

Because the potential impacts of forestry and agricultural sinks, offsets from other greenhouse gases, international trading, and other international activities are uncertain, a single target for the required reductions in energy-related carbon emissions in the United States cannot be developed at present. This analysis includes a number of cases, as requested by the Committee, assuming different levels of reductions in energy-related carbon emissions, in order to develop the energy and economic impacts of achieving those reductions. By establishing this range of carbon reductions, the analysis allows others to perform their own analyses of the impacts of sinks, offsets, and international programs, derive their own targets for energy-related carbon emissions, and use one of the EIA target cases to assess the energy and economic impacts of the carbon reductions in that case.

In addition to a reference case, six targets for reductions in energy-related carbon emissions are considered.

- **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 comparison for the energy market impacts in the reduction cases. Although this reference case is based on the reference case from *AEO98*, as specified by the Committee, there are small differences between this case and *AEO98*. Some modifications were made in order to permit additional flexibility in NEMS 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. Significant changes to NEMS and its assumptions relative to *AEO98* are noted in Appendix A. As a result of these modifications, the projections of carbon emissions in the reference case for this analysis are slightly lower than those in the *AEO98* reference case—1,791 million metric tons in 2010 compared with 1,803 million metric tons. The carbon emissions projections in the reference case, as well as in all the carbon reduction cases, include EIA's estimate of the impacts of CCAP.

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

- **14 Percent Above 1990 Levels (1990+14%).** This case assumes that carbon emissions in the commitment period average 1,539 million metric tons, which is approximately the level estimated for 1998 in *AEO98* and is 14 percent above 1990 levels. This requires the average annual carbon emissions between 2008 and 2012 to be reduced by 253 million metric tons.

- **9 Percent Above 1990 Levels (1990+9%).** This case assumes that energy-related carbon emissions can reach an average of 1,467 million metric tons in the commitment period, 9 percent above 1990 levels, an average reduction of 325 million metric tons from the reference case projection.

- **Stabilization at 1990 Levels (1990).** This case assumes that carbon emissions are stabilized approximately at the 1990 level of 1,346 million metric tons, averaging 1,345 million metric tons during

[18]The discussion about the resolution can be accessed in the *Congressional Record* of July 25, 1997, from web site www.access.gpo.gov/su_docs/aces/aces150.html.

the commitment period, a 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 in the commitment period. A reduction of 485 million metric tons from the reference case level is required.
- **7 Percent Below 1990 Levels (1990-7%).** In this case, energy-related carbon emissions are reduced to an average of 1,250 million metric tons in the commitment period, a reduction of 542 million metric tons from the reference case projection. This case essentially assumes that energy-related carbon emissions must meet the 7-percent target in the Kyoto Protocol with no net offsets from sinks, other greenhouse gases, or international activities.

Reductions in both the 1990-3% and 1990-7% cases would likely come from domestic actions only. The reductions in the other carbon reduction cases imply some international trade in carbon permits, CDM activity, or joint implementation projects, but this analysis does not address the shares that might result from international and domestic actions.

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, in accordance with the Kyoto Protocol. The Protocol provides the flexibility for the target to be achieved on average over the 5-year commitment period, to accommodate short-term fluctuations that might occur, such as severe weather or unanticipated economic growth. 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 NEMS forecast horizon. This assumption may be optimistic in that the possibility of further reductions has been advocated.

The target is assumed to be phased in over a 3-year period, beginning in 2005; that is, one-fourth of the reduction is imposed in 2005, one-half in 2006, and three-fourths in 2007. This analytical simplification allows energy markets to begin adjustments to meet the reduction targets in the absence of complete foresight, although a longer or delayed phase-in may lower the adjustment cost. Phase-in is also consistent with the requirement in the Protocol that countries achieve demonstrable progress toward the reductions by 2005; however, reductions prior to the commitment period are not credited against the required reductions.

Given the scope and potential costs of compliance with the reduction targets of the Protocol, there is a possibility that consumers might react differently—either taking more immediate action or waiting. Consumers could begin to modify their energy decisions even before the 3-year phase-in period, either in anticipation of future price increases or because of a national commitment to reduce greenhouse gases. On the other hand, it is possible that consumers could delay actions either until or beyond energy price changes, taking a cautionary approach to the magnitude and duration of price increases or even anticipating a reversal of policy.

Although each of the six reduction cases is modeled using NEMS, the analysis in this report focuses on three of the cases, the 1990+24%, 1990+9%, and 1990-3% cases. Three cases are chosen in order to keep the subsequent presentation and discussion of the results manageable, particularly since many of the basic trends are the same across the reduction cases, varying only in the magnitude of the impact. Where there are specific trends to note in any of the other cases, they are included in the appropriate section of this report. The full results of each of the cases are presented in Appendix B, and results across all cases are presented graphically, where practical. Any of the reduction targets may be plausible; however, it is likely that some mitigation of the 7-percent target will be achieved through a combination of offsets from forestry and agriculture, reductions in other greenhouse gases, international trading, and other flexible international mechanisms.

Carbon Prices

Each of the carbon reduction targets is achieved by assuming that a carbon price is applied to the cost of energy, which could result from a carbon emissions permit system. The carbon price is applied to each of the energy fuels at its point of final consumption relative to its carbon content. Imported energy products receive the same carbon price at the point of consumption, but no carbon price is levied on other imported products. Of the fossil fuels, coal has the highest carbon content. Natural gas produces about half the carbon emissions of coal per unit of energy content. Average emissions from petroleum products are between those for coal and natural gas. Nuclear generation and renewable fuels produce no net carbon emissions. As an example, the carbon emissions factors and energy costs for a hypothetical carbon price of $100 dollars per metric ton are shown in Table 1.

Electricity produces no carbon emissions at the point of use; however, its generation currently produces about 35 percent of the total carbon emissions in the United States. The carbon price is applied to the fuels used to generate electricity, and the higher prices are reflected in the delivered price of electricity.

Placing a value on the carbon released during the combustion of fossil fuels affects energy consumption and emissions in three ways. First, consumers may reduce the demand for energy services by driving less, reducing the use of appliances, or shifting to less energy-intensive

Table 1. Carbon Emissions Factors for Major Energy Fuels and Calculated 1996 Delivered Energy Prices With a Carbon Price of $100 per Metric Ton

Parameter	Steam Coal	Gasoline	Natural Gas
Carbon Emissions Factor			
(Kilograms of Carbon per Million Btu)	25.49	19.19	14.40
Average Delivered Price in 1996			
(1996 Dollars per Million Btu)	1.32	9.89	4.13
(1996 Dollars per Fuel Unit)[a]	27.52	1.23	4.25
Average Delivered Price With Carbon Price of $100 per Metric Ton			
(1996 Dollars per Million Btu)	3.87	11.81	5.57
(1996 Dollars per Fuel Unit)[a]	80.68	1.47	5.73

[a]Fuel units are short ton (coal), gallon (gasoline), and thousand cubic feet (natural gas).
Source: Office of Integrated Analysis and Forecasting.

goods and services, as examples. Second, more energy-efficient equipment may be chosen, reducing the amount of energy required to meet the demand for energy services. Finally, there may be a shift to noncarbon or less carbon-intensive fuels, reducing the carbon released per unit of energy consumed.

In the energy market analysis in this report, the carbon prices represent the marginal cost of reducing carbon emissions to the specified level or, conversely, the value of consuming the last metric ton of carbon. Although there may be a number of easy, low-cost options for reducing energy use and emissions, higher levels of reductions will require more expensive investment and changes in patterns of energy demand. The projected carbon prices reflect the price that the United States would be willing to pay to achieve a given emissions reduction target. The energy market analysis does not address the international implications of achieving a particular target at the projected carbon price. In the absence of modeling international trade of emissions permits, the energy market analysis makes no link between the U.S. carbon price and the international market-clearing price of permits, or the price at which other countries would be willing to offer permits for sale in the United States.

Carbon prices, or similar mechanisms, are used by most analysts in assessing the implementation and impacts of the Kyoto Protocol or other emissions reduction targets, such as carbon stabilization. Carbon prices are used because they effect all three ways of reducing emissions—demand reduction, improved efficiency, and fuel switching—and may be the most efficient mechanism. Estimates of the carbon price necessary to achieve reductions vary widely. Lower estimates are suggested by those who assume that there are a number of low-cost options to reduce energy use or to shift to low-carbon or noncarbon fuels that are readily available and will be quickly adopted with higher energy prices. Higher estimates are suggested by analysts who think that the effective price of carbon-intensive fuels will have to be raised significantly to encourage changes in consumer choices and the development of additional alternative technologies.

The projected energy market costs in this study represent only the marginal cost of reducing energy-related carbon emissions and do not reflect other costs that could occur as a result of business cycle fluctuations, capital constraints, or implementation of emissions reductions through less efficient mechanisms. No costs are included for damage or adaption to potential climate change. In addition, no benefits for avoided damage or other ancillary benefits are included, unlike some analyses that represent the net cost of emissions reductions, net of benefits.

Macroeconomic Analysis

EIA analyzes the macroeconomic impacts of the carbon reduction cases using the Data Resources, Inc. (DRI) Macroeconomic Model of the U.S. Economy. The DRI Model is a representation of the U.S. economy with detailed output, price, and financial sectors, incorporating gradual adjustment of the economy to policy changes. Macroeconomic models focus on adjustment processes of the economy associated with changing market conditions, including economic policies. Real-world economic behavior involves adapting to changes in conditions of supply and demand, which can lead to dislocations and less than optimal use of resources in the short run. Short-run movements in actual income are portrayed against projected long-run levels of potential output.

The linkage between the DRI macroeconomic model and NEMS is a set of energy variables. Twenty-seven energy variables in the DRI macroeconomic model are directly related to similar NEMS variables by ensuring that the DRI variables show the same percentage change from the baseline as the NEMS variables. These energy variables include energy prices, energy production, and energy consumption by different end uses, and the revenue from auctioned carbon permits. Energy prices include world oil prices; residential heating oil, electricity, and natural gas prices; transportation fuel prices for both diesel and gasoline; residual fuel oil prices; average refined oil price; wellhead natural gas price; and industrial coal and electricity prices. Coal, natural gas, and crude oil production from NEMS is used in the DRI macroeconomic model as well as the end-use demand for oil, natural gas, electricity, and coal.

Energy prices and end-use demands for fuels are the key energy inputs, along with the level of auctioned carbon revenues, because energy prices affect inflation, and the end-use fuel demand represents energy in the DRI aggregate production function, which describes the supply potential of the economy. The amount of auctioned carbon revenue dictates how much energy consumers can expect to receive as rebated revenue, which in turn affects disposable income. Changes in the values of these variables relative to the reference case would have major impacts on the macroeconomy.

When a system is developed for the trading of carbon permits within the United States, a number of initial decisions must be made: How many permits will be available? Will they be freely allocated or sold by competitive auction? If they are allocated, how will the initial allocations be made? If they are sold, what will be done with the revenues? How many permits will be bought in international markets? If the permits are traded in a free market, holders of permits who can reduce carbon emissions at a cost below the permit price will sell their permits, and those with higher costs of reduction will buy permits, resulting in a transfer of funds between private parties. If the permits are sold by competitive auction, there will be a transfer of funds from emitters of carbon to the Federal treasury. This analysis makes the explicit assumption that the permits will be sold in a competitive auction run by the Federal Government.[19]

The macroeconomic analysis in Chapter 6 considers the flow of funds overseas that would be represented by international purchases of carbon permits, explicitly assuming that the carbon price determined in the NEMS model is the international price at which permits would be traded. Although the U.S. target established by the Protocol is a 7-percent reduction in greenhouse gas emissions relative to 1990 levels, the method of accounting for sinks and the flexibility to use 1995 as the base year for the synthetic greenhouse gasses may mean that the reduction would be no more than 3 percent below 1990 levels, according to the U.S. State Department. The differences between the reduction level in the 1990-3% case and the reductions in the cases with higher levels of energy-related carbon emissions are assumed to be met by permits purchased in the international market at the carbon price calculated for each case.

Many analyses of carbon mitigation have used a class of models that are characterized as computable general equilibrium (CGE) models. The CGE structure focuses on the interconnectedness of the economy and calculates the equilibrium of the economy in the long term, abstracting from the short-run adjustment processes. Most often the time horizon of these models is much longer—20, 50, or 100 years into the future. In contrast, the DRI macroeconomic model used in this analysis focuses on the adjustment of the economy over time, allowing for dislocations within the economy that yield less than optimal levels of economic activity. While climate change can arguably be considered a long-run phenomenon, the policies and measures to induce change may take effect in a near-term horizon.

Chapter 7 gives a more detailed comparison of the similarities and differences in the alternative model structures and results. Models of both types can contribute to the assessment of the possible impacts on the economy of greenhouse gas reduction. However, past analyses of the issue using CGE and macroeconomic models have often disagreed with each other over the concepts of the full employment GDP of the CGE models and the actual GDP measure presented in the macroeconomic models. Potential GDP is a concept calculated within the DRI Model but rarely presented as an output measure. The discussion in Chapter 6 considers the alternative views and introduces the concept of potential GDP into the discussion of the economic impacts of the Protocol.

International Energy Markets

The focus of the analysis is U.S. energy markets; however, changes in international markets may have a significant influence on the United States. In particular, crude oil and petroleum products constitute an international market, and the world price of oil has a strong impact on consumption and production of oil in the United States. Conversely, U.S. demand for and production of oil affects the world price of oil. The feedback of U.S. oil markets on international markets is represented within the NEMS framework. World oil prices are determined by means of a price reaction function, assuming that the Organization of Petroleum Exporting Countries will expand oil production capacity to meet world oil demand.

For this analysis, it is assumed the other Annex I countries will reduce their consumption of oil in order to help meet their reduction targets. Each country is assumed to

[19] A permit auction system is identical to a carbon tax as long as the marginal abatement reduction cost is known with certainty by the Federal Government. If the target reduction is specified, as in this analysis, then there is one true price, which represents the marginal cost of abatement, and this also becomes the appropriate tax rate. In the face of uncertainty, however, the actual tax rate applied may over- or undershoot the carbon reduction target. Auctioning of the permits by the Federal Government is evaluated in this report. To investigate a system of allocated permits would require an energy and macroeconomic modeling structure with a highly detailed sectoral breakout beyond those represented in the NEMS and DRI models. For a comparison of emissions taxes and marketable permit systems, see R. Perman, Y. Ma, and J. McGilvray, *Natural Resources and Environmental Economics* (New York, NY: Longman Publishing, 1996), pp. 231-233.

reduce its oil demand by the same percent that the United States reduces oil demand from the reference case level. Oil consumption in non-Annex I countries is assumed to respond to changes in the world price of oil with no additional reactions as a result of carbon reduction policies.

Coal exports are a significant portion of U.S. coal production, with exports going to both Annex I and non-Annex I countries. Because Annex I countries must reduce carbon emissions, it is assumed that coal production and imports in Western Europe and coal imports in Japan would be reduced and that coal consumption in those countries would be reduced by more than their emissions reductions in the Protocol. In the target cases where U.S. carbon emissions are allowed to rise above 1990 levels in 2010, U.S. steam coal exports to Europe in 2010 are assumed to be lower by 16 million tons, and exports to Asia are 4 million tons lower than in the reference case. In the more stringent target cases, exports to Europe and Asia are 26 and 7 million tons lower, respectively, in 2010.

As a result of the Kyoto Protocol, energy prices in the Annex I countries may be higher than in the non-Annex I countries, which do not have emissions reduction targets in the Protocol. As a result, it is possible that more energy-intensive industries could shift from those countries with higher energy costs. Energy-intensive industries also may face reduced demand as consumers shift their consumption patterns to less energy-intensive goods and services. Consequently, the composition of U.S. industrial output is likely to change toward the less energy-intensive industries. Because this analysis does not cover international energy markets, international trade, or the international activities of the Protocol, a complete analysis of potential changes in U.S. industrial output is not possible (for discussion, see the box on “Industrial Composition” in Chapter 3).

Sensitivity Cases

A number of factors combine to determine the NEMS projections of energy consumption and carbon emissions. Typically, *AEO* explores a wide range of cases that vary the reference case assumptions on economic growth, world oil markets, technology improvement, and potential regulatory changes. In this analysis, a variety of sensitivity cases are used to examine the factors that have the most significant impacts on energy demand and carbon emissions. With the exception of the nuclear power sensitivity case, all the sensitivity cases are analyzed relative to the 1990+9% case.

Low and High Economic Growth

These cases analyze the effects of different assumptions about U.S. economic growth. The *AEO98* reference case assumes that the output of the Nation's economy, measured by GDP, will increase by an average of 1.9 percent a year between 1996 and 2020. The same assumption is used in all the carbon reduction cases in this analysis, although there is a feedback within the NEMS framework that alters the baseline economic assumptions as a result of changes in energy prices. Therefore, as emissions reductions become more stringent and the resulting carbon prices become higher, there will be a reduction in economic growth.

In order to reflect the uncertainty in potential economic growth, *AEO98* included high and low economic growth cases. The same alternative assumptions are used in this analysis. The high economic growth case includes higher population, labor force, and labor productivity, resulting in higher industrial output, lower inflation, and lower interest rates. As a result, the GDP increases at an average rate of 2.4 percent a year through 2020. The opposite assumptions in the low economic growth case lead to an average annual growth rate of 1.3 percent.

Low and High Technology

These sensitivity cases examine the effects of assumptions about the development and penetration of energy-consuming technologies on the analysis results. The reference cases in this analysis and in *AEO98* include continued improvement in technologies for both energy consumption and production—for example, improvements in building shell efficiencies for both new and existing buildings; efficiency improvements for new appliances; productivity improvements for coal production; and improvements in the exploration and development costs, finding rates, and success rates for oil and gas production. Additional technology improvements in the end-use demand sectors and in the electricity generation sector could reduce energy consumption and energy-related carbon emissions below their projected levels in the reference case. Conversely, slower improvement than that assumed in the reference could raise both consumption and emissions.

AEO98 presented alternative cases that varied key assumptions concerning technology improvement and penetration in the end-use demand and electricity generation sectors. This analysis uses the same low technology assumptions for a low technology sensitivity. In the residential and commercial sectors, it is assumed that all future equipment purchases will be made only from the equipment available in 1998 and that building shell efficiencies will be frozen at 1998 levels. Similarly, in the transportation sector, efficiencies for new equipment are fixed at 1998 levels for all travel modes. In the industrial sector, plant and equipment efficiencies are fixed at 1998 levels. No new advanced generation technologies are assumed to be available during the projection period.

Technology Improvement in the Reduction Cases and the Sensitivity Cases

In *AEO98*, energy intensity—primary energy consumption per dollar of GDP—is projected to decline by an annual average of 0.9 percent between 1996 and 2020. This decline is significant but considerably less than the decline in the 1970s and early 1980s, which averaged 2.3 percent a year between 1970 and 1986. Approximately half the decline in energy intensity during that period resulted from shifts in the economy to service industries and other less energy-intensive industries; however, the other half of the decline was due to the use of more energy-efficient technologies, resulting, in part, from the rapid escalation in the price of energy from the mid-1970s through the mid-1980s. The decline in energy intensity slowed during the late 1980s and early 1990s as the growth in energy prices slowed and growth in some energy-intensive industries resumed. In the reference case projections, continued modest increases in the price of energy and growing demand for certain energy services, such as appliances, office equipment, and travel, moderate further declines in energy intensity.

Energy intensity improvement results from opposing forces of growth in energy service demand and improvement in the stock of energy-using equipment. New, more efficient technology must be developed and available, but it also must be adopted in order to contribute to energy efficiency improvements. Energy prices play a role in the consumer's decision when purchasing new equipment; however, other factors also influence equipment choice. More advanced, energy-efficient technology is typically more expensive than standard equipment. The methodology for technology choice accounts for the relative roles of first cost and energy cost savings over the life of the equipment through the use of the discount rate, the implied payback period for the consumer who is considering the choice of more efficient equipment. Perceived consumer preferences are also a factor in technology choice—for example, preferences for larger, higher horsepower vehicles and larger televisions, and for purchases of new heating equipment that uses the same fuel as the equipment it replaces. Improvements in energy intensity can be slowed by continued growth in energy services—more travel, household appliances, and office equipment, larger homes, and higher industrial output—some of which are assumed to respond to energy prices.

In the carbon reduction cases, energy prices rise with increasingly stringent reduction targets. Intensity improvements in those cases result both from reductions in energy service demand and from the choice of more efficient equipment as a result of higher prices. These cases use the same assumptions of technology availability and characteristics. Additional research and development in energy-efficient or alternatively fueled technologies would likely expand the slate of choices available to consumers, leading to further improvements in energy efficiency. The high technology case explores the impacts of improvements in the availability, characteristics, and costs of technology as a result of increased research and development, thus separating the impacts of energy prices and technology development.

Efficiency standards have contributed to past improvements in energy intensity. The Corporate Average Fleet Efficiency and National Appliance Energy Conservation Act of 1987 standards, among others, are included in the *AEO98* reference case; however, no new efficiency standards or improvements in current standards are assumed. The same assumptions are used for all the carbon reduction and sensitivity cases in this analysis.

High technology assumptions were developed specifically for this analysis 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 assumptions include earlier years of introduction, lower costs, high maximum market potential, and higher efficiencies than assumed in the reference case. In addition, the high technology sensitivity case includes carbon sequestration technology for coal- and natural-gas-fired generators to remove carbon dioxide and store it in underground aquifers. By design, the effect of the high technology assumptions is distinct from the technology changes that are induced by the higher energy prices in the carbon reduction cases. Because the future costs of the public and private investment that would be needed to develop and deploy more advanced technologies are not known, they are not represented in the analysis; thus, the full economic cost may be understated. It is possible that further technology improvements could occur beyond those represented in the high technology sensitivity case if a very aggressive research and development effort were established. Innovative, breakthrough technologies not foreseen in the analysis of technology could also be developed and lead to improvements beyond those represented in the high technology assessment, but limited time is available for such technologies to become economically competitive and achieve significant market share by 2010.

New Nuclear Capacity

The nuclear power sensitivity case examines the role of nuclear generation in reducing carbon emissions. In *AEO98*, electricity generation from nuclear plants declines significantly over the forecast period. It is assumed that 65 units, about 51 percent of the total nuclear capacity available in 1996, will be retired by 2020. Twenty-four units are assumed to be retired before the end of their 40-year operating licenses, based on industry announcements and analysis of the age and operating costs of the units. No new nuclear plants are constructed by 2020.

In all the carbon reduction cases, nuclear plants are life-extended if economical; however, in this sensitivity case, new nuclear plants can be built if they are economically competitive with other generating technologies. In the 1990+9% case, nuclear plants are not projected to be economically competitive with other plants. They do become competitive, however, with the higher carbon prices projected in the 1990-3% case. Therefore, this sensitivity case is analyzed against the 1990-3% case.

Use of Models for Analysis

The reference case projections in both *AEO98* and this analysis represent business-as-usual trend 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. On the other hand, models provide a structured accounting framework that allows analysts to capture the interrelationships of a complex system in a consistent manner. Also, the assumptions and data underlying a model can be explicitly cited, in contrast to a more *ad hoc* analysis. The results of any analysis depend on the specific data, assumptions, behavioral characteristics, methodologies, and model structures included. In addition, many of the factors that will influence the future development of energy markets are inherently 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 in terms of the relative changes from the baseline cases with which they are compared.

It has been suggested that models may be inherently pessimistic in analyzing the potential impacts of policy changes. For example, in the *Annual Energy Outlook 1993* (*AEO93*),[20] the first EIA analysis of CAAA90 compliance, the cost of a SO_2 allowance was projected to be $423 a ton in 2000, in 1996 dollars, rising to $751 a ton in 2010. Currently, the cost of an allowance is $95 a ton, and *AEO98* projects that the cost will be $121 a ton in 2000 and $189 in 2010. Projected coal prices in *AEO98* are 34 and 48 percent lower in 2000 and 2010, respectively, than those projected in *AEO93*, reflecting recent improvements in mine design and technology, economies of scale in the mining industry, and lower transportation costs induced by rail competition. There has been more fuel switching to low-sulfur, low-cost Western coal than previously anticipated (it was initially assumed that many eastern coal-fired plants would not be able to burn western coal without considerable loss of performance). There has also been downward pressure on short-run allowance costs because generators have taken actions to comply with the SO_2 limitations earlier than anticipated.[21] Finally, technology improvements have lowered the costs of flue-gas desulfurization technologies, or scrubbers, from $313 per kilowatt for scrubber retrofitting as assumed in 1993 to $191 per kilowatt in 1998. The cost of SO_2 compliance was overestimated to a large extent because compliance relied on scrubbing, a relatively new technology with which there was little experience. On the other hand, the current analysis of carbon reduction does not rely on a single technology but rather on fuel switching and efficiency improvements, both issues of long experience in energy markets.

In contrast, however, analyses of policies can also be too optimistic. As noted earlier, reductions in greenhouse gas emissions as a result of CCAP have been overestimated. In addition, some early analyses of the potentially beneficial impacts of price controls on oil and natural gas proved in error because of the negative effects on production and competition in the industry.

A number of uncertainties may affect the costs of achieving emissions reductions. As previously noted, the interpretation and implementation of many provisions of the Kyoto Protocol are undetermined at this time. The flexibility allowed by the international activities may considerably lower the costs of the Protocol.

[20]Energy Information Administration, *Annual Energy Outlook 1993*, DOE/EIA-0383(93) (Washington, DC, January 1993).

[21]A.E. Smith, J. Platt, and A.D. Ellerman, "The Cost of Reducing SO_2," *Public Utilities Fortnightly* (May 15, 1998).

The availability and costs of technology remain one of the more significant factors in determining the cost of emissions reductions, and this analysis seeks to quantify that uncertainty to some degree with low and high technology sensitivity cases. Although it is sometimes hypothesized that more cost-effective technologies are developed once the requirements are established, it must be noted that the cost and availability of some of the more advanced technologies in the reference case are not certain, and even the reference assumptions may be optimistic.

Although the Kyoto Protocol specifies reduction targets, signature and ratification by the United States would need to be followed by the formulation of policies and programs to achieve the carbon reductions. This analysis has chosen one possible mechanism, the imposition of a carbon fee with revenue recycling by two alternative methods. Other programs—voluntary initiatives, mandatory standards, or other nonmarket policies—could result in higher or lower costs. Even with a carbon fee, other fiscal policies for recycling the revenues, including not recycling, are likely to have different impacts on the U.S. economy.

The timing of policy initiatives may also be an important factor in the cost of emissions reductions. Given that the Kyoto Protocol includes a specific timetable for reducing emissions, policies and initiatives that begin earlier may allow for more gradual adoption and a less costly transition, particularly if consumers react with foresight of anticipated price increases and emissions restrictions. Consumer response to anticipated or realized price increases and other policy initiatives is likely to be another significant determinant of the cost of the Kyoto Protocol. Finally, other energy policies formulated for purposes other than the Protocol, such as electricity industry restructuring and other emissions controls, may have ancillary impacts on carbon emissions.

In the next chapter, Chapter 2, the results from the carbon emissions reduction cases and the sensitivity cases are summarized. Chapters 3 through 6 present more detailed analysis of the results for the end-use demand sectors, electricity generation, fossil fuel markets, and the macroeconomy, respectively. Chapter 7 concludes with a comparison of this analysis and similar studies of the costs of carbon emissions reductions.