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Annual Energy Outlook Forecast Evaluation

by

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This paper evaluates the projections in the Annual Energy Outlook (AEO),¹ by comparing the projections from the Annual Energy Outlook 1982 through the Annual Energy Outlook 1998 with actual historical values and providing the rationale for the differences. A set of 16 major consumption, production, imports, price, and economic variables were chosen for evaluation, updating a similar analysis published in the previous edition of *Issues in Midterm Analysis and Forecasting*.² This paper expands on the previous one by adding the most recent AEO to the evaluation, including 1997 as an additional historical year, adding a comparison of high and low economic growth cases when available, and including a regression analysis of the historical data.

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Introduction

This paper presents an analysis of the forecast record of the *Annual Energy Outlook (AEO)*. It compares the projections for major energy variables from the reference case for each of the *AEOs* published from April 1983 through December 1997 with actual data.³ The purpose of the analysis is to provide a measure of the accuracy of the forecasts; however, prediction of future energy markets is not the primary reason for developing and maintaining the models that the Energy Information Administration (EIA) uses to produce the *AEO*. Because the EIA models are developed primarily as tools for policy analysis, a key assumption of the forecasts is that current laws and regulations will remain in effect throughout the forecast horizon. This assumption, while necessary to provide a baseline against which changes in policy can be evaluated, also virtually guarantees that the forecasts will be in error, as laws and regulations pertinent to energy markets change considerably over the years.

The National Energy Modeling System (NEMS)—the current EIA model used to produce the midterm projections in the *AEO*—and the predecessor models were designed to enforce a discipline on the process of energy market analysis by providing a comprehensive set of assumptions that are consistent with our understanding of the factors that affect energy markets—for example, technological innovation, energy service demand growth, and energy resources. The models are modified each year to ensure their relevance to evolving energy issues and to update baseline data, parameters, and assumptions with the most recent historical data. NEMS, first used for the *Annual Energy Outlook 1994 (AEO94)*,⁴ was specifically designed for a high level of technological detail and flexibility to address a wide range of policy options.

These models are frequently used in studies conducted for the U.S. Congress, the Department of Energy, and other Government agencies to analyze the impacts of changes in energy policies, regulations, and other major assumptions on future energy supply, demand, and prices, typically using assumptions specified by the client. The most recent examples of analytical studies include an analysis of the Electric System Public Benefits Protection Act of 1997⁵ at the request of Senator James M. Jeffords (R-Vt), Chairman of the Senate Committee on Labor and Human Resources; a study of carbon reduction policies⁶ for the U.S.

Department of Energy, Office of Policy and International Affairs; a study on the costs and economic impacts of oil imports⁷ for the U.S. General Accounting Office; an analysis for Senator Jeffords on open access regulatory changes and their impacts on the electricity industry;⁸ and an analysis of carbon mitigation policies⁹ prepared for the U.S. Environmental Protection Agency.

During the period analyzed in this paper, many legislative actions and policies have been enacted, including the National Energy Conservation Act of 1987, the Natural Gas Wellhead Decontrol Act of 1989, the Clean Air Act Amendments of 1990 (CAAA90), the Energy Policy Act of 1992, the repeal of the Power Plant and Industrial Fuel Use Act of 1978 (FUA), the North American Free Trade Agreement, the Omnibus Budget Reconciliation Act of 1993, the Outer Continental Shelf Deep Water Royalty Relief Act of 1995, the Tax Payer Relief Act of 1997, the Climate Change Action Plan developed by the Clinton Administration in 1993 to achieve stabilization of greenhouse gas emissions, and various orders issued by the Federal Energy Regulatory Commission (FERC). Examples of FERC orders include Order 636, which restructured interstate natural gas pipeline companies and required the separation of sales and transportation functions, and Orders 888 and 889, which provided open access to interstate electricity transmission lines. These actions have had significant impacts on energy supply, demand, and prices, but because of the assumption on current laws and regulations, the impacts were not incorporated in the *AEO* projections until their enactment or effective dates.

In several cases, EIA's models have been used to evaluate some of the potential impacts of these changes in laws and regulations before they were enacted, thus fulfilling EIA's designated role in policy analysis. For example, EIA provided comprehensive analysis to the House Energy and Commerce Committee concerning the impacts of the CAAA90 on the coal and electricity industries. In other cases, the models have been used to analyze policies that were eventually rejected; a prime example is the British thermal unit (Btu) tax proposed in early 1993. Both of these uses of the models illustrate the importance of maintaining a modeling capability apart from the forecasting function, using current laws and regulations as a baseline assumption.

In addition to changes in laws and regulations, a number of other factors can cause energy markets to deviate from the longer term trends represented by the forecasts in the *AEO*. For example, the forecasts assume normal weather patterns; however, the weather rarely, if ever, be normal in any given year. Although the *AEO* models have not generally been used for analysis of weather conditions on energy markets, temperatures that are colder or warmer than normal for sustained periods have a significant impact on energy consumption. Strikes and political incidents, such as the Iraqi invasion of Kuwait in 1990, are other unanticipated events whose impacts on energy markets are not captured in a mid- to long-term energy projection. Any of these events can cause the volatility and fluctuations in energy consumption and supply. EIA's *Short-Term Energy Outlook (STEO)*¹⁰ reflects the impacts of these events and the near-term adjustments to them, and each *AEO* adjusts its near-term forecasts to the most recent *STEO* projections. By presenting quarterly projections and accounting for stock fluctuations and other short-term adjustments, the *STEO* is more applicable to the analysis of such events than is the *AEO*, which presents annual average projections.

Although the primary purpose of the models is policy analysis, many users of the *AEO* view the projections as forecasts. Thus, analyzing the models' performance and the reasons for differences between the projections and history is important both for users and for those responsible for the projections. The models and assumptions used in the *AEOs* undergo continuous evaluation and change, in part because of changes in energy markets and in part as a result of internal assessment of the models' performance. Natural gas markets are an example of both points. The representation of natural gas markets has been revised significantly to reflect deregulation. In addition, the fundamental assumptions about the size and potential growth of natural gas resources have been revised because evaluations of past forecasts have shown that price projections for gas were too high.

This paper presents projections for each *AEO* from 1982 to 1998.¹¹ The forecast horizon has expanded over the period examined in this paper; for example, the *Annual Energy Outlook 1982 (AEO82)*¹² projections of energy markets extended only through 1990. Also, although year-by-year forecasts were produced for each *AEO*, many *AEOs* published only selected years. This evaluation includes all projected years, including unpublished projections where available. A set of 16 key energy variables is used to provide a comprehensive picture of the projections. The projections in this analysis were produced by the models in use at the time. Before 1994, the Intermediate Future Forecasting System was the primary model for midterm projections; however, this evaluation is not meant to assess a specific model but rather to assess the forecasts and the underlying assumptions that shape the results. An evaluation of models is inappropriate at this point, because NEMS—a longer run model—was first used for the 1994 forecasts, and historical data for comparison are available only for four short-term years. In this case, the best effort is to compare the NEMS results with forecasts from other organizations, as is done in each *AEO*.

Overview

Table 1 provides a summary of the average absolute forecast errors,¹³ expressed as percentage differences from actual, for each of the major variables included in this analysis.¹⁴ As the table indicates, the forecasts of consumption, production, and economic variables have generally been the most accurate; net import projections have been less accurate; and the price projections¹⁵ have

the least accurate when evaluated on the basis of average absolute percent errors.

Table 1. Average Absolute Percent Errors for AEO Forecasts, 1982-1998

Variable	Average Absolute Percent Error
Consumption	
Total Energy Consumption	1.7
Total Petroleum Consumption	2.9
Total Natural Gas Consumption	5.7
Total Coal Consumption	3.0
Total Electricity Sales	1.7
Production	
Crude Oil Production	4.3
Natural Gas Production	4.8
Coal Production	3.6
Imports and Exports	
Net Petroleum Imports	9.5
Net Natural Gas Imports	16.7
Net Coal Exports	22.8
Prices and Economic Variables	
World Oil Prices	51.3
Natural Gas Wellhead Prices	72.1
Coal Prices to Electric Utilities	35.3
Average Electricity Prices	11.0
Gross Domestic Product	5.0
<i>AEO = Annual Energy Outlook.</i>	
Source: Tables 2 through 17.	

Each of the consumption, production, and economic variables has been projected with an average absolute percent error of 5.7 percent or less. For both total energy consumption and total electricity sales, the most accurately projected variables during this period, the average absolute percent error is 1.7 percent. Average absolute percent errors for net imports range from 9.5 percent for petroleum to 22.8 percent for coal. For prices, forecasting has proven to be a much greater challenge. Average absolute percent errors for the world oil price, the price of coal to electric utilities, and the average natural gas wellhead price range from 35.3 to 72.1 percent over the period, with natural gas wellhead prices proving to have the highest error of the variables evaluated. Average electricity price projections, however, fared better, with an 11.0-percent average absolute percent error.

The following sections discuss the underlying results in some detail; however, it is clear that quantities are more amenable to the forecasting methods used in the AEO than are prices; that the errors in forecasting prices have not, in general, affected the accuracy of projected quantities; and that natural gas has tended to have the highest average forecast error within most categories—consumption, production, and prices. Some of the major factors leading to inaccurate forecasts include the assumption in the earlier AEOs that the Organization of Petroleum Exporting Countries (OPEC) cartel would maintain the market power and cohesiveness to set world oil prices; the decline of oil production in the former Soviet Union; underestimates of the impact of technology improvements on the production and prices of oil, natural gas, and coal; the impacts of changes in laws and regulations on natural gas prices; the treatment of fuel supply contract provisions for natural gas and coal as fixed and binding; and other events that have caused the actual trends to differ from projected long-term trends, as discussed above.

Energy Consumption

Total Energy Consumption

Total energy consumption forecasts have shown a generally good track record for most of the *AEO* publications.¹⁶ The overall average absolute percent error for the period examined here is 1.7 percent (Table 2), with the largest errors occurring in forecasts for the year 1996 (3.0 percent), and the smallest errors in forecasts for 1991 (0.9 percent).

In terms of the *AEO* publications, the *Annual Energy Outlook 1986 (AEO86)*¹⁷ had the largest absolute and average absolute percent errors for total energy consumption, at 3.0 quadrillion Btu and 3.4 percent, respectively. There was a significant underestimate of energy consumption for most of the projected years in *AEO86*, in part due to the high fossil fuel prices projected for the publication, which was completed prior to the 1986 collapse in oil prices and published early in 1987. After *AEO86*, there was general improvement in the forecast record, as EIA's experience with lower priced energy markets expanded. It is worth noting, however, that the overall average absolute percent errors for oil price forecasts in *AEO86* were better than in the preceding *AEOs*. Price forecasts for some years in *AEO86* were also better than in some subsequent *AEOs*; for example, some of the subsequent *AEOs* projected world oil prices that were too low for the years 1989 and 1990, and the *Annual Energy Outlook 1991 (AEO91)*¹⁸ projected much higher prices for 1991 and 1992.

One of the aspects of modeling energy consumption that is important in the evaluation of the forecasts is the effect of regulations such as appliance and automobile efficiency standards. When such standards are incorporated, some decisions that would otherwise be made by the interaction of supply and demand factors are in fact set by fiat, helping to reduce some of the uncertainty associated with the forecasts and reducing at least one source of forecast error.

Total Petroleum Consumption

Total petroleum consumption forecasts have an average absolute percent error of 2.9 percent during the period covered in this evaluation (Table 3). The least accurate forecast year was 1988, for which the *AEOs* averaged about 0.75 million barrels per day lower than the actual consumption of 17.3 million barrels per day. For 1988, the forecasts of the world oil price were also consistently too high, as noted later, with an average absolute percent error of 80.9 percent, the highest error for any year other than 1986 and 1995. As described in the section on world oil prices, the early *AEO* world oil price projections were influenced by the notion that OPEC could curtail production sufficiently and hold prices up throughout the forecast horizon. This led to extremely high forecasts for 1995 in the early *AEOs*, like *AEO83* and *AEO84*. In addition, the forecasts of economic growth in 1988 tended to be too low in most of the *AEO* publications, which would also lead to an underestimate of demand.

AEO82, the earliest publication considered in this analysis,¹⁹ and *AEO86* had the highest average absolute percent errors for petroleum consumption at 5.3 and 5.7 percent, respectively. Projections of petroleum consumption were underestimated for all years in *AEO86*, which was the last *AEO* completed before the oil price collapse. The projections for the years 1985 through 1987 in *AEO82* were above actual demand; however, the errors for 1988 through 1990 were much smaller and in the opposite direction.

The *AEO82* forecast for the year 1985 had the highest percent error of all the petroleum forecasts evaluated. Residential and commercial consumption was projected to be more than 0.4 million barrels per day higher in 1985 than it actually was, and consumption of petroleum for electricity generation was projected to be more than 1.8 million barrels per day higher in 1985, more than triple the actual value. Both numbers were reduced in the *Annual Energy Outlook 1983 (AEO83)*²⁰ and were considerably more accurate. Although the *AEO82* total petroleum consumption projection for 1990 was equal to the historical value at 16.99 million barrels per day, the sectoral projections were not accurate. Residential and commercial demand was projected to be about 0.6 million barrels per day higher, industrial 1.0 million barrels per day higher, transportation 2.5 million barrels per day lower, and electricity generation 1.2 million barrels per day higher than actual. Between *AEO82* and *AEO83*, the role of natural gas had been reevaluated, giving it a larger role in the residential and commercial sectors and, in particular, in the electricity sector. The projections for oil demand in these sectors declined between *AEO82* and *AEO83*, and those for natural gas demand increased.

Following *AEO82*, the projections of residential and commercial oil consumption remained rather close to the actual values, although the slight downturn in 1990 was missed. A general characterization of the forecasts is a tendency to underestimate energy consumption for several years after the *Annual Energy Outlook 1984 (AEO84)*.²¹ At that time, there was an assumption that residential and commercial customers would purchase the most energy-efficient technologies, an assumption that led to overly optimistic expectations of efficiency improvements. The *Annual Energy Outlook 1985 (AEO85)*²² shows this impact in the residential and commercial sectors.

In the early forecasts, industrial consumption of oil was overestimated, partially reflecting somewhat optimistic assumptions about the growth of energy-intensive industries but also due to an underestimation of the potential growth of natural gas in an era of high oil prices. Later projections were somewhat underestimated due to assumptions of higher efficiency gains.

Through many of the forecasts, transportation consumption was significantly underestimated. The projected world oil prices were too high; and, in reaction to the higher prices, estimated vehicle efficiency improvements were too high and vehicle miles traveled too low, leading to transportation demand forecasts that were up to 2.5 million barrels per day too low in *AEO82* and frequently up to 1 million barrels per day too low in the next several *AEOs*. These forecasts improved significantly in the *Annual Energy Outlook 1987 (AEO87)*,²³ which contained the first set of projections after the oil price collapse in 1986.

Total Natural Gas Consumption

The average absolute percent error for natural gas consumption forecasts for this period is 5.7 percent (Table 4). Projections for 1995 had the highest average absolute percent error at 9.2 percent. For 1995, all the *AEOs* underestimated consumption by anywhere from 1 to 22 percent, primarily due to high natural gas price projections. For many of the statistics presented in this paper, 1995 through 1997 show some of the highest percent errors, because these years have many of the oldest projections, which were made 10 to 12 years earlier. Particularly in the natural gas industry, there were significant changes in energy markets throughout the 1980s. Natural gas price forecasts were very high, as discussed later, and were important causes for the underestimation of consumption in many years in the analysis period, as prices were overstated considerably in comparison with the actual prices.

The FUA also contributed to low estimates of gas consumption by industrial customers. In reaction to a perceived scarcity of natural gas, the FUA legislation attempted to restrict gas use by large electric utility and industrial customers. Because of the number of exemptions granted to electric utilities; however, the FUA had little impact on the forecasts of gas consumption by utilities, except in *AEO82*. The legislation did have some restraining influence on industrial gas consumption forecasts until its repeal in 1987.

With the exceptions of the projections for 1985 through 1988 made in *AEO83* through *AEO85*, natural gas consumption was generally underestimated, concurrent with high price projections. Where consumption was overestimated, the tendency to conservation and the impact of higher prices on demand were not fully captured, even though prices were generally overestimated as well. Before 1995, 1986 was the year with the highest average absolute percent error, at 7.0 percent. Except for *AEO82*, all the errors for 1986 were overestimates. Although natural gas price projections for 1986 were high, oil price projections were also high, and fuel switching from oil to gas was projected.

Among the *AEOs*, overall average absolute percent errors ranged from 1.1 to 9.5 percent, excepting the *Annual Energy Outlook 1998 (AEO98)*,²⁴ which included a single estimate of the most recent historical year, with a 0.7-percent error. *AEO86* and *AEO87* had the highest average absolute percent errors, mainly because of underestimates of natural gas use in the industrial sector, although projections for the residential and commercial sectors were also low in the later years. Projections in the 1980s underestimated natural gas consumption for most years, particularly the later years in the horizon, with high price forecasts contributing to the errors. Consumption forecasts improved considerably starting with the *Annual Energy Outlook 1990 (AEO90)*,²⁵ with average absolute percent errors of 4.1 percent or less. Natural gas price forecasts improved starting with *AEO91*, with average absolute percent errors no more than 20.1 percent.

Total Coal Consumption

The forecasts for coal consumption have been stable and displayed fairly low average errors, in part due to the good record in forecasting electricity sales, for which coal is a major fuel. The average absolute percent error for coal consumption is 3.0 percent (Table 5). As has generally been the case, forecasts for the years 1995, 1996, and 1997 tend to have the highest errors, averaging 4.1, 5.0, and 5.3 percent, respectively. There was a strong tendency to overestimate in the earlier *AEOs*, particularly *AEO84*, whose forecast for 1995 was 15.4 percent over actual consumption. Factors contributing to the overestimate included a 5.6-percent overestimate for electricity sales, an estimate of efficiency that was about 5 percent too low for coal-fired generating plants, and a share for coal in generation that did not account for the eventual greater role of natural gas, particularly among the utility electricity producers. The shares of coal and natural gas in the industrial sector were similarly affected, with high natural gas price forecasts and an overly optimistic view of the future of metallurgical coal in steelmaking being the primary factors.

Until the later *AEOs*, *AEO84* had the highest average absolute percent error for coal consumption at 5.4 percent, because of the high 1995 projection. Following an increase in natural gas prices in 1996 and 1997, coupled with declining coal prices, there was a drop in gas consumption by electricity generators and a notable surge in coal consumption by generators in 1996 and 1997,

which caused some of the larger errors for those years in most *AEOs*. Consequently, the *Annual Energy Outlook 1996* (*AEO96*)²⁶ and *Annual Energy Outlook 1997* (*AEO97*)²⁷ have average absolute percent errors of 5.4 and 5.7, respectively.

Total Electricity Sales

Electricity sales have an average absolute percent error of 1.7 over the period studied (Table 6); 1996 is the year with the highest average absolute percent error of 2.5 percent. Electricity sales for all years were overestimated in *AEO82*, and, with the exception of *AEO87*, *AEO85* through *AEO90* tended to underestimate the earlier years and overestimate the later years. In earlier *AEOs*, overestimates tended to occur because of strong growth in electricity demand in the industrial sector resulting from high projections of oil and gas prices and strong growth in consumption in the sector in general. This growth projection was moderated in later forecasts, which incorporated energy efficiency gains and structural shifts in the industrial sector to less energy-intensive industries.

In the forecasts since *AEO91*, electricity sales have been underestimated in most years, primarily as a result of optimistic estimates of efficiency improvements, coupled with continued growth in new uses for electricity that was not captured in the projections. In addition, electricity price forecasts have tended to be overstated in most years, largely due to the influence of overstated natural gas and coal prices to electricity producers, as discussed later.

In terms of the *AEO* publications, the highest average absolute percent error was that of *AEO82*, at 2.7 percent, as the models used in that *AEO* continued to anticipate electricity growth at a pace near that of economic growth, a ratio that has actually been reduced considerably in this decade. The error in electricity sales was more than halved in *AEO83*.

Energy Production

Crude Oil Production

Crude oil production forecasts have an overall average absolute percent error of 4.3 percent over the period evaluated (Table 7). The largest error for any year was 1989, with an average absolute percent error of 7.8 percent and all *AEOs* overestimating actual production for that year. Since domestic oil production is assumed to be determined by prices rather than demand, an important input to production forecasts is the world oil price, which has also been overestimated for most years, particularly in the *AEO82* through *AEO85* projections. For 1989, the first four *AEOs* had significantly high world oil price projections, leading to high production forecasts. Following *AEO85*, EIA's price forecasts were either very close to, or significantly under, the actual 1989 price, with a consequent improvement in production projections.

Each of the *AEOs* has had average absolute percent errors for crude oil production of 7.2 percent or lower, with the exception of *AEO83*, which had an average absolute percent error of 10.2 percent. *AEO83* overestimated crude oil production for all years after 1985, with particularly large errors for 1989, 1990, and 1995, the latter of which was 23.6 percent, primarily because of high price forecasts.

Following the oil price collapse of 1986, there were more underestimations than overestimates of crude oil production. As price projections have been reduced over time, the forecasts have captured the impacts of technological improvements in the oil industry, preventing the production forecasts from falling as precipitously as the price projections.

Natural Gas Production

The overall average absolute percent error for natural gas production forecasts is 4.8 percent (Table 8), lower than the 5.7-percent average absolute percent error for consumption forecasts. Unlike crude oil, most demand for natural gas is met by domestic production; thus, natural gas production tends to follow the projections for consumption. Forecasts for 1994 display the highest average absolute percent error, at 6.8 percent, followed by 1995 at 6.5 percent. The highest error for 1995, and for all the production forecasts, occurred in *AEO83*, the first *AEO* to project 1995 production. Despite a very high price forecast, the *AEO83* production projection was about 20 percent below the 1995 actual production, reflecting the low demand projection.

AEO82 underestimated gas production in all years and had an 11.7-percent average absolute percent error, followed by *AEO87* at 7.7 percent; for all the other *AEOs* the average error rate has been 6.4 percent (for *AEO86*) or less. The errors in production forecasts have resulted primarily from the low consumption forecasts, due to high price forecasts. In general, the *AEOs* have understated production, with the exception of the years prior to 1990 in *AEO84* and *AEO85*, and most of the errors have been similar to those for the forecasts of natural gas consumption.

The difficulty of predicting technological improvement in the industry—and, consequently, of predicting the amount of gas that would be available at a given price—led to the high price and low production forecasts in the earlier *AEOs*. Following the gas shortages of the late 1970s and the low resource estimates by most geologists, the conventional wisdom of the early to mid-1980s was that natural gas was a scarce resource. This perception changed as the impact of price controls that had curtailed production began to diminish. Also, beginning in the mid-1980s, a number of technological advances, such as directional drilling, 3-D seismic imaging, and slim-hole drilling, lowered the cost of gas exploration and production and expanded the estimates of the resource base. Beginning with *AEO90*, the forecasts of both production and price improved.

Coal Production

Similar to coal consumption, coal production forecasts have an overall average absolute percent error of 3.6 percent (Table 9). Like those for natural gas, the forecasts for coal production have generally followed the consumption forecasts, with electricity sales being the dominant factor. However, an additional input is the level of coal exports, which also affects coal production significantly. Where coal production has been overestimated, a large part of the reason has been an overstating of the level of coal exports, especially for the years 1993 through 1995, as discussed below.

The year 1993 shows the highest average absolute percent error for coal production, at 9.7 percent. In 1993, there was a strike by coal miners that sharply curtailed production. Consequently, all *AEOs* produced before the strike show high forecast errors for 1993. The second highest average absolute percent error is for 1995, at 5.7 percent. The forecasts for 1995 in *AEO83* through *AEO86* range from 8.0 to 18.2 percent above the actual 1995 level, although later forecasts show errors of 5 percent or less. This reflects the overestimation of coal consumption, particularly in *AEO83* and *AEO84*, and the higher-than-realized coal export projections in *AEO83* through *AEO86*, discussed below. The forecasts for other years average much closer to the actual values, with average absolute percent errors ranging from 1.3 to 3.8 percent. The *AEO* publications display little variation in their overall average errors, with *AEO84* showing the highest average absolute percent error of 5 percent, mainly because of its very high projection for 1995.

Energy Imports and Exports

While the United States is a major importer of petroleum, it also imports natural gas, although in much smaller quantities. Coal is the only fuel for which the United States is a net exporter.

Net Petroleum Imports

Because domestic production of petroleum is insufficient to meet demand, imports make up the difference between demand and supply.²⁸ The average absolute percent error for net petroleum imports over the period studied was 9.5 percent (Table 10). The forecast year with the highest average absolute percent error proved to be 1985, for which the *AEOs* averaged a 28.1-percent error; subsequent years showed considerable improvement. In general, there was a tendency to underestimate imports for the mid-1980s, because of underestimates of consumption and overestimates of production. Except for *AEO83* and *AEO85*, this tendency was generally reversed in projections of the 1990s, with significant overestimates of net petroleum imports for many years in *AEO84* through the *Annual Energy Outlook 1995 (AEO95)*.²⁹ Although in some *AEOs* this corresponded to overestimates of consumption and/or underestimates of production, it was also exacerbated by the contribution of inaccurate forecasts for other sources of supply, such as natural gas liquids and processing gain, the treatment of stocks, and assumptions about the pace of acquisition of crude oil for the Strategic Petroleum Reserve.

By publication, the *AEOs* for 1982 through 1985, 1987, 1989, and 1994 proved to have the highest average absolute percent errors for forecasts of net petroleum imports. *AEO82* strongly overestimated imports for 1985 through 1987; however, its forecasts for the subsequent years were markedly better. Because high estimates of oil prices led to high production forecasts, *AEO83*, *AEO84*, and *AEO85* strongly underestimated imports in many years, as did *AEO86* for the late 1980s. Later reports tended to overestimate imports due to underestimates of production.

Net Natural Gas Imports

Net natural gas imports play a small, but important, supplementary role in meeting natural gas demand. The overall average absolute percent error for the period covered in this study is 16.7 percent, with the largest average absolute percent error for the year 1986 at 49.2 percent (Table 11). All the forecasts for 1986 were overstated, with errors as high as 72.7 percent (*AEO82*). There was a substantial oil price collapse in 1986, and petroleum imports displaced other energy sources, such as Canadian gas, for much of the Nation's consumption needs, especially in the industrial and electricity generation sectors. Forecasts for 1987 were overstated in the first four *AEOs*, but *AEO86* and *AEO87* reversed the pattern with underestimates. *AEO85* also showed

high overestimates through 1992 and underestimates for later years. Most *AEOs* tended to underestimate imports, with errors as high as 54.2 percent for 1995 in *AEO83*.

The major determining factors of natural gas imports have been the economics of natural gas trade with Canada, the assumptions of pipeline capacity from Canada, the assessment of liquefied natural gas imports from Algeria, and prospects for trade with Mexico and Japan. The tendency was for net gas imports to be overstated for the first four *AEOs*, except for the 1989, 1990, and 1991 through 1995 forecasts. Since the *AEO86* forecast, there has been a greater tendency to underestimate gas imports. Since the *Annual Energy Outlook 1993 (AEO93)*,³⁰ the projections have been much closer to the actual values, with average absolute percent errors of 5.6 percent or less, although the *AEO98* projection for 1997 reflects an historical update.

Net Coal Exports

The absolute percent errors in projections for net coal exports have averaged 22.8 percent over the period of this study (Table 13). The forecast year 1994 had the highest average absolute percent error at 48.1 percent, followed by 1993 at 39.9 percent. All *AEOs* except *AEO95* overstated 1994 coal exports by anywhere from about 30 to 77 percent. For *AEO84* through *AEO94*, coal exports were generally underestimated through 1992 and overestimated in later years. *AEO95* and *AEO96* underestimated exports by a range of 8 to 19 percent.

AEO82 overestimated future coal exports with an average absolute percent error of 37.5 percent, due largely to the assumption that U.S. coal exports would garner an ever-increasing share of world coal trade, which was also expected to grow in reaction to high world oil prices. *AEO83*, in contrast, had a much more realistic view of future coal exports and, with the exception of 1995, had much smaller errors. *AEO83*, *AEO96*, *AEO97*, and *AEO98* were the closest of all the *AEOs* with respect to projected coal exports. Projections for 1993 through 1997 in *AEO91* through *AEO94* were far too high, in part because of the 1993 coal miners' strike that reduced this country's competitive position in world coal markets. In addition, world coal trade has not grown as much as previously assumed, because European consumers have turned increasingly to natural gas for industry and power generation, and environmental concerns have led some countries to reduce coal consumption as a means of reducing carbon emissions. *AEO95* and *AEO96* appear to be overcompensating for this trend. *AEO98* reflects historical data for 1997.

Energy Prices and Economic Growth³¹

World Oil Prices

World oil prices have the second highest average absolute percent errors of all the variables evaluated in this paper, with natural gas prices at the wellhead having the highest. Overall, the average absolute percent error for world oil price forecasts has been 11.3 percent (Table 13). However, the earlier *AEOs* had a much higher average absolute percent error, and the publications after *AEO86* show considerable improvement, with the exception of *AEO91*, which was affected by the Iraqi invasion of Kuwait. *AEO91*, prepared during the short-term escalation of oil prices caused by the invasion, projected continually rising prices. In fact, oil prices declined over each of the next 4 years. Similarly, the year with the highest average absolute percent error was 1995, followed closely by 1986, with very high percentage errors in the earliest *AEOs* only partially offset by smaller errors in the more recent forecasts. In nominal terms, the first forecast for 1995, from *AEO83*, was nearly \$75 per barrel, compared with the actual 1995 price of \$17.14 per barrel.

For many of the variables examined in this paper, the highest average errors are seen for the year 1995. As mentioned before, the 1995 projections include those made furthest in the past—up to 12 years earlier. In addition, projections for 1991 through 1994 were not available from the earliest publications, so that 1995 appears to be more of an outlier.

Although the forecasts of world oil prices appearing in the earlier *AEOs* were almost uniformly too high, from *AEO86* on there were several instances of forecasts that were too low. These included the 1987 and 1990 forecasts appearing in *AEO86* and *AEO87*, the forecasts for 1989 through 1991 appearing in the *Annual Energy Outlook 1989 (AEO89)*³² and *AEO90*, and the most recent forecasts for 1996. Clearly, following the oil price collapse of 1986, EIA's forecasts were significantly reduced; as a consequence, the projections for 1990 tended to be too low, in part because of the rise in oil prices beginning in August 1990 associated with Iraq's invasion of Kuwait. Even with the lower price forecasts, 1995 had high percentage errors until *AEO94*, as most *AEOs* continued to show rising prices in response to perceived rising world oil demand.

The early *AEO* projections were strongly influenced by the notion that OPEC would continue to hold a large measure of power in world oil markets. Conventional wisdom in the early projections assumed that OPEC would be able to curtail production sufficiently to hold prices up, and that the cartel's members would continue their cooperation throughout the forecast horizon.

As it became clear that OPEC's cohesiveness was not permanent, EIA continued to assume that oil prices would rise with increasing demand, although at a much slower rate of growth than in the 1970s. Increasing investment in areas outside OPEC and technological advances in oil exploration and production have contributed to the growth in oil reserves and production capacity of non-OPEC producers. These trends, combined with competition from natural gas and energy conservation, have kept prices lower than expected in the earlier forecasts.

Natural Gas Prices

Natural gas prices at the wellhead have had the highest average absolute percentage forecast errors in the *AEOs*, with an overall average error of 72.1 percent (Table 14). Occasionally, near-term gas prices have been underestimated, but most of the projections were overestimates. Similar to the forecasts for world oil prices, those for natural gas prices were highest in the earlier *AEOs*, when the projections for all prices were influenced by the assumption that market forces would tend to increase demand and therefore prices of, natural gas and coal in response to higher world oil prices.

The year 1995 had the highest average absolute percent error; with the exception of *AEO96*, which was essentially estimating the current historical year for 1995, the smallest error for 1995 was 28.6 percent in *AEO95*. The year with the lowest average absolute percent error was 1985, with an average absolute error for four *AEOs* of 23.3 percent, even including the 65.2-percent error in the *AEO82* projection for 1985. Despite the large errors, the forecasts in each subsequent *AEO* have tended to show considerable improvement, as the downward trend in gas prices has been better captured from one *AEO* to another.

Nevertheless, each *AEO* has tended to predict rising prices over time, either because of the assumption in the earlier *AEOs* that long-term, high-priced contracts would continue or because the depletion effects associated with rising consumption were expected to overcome technological improvement in the more recent forecasts. In summary, three factors have had significant impacts on the projections:

- In the earlier *AEOs*, it was assumed that natural gas contracts whose provisions were governed by the Natural Gas Policy Act of 1978 would not be abrogated and that the prices that prevailed under those contracts would essentially set the market price over time. In fact, when oil prices fell in 1986, many of those contracts were abrogated, and the price of natural gas fell, although not as much as the price of oil.
- Estimates of the recoverable resource base rose and estimates of exploration and production costs fell over time, in contrast to the assumptions in the earlier forecasts. Because the models use this information as an input, higher assumed levels of recoverable resources and lower assumed costs would have resulted in forecasts characterized by more gas available for production at lower prices. More recent *AEOs* have allowed for increases in the resource base and decreases in costs due to technology improvements.
- Consistent with the assumption of existing regulations, the earlier *AEOs* did not assume that there would be additional competition in the transmission and distribution sectors of the market; however, from 1985 on, FERC moved to open access to the interstate pipeline transmission system, lowering end-use prices and stimulating additional price competition at the wellhead as well.

Thus, although the forecasts have improved with additional information, they have continued to be affected by the impacts of wellhead price deregulation and the changing competitive structure of the industry and by overestimates of the impacts of reserve depletion relative to technology improvements.

It is worth noting that approximately one-fourth of the domestic production of natural gas is as a coproduct of the crude oil extraction process, which means that, as crude oil production rises with higher oil prices, there may be a depressing effect on the wellhead price of gas. This effect has added to the complexity of forecasting natural gas prices.

Coal Prices to Electric Utilities

Although they are better than those for oil and gas prices, the *AEO* forecasts of coal prices to electric utilities still show an average absolute percent error of 35.3 percent over the period studied (Table 15). All forecasts were overstated. The forecasts for 1995 had the highest average absolute percent error of 57.5 percent. There was, however, significant improvement in the 1995 forecast over time, with the error improving from 137.9 percent in *AEO83* to 10.6 percent in *AEO95* (excluding *AEO96*, which provided an estimate for the historical year 1995 based on partial year data). Across forecast years, the further out the forecast, the higher the error, with the lowest average absolute percent error shown for the year 1985 at 13.3 percent.

The early *AEOs*—*AEO82* through *AEO86*—tended to have the highest average absolute percent errors, exacerbated by their

forecasts for 1995. There was steady improvement in the *AEOs* through *AEO90*, which had an average absolute percent error of 8.8. After *AEO90*, overestimates for 1995 through 1997 adversely affected the overall average errors for a number of the subsequent *AEOs*.

The major factors in the high forecasts of coal prices were assumptions about depletion effects, productivity improvements, capacity utilization, transportation, and the impacts of CAAA90. Depletion was assumed to overcome productivity improvements in the long run; however, the onset of such new technology as longwall mines and the growth of surface mining in the West have led to continuing productivity improvements. Similarly, with high world oil price forecasts, the impacts of excess capacity and competition among existing mines were not seen to be as important as they in fact became. In addition, high world oil prices were assumed to affect both the production process and the costs of transportation. In fact, the collapse of oil prices in 1986 reduced the impact on both, and the increasing competitiveness of rail transportation has held transportation costs below expectations. Finally, it was assumed that high prices would follow the enactment of CAAA90 as the demand for low-sulfur coal increased. Price increases did not materialize, however, as productivity increases and transportation cost reductions made increased production from western mines possible at lower-than-anticipated prices.

Average Electricity Prices

Average electricity prices showed the best forecasting record among the prices examined here, with an average absolute percent error of 11.0 percent (Table 16). As with all the price forecasts, because of the projections made 12 years earlier, the year with the highest average absolute percent error was 1995, which had an average error of 15.5 percent. Except for the two near-term forecasts of 1985 for *AEO82* and 1989 for *AEO90*, price forecasts have been higher than actual. By publication, *AEO83* had the highest average absolute error of 18.2 percent, and *AEO97* had the lowest at 3.3 percent (with the exception of the *AEO98* estimate of the most recent historical year of 1997 based on partial year data). Recent *AEOs*, from the *Annual Energy Outlook 1992* (*AEO92*)³³ on, have had average absolute percent errors of 9.4 percent or less.

The primary reason for high price forecasts was the impact of fuel costs and capital costs on expected prices. Fuel costs were consistently overestimated for oil, natural gas, and coal, with a strong effect on the estimates of electricity prices, especially for *AEO82* through *AEO84*. In addition, the costs of new capacity were assumed to be higher in earlier projections than they actually turned out to be, and this assumption also helped to raise the forecasts. Finally, a 1992 study³⁴ on the accuracy of *AEO* electricity forecasts for 1985 and 1990 indicated that part of the explanation for high price estimates was public utility commission disallowances and phase-ins of costs of some capital-intensive generating capacity that were not incorporated in the projections because actual regulatory practices varied from those assumed in the projections. For example, some nuclear units had significant portions of their costs disallowed, and the remaining costs were phased in on a longer time schedule than the utilities had requested, contributing to lower-than-expected prices in some years.

Gross Domestic Product

The economic forecasts in the *AEOs* are based on projections from DRI/McGraw-Hill, adjusted for EIA's world oil price projections. The forecasts for gross domestic product (GDP) show an average absolute percent error of 5.0 percent (Table 17). Most of the projections have been less than 10 percent from actual, with the exception of some of the forecasts in *AEO83*, *AEO84*, *AEO85*, *AEO86*, and *AEO89* for the mid-1990s, which ranged up to 28.9 percent above the actual GDP. In general, from *AEO82* through *AEO90*, the GDP forecasts tended to be underestimated for the earlier years and overestimated for the later years. In subsequent reports, GDP has been consistently underestimated.

The major reason for the pattern of overestimates in the longer term forecasts in the early *AEOs* is the recession that began in the latter part of 1990 and continued into 1991. The economic forecasts produced for the *AEO* are trend forecasts, which do not attempt to foresee the timing or magnitude of business cycles. The economic cycle in 1990-91 created a breakpoint in the series being used for evaluating forecast errors. Therefore, early *AEOs* did not forecast the recession and, consequently, overestimated long-term growth beyond 1991. Conversely, the underestimates in later *AEOs* resulted in part from overestimates of world oil prices, which tend to dampen economic growth, plus several other factors such as actual utility bond rates being lower than expected.

High and Low Economic Growth Cases

All the preceding analysis has focused on the reference case projections from the *AEOs*. In fact, all the *AEOs* have presented projections for more than one case. During the period covered in this paper, the reports have included two to six alternative cases, which have varied key reference case assumptions and examined the impacts of those assumptions across all energy markets.

Most frequently, the alternative cases have varied the macroeconomic growth or world oil market assumptions, although other cases have been examined, such as different oil and gas resource base assumptions. Also, many *AEOs* have included a variety of additional cases that have analyzed the impacts of different assumptions on a portion of the energy market. *AEO98*, for example, included 28 such cases in addition to the reference case, high and low macroeconomic growth cases, and high and low world oil price cases.

To analyze the uncertainty associated with varying economic conditions, many *AEOs* included two cases with alternative economic growth rates. Where available, the domestic GDP projections for the high and low economic growth cases are presented here, along with the accompanying total energy consumption, electricity sales, and coal consumption projections in Tables 18 through Table 25. These variables were chosen because total consumption and electricity sales tend to be closely related to economic growth, with coal consumption determined by electricity sales to a large degree. Note that *AEO85*, *AEO89*, and *AEO90* had no high or low economic growth cases, and *AEO91* included no low economic growth case.

Some caution must be used in interpreting the results from these cases. First, during the mid-1980s, attention in the *AEOs* was focused on international and domestic oil markets. In *AEO86* and *AEO87*, the high economic growth cases included low world oil price assumptions that would tend to increase projected energy consumption beyond the level caused by the higher economic growth alone. Conversely, in *AEO86* and *AEO87*, the low economic growth cases included high world oil price assumptions. The cases were designed in this way to examine the uncertainty in petroleum imports that results from changes in both prices and economic growth. The high economic growth case in *AEO91* also included the assumption of low world oil prices in order to present a case with the highest level of energy consumption from the combination of various price and growth assumptions. For all the other *AEOs* examined in this paper, the economic growth cases included moderate world oil price assumptions.

The second cautionary note concerns the definition of the economic growth cases. Through the years, the low and high economic growth cases have sometimes been defined by varying only the growth in economic output. At other times, labor productivity (output per person), labor force growth rates, and population have also varied at different rates for the high and low economic growth cases. In addition, some of the *AEOs* attempted to define a broad band of uncertainty around the reference case projections of economic growth rate, while others defined a more narrow range. In short, the definitions of the economic growth cases have not been consistent. Nevertheless, the presentation of these results should highlight some of the ranges of the forecasts presented over the years.

Overall, the GDP projections for both the low and high economic growth assumptions (Tables 21 and 25) have lower error rates—average absolute percent errors of 4.6 and 3.9, respectively—than the reference case projections (5.0 percent average). In part, this is because the *AEOs* with the worst errors for the reference case GDP had no economic growth cases (*AEO82*, *AEO83*, *AEO85*, and *AEO89*). Excluding these reports and *AEO91*, which had no low growth case, yields average absolute percent errors of 4.6, 4.4, and 3.7 percent for the low, reference and high growth cases, respectively. The largest errors are for the year 1995 in the earlier *AEOs*; as a result, those *AEOs* have the highest average absolute percent errors in all cases. In the later *AEOs*, GDP was consistently underestimated in both the high and low economic growth cases. The low and high growth GDP paths, in real terms, bracket the reference case. In the short term, low economic growth results from higher prices, which lead to a higher set of deflators and some apparent anomalies—with nominal GDP in the low growth case higher than in the reference case, as in the *AEO94* projections for 1993 to 1997.

Total energy consumption in the low economic growth case (Table 18) shows a larger average absolute percent error (2.3 percent) than in the reference and high growth cases (1.7 and 1.6 percent, respectively). The majority of the errors in the reference case were underestimations, many of which became even worse with the lower economic growth assumptions and were further exacerbated by the *AEOs* with high world oil price assumptions (*AEO86* and *AEO87*).

Coal consumption errors appear worse in the low and high economic growth cases (Table 19 and Table 23), with average absolute percent errors of 3.5 percent and 3.4 percent, respectively, compared with 3.0 percent for the reference case. When the *AEOs* with no economic growth cases (*AEO82*, *AEO83*, *AEO85*, and *AEO89*) are eliminated, some of the smaller errors in the reference case are eliminated, raising the average absolute percent error to 3.4 percent for the reference case, similar to those in the high and low growth cases.

The average absolute percent error for total electricity sales in the low economic growth case (Table 20) is higher at 2.4 percent than those in the reference and high economic growth cases (1.7 and 1.6 percent, respectively). In the reference cases, most *AEOs* tended to underestimate electricity sales in most years; however, the underestimates were exacerbated by the lower economic growth assumptions leading to the larger average errors in the low economic growth cases.

Across comparable *AEOs*, the reference case tended to underestimate GDP growth. Therefore, in the low economic growth cases, error rates for GDP and consumption were exacerbated. Error rates in the high economic growth cases tended to be equal to or slightly lower than those in the reference case.

Regression Analysis on Historical Data

Methodology

In the preceding analyses have focused on comparing the projections from previous *AEOs* with actual historical values. This section describes simple regression analyses on historic data for the 16 variables from Table 1, as recommended by reviewers of an earlier version of this paper. The results of the regressions are compared with actual values to determine whether a simple regression analysis would have performed better than the *AEO* models. (There are other time series or trend analysis models, such as vector autoregression (VAR), Bayesian vector autoregression (BVAR), or moving averages, that could also be used for comparisons with the *AEO* forecasts and may prove better than a simple regression analysis.) Historical data for the regressions were obtained from the *Annual Energy Review 1996*,³⁵ and in most cases go back to 1950.

A simple lag regression was performed for each of the 16 variables, using the following estimation equation:

$$Y_i(t) = A + B \times Y_i(t-1) \quad ,$$

where $i = 1, \dots, 16$. Two sets of estimations were made—TREND 85 and TREND 90. TREND 85, for a given energy variable, is the result of a simple trend analysis, or regression, in which the one independent variable is the energy term lagged one year, and the last historical year is 1985. TREND 90 has the same definition, except that the last historical year is 1990. Appendix A provides an example of the estimation performed for total energy consumption.

- **TREND 85:** Sixteen estimations were performed, one for each variable in Table 1. The total energy consumption example had 36 observations, 1950 to 1985. After the coefficients, A and B , were determined, the above equation was used to compute the values for the forecast period, 1986 to 1997. The values in the total energy (*TE*) column of Appendix A for years 1986 to 1997 correspond to the TREND 85 row for total energy consumption in Table 26. The estimations were repeated for the remaining 15 variables, with the results shown in Table 26 in the TREND 85 rows.
- **TREND 90:** The methodology for determining the TREND 90 rows in Table 26 was the same as for TREND 85, except that there were 41 observations for the time period 1950 to 1990. After the coefficients were determined, the values were computed for the forecast period 1991 to 1997. The results are shown in the TREND 90 rows of Table 26.

Table 26 also contains, for each energy variable, the average absolute percent errors between *AEO86*, TREND 85, *AEO92*, and TREND 90, compared with the actual values. *AEO86* corresponds to TREND 85 because the first forecast year is 1986. Similarly, the first forecast year for *AEO92* and TREND 90 is 1991.³⁶

Results

In general, the trend regressions had higher average absolute percent errors than the *AEO* projections (Table 26). Trend regressions do not pick up major reversals that occur in the forecast period. For example, for crude oil production, which declined steadily after 1991, both TREND 85 and TREND 90 overestimated by a large amount, whereas the *AEOs*, especially *AEO92*, were better at picking up the turnaround.

Trend analysis did poorly for price paths, especially when the directions of the price paths changed. For example, average electricity prices were initially flat, rose from 1989 to 1993, then flattened again. TREND 85 overestimated future electricity prices by a large margin, but *AEO86* did better. Another example is natural gas wellhead prices, which TREND 85 tended to overestimate and TREND 90 to underestimate; however, the *AEOs* also did poorly at catching the turns in the price path, even though *AEO86* performed better than TREND 85.

Of the 16 variables examined in this analysis, *AEO86* had lower average absolute percent errors than TREND 85 for 10 of the variables. Even for the 6 variables for which TREND 85 had a lower error rate, the differences between the average absolute percent errors for *AEO86* and TREND 85 were less than 1 percent for 3 of them. For all the consumption, production, import, and macroeconomic variables, *AEO92* was consistently better than TREND 90, with the exception of natural gas production and exports. In the case of gas production, the average absolute percent errors for the two analyses differed by less than 1

percent. For the price variables, TREND 90 performed somewhat better than *AEO92*, although average absolute percentage errors for the two analyses were the same for electricity prices and both had relatively high error rates for all other prices.

In conclusion, a simple trend analysis model of the type used in this report does not pick up major reversals occurring in the forecast period; does poorly where many turns occur; and does not pick up the effects of legislative actions or regulations on the forecast.

Conclusion

Although a primary function of the models used by EIA to produce its *AEO* forecasts has been and remains the analysis of alternative policies, many readers of the *AEO* use the projected numbers as forecasts for their own purposes. Thus, it is useful for EIA analysts and users of the *AEO* to know the size of and reasons for the differences between the projections and actual values.

Throughout the *AEOs*, the variables with the highest errors, expressed as average absolute percent errors, have been prices and net imports of natural gas and coal. Natural gas, in general, has been the fuel with the most inaccurate forecasts, showing the highest average error of all the fuels for consumption, production, and prices. Natural gas was the last fossil fuel to be deregulated following the heavy regulation of energy markets in the 1970s and early 1980s, and the early *AEOs* assumed that natural gas would continue to be regulated until new rules were actually promulgated. Even after deregulation, the behavior of natural gas in competitive markets was difficult to predict.

The overestimation of prices is the most striking feature of this evaluation. In general, more rapid technological improvements, the erosion of OPEC's market power, excess productive capacity, and market competitiveness were the factors that the *AEO* forecasts failed to anticipate. While the errors for prices were large, they appeared to have a relatively minor impact on the overall projections of demand and production, although some forecasts were clearly affected, possibly confirming the relatively low price elasticities of supply and demand embedded in the models. For the period covered by this study, productivity and technology improvements and the effects of gradual deregulation and changes in industry structure, such as the treatment of contracts, have more than offset the factors that have tended to raise fossil fuel prices. In addition, energy markets have evolved differently than projected as a result of changes in the regulatory environment and the enactment of changes in legislation, regulations, and standards.

Caution should be used in drawing conclusions from the analysis of economic growth cases. First, these cases did not have consistent world oil price assumptions (low, mid, and high). Second, the definition of the economic growth cases varied for different *AEOs*. In general, for the GDP and consumption variables compared, the low growth cases had higher error rates than the reference cases when comparing across the *AEOs* that had low economic growth cases. In general, reference case projections underestimated economic growth, and the high growth cases thus tended to have lower or similar error rates for the variables compared.

The most striking result of the regression analysis described here is that a simple trend analysis model of the type used does not perform well for projections where many turns occur. This is especially true for major reversals in the forecast period. Trend analysis also does not pick up technological improvements or regulatory or legislative changes. *AEO86* was better than its comparable trend analysis for the majority of the variables examined. With the exception of natural gas production and coal exports, *AEO92* consistently outperformed its comparable trend analysis for all nonprice variables. *AEO92* and the trend analysis had similar errors for electricity prices, and although the trend analysis was better than the *AEOs* for all other prices, both had relatively high error rates.

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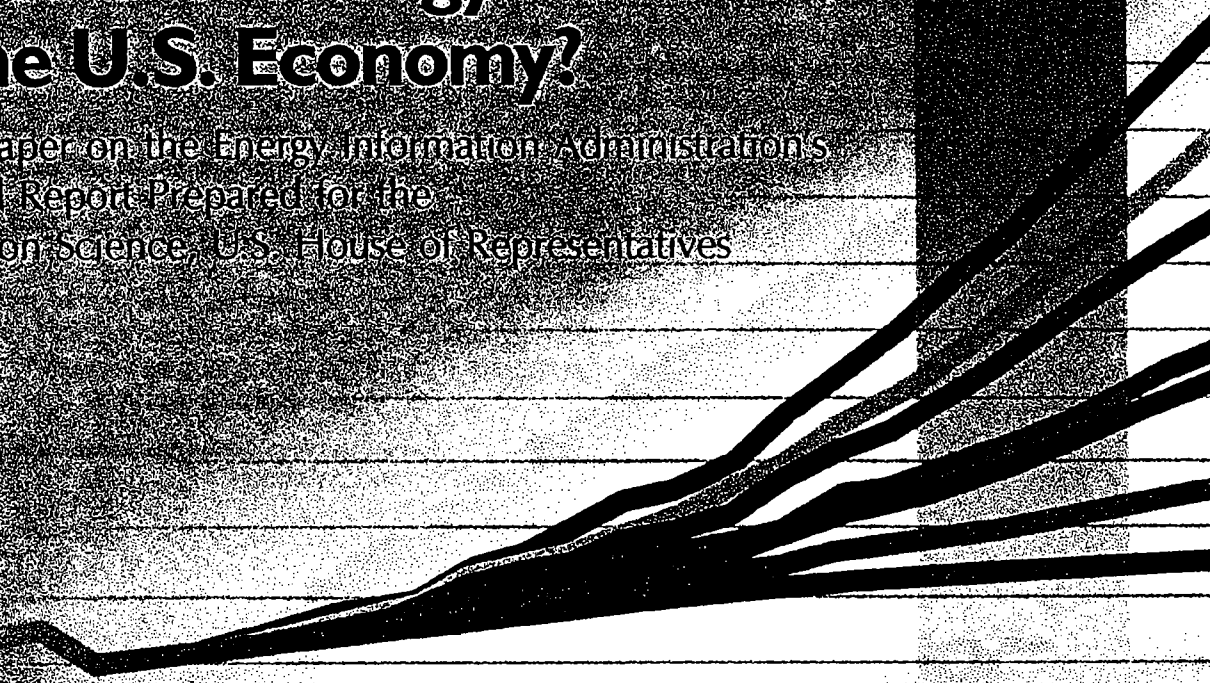
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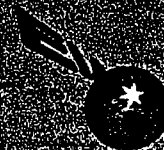
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What Does the Kyoto Protocol Mean to U.S. Energy Markets and the U.S. Economy?

A Briefing Paper on the Energy Information Administration's Analysis and Report Prepared for the Committee on Science, U.S. House of Representatives



- Energy Prices
- Values of Carbon Emissions Credits
- Changes in Energy Mix
- Impacts on Motor Fuel and Electricity
- Market Penetration by New Technologies
- Improvements in Efficiency
- Changes in Potential vs Actual Growth of the Economy
- A Range of Cases, Based on Means of Compliance



Prepared for the
Committee on Science
U.S. House of Representatives

October 1998

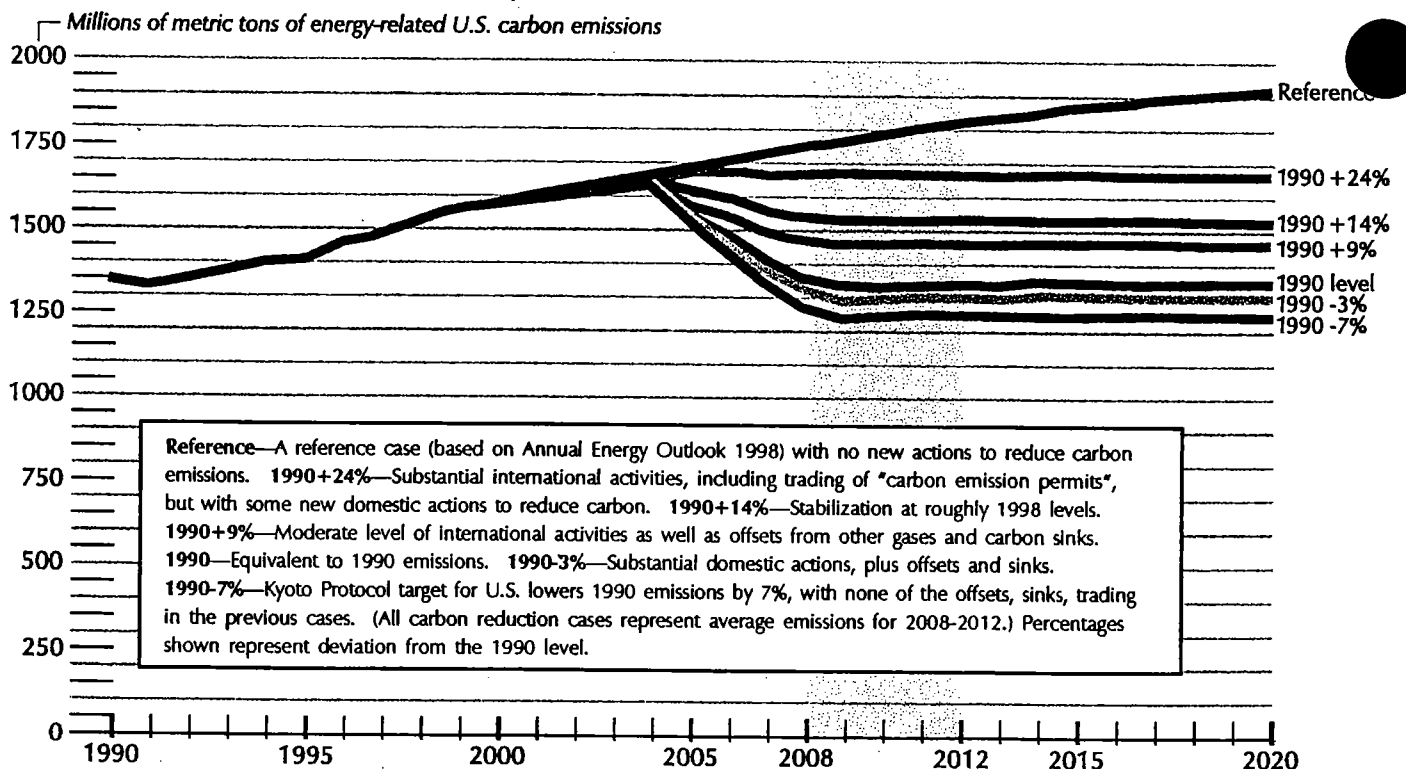
Economic Effects of a Complex Agreement

The Kyoto Protocol, negotiated by more than 160 nations in December 1997, aims to reduce net emissions of certain greenhouse gases (primarily carbon dioxide (CO₂)). Each of the participating developed countries must decide how to meet its respective reduction goal during a five-year period (2008-2012); but specific ground rules remain to be worked out at future negotiating sessions. The next meeting is in Buenos Aires (November 1998).

In a study entitled *Impacts of the Kyoto Protocol on U.S. Energy Markets and Economic Activity*, the Energy Information Administration (EIA), an independent statistical and analytical agency in the U.S. Department of Energy, has projected that meeting the U.S. targets under the Protocol will call for significant market adjustments:

- Reductions in CO₂ emissions will result in between 18 and 77 percent less coal use than projected in the EIA Reference Case in 2010, particularly affecting electricity generation, and between 2 and 13 percent less petroleum use, mainly affecting transportation.
- Energy consumers will need to use between 2 and 12 percent more natural gas in 2010 and between 2 and 16 percent more renewable energy, and extend the operating life of existing nuclear units.
- To achieve these ends via market-based means, average delivered energy costs (in inflation-adjusted 1996 dollars) must be between 17 and 83 percent higher than projected in 2010.

EIA Analyzed 6 Cases for Reducing Energy's Carbon Emissions To Comply with the Kyoto Protocol



Depend on Many Assumptions

- The amount prices must rise is uncertain. Accounting procedures and international trading rules for greenhouse gases are not finalized. Forecasting technological change and public response to it under various pricing scenarios is an inexact science. The more stringent the need for domestic emission reductions, however, the more costly the adjustment process will be.

EIA undertook this study in response to a request by the Chairman and Ranking Minority Member of the House Committee on Science that it analyze impacts of the Protocol (which the President has not yet submitted to the U.S. Senate for ratification) on U.S. energy use, prices, and the general economy in the 2008-2012 time frame. That is when this country is supposed to reach an average level of net greenhouse gas emissions 7 percent lower than they were in 1990—having shown demonstrable progress toward that goal by 2005. At the Committee's request, EIA assumed that actions begin in 2005.

EIA was asked to do the study for several reasons. More than 80 percent of the human-originated greenhouse gas emissions are energy-related. EIA's National Energy Modeling System (NEMS) is perhaps the most complete, integrated, regional computer model available to simulate all elements of U.S. energy supply and demand in the context of the full U.S. macroeconomy. NEMS presents year-by-year projections over a 20-year horizon, accounting for capital stock turnover and the availability and penetration of specific energy-consuming technologies. Its annual "Reference Case" assumes no change from existing laws and regulations, and so it provides a base from which to evaluate policy options or alternative assumptions.

EIA analyzed six cases to investigate the uncertain range of impacts which could result from the Kyoto Protocol. Differences among the cases analyzed arise from three facts: 1) The Protocol gives credit for "CO₂-equivalent" reductions in five gases other than CO₂—methane, nitrous oxide, and three synthetic gases—as well as for certain actions that take carbon out

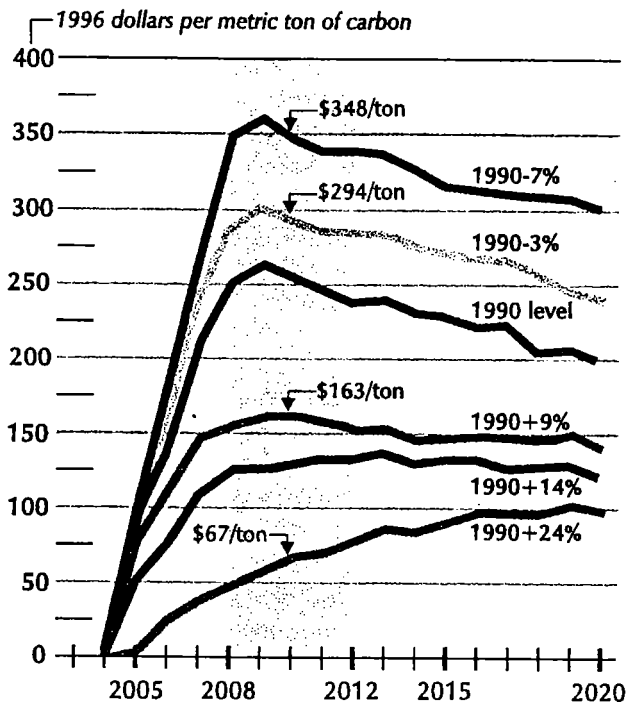
of the atmosphere (such as preserving or extending forests); 2) participating developed countries are allowed to sell excess "permits" (e.g., because of economic problems since 1990 in the participating countries of the former Soviet Union, they may have about 165 million metric tons of carbon permits easily available); and 3) support for effective programs in other countries can earn permits. Details of this last process (called "Joint Implementation" among developed countries and the "Clean Development Mechanism," or CDM, for developing countries) are unsettled.

EIA's six cases cover a range of reductions in energy-linked carbon emissions from an annual average of 122 million metric tons below the expected baseline emissions (1990+24% Case) to 542 million metric tons (1990-7% Case) in 2008-2012. In the 1990+24% Case, domestic actions may furnish about one-fifth of all reductions, with the rest coming from international activities (including trading), offsets of other gases, and carbon sinks in the U.S., while the 1990+9% Case assumes that nearly 60 percent of the reductions result from such domestic initiatives as fuel-switching, improved technology, and cutbacks in energy use. EIA did not separately calculate the contributions of international activities, offsets or sinks for any case. The 1990-3% Case assumes all reductions are from domestic actions, with a 4 percentage point contribution from sinks and offsets from other gases. In the 1990-7% case, all reductions must come from domestic energy-related reductions.

The Kyoto Protocol does not specify targets for greenhouse gases after the period 2008-2012. At the Committee's request, EIA held the target for energy-related carbon emissions in the commitment period constant to 2020, the end of the forecast horizon. Targets following the 2008-2012 period will be a topic at future negotiating sessions.

To reduce carbon emissions, EIA assumes that a "carbon price" is added to the price of delivered energy fuels based on their carbon content. For example, coal prices rise more than petroleum and natural gas prices; and

"Carbon Price" For a Range of Deviations From 1990 Carbon Emission Levels



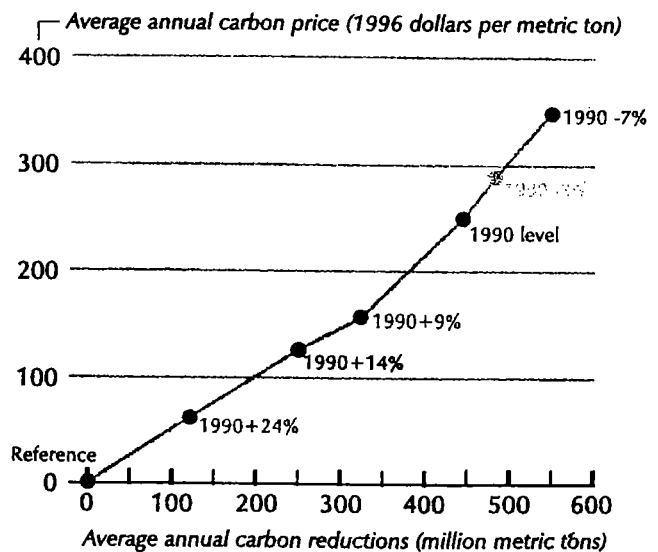
the cost of generating electricity from non-carbon-emitting nuclear and renewable fuels is not increased due to the carbon price. Although electricity does not have the carbon price directly added to it, its price is increased due to the higher cost of fossil fuels used for generation.

The price increases encourage a reduction in the use of energy services (heating, lighting, and travel, for example), the adoption of more energy-efficient equipment, and a shift to less carbon-intensive fuels. The carbon price reflects the amount fossil fuel prices in the U.S., adjusted for the carbon content of the fuel, must rise to achieve the removal of the last ton of carbon emissions that meets the carbon reduction target in each case.

In most of the cases, the carbon price peaks early in the 2008-2012 period, reaching between \$67 and \$348 per metric ton in 2010, and then declines as energy markets adjust and more efficient, new technologies become available and gradually penetrate the market. In the least stringent reduction cases, the increase is more gradual throughout the period because less severe reductions need to be made. Looking at average carbon prices over the commitment period 2008 to 2012 shows how the cost of compliance increases with increasingly stringent targets.

Differences in the cost of energy will affect the outlook for U.S. jobs, consumer prices, investment, technical change, and economic growth. Whenever use of a factor of production such as energy is restricted, economic performance falls for some period of time, the price of energy and other goods and services rises, and consumption and employment decline. Hence the various cases affect the national economy to varying degrees.

"Carbon Price" Rises with Higher Emissions Reductions, 2008-2012



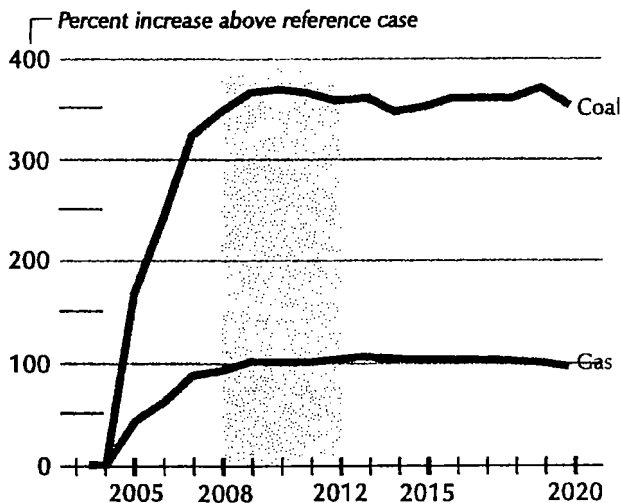
Electricity and Coal Industries Face Major Adjustments

Well over one-third of all primary energy consumed by the United States today goes into producing and delivering electricity. At the point of use, electricity can be highly efficient; and there are certain end uses where fuel substitution is not feasible. More than one-half of all U.S. electricity generated in 1997 was produced from coal—a fuel that emits more carbon dioxide during combustion than any other fossil fuel. Thus, electricity production and consumption is likely to be a major focus in meeting Kyoto targets, accounting for between two-thirds and three-fourths of the domestic carbon reductions in 2010 in the various cases examined. Historically, this industry has responded when relative fuel prices have changed.

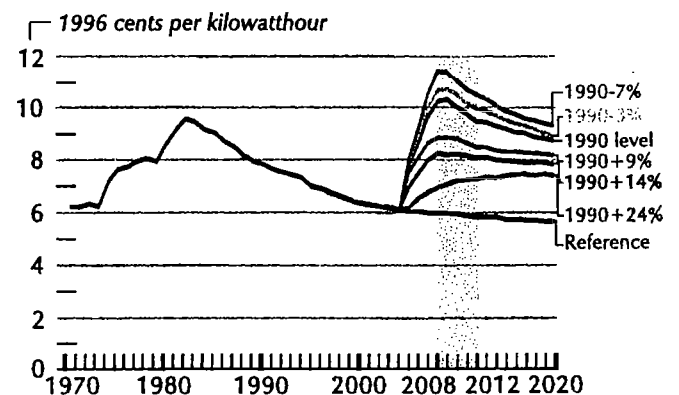
Because coal is the most carbon-intensive of the fossil fuels, delivered prices for coal are affected by carbon prices more than other fuel prices. They are between

153 and 800 percent higher in 2010. The various cases studied for show prices for electricity between 20 and 86 percent higher in all end-use sectors, reflecting both the increased fuel costs and the incremental capital investments for non-coal generating capacity—either by traditional utilities or by non-utility generators in an increasingly restructured industry. The price rise for electricity is moderated somewhat by the fact that fuel is only part of the cost of generating electricity and that the cost of generation from renewables and nuclear power are unaffected by carbon prices. Neither of these fuels, however, can replace significant amounts of coal in the 2008-2012 timeframe. By 2020, non-hydro renewables (chiefly wind turbines, biomass in advanced technological applications, and to a lesser extent, geothermal facilities) penetrate the market in a significant way—providing as much as one-fifth of generation at the highest carbon prices. While hydroelectric dams have accounted for four-fifths of the renewable energy used for U.S. electricity production to date, the expansion of hydroelectric capacity is capital-intensive and is likely to meet with environmental objections; thus little additional

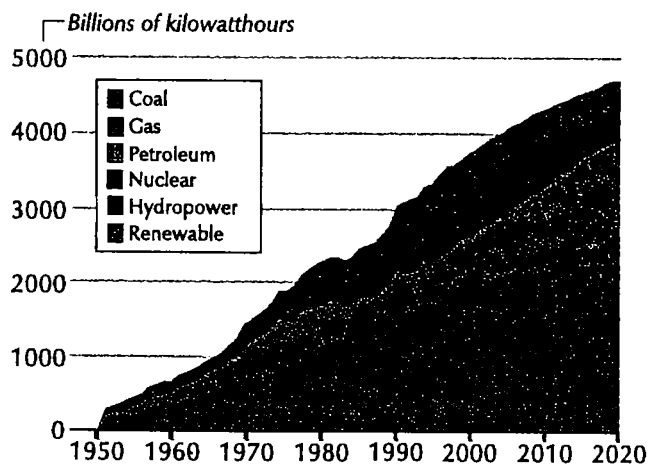
Cost of Fuels Used to Generate Electricity in the 1990 + 9% Case



Average Price of Electricity to End-Users



Electricity Generation by Fuel (Reference)

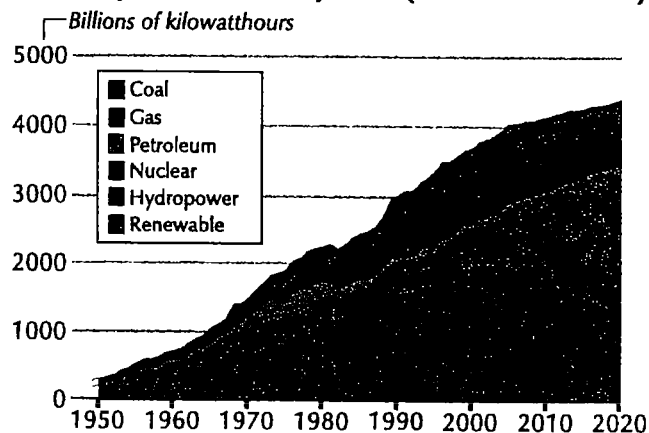


hydroelectric capacity is expected. The bulk of the substitution for coal generation would be natural gas, because of its lower carbon content and the high efficiency of gas-fired combined cycle plants.

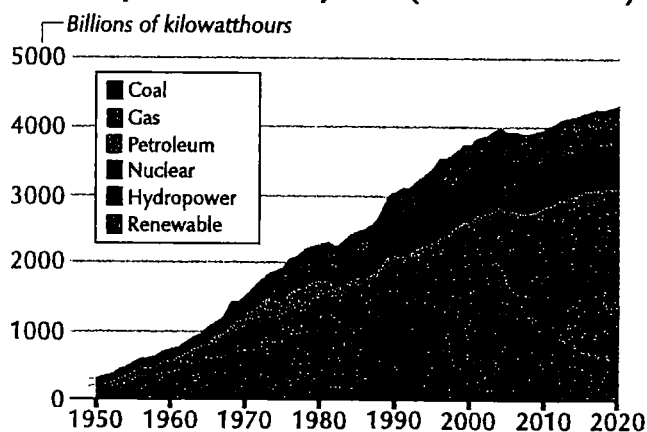
Furthermore, demand for industrial steam coal and metallurgical coal is also reduced because of a shift to natural gas in industrial boilers and a reduction in industrial output.

Because domestic coal consumption is between 18 and 77 percent lower in 2010 in the carbon reduction cases, there would be ripple effects on the industry. For example, even though total coal production drops, the average price per ton for coal at the minemouth in 2010 is between 3 and 28 percent higher than the Reference Case price. This is because a larger share of production would come from higher-cost Eastern coal mines, which tend to serve the remaining markets. Carbon prices raise the cost of rail transportation (involved now in delivering two-thirds of all coal) and make Western coal less competitive. The production of Western coal is discouraged further by the reduced size of the market and the reduced profitability of investing in new coal mines (which have been mostly in the West).

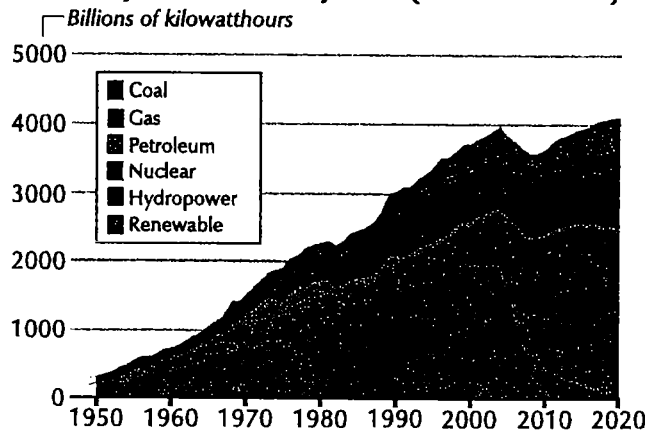
Electricity Generation by Fuel (1990+24% Case)



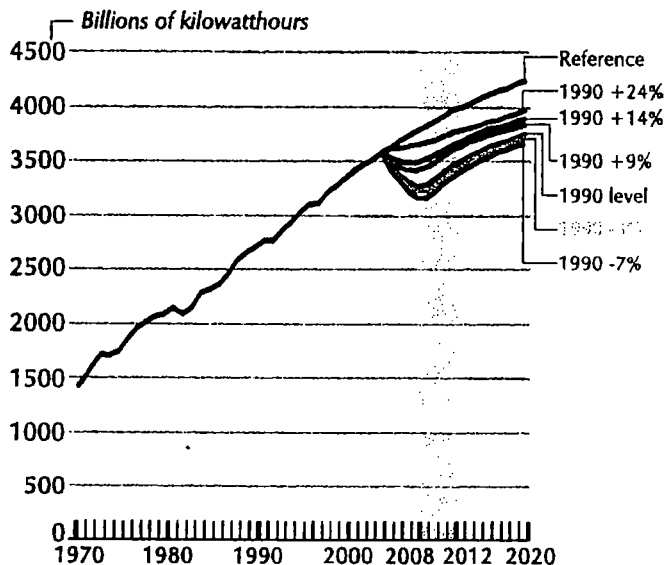
Electricity Generation by Fuel (1990+9% Case)



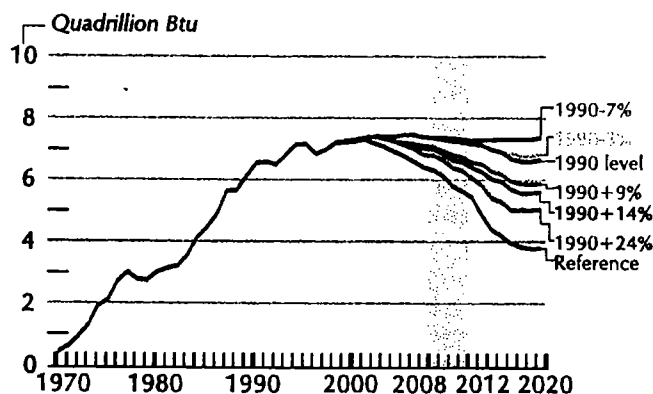
Electricity Generation by Fuel (1990-7% Case)



U.S. Sales of Electricity



Nuclear Inputs to Electricity Generation



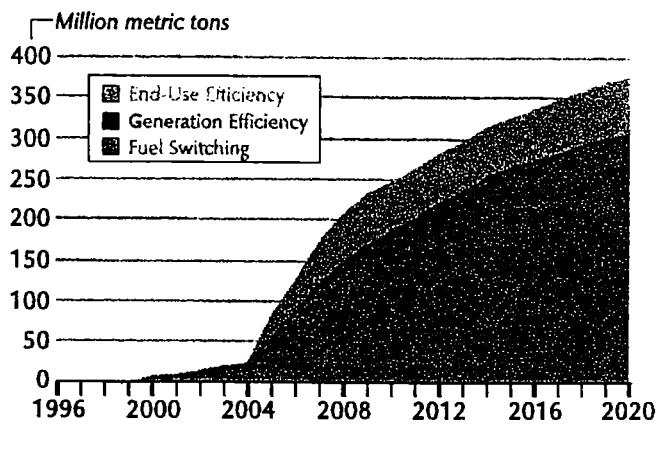
For the past two decades or so, the number of coal miners in this country has been declining by nearly 6 percent per year, primarily as a result of improved labor productivity (especially in large Western surface mines). Without taking the Kyoto Protocol in consideration, the Reference Case already projects a further employment drop of more than 15 percent—leaving only about 69,000 U.S. coal miners by 2010. In the carbon reduction

cases, between 10,000 and 43,000 more jobs could be lost. Some of these job losses could be offset by growth in employment in the natural gas and renewable industries.

While no new nuclear power plants are considered in these cases, extending the licenses of existing plants is projected to become more economical with higher carbon prices. In more stringent carbon reduction cases, most existing nuclear plants are operated through 2020, in contrast to the Reference Case outlook that projected about half of the nuclear plants would be retired by that time.

Although reduced demand for electricity and improved efficiency in its generation can contribute to reducing carbon emissions from electricity generation, fuel-switching accounts for most of the reductions. In the short run, power suppliers would increase their use of less carbon-intensive plants, including steam plants that use oil and gas to heat their boilers. Much more efficient and cost-effective combined-cycle systems increase their share as new capacity is added.

How Carbon Cuts Would Be Achieved In Electricity Generation (1990 + 9% Case)



All Sectors Need to Adjust; Motor Vehicles

EA assumes that carbon prices would be imposed at the point of consumption—raising the “delivered” prices of both primary fuels and electricity across the board. Because various fuels face different price increases (based on their different carbon contents), all end-use sectors will not be affected identically. History has shown that residential, commercial, industrial, and transportation users of energy react differently to price changes.

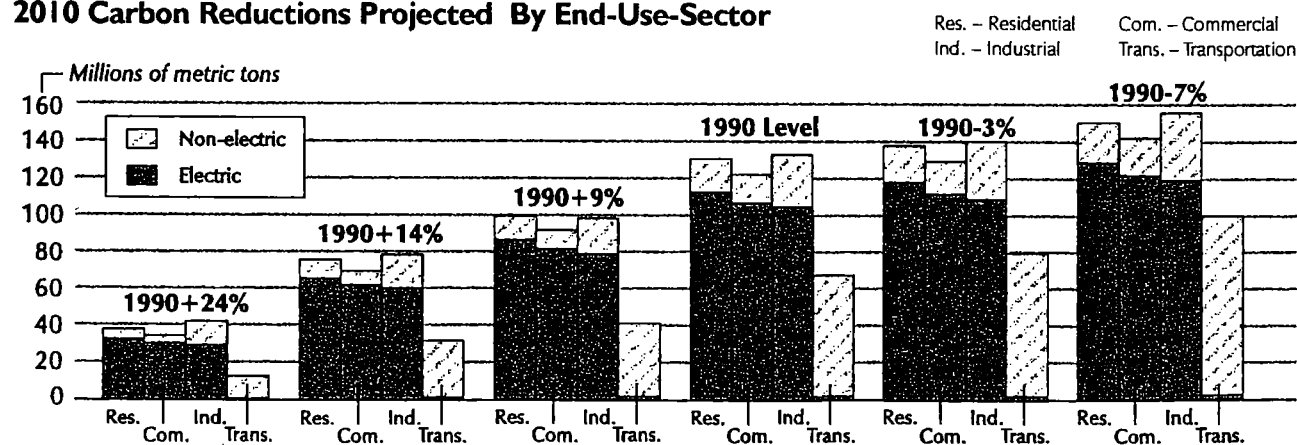
As energy costs rise, all consumers tend to use less. In the broadest terms, the required carbon reductions could prompt the nation to lower “energy intensity” (the quantity of energy consumed per dollar of Gross Domestic Product) as much as three times faster between 2005 and 2010 than in the Reference Case. The rate of decline slows after 2010 reaching a decline rate from 1.4 to 1.7 percent for the 2005 to 2020 period. In the Reference Case, energy intensity declines at 0.9 percent per year.

In all cases, consumers have a price incentive to reduce their demand for energy services, to switch to lower-carbon energy sources, and to invest in more energy-efficient technologies. A number of more efficient and lower-carbon technologies for electricity generation

become economically available as the carbon price raises fossil-fuel prices. Those who produce and sell electricity are likely to respond vigorously to higher fuel prices because this industry has long been accustomed to factoring future energy prices into investment choices; and competition is becoming keener because of ongoing regulatory reforms. By contrast, residential consumers tend to respond less to fuel prices, paying more attention to other factors (such as style, familiarity, convenience).

However, electricity prices, which are 20 to 86 percent higher than the reference case in 2010, are more than matched in percentage terms by the projected 25- to 147-percent rise in natural gas prices due to increased demand and the inclusion of the “carbon price.” Thus, in end-uses where electricity competes with natural gas (such as home heating), the former becomes relatively more attractive. Although petroleum products, on average, contain more carbon than does natural gas, the price of natural gas would be increased by a greater percentage, in part because current prices for gasoline (a major end use of petroleum) incorporate Federal and State taxes. Also, lower world oil demand as a result of the Protocol would lower crude oil prices and offset part of the “carbon price” on oil products.

2010 Carbon Reductions Projected By End-Use-Sector



(Electricity emissions include the entire production and delivery cycle)

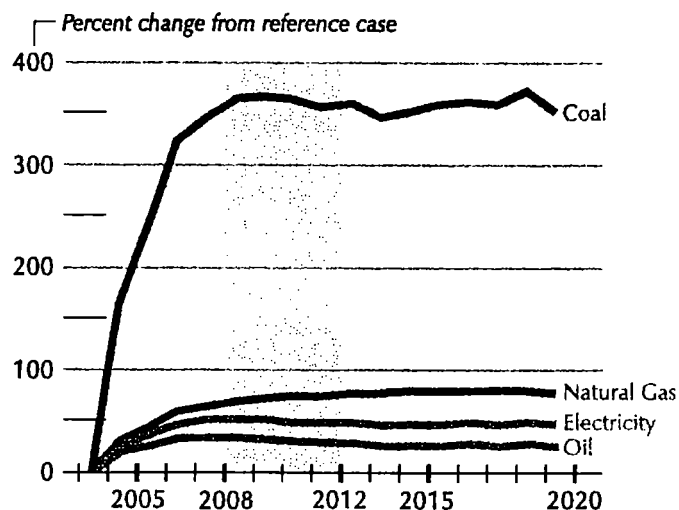
Face Main Non-Electric Impact

As prices for any factor of production increase, all goods and services reflect some cost increases they otherwise would not see. As higher energy prices are transmitted throughout the economy, people will react in part by buying less of everything. To some extent, this means U.S. industry and business must cope with smaller product demand, so that total output falls (thus cutting back further on emissions). In addition, industrial consumers of energy are prompted to replace existing facilities and adopt more efficient technology faster (assuming investment dollars are available), besides switching to less carbon-intensive fuels. The net result is an incremental gain in energy efficiency. If demand for energy-efficient products in the U.S. market should coincide with the appearance of new inventions and processes, a situation analogous to the rapid improvements and cost reductions in computers might occur. However, EIA does not include "breakthroughs" in end-use and generating technologies that are not yet on the drawing board because it is unlikely that they could be developed and penetrate rapidly enough to be significant in the 2008-2012 time period.

Higher fuel prices reduce total residential demand for energy, by promoting the installation of more efficient building shells, heating- and cooling- units, water heaters, and other end-use technologies, which results in larger carbon reductions than cutting back on miscellaneous items such as computers, TV sets, and VCRs. While total energy use by 2010 was projected at 184 million Btu per household in the Reference Case, it ranges between 145 and 173 million Btu in the six carbon reduction cases analyzed.

Space conditioning (heating, cooling, and ventilation) is the most significant energy use in the commercial sector, representing the best opportunity for reducing carbon emissions in the future. More efficient lighting and office equipment also contribute to carbon reductions (along with some modifications in the use of computer and telecommunications equipment). Total energy use per square foot of commercial floorspace in 2010 (206

Differential Rises In End-Use Prices Affect Sectoral Energy Demand in the 1990 + 9% Case



thousand Btu in the Reference Case) is projected across the cases to drop to between 148 and 192 thousand Btu.

The U.S. transportation sector represents the single largest target for carbon reductions apart from electricity generation, because the transport sector is the biggest U.S. consumer of petroleum by far. A combination of more efficient vehicles and less travel would be needed across all modes. Total petroleum consumption in the transportation sector is between 2 and 16 percent lower in 2010 than in the Reference Case. Because of the impact of higher energy prices on the economy, there is less demand for air travel and freight shipment. In addition, airline fares are higher as a result of higher jet fuel prices, so air travel is between 1 and 18 percent lower. Consumption by aircraft is between 1 and 16 percent lower and freight trucks consume 1 to 6 percent less fuel.

Rising Price Could Level Off or Lower Gasoline Use

In approximately the past 25 years Americans have doubled the number of vehicle-miles traveled on U.S. streets and highways, increasing the average miles traveled per vehicle by about 12 percent. In the Reference Case, however, this rising trend is projected to slow modestly—even without the addition of a “carbon price” at the gasoline pump. Baby-boomers are aging, driving age population growth is slowing, miles driven by women are approaching a gender-equilibrium, and there are more older cars on the road (which typically are not driven as much as new cars). Historically, increases in gasoline prices have not done much to decrease the overall steady upward climb in motor fuel consumption.

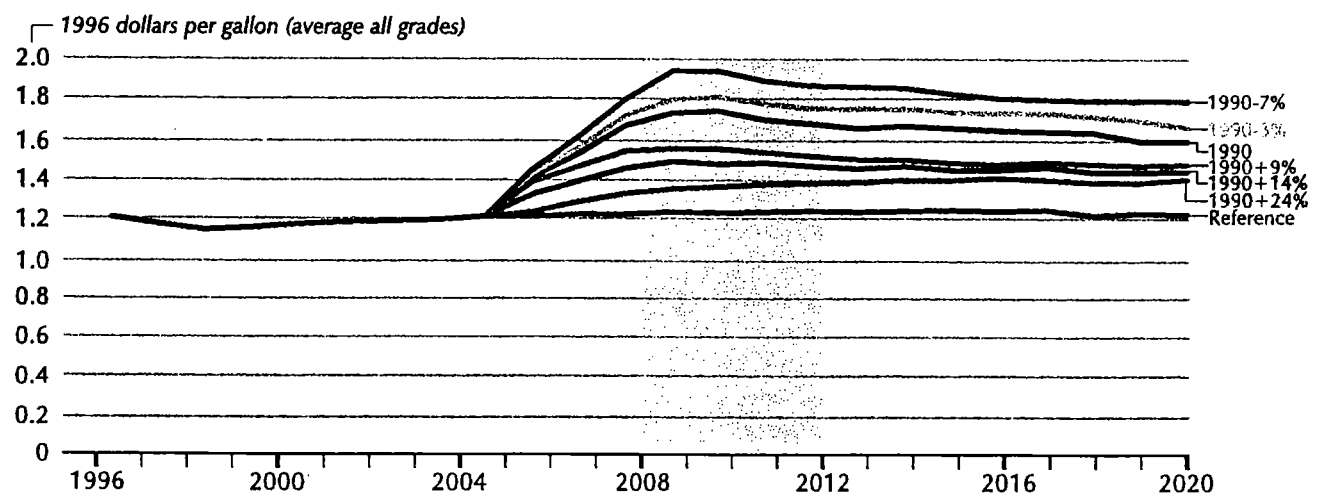
Across the cases, the average price of gasoline increases by between 11 and 53 percent beyond the Reference Case price in 2010. In the 1990+24% Case, the average price of gasoline is only about 15 cents above 1996 prices in 2010 (1996 dollars). For the 1990+9% Case, the average price of gasoline peaks around 2008 at approximately 30 cents per gallon above where it was

in 1996 ... and about 10 cents more than it was in 1990. In the 1990-3% Case, the average price of gasoline peaks at slightly more than \$1.80 a gallon in 2009, while in the 1990-7% Case, it almost reaches \$2.00 a gallon.

The addition of a “carbon price” is expected to reduce auto travel and increase the purchase of more efficient vehicles, reducing gasoline demand between 3 and 18 percent in 2010. Improvements in truck, auto, and plane efficiency are moderated by slow turnover rates. The stock of U.S. vehicles is so large that its average performance lags far behind advances in new car mileage. Increasing new car efficiency in 2010 by 1 to 6 miles per gallon above the 30.6 miles per gallon in the Reference Case improves the rating of the entire stock of light-duty vehicles by only about one mile per gallon or less.

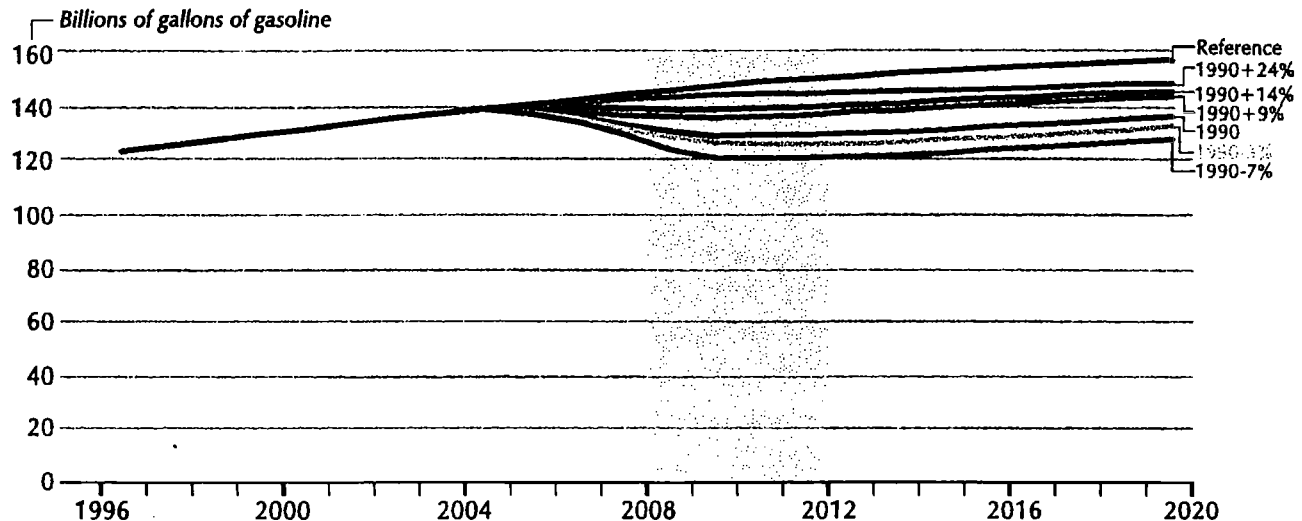
EIA assumed that more than 50 fuel-saving technologies would be available to makers of light-duty vehicles during the period examined—ranging from electronic transmission controls to reduced cylinder friction; but a

Average Price of Motor Gasoline



► For more detail, see “Transportation Demand” section in Chapter 3 of the main report

Consumption of Motor Gasoline

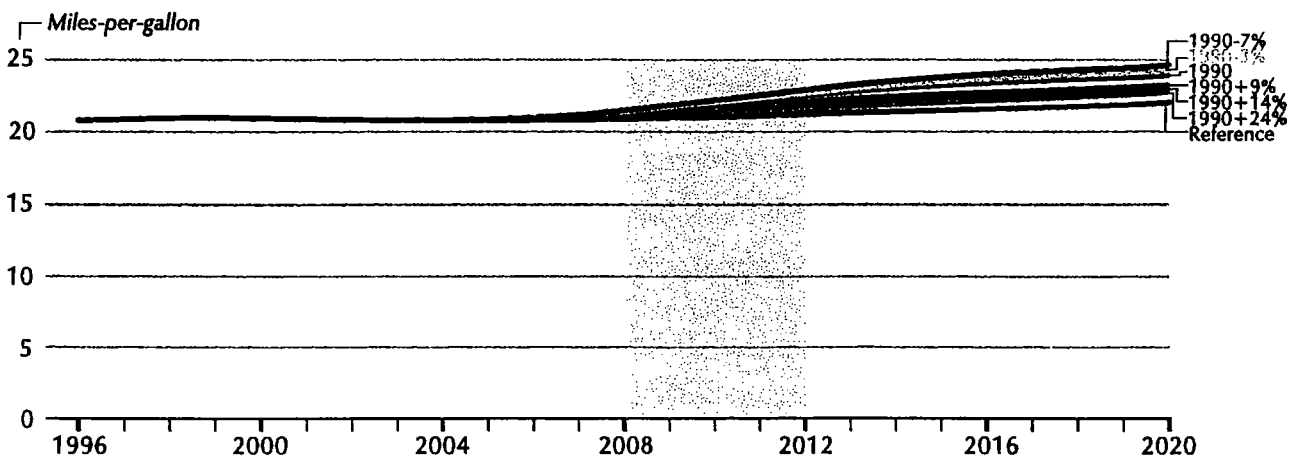


major uncertainty is whether consumers will purchase fuel efficient vehicles or continue the recent trend toward light trucks and sports utility vehicles. Some reversal is expected, particularly when the carbon price is relatively high. For example, in the 1990+9% case, the subcompact share of new car sales in 2010 is 19 percent compared to 12 percent in the Reference Case, reducing sales of compact, midsize, and large vehicles by 2 percentage points each. The annual increase in average

horsepower ratings in the 1990+9% Case is about half that of the Reference Case.

The Reference Case foresaw sales of about 1.8 million alternative-fuel vehicles by 2010, but this number would not be affected much by imposition of a carbon price. While AFV's use less fuel than autos with gasoline engines, they are generally more expensive overall due to their higher vehicle prices.

Average Mileage Ratings for the Stock of Light-Duty Vehicles



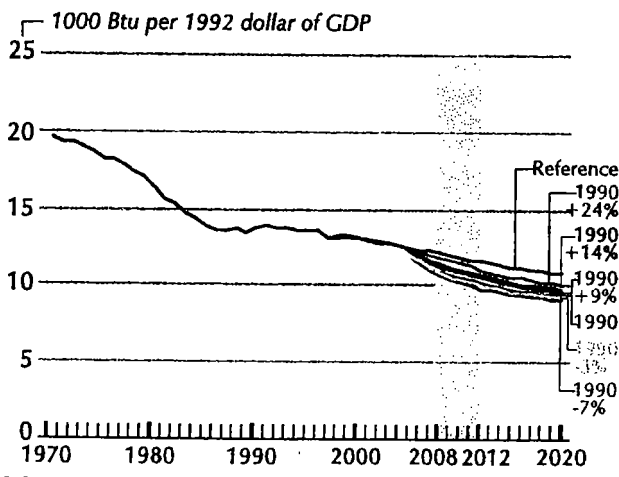
► For more detail, see "Transportation Demand" section in Chapter 3 of the main report

Industrial Energy Efficiency, Already Rising, Would Further Improve

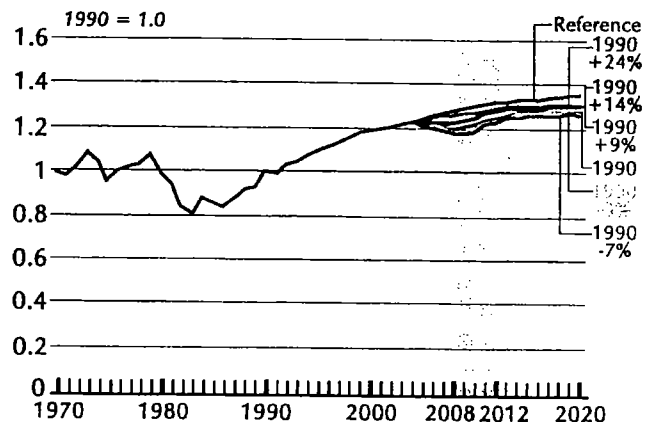
The industrial sector includes agriculture, mining, construction and manufacturing. Energy has represented a relatively small fraction of total production costs in most industries (ranging from less than 2 percent for the food industry to as much as 30 percent of production costs annually for the cement industry.) Consequently, the price of energy has not played a dominant role in recent years in improving industrial energy efficiency.

U.S. energy intensity (energy input per dollar GDP output) has been influenced by two factors in the U.S. economy. First, structural shifts have occurred where the mix of goods and services has shifted away from the production of energy intensive goods (e.g., iron and steel) and toward services (e.g., telecommunications, entertainment). Second, technological improvements (e.g., continuous casting and electric arc furnaces) have impacted industrial efficiency. For more than a quarter century, the gradual migration of heavy industry and primary metals abroad, growth in the U.S. service sector and technological progress have combined to reduce U.S. energy intensity by about 1.4 percent annually.

Total U.S. Energy Use Falls in Relation to the Value of Output



Growth in Industrial Delivered Energy Consumption Slowed by Higher Prices



The Reference Case projection embodies considerable improvement in energy intensity. Just as lower real prices for oil, gas, and electricity during the late 1980s lowered incentives for energy conservation, the higher prices projected in connection with meeting the Kyoto carbon emission reduction goals result in less energy consumed for each constant dollar of output produced. This analysis projects a replay of the early 1980s, when the cost of both energy and capital inputs were rising. Across the cases, about two-thirds of the projected reduction in industrial energy intensity is attributable to the structural effect (change in the mix of goods and services); the remaining one-third to increased energy efficiency.

In the carbon reduction cases, relative to the Reference Case in 2010, total carbon emissions from the industrial sector are between 7 and 28 percent lower. Part of this is due to lower U.S. industrial production because higher energy prices lower domestic demand and make U.S. exports relatively more expensive. In addition, industrial consumers are likely to replace existing capacity somewhat faster, invest in more efficient technology, and switch to less carbon-intensive fuels.

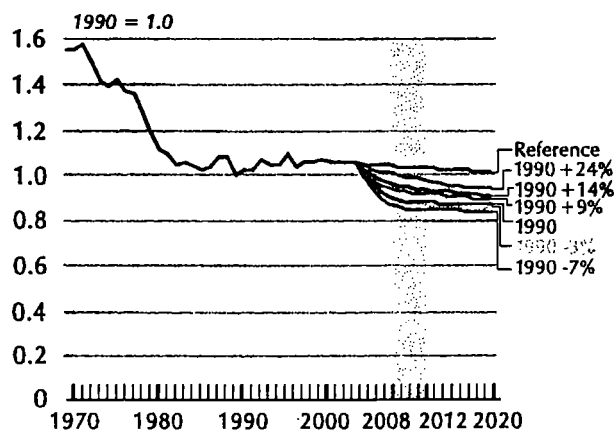
Energy Efficiency Could Improve in the Buildings Sectors With Rising Prices

Rapid development and adoption of new electrical devices—computers, telecommunications equipment, and other appliances—have expanded energy demand in the residential and commercial sectors. Increasing energy prices could lower total demand in the two sectors by between 7 and 25 percent in 2010.

Periods of increasing energy prices appear to have had little impact on commercial energy demand, as seen by comparing the price increases in the 1970s with the change in demand. Energy prices are only one factor in choices for buildings, appliances, and equipment in these sectors. How consumers react to higher prices by reducing the demand for energy services—less heating and cooling, reduced lighting, etc.—will be a major factor in lowering energy demand.

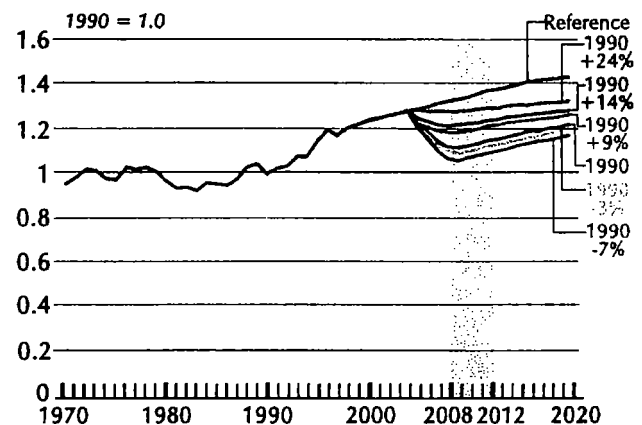
Technology improvements could have the largest impact for space conditioning— heating, cooling, and ventilation—which is the most intensive use of energy in buildings, but the penetration of more efficient equipment is slowed by the gradual pace of stock turnover. Improved lighting technologies will also be important, as well as improvements in building shells—insulation and windows.

Energy Use Per Household Could Fall But Not Match Earlier Decline

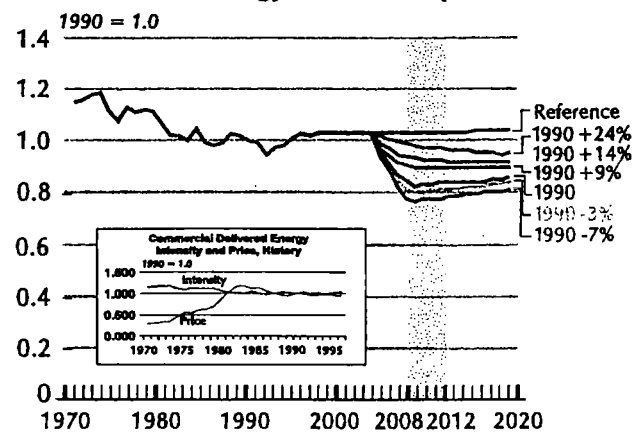


Standards on new buildings and some energy-using equipment have been important in dampening the growth in energy consumption, leaving less opportunity for future improvements. Energy demand by white goods—freezers, refrigerators, dishwashers, clothes washers and dryers, stoves—declines even in the Reference Case primarily due to past standards on refrigerators and freezers and one that becomes effective in 2001.

Buildings Delivered Energy Consumption Drops with Higher Prices



Rising Prices Could Reduce Commercial Energy Use Per Square Foot



► For more detail, see the "Residential and Commercial Demand" sections in Chapter 3 of the main report.

Shift Toward Natural Gas and Renewables

In order to meet the Kyoto Protocol targets, the proportion of each fuel used in the United States is projected to change from that of the Reference Case. Because of the higher relative carbon content of coal and petroleum products, those two energy sources would be used less—placing more reliance on natural gas and renewable energy, and slowing the decline in nuclear power. Although petroleum use declines relative to the Reference Case in absolute terms, its percentage-share increases slightly because total energy demand is lower in the carbon reduction cases. Most petroleum is used in the transportation sector—where there are limited economic options for fuel substitution. As noted earlier, domestic coal consumption declines substantially, with most of the reduction coming in electricity generation.

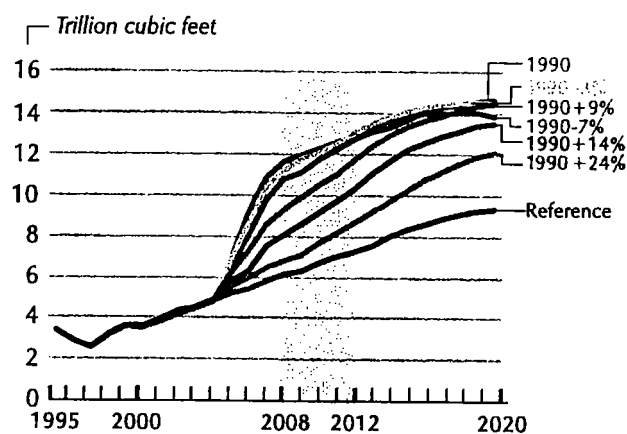
Because of lower demand for petroleum in the United States and other developed countries committed to reducing greenhouse gas emissions, world oil prices in 2010 would be about 4 to 16 percent lower than they would have been without the effect of any “carbon price.” At the same time, U.S. dependence on imported petroleum by 2010 would be lessened—from about 59 percent of all petroleum consumption in the Reference Case to as much as 53 percent.

More use of natural gas in electric generation is offset only partly by reductions from the end-use sectors. Although carbon emissions from burning natural gas are lower than from coal or petroleum, they are not zero. Later in the forecast period, natural gas starts to face stiffer competition from increasingly economic non-hydro renewables and, particularly in the more stringent carbon reduction cases, from refurbished existing nuclear power units. As a result, by 2020, natural gas use is highest in the 1990+9% Case.

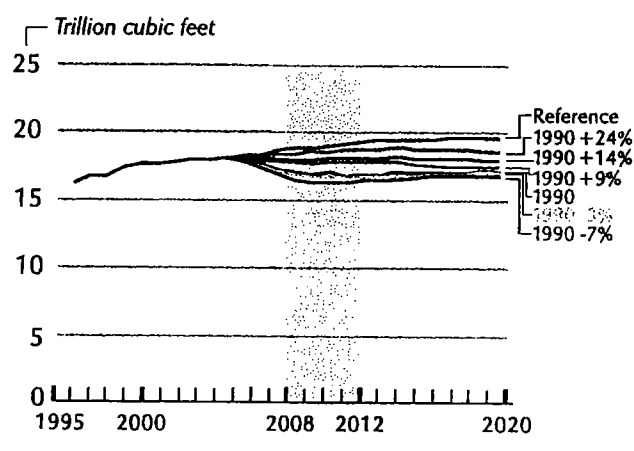
Higher demand forces up the average wellhead price of gas, relative to the Reference Case—moderately by 2010 (\$2.78 per thousand cubic feet for the 1990+9% Case, vs. \$2.33 for the Reference Case) but considerably by 2020 (\$3.71 vs. \$2.62). Although the natural gas

industry will be tested in meeting levels of production that may be required, sufficient resources are available. There is historic precedent for the necessary increases in drilling and pipeline capacity, but appropriate market incentives and careful planning will be needed.

Consumption of Natural Gas by Electric Generators



Consumption of Natural Gas by Industrial, Residential, Commercial and Vehicle Users

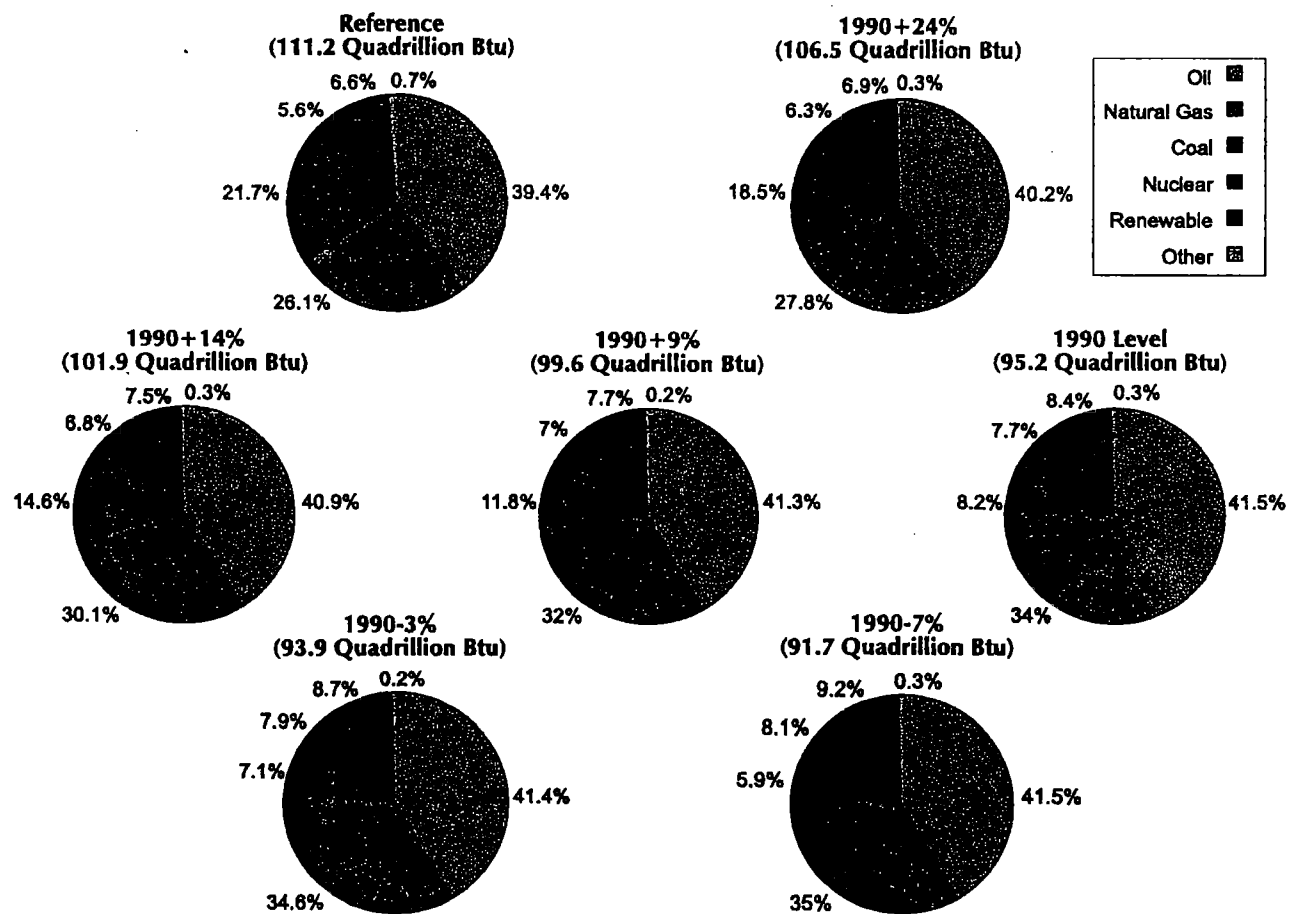


Characterizes New Energy Mixes

Most of the increase in renewable energy sources is likely to occur in electricity generation, primarily with additions to wind energy systems and an increase in the use of biomass (wood, switch grass, and refuse); but the overall renewable contribution by 2008-2012 will remain small

compared to traditional sources. If the market penetration of additional renewable technologies is enhanced by carbon pricing, however, the renewables' share of generation will continue to increase through 2020.

U.S. Fuel Mix Projections for 2010



Output and Cost-of-Living Impacted During

Even though energy represents only about 7 percent of our Gross Domestic Product (GDP), it is a crucial factor in virtually all the goods and services we produce and consume. The effects of alternative carbon scenarios can be expressed in terms of their impacts on the economy as a whole (e.g., GDP, capital investment, prevailing interest rates, inflation rates) as well as their impacts on individual families and enterprises (e.g., increased expenditures on energy, disposable income).

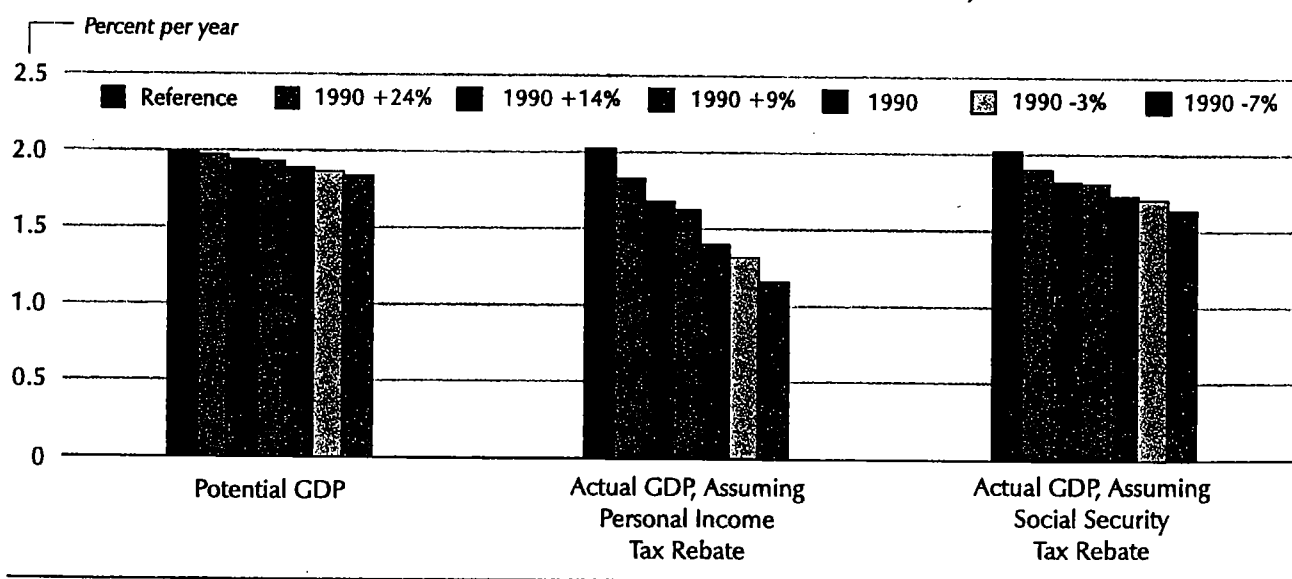
When energy costs rise, other factors of production—including labor and capital—become relatively less expensive. Energy price increases encourage adjustments in which labor and capital are substituted for more expensive energy to the extent practicable. In the process however, some economic potential is lost. This reduces the “potential” GDP for the Nation. EIA calculates that such losses would range from \$13 billion to \$72 billion in 2010 (1992 dollars). In an economy today of over \$7 trillion, which is expected to grow to over \$9.4 trillion (1992 dollars) in 2010, the percentage loss in output ranges from 0.1 percent to 0.8 percent.

In this context, the economy continues to grow, but at a slower rate.

Because it takes time to adjust to a new set of factor-costs, however, there are, in addition to losses in potential GDP, transitional costs—which probably cannot be avoided entirely. Such short-run costs arise whenever price increases disrupt capital or employment markets. The transitional costs are very uncertain, but possibly very significant. They impact the “actual” GDP. Hence, the actual GDP losses are greater than the “potential” losses. The transitional costs can be softened to the extent that price changes are anticipated and appropriate compensatory adjustments can be made to Federal monetary and fiscal policies.

This analysis assumes a carbon-permit trading system is introduced in the form of an auction run by the Federal Government (to focus on the most economically efficient means of reducing carbon emissions). The domestic auction would produce substantial revenue. This study assumes that the revenues would be recycled back into

Annual Growth Rates in Potential and Actual Gross Domestic Product, 2005-2010



the Transition Period

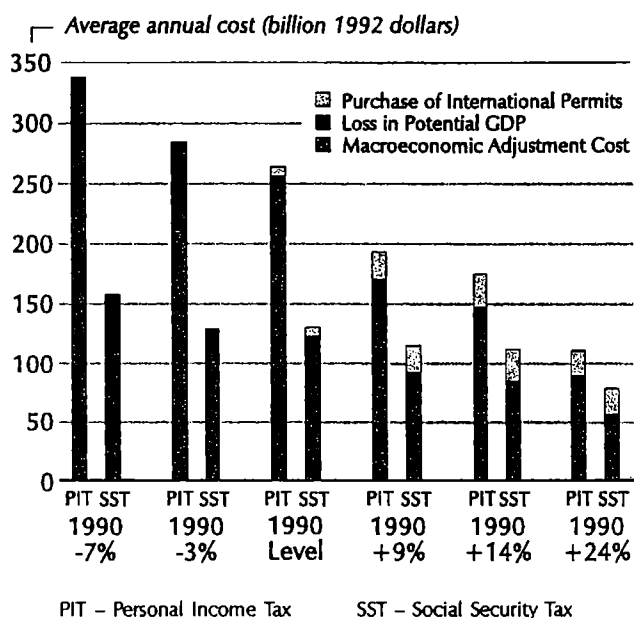
the economy to bolster disposable income and encourage both consumption and investment, counteracting the adverse short-term effects on the economy associated with higher energy prices and speeding the transition to equilibrium. Taking money out of the economy through a carbon price and then returning it encourages a shift in priorities that accomplishes the goal of achieving a carbon emissions reduction while moderating the impacts on the economy. It modifies the national energy mix and makes the overall economy less energy-intensive, while partly compensating consumers and business for the loss in income resulting from higher energy prices. EIA evaluates two illustrative recycling cases: one providing rebates via reductions in the personal income tax, and the other through the social security tax.

EIA projects the loss in actual GDP in 2010 to range between \$61 billion and \$183 billion if revenues are recycled via a reduction in social security taxes, and between \$96 billion and \$397 billion if they are recycled via a reduction in personal income taxes (1992 dollars). Again, the economy grows even during the period of adjustment but does not reach the levels of growth in potential GDP. Although there is a definite slowing of economic growth during the transition period, actual GDP returns to its potential path, so the effects on the economy are almost totally muted over the longer term.

The total cost to the economy can be estimated as the loss in actual GDP (the loss in potential GDP plus the macroeconomic adjustment cost) plus the purchase of international permits. It is assumed that the U.S. will purchase international permits at the marginal abatement cost in the U.S., i.e., the domestic carbon price. Total costs range from an average annual level for the period 2008 to 2012 of \$77 billion to \$338 billion 1992 dollars depending on the carbon reduction case and how funds are recycled back to the economy.

As energy prices rise in the United States, downstream prices for all goods and services are affected. A rule of

Annual Cost of Carbon Reductions to the U.S. Economy, 2008-2012



thumb for the year 2010 is that each 10-percent increase in the level of aggregate energy prices may lead to a 1.5- percent increase in producer prices and a 0.7- percent increase in consumer prices. Final prices for goods and services in the 1990+9% case, as shown by the CPI, are approximately 3.5 percent higher than the Reference Case by 2010 if carbon permit revenues are recycled through a personal income tax rebate, and 2.0 percent higher if revenues are recycled through a social security tax rebate.

Throughout these cases, the role of monetary policy is critical. Higher energy prices place upward pressure on interest rates. Based on past behavior of the Federal Reserve Board, it is assumed that they will adjust interest rates to moderate the impact on the economy and return it to its long-run path.

For Reference: A Matrix of Variables for

Selected Variables in the Carbon Reduction Cases, 1996 and 2010

Variable	1996	2010						
		Reference	1990 +24%	1990 +14%	1990 +9%	1990	1990 -3%	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—average all grades)	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 ^c	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 ^c	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 Percentage 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

^aThe carbon revenues do not include fees on the nonsequestered portion of petrochemical feedstocks, nonpurchased refinery fuels, or industrial other petroleum.

^bCarbon permit revenues are assumed to be returned to households through personal income tax rebates.

^cActual Gross Domestic Product can differ from the Potential Gross Domestic Product, a measure of the productive capacity of the economy, when labor is not at its full employment level and capital is not at a high level of utilization.

Cases Analyzed by EIA

Selected Variables in the Carbon Reduction Cases, 1996 and 2020

Variable	1996	2020						
		Reference	1990 +24%	1990 +14%	1990 +9%	1990	1990 -3%	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—average all grades)	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 ^c	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 ^c	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 Percentage 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

^aThe carbon revenues do not include fees on the nonsequestered portion of petrochemical feedstocks, nonpurchased refinery fuels, or industrial other petroleum.

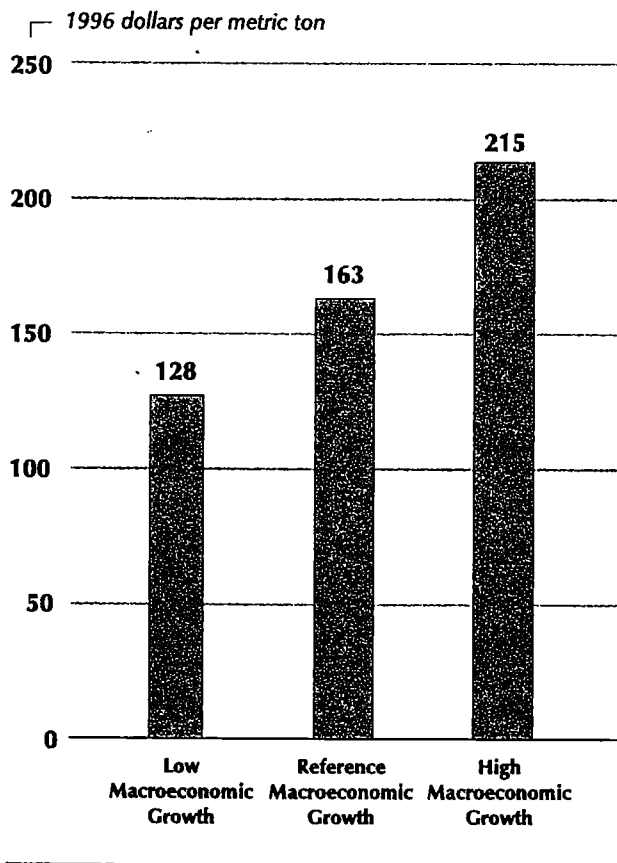
^bCarbon permit revenues are assumed to be returned to households through personal income tax rebates.

^cActual Gross Domestic Product can differ from the Potential Gross Domestic Product, a measure of the productive capacity of the economy, when labor is not at its full employment level and capital is not at a high level of utilization.

Would Some Changes In Assumptions Revise

The House Science Committee asked EIA to determine how sensitive the results of its analysis might be to changes in three basic assumptions made for the Reference Case. These were analyzed against the 1990+9% Case, except for the changes in nuclear power assumptions. The changes can be framed as three questions.

2010 Carbon Prices in Three 1990+9% Cases



Suppose . . . underlying economic growth of the nation were higher (or lower)?

If higher or lower growth is assumed in such factors as population, the labor force, and productivity, there would be differences in industrial output, inflation rates and interest-rate levels. Assuming a range of annual GDP growth between 1996 and 2020 from 1.3 to 2.4 percent, compared to 1.9 percent in the Reference Case, total U.S. energy consumption would be lower/higher in 2010 by about 2.2 quadrillion Btu. (A quadrillion Btu is equivalent to consuming about 500,000 barrels of oil per day for one year). To meet the same level of carbon reductions with higher (or lower) energy consumption, the "carbon price" would also be higher (or lower)—as shown on the adjoining graph. With a higher carbon price, less coal and more natural gas, renewables, and nuclear power are used.

Suppose . . . technology advanced more rapidly as a result of increased national emphasis on research and development (or suppose—technology choices stayed as they were in 1998)?

The technology assumptions in the main cases in the EIA report reflect expert engineering opinion of likely technological advances—i.e., they are not technologically pessimistic. Nevertheless, to analyze the effects of even more advanced technology, assumptions were developed by energy technology experts for the end-use and generation sectors, considering possibilities based on increased Research and Development. This could mean earlier introduction of products and processes, lower costs, and higher efficiencies than assumed in the Reference Case. It was also assumed that technology for extracting and storing carbon emissions from coal and natural

These Projections? How? How Much?

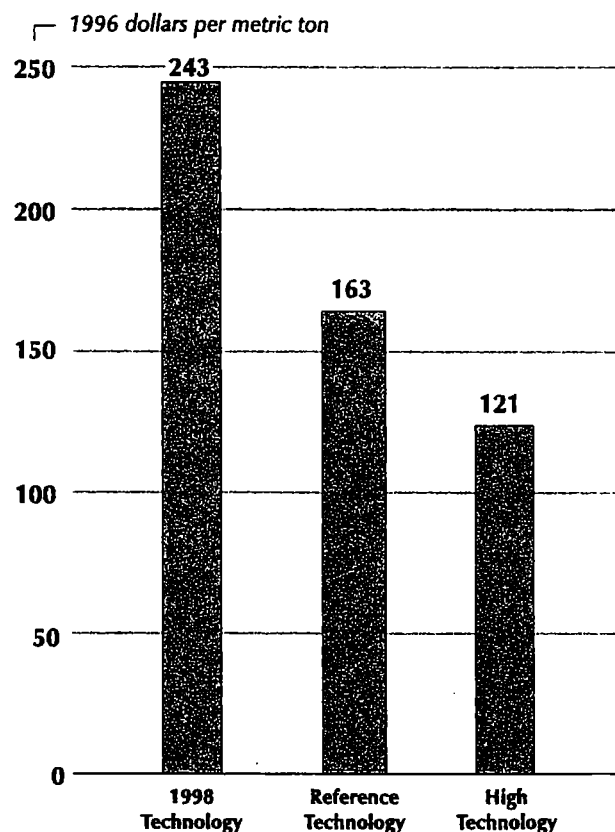
gas-fired electric generators might become available. A "low tech" sensitivity assumes all future choices are made from today's technology.

The range of energy consumption differences was similar to the GDP growth sensitivity. Higher technology lowers energy consumption in 2010 by 2.1 quadrillion Btu; freezing technological progress forces consumption to grow by an extra 1.5 quadrillion Btu. The related graph compares carbon price changes. In the residential and commercial sectors, lower carbon prices encourage higher consumption and balance the effect of advanced technology. Efficiency improvements and lower carbon prices allow coal use in generation to be about 40 percent higher in 2010. With low technology, converse trends prevail; more natural gas, nuclear energy, and renewables are needed to meet carbon reduction targets. The industrial and transportation sectors are more sensitive to technology changes than to price changes.

Suppose . . . building of nuclear power plants resumed in this country?

Because new nuclear plants did not compete economically with fossil and renewable plants in the 1990+9% Case, this sensitivity was analyzed against 1990-3% Case (with a carbon price of \$294 in 2010). Some of the extra costs assumed for "first of a kind" advanced-design plants were also relaxed. Under these conditions, 1 to 2 new 600-megawatt nuclear plants would be added by 2010; and 2020 could see about 68 new plants. Because most would start up after the 2008-2012 period, carbon prices in 2010 would be relatively unchanged. By 2020, however, the 1990-3% Case carbon price of \$240 per metric ton would be reduced to \$199. Because of the lower carbon price in this sensitivity, all sectors have higher energy consumption.

**2010 Carbon Prices in
Three 1990+9% Cases**



How (and Why) Do These Results Differ from Other Projections?

Why haven't all projections agreed? Other analyses of the Protocol have different results because of different assumptions for—

- Economic growth in the United States and the resulting emissions—these alter the base from which reductions must be made
- The extent of international trading, joint implementation, and the clean development mechanism
- Cost and efficiency of new technologies
- How rapidly and to what extent consumers respond to energy price increases—observations of past behavior indicate that consumers may change habits rather slowly
- How rapidly capital stock turns over—much of the equipment purchased in 1999 will likely still be in use in 2010 but some analyses do not capture all the transition costs
- When actions to reduce emissions begin—EIA assumes that actions begin in 2005 but some analyses assume actions have already begun
- How much knowledge consumers have of future events and how early they begin to adjust. EIA assumes that end-use consumers begin to adjust when a price increase occurs, but some analyses assume that adjustments begin well in advance

Six **other** projections of carbon prices and their effects, from various sources, are outlined in Chapter 7 of the full report. Two cases were analyzed: the 1990-7% Case in which the United States is assumed to reduce carbon emissions to 7 percent below 1990 levels for the period 2008-2020 without the benefit of sinks, offsets, international carbon permit trading, or the Clean Development Mechanism (CDM); and a best estimate of the impact on U.S. energy markets if sinks, offsets, and emissions trading among the participating developed nations (Annex I) were allowed, but not global trading or CDM.

If the United States is required to achieve stabilization at the 1990-7% levels without Annex I trading and no credit for sinks and offsets, the estimates of carbon prices required in 2010 range from a low of \$221 per metric ton to \$348 per metric ton, with the vast majority in the \$265 to \$295 per metric ton range. Actual GDP losses are projected to range from \$102 to \$437 billion dollars in 2010 (1996 dollars). With Annex I trading and credits for sinks and offsets from other gases, the carbon price ranges between \$100 per metric ton to \$175 per metric ton and the loss of actual GDP ranges between \$56 and \$207 billion dollars in 2010. Estimates of internationally purchased carbon credits by the U.S. range from 147 to 288 million metric tons.

This report was prepared by the Energy Information Administration, the independent statistical and analytical agency within the Department of Energy. The information contained herein should be attributed to the Energy Information Administration and should not be construed as advocating or reflecting any policy position of the Department of Energy or of any other organization. Service Reports are prepared by the Energy Information Administration upon special request and are based on assumptions specified by the requester.

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Energy Information Administration Reports on Greenhouse Gas Emissions:

- *Impacts of the Kyoto Protocol on U.S. Energy Markets and Economic Activity*, published in October 1998, with analysis of the Kyoto Protocol
- *Annual Energy Outlook 1998*, published in December 1997, with projections of domestic energy carbon emissions through 2020
- *International Energy Outlook 1998*, published in April 1998, with projections of international energy carbon emissions through 2020
- *Emissions of Greenhouse Gases in the United States 1996*, published in October 1997, with an inventory of all domestic greenhouse gas emissions
- *Mitigating Greenhouse Gas Emissions: Voluntary Reporting*, published in October 1997, reporting voluntary actions in 1995 to reduce greenhouse gases in the United States
- *Greenhouse Gas, Global Climate Change, and Energy*, an information brochure on greenhouse gases

What Are Some of the Issues in Reducing Carbon Emissions in the United States?

Availability and cost of technology

Consumer acceptance of more advanced or efficient technologies
—and of nuclear and renewable generating plants

Identification of fiscal and monetary policies
to moderate economic impacts

Feasibility of the electricity, natural gas, and renewable industries
to adjust to the new requirements

Possible changes in industrial composition

Timing and phase in of the necessary transitions

**TECHNOLOGY AND GREENHOUSE GAS EMISSIONS:
AN INTEGRATED SCENARIO ANALYSIS
USING THE LBNL-NEMS MODEL**

Jonathan G. Koomey, R. Cooper Richey, Skip Laitner,
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October 1, 1998

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EXECUTIVE SUMMARY

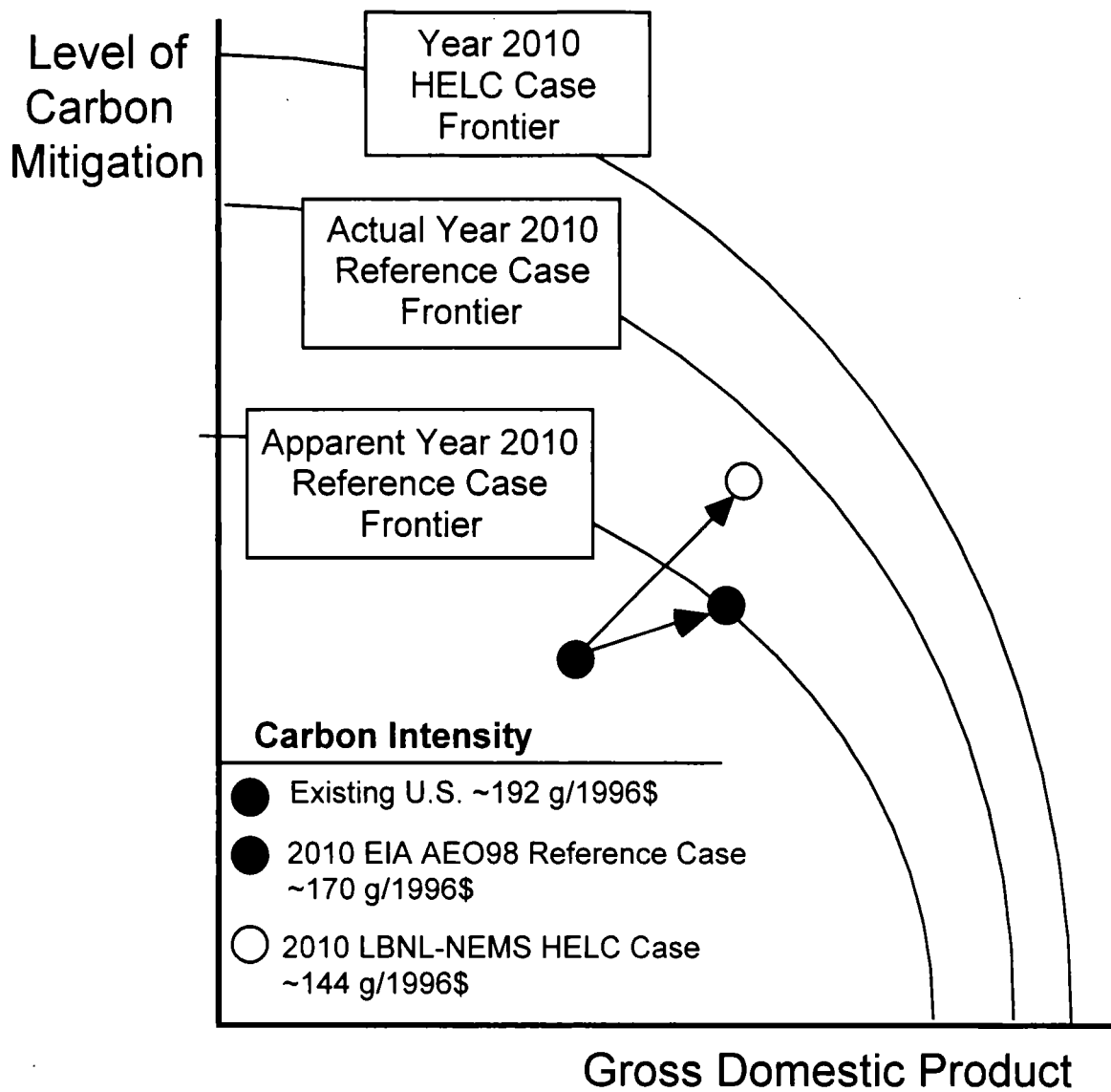
The common perception among many policy makers and industry leaders is that the twin objectives of reducing greenhouse gas emissions and promoting a more competitive economy are inherently contradictory. Many believe that anything done to lower such emissions will necessarily restrict economic activity. Others argue that allowing the economy to move forward with current levels of efficiency will promote the growth in greenhouse gas emissions. Because of the "unavoidable tradeoff" between these two objectives, the various industry, government and environmental groups wage a constant policy battle over which objective merits the greater support. From a perspective of cost-effective investments in technology, however, it becomes increasingly clear that these two goals are not at all contradictory. The reason is that the U.S. economy falls short of an optimal level of overall carbon efficiency.

Figure ES-1 on the following page illustrates the different points of view in a schematic way. Most modeling of the costs of reducing carbon emissions assumes that the reference case carbon intensity is on the frontier, and that any increase in carbon mitigation must also result in a decrease in Gross Domestic Product (this assumption corresponds to the curve labeled "Apparent Year 2010 Reference Case Frontier"). Our analysis demonstrates that the "Actual Year 2010 Reference Case Frontier" is further out than the apparent frontier, which means that both carbon mitigation and GDP can be increased at the same time. In addition, since the frontier is a function of technology, and the cost of that technology is a function of policy choices made between now and 2010, taking aggressive actions now to reduce carbon emissions can actually move the frontier further out than it would be given the technologies that exist in the reference case. This possibility is represented by the curve labeled "Year 2010 High Efficiency Low Carbon (HELC) frontier".

This report describes an analysis of possible technology-based scenarios for the U.S. energy system that would result in both carbon savings and net economic benefits. We use a modified version of the Energy Information Administration's National Energy Modeling System (LBNL-NEMS) to assess the potential energy, carbon, and bill savings from a portfolio of carbon saving options. This analysis is based on technology resource potentials estimated in previous bottom-up studies, but it uses the integrated LBNL-NEMS framework to assess interactions and synergies among these options.

Based upon the LBNL-NEMS analysis conducted in this study, the data suggest that the U.S. economy now emits 192 grams of carbon for each dollar of value-added (measured as GDP in constant 1996 dollars) that it produces. With a "normal" rate of improvement, it appears that by the year 2010, the nation could reduce this emissions rate to about 170 grams per dollar. Despite this improvement in the emissions rate, however, the anticipated growth in the economy will increase total carbon emissions to 1803 MtC in 2010, or to about 23 percent above 1996 levels. Perhaps more important, implementing a set of policies to encourage the development and deployment of energy-efficient and low-carbon technologies can close this gap — to the benefit of both the climate and the economy. In this study, we find a cost-effective path that can reduce the rate of carbon emissions to as low as 144 grams per dollar of GDP. This will reduce carbon emissions to about 1500 MtC by 2010. Other studies suggest that with the right mix of policies and technologies, the production possibilities frontier might actually extend well beyond that described in this report (ASE et al. 1997, Brown et al. 1998, Interlaboratory Working Group 1997, Krause 1996, Laitner et al. 1998).

Figure ES-1: Schematic production possibility frontiers



PREFACE

The U.S. Environmental Protection Agency (EPA) has a long history of examining the role of technology in strengthening both the nation's environmental quality and overall economic activity. Following that same path, EPA's Office of Atmospheric Programs (OAP) has initiated a number of analytical exercises to explore opportunities for reducing the emission of greenhouse gases through cost-effective investments in energy-efficiency and renewable energy technologies. This report builds on one set of results from this larger effort.

The work reviewed in this report was made possible through EPA funding of the Lawrence Berkeley National Laboratory (LBNL). In undertaking the assignment, LBNL was specifically asked to evaluate how different assumptions about technology diffusion might affect the opportunity for cost-effective reductions of energy-related carbon emissions. The work was done under the overall guidance of EPA's Skip Laitner and LBNL's Jonathan G. Koomey.

This report benefited from the contributions of a peer review panel. Their extensive comments are summarized in the appendix of this report, together with an indication of how we incorporated their suggestions into our analysis. Indeed, the comments of the review panel, together with our own thoughts in response to those comments, may provide an equally valuable background document for those interested in the climate change issue.

The members of the peer review panel (in alphabetical order) who generously shared their insights with us include:

Dr. Stephen Bernow, Tellus Institute
Boston, MA

Dr. Stephen DeCanio, University of California-Santa Barbara
Santa Barbara, CA

Dr. Neal Elliott, American Council for an Energy-Efficient Economy
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Washington, DC

Dr. Frances Wood, On Location, Inc.
Dunn Loring, VA

The listing of individual affiliation for each of our review panel members is for identification purposes only. Although we gladly acknowledge the involvement of the individual members of the peer review panel, we do not mean to imply their endorsement of this report. The final responsibility for the results of the analysis and the content of the report lies solely with the authors.

Please note: The current edition of this report has undergone extensive technical review and been modified to reflect the comments received. It is still undergoing administrative review at Lawrence Berkeley National Laboratory in preparation for becoming a final LBNL report. The authors do not anticipate any substantial changes based on that administrative review, but the report will not officially be a final report until that review is complete. This review will be completed before the end of September 1998.

This work was supported by the Office of Atmospheric Programs of the U.S. Environmental Protection Agency. Prepared for the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

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INTRODUCTION

The Kyoto protocol was a watershed event in the history of environmental policy. For only the second time in history, national governments have agreed to seek binding targets for pollutants that have global effects. If the U.S. decides to ratify the treaty and meet these targets, it will need to seek aggressive reductions of greenhouse gas emissions in the 2008 to 2012 time frame.

While many analyses have attempted to assess the potential costs of such a commitment, the debate is now shifting in a subtle way. An increasing number of business leaders and policy analysts are instead asking the question: "What are the key policy choices that might actually enhance our industrial competitiveness and still lead to a significant reduction of greenhouse gas emissions?" Critical to this policy perspective is an investment-led deployment of cost-effective technology that can both save money and reduce such emissions.

Unfortunately, none of the existing policy models have successfully incorporated a full range of technological change within their analytical framework. In other words, such models understate the opportunity for widely available but underutilized and cost-effective technologies to reduce greenhouse gas emissions. Nor do they anticipate or allow new technologies to emerge in response to changing conditions in the marketplace. Hence, much of the modeling response to any given climate change strategy reflects a more limited technical capacity to respond positively to changing price signals, non-price policy initiatives, and economic conditions. For that reason, there is a need: (a) to identify the broader range of possible technological change through off-line analysis; and (b) to capture the magnitude and direction of technological change within existing policy models to evaluate the potential economic impacts, using a scenario-based approach.

Developing a wide range of alternative technology scenarios can help us better understand the ordinary business of making better choices with respect to both the environment and the economy. In the words of Kenneth Boulding: "Images of the future are the keys to choice-oriented behavior." For this reason, the analysis in this paper builds on previous estimates of possible "technology paths" to investigate four major components of an aggressive greenhouse gas reduction strategy:

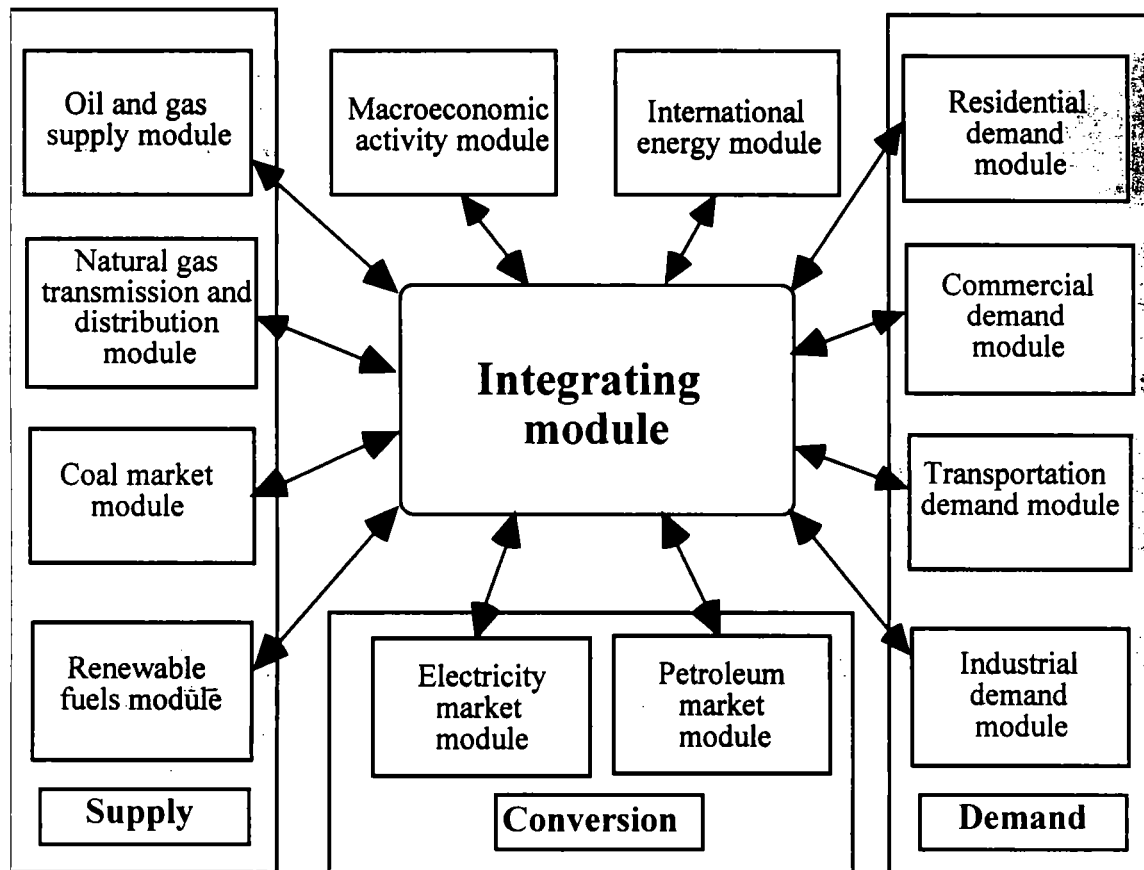
- (1) the large scale implementation of demand-side efficiency, comparable in scale to that presented in two recent policy studies on this topic;
- (2) a variety of "alternative" electricity supply-side options, including biomass cofiring, extension of the renewables production tax credit for wind, increased industrial cogeneration, and hydropower refurbishment.
- (3) the economic retirement of older and less efficient existing fossil-fired power plants; and
- (4) a permit charge of \$23 per metric ton of carbon (1996\$/t),¹ assuming that carbon trading is implemented in the US, and that the carbon permit charge equilibrates at this level. This level of carbon permit charge, as discussed later in the report, is in the likely range for the Clinton Administration's position on this topic.

¹In this paper, all monetary figures are in constant 1996 dollars, unless otherwise specified. All references to tons of carbon are to metric tons.

These four options are important contributors to large carbon reductions identified in the so-called "5-lab study" released in the fall of 1997. The extensive engineering and economic analysis contained in the 1997 study suggested that cost-effective technologies could reduce carbon emissions by as much as 390 million metric tons (MtC) by 2010 at a permit price of \$50/tC (Interlaboratory Working Group 1997). Perhaps more important for this analysis is that both the 5-lab study assumptions and each of the four options referenced above can be represented in the U.S. Department of Energy's (US DOE's) National Energy Modeling System (NEMS) in an accurate and conceptually clear way. Integrating the various technology assumptions within the NEMS framework allows us to capture dynamic feedbacks, particularly those between energy demand and prices.

NEMS is an all-sector, integrating model of the US energy system that is exemplary for its comprehensive treatment of supply-side technologies (particularly in the electricity sector) and its detailed treatment of energy demand at the end-use level (see Figure 1).

Figure 1: Schematic representation of the NEMS modeling system



Adapted from US DOE (1998b).

We rely on a modified version of the NEMS model² as an accounting tool, but also to capture the income, price, and intersectoral effects on both energy demand and fuel prices. Such interactions are treated exogenously in most bottom-up studies. We set out to determine whether an endogenous treatment within the LBNL-NEMS framework would alter the main conclusions of such studies.

Analytical objectives of this study

The goals of this analysis are twofold. The first is to generate scenarios using LBNL-NEMS to explore the effects of aggressive but cost-effective US effort to implement certain demand and supply-side technologies that reduce greenhouse gas emissions. The second is to investigate synergies and interactions between demand and supply-side options to derive lessons for policy. An integrating model such as LBNL-NEMS is particularly useful for such explorations.

Our analysis parallels at least two previous efforts undertaken by the Energy Information Administration (EIA) itself. In both 1996 and 1997, EIA analysts examined the effect of accelerated technological change on the U.S. energy markets (Boedecker et al. 1996, Kydes 1997). While the two previous EIA reports offer an important step forward with respect to understanding the role of technological progress within an energy and economic framework, the scenarios in this study differ in two ways.

First, in these earlier studies, the EIA analysts made less-detailed assumptions about technological progress than done for the Five-Lab study, for example. For instance, within the industrial model EIA assumed that the annual rate of change in energy intensity would decline by about 1.4% compared to the reference case forecast of 1.0%. In our analysis we relied on the Long-Term Industrial Energy Forecast (LIEF) model (Ross et al. 1993) and the Five-Lab Study to define cost-effective reductions in energy intensity (Interlaboratory Working Group 1997). Second, the EIA analyses were independent of any real policy scenarios while our analysis builds upon the kind of technological progress and behavioral changes one might expect to see in a post-Kyoto world. Indeed, many of the policy options that might drive the kind of technological changes envisioned in the Five-Lab study are now in various stages of review by the Administration and Congress (Laitner 1998).

Incomplete technology portfolio

This analysis, because of time constraints, implemented an incomplete portfolio of carbon reduction options. For example, the Five-Lab study included carbon savings from fuel cells, biomass and black liquor gasification, cement clinker replacement, industrial aluminum efficiency technologies, ethanol in light duty vehicles, repowering of coal plants with natural gas, life extension of nuclear power plants, and fossil power-plant efficiency improvements. Our analysis also includes less than one-third of the carbon savings from wind generation that is tapped in the Five-Lab study. It further omits carbon savings from the use of photovoltaics, landfill gas, combined heat and power in non-industrial space heating applications, and advanced efficiency options in the building sector. We include none of these carbon savings options, and for this reason, the total

² Hereafter we use the term LBNL-NEMS to refer to our version of NEMS, to denote that we make substantial modifications to the NEMS input data and some code changes to model the scenarios of interest. When we refer to generic characteristics of the model that apply to both the standard AEO 98 version and to our version, we still use the term NEMS.

carbon savings calculated in our High Efficiency/Low Carbon scenario should be viewed as significantly less than the full potential.

METHODOLOGY

The scenario approach

None of the existing policy models capture the full effects of policy-induced technological, institutional, and behavioral changes, especially as they relate to climate change strategies. For this reason we use the scenario approach in our analysis. The purpose of scenario analysis, as explained by Peter Schwartz in his now classic book, *The Art of the Long View*, is to explore several possible futures in a systematic way (Schwartz 1996). Schwartz builds on the work of Pierre Wack, a planner in the London Offices of Royal Dutch/Shell whose own scenario analysis helped the international petroleum enterprise respond quickly and successfully to the Arab oil embargo following the Yom Kippur war in 1973 (Wack 1985a, Wack 1985b).

Schwartz notes that scenarios are tools "for ordering one's perceptions about alternative future environments. The end result," he says, "is not an accurate picture of tomorrow, but better decisions about the future." No matter how things might actually turn out, both the analyst and the policy maker will have "on the shelf" a scenario (or story) that resembles a given future and that will have helped them think through both the opportunities and the consequences of that future. Such a story "resonates with what [people] already know, and leads them from that resonance to re-perceive the world". Scenarios, in other words, "open up your mind to policies [and choices] that you might not otherwise consider."

Most of the current thinking about how the United States might cope with climate change is built around a reference case (the Annual Energy Outlook 1998, or AEO98) that projects both energy use and carbon emissions through the year 2020. Under a business-as-usual strategy, the nation's economy is projected to grow by nearly 50 percent between 1998 and 2020. Reflecting some improvements in overall energy efficiency, carbon emissions are projected to grow slightly more than half as fast, increasing about 28 percent in the years 1998 and 2020 (US DOE 1997a). This scenario, which we use as our baseline, might be appropriately labeled as "The Official Future."

A number of studies suggest that enforcing the so-called Kyoto Protocol will force American businesses and consumers to drastically cut their energy use in order to reduced their carbon emissions. Such huge cuts, they assert, will greatly weaken overall economic activity (Novak 1998). These analyses are generally based on modeling methodologies that ignore the potential for energy efficiency technologies to concurrently save money and reduce pollution, and rely on inadequate characterizations of carbon saving energy supply options (Krause et al. 1993).

In contrast, our analysis investigates scenarios where programs and policies promote the adoption of new efficiency and low carbon supply technologies in an aggressive way. The emissions reductions contained in our scenarios *assume that the appropriate investments are actually made as a result of effective policies that are adopted within the United States*. Our report does not set forth the details of such policies, but explores the implications for a scenario in which they are assumed to take effect.

We believe that such policies are capable of promoting the adoption of carbon saving technologies at the levels contained in our scenario, as shown in other analyses. For example, an analysis of programs either now in place or now under consideration —

including such programs as the Climate Change Action Plan (CCAP), the President's Climate Change Technology Initiative (CCTI), and the Administration's proposed plan for electric utility restructuring — indicates that the proposed programs and funding levels might obtain as much as 250 MtC of carbon reductions. These are reductions that are not fully reflected in other analytical scenarios, including the reference case forecast. Hence, a reasonable extension of such programs might allow the nation to secure the balance of the reductions suggested in this report (Laitner 1998). Similarly, a recent analysis by the American Council for an Energy-Efficient Economy (Geller et al. 1998) indicates that just five major policy strategies could obtain more than 330 MtC of carbon reductions.

We base many of our assumptions for the low carbon resource potentials on the recently published study, *Scenarios of U.S. Carbon Reductions: Potential Impacts of Energy Technologies by 2010 and Beyond* (Interlaboratory Working Group 1997), but we rely on other sources as well. The Interlaboratory report is exemplary for its in-depth examination of technological options to reduce carbon emissions. The study uses a bottom-up modeling methodology to assess the carbon saving resource potentials in the U.S. residential, commercial, industrial, transportation, and utility sectors, relying on the technical expertise of staff at five national laboratories. It finds that, although significant investments and program spending are necessary to support a climate change mitigation strategy, large carbon reductions are possible at zero or negative total net costs to society.

We do not limit our analysis to those options contained in the Interlaboratory report, nor do we address all the options considered in that report. Rather, the scenarios we create are intended to show the carbon savings potential for some important options without claiming to be comprehensive. We believe that scenarios implemented in the LBNL-NEMS modeling framework (even those that are not comprehensive in scope) can help explore important policy issues related to creating a low-carbon world.

Demand side

The first step in building our scenarios was to create energy demand scenarios that are roughly comparable to those in the 5-lab study's High Efficiency Low Carbon case (HE/LC) or in the Energy Innovations study (ASE et al. 1997, Interlaboratory Working Group 1997). In this analysis we made changes in discount rates, technology costs, and growth trends (where necessary). We based these changes on our past experience of end-use demand modeling and associated data. These changes reflect a low-carbon world in which aggressive policies and programs accelerate the development of new efficiency technologies, reduce their cost, and make it more likely that people and institutions will adopt them. Appendix A describes in detail how the NEMS input files were modified to implement these changes. Once the changes are implemented, NEMS then evaluates the opportunity for technology improvements given normal capital stock turnover within each sector of the economy.

On the demand side, NEMS interprets a series of "hurdle rates" (sometimes referred to as "implicit discount rates") as a proxy for all the various reasons why people don't purchase apparently cost-effective efficiency technologies. They include constraints for both the consumer (purchasing) and for the supplier (product manufacturing and distribution). Among the constraints are transaction costs, manufacturer aversion to innovation, information-gathering costs, hassle costs, misinformation, and information processing costs. The hurdle rates, then, embody the consumers' time value of money, plus all of the other factors that prevent the purchase of the more efficient technologies. In this regard, the NEMS modeling framework follows a long and rich history in the economics of energy efficient technology adoption (DeCanio 1998, Howarth and Sanstad

1995, Koomey et al. 1996, Meier and Whittier 1983, Ruderman et al. 1987, Sanstad et al. 1993, Train 1985). See Ruderman et al. (1987) for a discussion of how implicit discount rates differ from the more standard use of the term "discount rate" with which most economists are familiar. In the residential and commercial sectors, for example, the financial component of the hurdle rate is set at 15 percent (in real terms) with the other institutional and market factors pushing such rates to well above 100 percent for some end-uses. Because our scenario embodies an emissions trading program that is coupled with a variety of non-price policies to eliminate many of the barriers to investing in cost-effective efficiency technologies, we reduce the implicit discount rates for many end-uses in our High-efficiency/low-carbon Case.

Residential and commercial

For the residential and commercial demand sectors, we roughly matched site energy consumption to the 5-lab study's HE/LC case results by end-use and fuel type. For major end-uses, logit parameters were modified such that the implicit discount rate was reduced to 15% for all residential technologies after the year 1999 and to roughly 18% for all commercial technologies after the year 1999. For minor end-uses that are treated in lesser detail in NEMS (such as miscellaneous electricity and residential lighting) basic input assumptions (such as energy consumption growth rates and lighting efficiencies and market shares) were modified to match the 5-lab study efficiency potentials.

Industrial

We started with the Energy Information Administration's (EIA) Hi-Technology Case in the Annual Energy Outlook (US DOE 1997a). We then modified parameters so that total electricity and fuel savings matched the results (in percentage terms) of the High Efficiency runs of Argonne National Laboratory's Long-Term Industrial Energy Forecasting (LIEF) model (Ross et al. 1993). In particular, we changed parameters in the Hi-Technology Case that characterize the rate of efficiency improvements over time and the rate of equipment turnover for all the NEMS industrial sub sectors, which include:

- 1) Agricultural Production - Crops
- 2) Other Agriculture including Livestock
- 3) Coal Mining
- 4) Oil and Gas Mining
- 5) Metal and Other Nonmetallic Mining
- 6) Construction
- 7) Food and Kindred Products
- 8) Paper and Allied Products
- 9) Bulk Chemicals
- 10) Glass and Glass Products
- 11) Hydraulic Cement
- 12) Blast Furnaces and Basic Steel
- 13) Primary Aluminum
- 14) Metals-Based Durables
- 15) Other Manufacturing

All other parameters other than equipment turnover and rate of efficiency improvements are identical to those found in the AEO98 reference case.

Transportation

For the transportation sector, the NEMS input files and source code modifications used in the 5-lab study were used as the basis for our LBNL-NEMS analysis. The 5-lab study NEMS technology input file was designed for the AEO97. We updated the technology input file by extending the trends implicit in the 5-lab study from 2015 to 2020 and accounting for changes in the model structure from AEO97 to AEO98. 5-Lab Study modifications to the NEMS input files and source code included changes to behavioral variables (discount rates, payback periods, load factors, and the tradeoff between horsepower and efficiency) and technological parameters (capital costs, entry years, penetration rates, and efficiency trends).

Supply side

On the supply side, we include carbon permit trading, forced retirements of old fossil-fired electric generators, hydroelectric refurbishments, extension of the renewables production tax credit for wind, biomass cofiring, and expansion of industrial cogeneration. We implement those measures as described below.

Carbon permit trading

We assume that the emissions trading system is implemented by giving away permits initially. Any transactions in the trading system to allow emissions up to the Kyoto cap constitute transfer payments between people and institutions within the U.S., while any such transactions to exceed the Kyoto cap are a real cost to the U.S. We treat these two components of the carbon trading separately in the aggregate cost-benefit analysis below.

We implemented the carbon trading system as a Carbon Charge early in the forecast period to give the model time to adjust before 2010. This assumption reflects the reality that consumers and companies will act with foresight, knowing that an emissions trading regime is soon to be implemented. The Carbon Charge values (in 1996 dollars) were increased linearly by year from \$0/t in 2000 to \$23/t in 2004, and kept constant in real terms at that level after 2004.

The size of the carbon permit trading fee is based on the recent consensus within the Clinton Administration about what equilibrium price might result from international emissions trading. We included this fee in our analysis to see what additional contribution might come from domestic carbon saving options when the alternative was purchasing carbon permits at \$23/tC. As a sensitivity case, we also estimated carbon savings from a permit trading fee of \$50/tC, which was the main fee level included in the 5-lab study's analysis (we include this estimate in Appendix D, but do not discuss it in this paper).

In the face of the carbon trading system, low or zero carbon emitting technologies, such as natural gas thermal or renewables, will be favored in utility dispatch and capacity expansion, resulting in a shift in the electricity generation fuel mix in favor of these options and against others, notably coal.

Economic retirement of fossil-fired plants

Existing fossil-fired generation is an important source of criteria air pollutants (particularly SO₂, NO_x, and particulates). These plants have largely been "grandfathered"

by existing clean air regulations, so they are much dirtier than new fossil-fired plants being built today. They are also generally less efficient, so their carbon emissions per kWh are also greater than those of new fossil-fired plants. Because they are relatively expensive to operate, they are relegated to peaking and intermediate operation, so they generate fewer kWh than a new baseload plant would.

The AEO98 version of NEMS does not allow endogenous premature retirement of existing plants, although the AEO99 version will. We found in previous analysis that some level of retirements beyond those considered in the AEO98 base case will actually reduce the total energy bills below those of AEO98 levels (or below that of our high efficiency/low carbon case without the retirements). We therefore implemented cost-effective capacity retirements for old, inefficient fossil-fired plants within LBNL-NEMS.

When we evaluate the costs of retirements of existing fossil-fuel fired generating capacity compared to the baseline, we base our decision rule for how many plants to retire on total energy bills, not just electricity bills. An analyst narrowly focused on the optimal level of retirements in a restructured electricity sector would examine the effect of such retirements by limiting her assessment to electricity bills. But one concerned with the total societal cost of carbon reductions associated with such retirements must focus on total energy bills, because fuel price changes and fuel switching will affect the overall results.

In this first phase of our analysis, we explore one level of coal retirements (16 GW), which corresponds to retiring all coal steam plants built before 1955 that are still existing in 2020 in the AEO98 reference case. We removed these plants over the years 2000 to 2008 through changing the "retirement year" field of the plant data file.

We also add retirements of all oil and gas-fired steam power plants (about 100 GW relative to the AEO98 reference case). We found that this level of retirements always saves money and reduces both criteria pollutant and carbon emissions, so we included it in our retirement scenarios. The monetary savings is the result of the relatively high fixed O&M costs for these plants combined with their low efficiency and low capacity factors.

Hydroelectric refurbishments

Refurbishing existing hydro facilities is one of the most cost effective options for expanding renewable power generation. Studies both in Europe and the U.S. show that refitting old dams with bigger and more efficient turbines is inexpensive and has small environmental effects (Krause et al. 1995a, SERI 1990). We model such refurbishments by increasing hydroelectric capacity by 13 GW by the year 2008, the same amount analyzed in the 5-lab study. This capacity is distributed in equal parts across all 13 NEMS electricity market module regions.

Extension of the renewables production tax credit for wind

The current renewables production tax credit of 1.5¢/kWh will expire on January 1, 1999. We extended this credit for wind through 2020 (it is implemented as a negative variable O&M charge). This policy change is distinct from the assessment of the wind generation potential in the 5-lab study, and it results in only about one third as much wind generation being implemented as was included in that study.

Biomass cofiring

We converted 10 GW of coal-fired capacity to combust biomass by 2010 (scaling up linearly from 0 GW/year in 2000). This level of cofiring is the same amount analyzed in the 5-lab study. We ensured that no plants affected by our retirement scenarios would be converted to burn biomass.

Expansion of industrial cogeneration

We roughly doubled current levels of gas-fired cogeneration by adding gas-fired industrial cogeneration capacity, increasing it by 35 GW by 2010 (ramped up linearly starting at 0 GW/year in 2000). This capacity generates 214 TWh per year (70% electrical capacity factor), while also supplying heat for process use. This level of capacity additions is based on the analysis in US DOE (1997b), but is less than the roughly 50 GW potential for advanced turbine cogeneration in the HE/LC case of the 5-lab study.

Combined scenarios

We combine these options in different scenarios to explore relevant dimensions of uncertainty. Our hypothesis is that some of these options will work together to achieve carbon reductions greater than the sum of the carbon reductions attributable to each option separately (we call this situation one with "positive synergy"). Others will work against each other, yielding carbon reductions less than the sum of the carbon reductions attributable to each option separately ("negative synergy").

We define the "synergy index" to describe these effects in a quantitative way. Given a set of distinct options to reduce carbon emissions, the synergy index is

$$SI = \frac{\text{carbon savings when options are implemented together}}{\text{sum of carbon savings for each option implemented separately}}$$

For example, if the carbon savings in 2010 for High Efficiency implemented alone is 179 MtC, the savings for the Carbon Charge is 36 MtC, and the total savings when these policies are implemented together are 207 MtC, the synergy index is

$$SI = \frac{207}{179 + 36} = 0.96,$$

which indicates negative synergy because $SI < 1.0$. When High Efficiency, coal retirements, and gas/oil retirements are implemented together, the SI in 2010 is

$$SI = \frac{205}{179 + 12 + 8} = 1.03.$$

The High Efficiency and retirements scenarios work together to create positive synergy.

When exploring the synergy between different policies in the HE/LC case, we focus on the 16 GW coal/100 GW oil-gas steam retirement case, because that is the level of retirements that is cost effective – based on our analysis of the present value of energy bills over the analysis period. When investigating the uncertainties surrounding

retirements, we use all the different retirement levels plus the demand reductions, supply-side options, and carbon permit charge.

Investment costs

Currently, LBNL-NEMS uses capital cost/efficiency curves to choose the appropriate efficiency level for new purchases for some end-uses in the building and transport sectors, but does not pass the total investment costs to the macroeconomic module. For end-uses that are "hard-wired" as well as for the industrial module, there is no investment cost accounting whatsoever.

We estimated investment costs for demand-side efficiency and cogeneration options in our HE/LC case using a spreadsheet that multiplies the costs of conserved energy by end-use from the 5-lab study by the energy savings. This calculation, which is identical in operation to the one used in the 5-lab study's cost-benefit analysis, yields the total annualized investment costs for efficiency improvements (Interlaboratory Working Group 1997). The energy and bill savings we calculate are somewhat different from those of the 5-lab study, as are the total investment costs, in part because of fuel price and other interactions not captured in the 5-lab study's bottom-up analysis, and in part because the technology portfolios differ between the two studies.

For cogeneration, we used capital costs of \$940/kW (1998\$) a lifetime of 20 years, and discount rates of 12.5% and 20% for the optimistic and pessimistic cases, respectively (the discount rates are the same as those used for the cost-benefit calculations in the 5-lab study).

The current cost treatment of LBNL-NEMS on the supply side is largely satisfactory, so with the additional calculation for demand-side costs and cogeneration investments, we can, in a simplified way, properly estimate the total costs of energy services for our HE/LC case.

The programs-based perspective

Our scenario assumes that programs and policies exist that can capture the energy savings potentials identified in the 5-lab study. We assign implementation costs to those programs based on real-world program experience, and express these costs as a percentage of the investment costs. The 5-lab study used a range of 7% to 15% of investment costs for their optimistic and pessimistic cases, respectively, and we follow that convention here. These costs represent a crude estimate of weighted average implementation costs for a mix of voluntary programs (like ENERGY STAR), efficiency standards, tax credits, government procurement, golden carrots, and other non-energy-price components of a carbon reduction strategy. For a detailed example of how to create such a programs-based scenario, see Krause et al. (1995b).

RESULTS

Tables 1a and 1b, on the following page, show the main results for 2010 and 2020 from a subset of our modeling runs. We describe these results below. The High Efficiency case reduces demand in each of the sectors, and in response, the electricity capacity expansion model in LBNL-NEMS builds 30 GW less coal capacity, 77 GW fewer gas-fired combined cycle plants, and 30 GW fewer combustion turbines by 2020. The high efficiency case also reduces natural gas demand, thus reducing gas prices and making gas more competitive with coal. The Carbon Charge promotes fuel switching towards less carbon intensive fuels, favoring natural gas and renewables over coal and oil. The

Retirements Case forces old fossil-fired plants out of the fuel mix, and LBNL-NEMS chooses new plants to replace them. The supply-side options include adding additional capacity for hydroelectric refurbishments, biomass cofiring, cogeneration, and wind.

Primary energy use

All options affect primary energy use, with the High Efficiency Case reducing primary energy demand the most, and the Carbon Charge, other electricity supply-side, and retirements options following far behind. Total primary energy demand, when all options are combined, is reduced by about 13 percent in 2010 and 22 percent in 2020.

Table 1a: Primary energy and carbon results from LBNL-NEMS runs in 2010

Case #	Name of case	Primary energy	Change in prim. energy relative to AEO 98	Synergy index prim. energy	Carbon emissions	Change in C emissions relative to AEO 98	Synergy index carbon
		2010 quads	2010 quads	2010 no syn. = 1.0	2010 MtC	2010 MtC	2010 no syn. = 1.0
1	AEO98 Reference Case	112.2	0.0	1.0	1803	0	1.0
2	23 \$/tC Carbon Charge	110.8	-1.4	1.0	1767	-36	1.0
4	High Efficiency	102.3	-9.9	1.0	1624	-179	1.0
5	Coal Retirements (16GW)	111.7	-0.5	1.0	1791	-12	1.0
8	Gas-Oil Retirements (100GW)	111.4	-0.8	1.0	1795	-8	1.0
16	Supply-Side (cog., cofire, hydro, wind)	111.2	-1.0	1.0	1768	-35	1.0
17	C-Charge + High Efficiency	101.1	-11.1	0.98	1596	-207	0.96
19	Retirements + High Efficiency	101.0	-11.2	1.00	1598	-205	1.03
18	C-Charge + Retirements	109.9	-2.3	0.85	1749	-54	0.96
20	HELC (0GW Coal + 0GW Gas-Oil)	100.0	-12.2	0.99	1552	-251	1.00
21	HELC (16GW Coal + 0GW Gas-Oil)	99.8	-12.4	0.97	1548	-255	0.97
24	HELC (0GW Coal + 100GW Gas-Oil)	99.2	-13.0	0.99	1531	-272	1.05
25	HELC (16GW Coal + 100GW Gas-Oil)	99.1	-13.1	0.96	1529	-274	1.01

Note: Case numbers refer to cases listed in Appendix B.

Table 1b: Primary energy and carbon results from LBNL-NEMS runs in 2020

Case #	Name of case	Primary energy	Change in prim. energy relative to AEO 98	Synergy index prim. energy	Carbon emissions	Change in C emissions relative to AEO 98	Synergy index carbon
		2020 quads	2020 quads	2020 no syn. = 1.0	2020 MtC	2020 MtC	2020 no syn. = 1.0
1	AEO98 Reference Case	118.6	0.0	1.0	1956	0	1.0
2	23 \$/tC Carbon Charge	117.2	-1.4	1.0	1901	-55	1.0
4	High Efficiency	99.5	-19.1	1.0	1601	-355	1.0
5	Coal Retirements (16GW)	118.2	-0.4	1.0	1942	-14	1.0
8	Gas-Oil Retirements (100GW)	118.3	-0.3	1.0	1952	-4	1.0
16	Supply-Side (cog., cofire, hydro, wind)	117.6	-1.0	1.0	1915	-41	1.0
17	C-Charge + High Efficiency	98.2	-20.4	0.99	1564	-392	0.96
19	Retirements + High Efficiency	98.7	-19.9	1.01	1585	-371	0.99
18	C-Charge + Retirements	116.6	-2.0	0.95	1897	-59	0.81
20	HELC (0GW Coal + 0GW Gas-Oil)	97.3	-21.3	0.99	1527	-429	0.95
21	HELC (16GW Coal + 0GW Gas-Oil)	97.1	-21.5	0.98	1520	-436	0.94
24	HELC (0GW Coal + 100GW Gas-Oil)	96.9	-21.7	0.99	1517	-439	0.96
25	HELC (16GW Coal + 100GW Gas-Oil)	96.6	-22.0	0.99	1508	-448	0.96

Note: Case numbers refer to cases listed in Appendix B.

Energy synergy is negative in 2010 and 2020 for the Carbon Charge + High Efficiency and HE/LC cases with varying retirement levels, while it is neutral in 2010 or slightly positive in 2020 for the Retirements + High Efficiency Case. The negative synergy in the Carbon Charge + High Efficiency Case is caused because the High Efficiency Case

additional reductions are not incorporated into the scenarios that are described in this report.

In 2010, total carbon savings are about 274 MtC, which brings total emissions to about 14% above 1990 levels (1346 MtC). If the Kyoto emissions goal of 7% below 1990 levels (which includes other greenhouse gases in addition to carbon) is applied strictly to carbon, the U.S. would need total emissions savings relative to the AEO98 baseline in 2010 of 554 MtC. According to this analysis, then, about half of the savings needed to meet the Kyoto goal by 2010 could be achieved domestically, and the rest would have to come from international trading of greenhouse gas permits (this result depends on the assumptions detailed above, including a \$23/ton carbon permit price).

Power plant retirements

The AEO 98 Reference Case appears to contain at least a few GW of coal-fired power plants that would be cost effective to retire (from a societal perspective), regardless of any greenhouse gas strategy at all. It becomes progressively more cost effective to retire more fossil capacity as electricity supply side options, carbon charges, and high efficiency technologies are implemented. The AEO98 version of NEMS does not currently retire such capacity automatically, so any modeling runs using NEMS to simulate a low carbon world MUST contain some exogenous retirements to account for this effect. Calculating the exact amount is laborious because it involves iteration, but it is an essential part of any such analysis.

Our own retirement cases provide a useful example. Relative to the AEO98 reference case, retiring 16 GW of coal and 100 GW of gas and oil steam plants costs about \$9B in present value terms by 2020 (calculated using total energy bills at a 7% real discount rate, base year 1999). Relative to the HELC case without retirements, however, adding the retirements *saves* about \$6B in present value terms by 2020 and saves carbon. Any high efficiency low carbon scenario that did not include retirements beyond those found in the AEO98 reference case would therefore be omitting an important carbon and money saving option.

Energy bill savings

As shown in Tables 2a and 2b, the impact of the "Climate Change Investment Strategy" appears to be highly positive in terms of the nation's overall energy expenditures. Total energy costs for all sectors in 2010, for example, are decreased by \$89 billion (in 1996 dollars). This result is made possible by the cost-effective technology investments outlined in the scenario analysis. When the carbon permit charge transfer payments are removed, the total energy bill falls even further, by an additional \$35 billion.

The price response to the reduced demand in this scenario more than offsets the increase in energy prices created by a \$23/MtC cost of carbon. Indeed, the reduced demand for petroleum and natural gas lowers energy prices by \$0.52 and \$0.35 per MBtu, respectively. Although coal and electricity prices are up \$0.53 and \$0.92 per MBtu, respectively, the weighted price for all energy resources actually falls by about \$0.15 per MBtu. The significantly lower energy consumption, when coupled with the lower energy prices, reduces the nation's energy bill by about 13 percent over the reference case.

Figure 2: Energy/GDP ratio over time, historical and projected

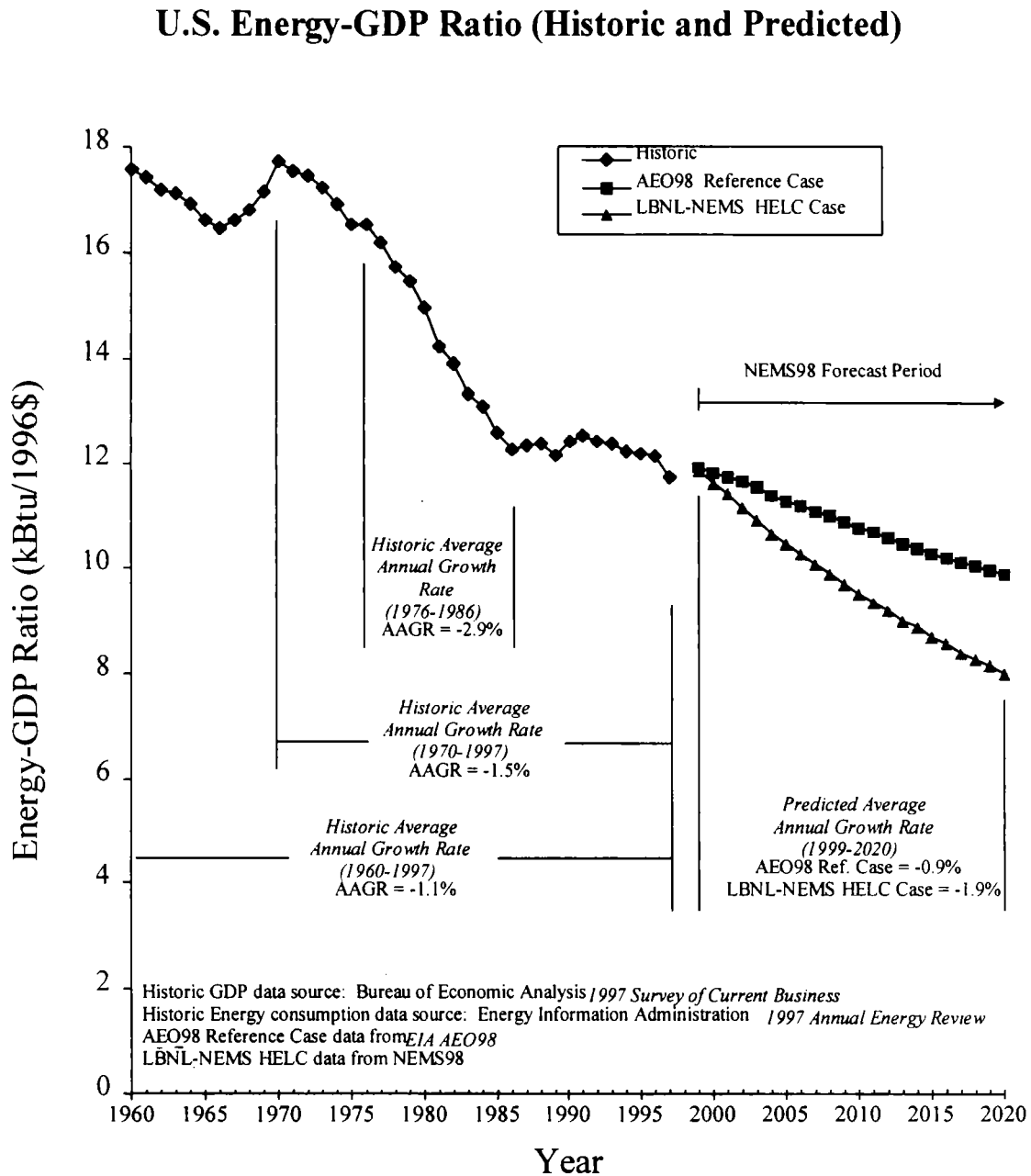


Table 2a: Energy bill savings results from LBNL-NEMS runs in 2010

Case #	Name of case	Energy bill	Change in Energy bill relative to AEO 98	Synergy index Energy bill	C charge transfers	Energy bill without C charge	Change in Energy bill relative to AEO 98
		2010 B 1996\$	2010 B 1996\$	2010 no syn. = 1.0	2010 B 1996\$	2010 B 1996\$	2010 B 1996\$
1	AEO98 Reference Case	639	0	1.0	0	639	0
2	23 \$/tC Carbon Charge	683	43	1.0	41	642	3
4	High Efficiency	521	-118	1.0	0	521	-118
5	Coal Retirements (16GW)	640	1	1.0	0	640	1
8	Gas-Oil Retirements (100GW)	634	-5	1.0	0	634	-5
16	Supply-Side (cog., cofire, hydro, wind)	626	-13	1.0	0	626	-13
17	C-Charge + High Efficiency	559	-80	1.08	37	522	-117
19	Retirements + High Efficiency	517	-122	1.00	0	517	-122
18	C-Charge + Retirements	683	43	1.10	40	642	3
20	HELC (0GW Coal + 0GW Gas-Oil)	550	-89	1.01	36	515	-125
21	HELC (16GW Coal + 0GW Gas-Oil)	551	-89	1.02	36	515	-124
24	HELC (0GW Coal + 100GW Gas-Oil)	549	-90	0.97	35	514	-125
25	HELC (16GW Coal + 100GW Gas-Oil)	550	-89	0.97	35	515	-124

Note: Case numbers refer to cases listed in Appendix B.

Table 2b: Energy bill savings results from LBNL-NEMS runs in 2020

Case #	Name of case	Energy bill	Change in Energy bill relative to AEO 98	Synergy index Energy bill	C charge transfers	Energy bill without C charge	Change in Energy bill relative to AEO 98
		2020 B 1996\$	2020 B 1996\$	2020 no syn. = 1.0	2020 B 1996\$	2020 B 1996\$	2020 B 1996\$
1	AEO98 Reference Case	684	0	1.0	0	684	0
2	23 \$/tC Carbon Charge	727	44	1.0	44	684	0
4	High Efficiency	459	-225	1.0	0	459	-225
5	Coal Retirements (16GW)	685	1	1.0	0	685	1
8	Gas-Oil Retirements (100GW)	691	8	1.0	0	691	8
16	Supply-Side (cog., cofire, hydro, wind)	678	-6	1.0	0	678	-6
17	C-Charge + High Efficiency	499	-185	1.02	36	463	-221
19	Retirements + High Efficiency	460	-224	1.03	0	460	-224
18	C-Charge + Retirements	739	56	1.07	44	696	12
20	HELC (0GW Coal + 0GW Gas-Oil)	491	-193	1.03	35	456	-228
21	HELC (16GW Coal + 0GW Gas-Oil)	491	-193	1.03	35	456	-228
24	HELC (0GW Coal + 100GW Gas-Oil)	491	-192	1.07	35	456	-227
25	HELC (16GW Coal + 100GW Gas-Oil)	491	-193	1.08	35	456	-228

Note: Case numbers refer to cases listed in Appendix B.

Investment costs

The results of our simplified calculation of annualized investment costs for our HE/LC case are shown in Tables 3a and 3b. We applied costs of conserved energy from the 5-lab study to the energy savings calculated from our scenarios in each of the demand sectors. We also estimated the cost of cogeneration investments. The optimistic and pessimistic assumptions for discount rates and program costs correspond to those used in the 5-lab study cost analysis. Total investment costs in 2010 are \$40 to \$60B/year, and program implementation costs range from \$3 to \$8B/year.

Table 3a: Summary of costs of energy services in 2010 (B1996\$/year)

	<i>AEO98 Reference case 2010</i>	<i>HE/LC case Optimistic costs 2010</i>	<i>HE/LC case Pessimistic costs 2010</i>
Energy bills without carbon permit trading transfer payments	639	515	515
Additional incremental investment beyond that captured in energy bills (energy efficiency and cogeneration)	0	37	56
Program implementation costs	0	3	8
Total cost of energy services	639	555	579
<i>Net cost</i>	<i>N/A</i>	<i>-84</i>	<i>-60</i>
Cost of additional permits to meet Kyoto goal (@ \$23/t)	13	6.4	6.4
<i>Net cost including cost of additional permits</i>	<i>13</i>	<i>-77</i>	<i>-53</i>

(1) Cost of additional permits to meet Kyoto goal of 7% below 1990 levels is calculated assuming that this goal is met by purchasing permits internationally for any emissions above that target. AEO98 reference case carbon emissions are 1803 MtC in 2010, while our HE/LC case carbon emissions are 1529 MtC. U.S. carbon emissions in 1990 were 1346 MtC, so the Kyoto goal implies reaching 1250 MtC (assuming that this goal is applied strictly to carbon). International emissions credit purchases in 2010 will therefore need to cover 554 MtC in the reference case, and 279 MtC in our HE/LC case.

Table 3b: Summary of costs of energy services in 2020 (B1996\$/year)

	<i>AEO98 Reference case 2020</i>	<i>HE/LC case Optimistic costs 2020</i>	<i>HE/LC case Pessimistic costs 2020</i>
Energy bills without carbon permit trading transfer payments	684	456	456
Additional incremental investment beyond that captured in energy bills (energy efficiency and cogeneration)	0	77	104
Program implementation costs	0	5	16
Total cost of energy services	684	538	576
<i>Net cost</i>	<i>N/A</i>	<i>-146</i>	<i>-108</i>
Cost of additional permits to meet Kyoto goal (@ \$23/t)	16	5.9	5.9
<i>Net cost including cost of additional permits</i>	<i>16</i>	<i>-140</i>	<i>-102</i>

(1) Cost of additional permits to meet Kyoto goal of 7% below 1990 levels is calculated assuming that this goal is met by purchasing permits internationally for any emissions above that target, and that the goal remains constant through 2020. AEO98 reference case carbon emissions are 1956 MtC in 2020, while our HE/LC case carbon emissions are 1508 MtC. U.S. carbon emissions in 1990 were 1346 MtC, so the Kyoto goal implies reaching 1250 MtC (assuming that this goal is applied strictly to carbon). International emissions credit purchases in 2020 will therefore need to cover 706 MtC in the reference case, and 258 MtC in our HE/LC case.

Impact on the Nation's Economy

Total net savings in 2010 (after accounting for investment costs and program implementation costs) are between \$80 and \$60 billion per year for the optimistic and pessimistic cases, respectively. While these investment cost estimates, at best, are of "one significant figure" accuracy, they convey a qualitative picture that is similar to the

DISCUSSION

The importance of "hard-wired" end-uses and technologies

Our analysis explicitly treats carbon savings from end-uses and technologies that are currently "hard-wired" in the NEMS framework, including miscellaneous electricity and residential lighting. Any policy study using NEMS that merely uses carbon charges or other price instruments to achieve carbon reductions essentially assumes that no savings can be achieved in these building sector end-uses. Since miscellaneous electricity and residential lighting are responsible for a large fraction of growth in the buildings sector, it is inappropriate to ignore them.

Similarly, carbon charges do not affect the growth in industrial cogeneration in the NEMS AEO98 framework, so any policy study that does not exogenously alter the adoption of industrial cogeneration in response to a changing policy context is ignoring a potentially large source of cost effective carbon reductions.

Implementing technological change

Many top-down modelers, in assessing the costs of reducing carbon emissions, fail to consider technological change that may be induced by climate change mitigation policies. Part of this failure stems from the current generation of models that cannot adequately capture such changes. Yet, any policy case that involves significant price changes or aggressive non-price policies will lead to changes in behavior and to technology-costs. For example, it is a fundamental oversight to model a large carbon tax, on the one hand, and fail to change the discount rates and the technology costs associated with behavioral changes and learning curve effects for low carbon and efficiency technologies on the other. The size of these changes in behavior are uncertain, so it is difficult to ascribe exact changes in discount rates due to different policies, but it is inappropriate to make NO such changes in the face of massive policy shifts like carbon permit trading and aggressive efficiency programs.

Understanding power plant retirements

Many studies of options for reducing carbon emissions focus on new gas-fired power plants, efficiency technologies, and non-fossil resources, but neglect to incorporate power plant retirements. Our analysis shows that such retirements work together with energy efficiency and Carbon Charges to achieve higher carbon savings than could be achieved by any of these policies in isolation.

The costs of these retirements does not include the reduced damages from criteria air pollutant emissions that are the direct result of the retirements. The older plants that are retired contribute disproportionately to emissions of these pollutants, in part because they are extremely dirty, but in part because they tend to be located closer to urban areas than do the more modern plants.

Effect of integrated analysis

There does appear to be an effect of using an integrated modeling approach, though it is smaller than we initially expected. When all the options in our HELC case (with the \$23/tC charge) are implemented separately in the LBNL NEMS framework, we find total savings of 280 MtC in 2010. When implemented together in the LBNL-NEMS model,

that created by Brown (1993, 1994) for the residential sector, but would cover policies and programs in all sectors.

Logistic constraints in ramping up programs would be incorporated in this roadmap. For example, it takes years to complete all the legal requirements to create a new standard, and it often takes years for a new ENERGY STAR program to achieve significant market penetration. These logistic constraints should be characterized based on recent evaluations of the experience for the programs in question.

Implementation costs needed to achieve the level of reductions described above would also be incorporated explicitly in such a roadmap. According to the 5-Lab study, these costs are on the order of 7-15 percent of the level of technology investments needed to reduce carbon emissions, but these costs should be calculated explicitly, based on the cost of each policy or program and its expected contribution to future energy savings.

Ancillary benefits of power plant retirements

One variable that we have not explicitly treated in our retirements analysis is the interaction between criteria pollutants (e.g., SO₂, NO_x, and particulates), energy efficiency, and retirement levels. Efficiency improvements and retirements both reduce criteria pollutant emissions, and within many urban airsheds, these pollutants have a value to society that is known or can be approximated. An analysis using Geographic Information Systems that assesses the economic characteristics of specific power plants and the local value of reducing urban air pollution could determine which additional power plants it might be cost effective to retire given those ancillary benefits.

Other aspects of power plant retirements

A regional analysis of retirements would also help us better understand the interactions between retirements, utility deregulation, and regional fuel prices. The AEO98 electricity supply module assumes regulated electricity markets in all States except California, New York and New England, and this representation affects the potential benefits from retirements in a complicated way. More investigation is needed on this point.

Power plant efficiency

Although the average heat rates of existing power plants improve over time in the AEO98 reference case forecast (due to retirements of less efficient units), studies indicate that policies to promote restructuring within the electric utility sector may promote such improvements for many existing plants (US DOE 1998a). Those opportunities should be examined carefully in future work. However, we anticipate that resulting carbon savings can, to first approximation, be added to the results presented in this analysis (assuming that the benefits of these improvements apply only to those existing plants that are not retired in our analysis).

Macroeconomic effects in NEMS

The AEO98 version of NEMS used for this analysis relies on a very simple reduced form version of the DRI macroeconomic model. When EIA runs NEMS, they use the full DRI model to capture macroeconomic effects. It is important to understand, however, that even this full model cannot capture macroeconomic investment effects if the capital expenditures on cogeneration and end-use efficiency investments are not tracked and

passed on to the macro model. Fully tracking these investments and reporting them to the macro model would be a major improvement to the NEMS modeling framework.

In addition, it is clear that the macroeconomic forecast generated by the reduced form version of the DRI model is solely dependent on energy prices passed from the integrating module of the NEMS model. It is therefore impossible for the NEMS modeling framework using the reduced form macro model to reflect accurately the effect of a reduction in energy *bills*. This problem limits the usefulness of this tool in assessing macroeconomic impacts from programs and policies that are designed to reduce energy bills. We do not know if the EIA version of NEMS using the full DRI model suffers from this limitation, but if it does, it is a fundamental one.

Review of gas supply and demand interactions

Because of the importance of gas demand and prices to our results, and because our scenario incorporates relatively large perturbations of reference case gas consumption, we believe that more attention to the feedback between demand-side efficiency and natural gas prices would yield important lessons. This feedback is clearly one of the critical ones affecting the costs of reducing carbon emissions, and a more detailed assessment of its effects is needed.

Regional distribution of hydroelectric refurbishment capacity

More research is needed on how hydroelectric refurbishment opportunities are distributed geographically. Future work should estimate the potential by region, because this distribution will affect carbon savings from this option.

CONCLUSIONS

The LBNL-NEMS analysis demonstrates some key policy conclusions:

- (1) The domestic U.S. options analyzed here (all domestic U.S.) achieve about half of the carbon reductions needed to meet the Kyoto commitments. This is a significant fraction of the total commitment that actually reduces the nation's energy bill. The rest of the savings will need to come from international emissions trading and other options we did not analyze. This result is dependent on our assumption of a \$23/ton carbon permit price, as well as the other assumptions detailed above.
- (2) Many carbon savings options are not included in our analysis. These include fuel cells, biomass and black liquor gasification, cement clinker replacement, industrial aluminum efficiency technologies, ethanol in light duty vehicles, repowering of coal plants with natural gas, life extension of nuclear power plants, fossil power-plant efficiency improvements, photovoltaics, landfill gas, combined heat and power in non-industrial space heating applications, and advanced efficiency options in the building sector. The potential of some other options (such as wind generation and industrial cogeneration) are probably underestimated in our study. For these reasons, we believe the total carbon savings calculated here are substantially less than the full potential.
- (3) Power plant retirements are a key option for carbon reductions that have been inadequately explored heretofore. They combine ancillary benefits from criteria air pollutant reductions with positive carbon synergy when implemented in combination with energy efficiency.

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APPENDIX A: TECHNICAL DESCRIPTION OF LBNL-NEMS HIGH-EFFICIENCY LOW CARBON CASE

The LBNL-NEMS High-Efficiency Low Carbon (HELC) Case is produced using the Energy Information Administration's (EIA) National Energy Modeling System (NEMS). EIA's 1998 *Annual Energy Outlook* (AEO98) Reference Case is used as a baseline for this scenario. All changes described below are relative to the AEO98 Reference Case version of NEMS.

The HELC Case is designed to reproduce the demand-side energy efficiency energy savings found in the *5-Lab Study*⁵ by sector and fuel type in 2010. Supply-side options are taken from several different sources, including the *5-Lab Study*.

All of the files used to create the LBNL-NEMS HELC Case from the EIA AEO98 Reference Case are available by anonymous ftp from [enduse.lbl.gov](ftp://enduse.lbl.gov). The files are located in the "/LBNL-NEMS/98/HELC" directory. See the README file for an annotated list of files.

A.1 All sectors

Carbon charge

A carbon charge is implemented in the LBNL-NEMS HELC case. In the *5-Lab Study*, a 50 \$/tC carbon charge is implemented, whereas we modeled both 23 \$/tC and 50 \$/tC carbon charges in our HELC case.

In LBNL-NEMS, the carbon charge is implemented by modifying the `epmcntl.v1.2` and `epmdata.v1.7` input files used by the energy policy module in NEMS. The carbon charge is phased-in linearly from 1999 to 2004. The following steps are taken to implement a carbon charge.

(1) Changing the `epmcntl` file

In the `epmcntl` file, the "TAX FLAG" is changed from "F" to "T."

⁵ In this Appendix, "*5-Lab Study*" is used to refer to the following report: Interlaboratory Working Group. 1997. *Scenarios of U.S. Carbon Reductions: Potential Impacts of Energy-Efficient and Low-Carbon Technologies by 2010 and Beyond*. Oak Ridge, TN and Berkeley, CA: Oak Ridge National Laboratory and Lawrence Berkeley National Laboratory. ORNL-444 and LBNL-40533. September.

A.2 Electric utility sector

Early retirement of coal plants

In the LBNL-NEMS HELC case, coal capacity is retired through modifying the “retirement year” field of the plant data file (pltf860.v1.68). These plants are retired over the years 2000 to 2008.

Plants are selected among existing coal plants that are not retired by NEMS in the AEO98 Reference Case. The online year for a plant is used as the criteria to select plants to be retired. The online year criteria for three levels of coal plant retirements are shown below:

Table A.2.1 Coal plant retirement level criteria

Retirement Level (GW)	Retirement Criteria (1)
16	All coal plants online before 1955
42	All coal plants online before 1960
63	All coal plants online before 1965

(1) Plants retired by NEMS during the AEO98 Reference Case forecast period are not eligible for retirement

Early retirement of gas/oil steam turbine plants

A large portion of gas and oil steam turbine capacity is retired by NEMS in the baseline AEO forecast. In the LBNL-NEMS HELC case, all the remaining capacity for this technology (~100GW) is retired over the years 2000 to 2008 through modifying the “retirement year” field for these plants in the plant data file (pltf860.v1.68).

Biomass co-firing

In section 7.3.1.1 of the *5-Lab Study*, the potential for biomass co-firing capacity is estimated to be between 8 and 12 GW by the year 2010. Using 10 GW of capacity as a midpoint, 10 GW of coal capacity is “converted” to biomass co-firing in regions of the US thought to have the greatest potential for this type of activity (the northeast and southeast). Since NEMS currently has no ability to handle biomass co-firing as a separate technology, modifications to simulate the adoption of biomass co-firing have been made to the plant data file. This involves the gradual reduction of coal capacity through retirements coupled with the addition of new biomass capacity. Individual coal plants chosen to have biomass co-firing are picked so that they do not fall within the retirement criteria for coal plant retirements (see above.)

The conversion of coal capacity to biomass capacity is achieved by first separating the coal capacity to be retired through creation of an additional unit at a plant with a capacity corresponding to the retirement amount. This unit is then given a retirement year between 2000 and 2008, and remaining units at the plant have their capacities reduced by the retirement amount. Finally, new biomass capacity is added to the plant with an on-line year corresponding to the retirement year of the retired coal unit.

A.3 Residential sector

Energy efficiency

In the 5-Lab Study HELC Case, increased energy efficiency reduces energy consumption in 2010 by amounts shown in Table A.3.1.

Table A.3.1 5-Lab Study residential sector energy efficiency site energy savings (Quadrillion Btu)

	Electricity	Natural Gas	Distillate	LPG
5-Lab Study HELC Case	-0.77	-0.13	-0.03	-0.02

The following changes are made to the AEO98 Reference Case version of the NEMS residential model to implement energy savings comparable to the 5-Lab Study energy savings: implicit discount rates (Beta1/Beta2) are changed to 15% for all technologies after the year 1999 in the rteky.v1.61 input data file, lighting efficiencies and market shares are modified in the resd.f source code, and the growth in "Other" electricity consumption is limited in the resd.f source code. Detailed descriptions of these changes are listed below:

(1) Implicit discount rates are changed to 15% for all technologies after the year 1999 in the rteky.v1.61 data file

For each technology in the rteky.v1.61 input file the following changes are made:

the line containing the technology characteristics for the year 2000 is duplicated

the lastyear field of the original line is set to 1999

the firstyear field of the duplicate line is set to 2000

the Beta1 field is changed so that the implicit discount rate (Beta1/Beta2) equals 0.15 for all lines with firstyear fields greater than 1999

(2) Lighting efficiency and market share changes in the resd.f source code

Line 10043 is changed from

EFF(3)=88.00 ! SHOULD BE 88.00

to:

EFF(3)=20.90 ! LBNL ! SHOULD BE 88.00

Lines 10047 through 10055 are changed from the following values:

LTMSHR(15,1)=0.93
LTMSHR(15,2)=0.07
LTMSHR(15,3)=0.00
LTMSHR(26,1)=0.90
LTMSHR(26,2)=0.10
LTMSHR(26,3)=0.00
LTMSHR(31,1)=0.88
LTMSHR(31,2)=0.12
LTMSHR(31,3)=0.00

to the following values:

LTMSHR(15,1)=0.70
LTMSHR(15,2)=0.10
LTMSHR(15,3)=0.20
LTMSHR(26,1)=0.20
LTMSHR(26,2)=0.20
LTMSHR(26,3)=0.60
LTMSHR(31,1)=0.20
LTMSHR(31,2)=0.20
LTMSHR(31,3)=0.60

(3) *Changes to the growth in "other" electricity use in the resd.f source code*

The following code is inserted on line 10512 (after individual electric other consumptions have been calculated)

```
C LBNL *** HI-EFFICIENCY ELEC OTHER ***
  IF (Y.GT.11) THEN
    DO D=1,MNUMCR-2
      IF (Y.LT.21) THEN
        ELTRCN(Y+1,D) = ELTRCN(Y+1,D) *
          (1.0 - 0.5 * (Y-11.0)/(10.0))
        *
        COILCN(Y+1,D) = COILCN(Y+1,D) *
          (1.0 - 0.1 * (Y-11.0)/(10.0))
        *
        MOTRCN(Y+1,D) = MOTRCN(Y+1,D) *
          (1.0 - 0.3 * (Y-11.0)/(10.0))
        *
      ELSE
        ELTRCN(Y+1,D) = ELTRCN(Y+1,D) * (1.0 - 0.5)
        COILCN(Y+1,D) = COILCN(Y+1,D) * (1.0 - 0.1)
        MOTRCN(Y+1,D) = MOTRCN(Y+1,D) * (1.0 - 0.3)
      ENDIF
    ENDDO
  ENDIF
C LBNL END
```

TVs and electric furnace fan minor electric end-uses are not modified.

These changes result in the annual average adjusted growth rates in the "other" category as shown in Table A.3.2.

Table A.3.2 Residential sector annual average adjusted growth rates in the "other" category

	1999-2010	1999-2020
AEO Ref. Case	4.0%	3.2%
HELC	0.9%	1.2%

A.4 Commercial sector

Energy efficiency

In the 5-Lab Study HELC Case, increased energy efficiency reduces energy consumption in 2010 by amounts shown in Table A.4.1.

Table A.4.1 5-Lab Study commercial sector energy efficiency site energy savings (Quadrillion Btu)

	Electricity	Natural Gas	Distillate
5-Lab Study HELC Case	-0.59	-0.34	-0.03

The following three changes are made to the AEO98 Reference Case version of the NEMS commercial model to implement energy savings comparable to the energy savings in the 5-Lab Study: implicit discount rates used in evaluating purchase decisions are changed to 14% plus the 10 year government bond interest rate for all end-uses in the years after 1999 (which results in about an 18% discount rate in total), behavior rule constraints on new equipment purchases for space heating and space cooling are relaxed after the year 1999, and growth in the penetration of "Other" electricity use is limited. Detailed descriptions of these changes are listed below:

(1) Discount rate changes in the kprem.v1.10 input data file

The distribution of time preference premiums is modified for all end-uses in all years after 1999. The share of consumers using the 0.136 discount rate is set to 1.0 and all other categories (10, 1.529, 0.554, 0.309, and 0.199) are set to 0.0. Note that the effective discount rate used in the commercial module is the discount rate in the kprem.v1.10 input file plus the 10 year government bond interest rate (3.7% to 4.0% real interest rate.)

(2) *Changes to behavior rules in the kbehav.v1.11 and the comm.f source code*

The kbehav.v1.11 file is duplicated and renamed "kbehav_sf." In the kbehav_sf file, for space cooling and space heating new purchase decisions, all shares allocated to the "same technology" behavior rule are moved to the "same fuel" behavior rule.

The behavior rules in the kbehav_sf input file are then used for forecast years after 1999 by making the following change in the comm.f source code:

Line 3295 is changed from

```
IF (CURIYR.EQ.CMFirstYr .AND. CURITR.EQ.1) THEN
```

to

```
IF ((CURIYR.EQ.CMFirstYr .AND. CURITR.EQ.1) .OR. ! LBNL  
* (CURIYR.EQ.11 .AND. CURITR.EQ.1)) THEN ! LBNL
```

and after Line 3318, the following code is added

```
IF (CURIYR.EQ.11) THEN ! LBNL  
  WRITE(*,*) 'YEAR 2000 CHANGING KBEHAV FILE' ! LBNL  
  OPEN(INFILE,file='input/kbehav_sf',STATUS='old')! LBNL  
ENDIF
```

(3) *Changes to the growth in "other" electricity use in koffpen.v1.9 input data file and the commercial source code*

In the koffpen.v1.9 file, the annual market penetration index for "other" end-uses is set to 85% of its default value. This 15% reduction is phased in linearly from 2000 to 2009 and is then constant from 2010 to 2020.

In the commercial source code (comm.f), the following code is inserted on line 7303 to decrease the non-building electricity energy use (a component of the electricity 'other') by 15%. This reduction is phased in linearly from 2000-2009 and held constant from 2010 to 2020.

```
C RCR LBNL decrement non-bldg energy use by 20%
  IF (CURIYR.GT.11) THEN
    DO r= 1, MNUMCR-2
      IF (CURIYR.LT.21) THEN
        CMNonBldgUse(1,r,CURIYR) = CMNonBldgUse(1,r,CURIYR) *
          (1.0 - 0.15 * (CURIYR-11.0)/(10.0))
      ELSE
        CMNonBldgUse(1,r,CURIYR) = CMNonBldgUse(1,r,CURIYR) *
          (1.0 - 0.15)
      END IF
    END DO
  END IF
C RCR LBNL END
```

These changes result in the annual average adjusted growth rates in the "other" category as shown in Table A.4.2.

Table A.4.2 Commercial sector annual average adjusted growth rates in the "other" category

	1999-2010	1999-2020
AEO Ref. Case	3.1%	2.5%
HELC	1.6%	1.7%

A.5 Industrial sector

Energy efficiency

Energy efficiency savings estimated using the LIEF model (rather than 5-Lab Study savings) are implemented in the industrial module; see Table A.5.4 for energy savings by industrial sub-sector.

The changes made to the industrial model represent modifications to the EIA Hi-Tech Case. The following parameters are changed: the variable RETRATE is modified by sub-sector for all sub sectors, the HITECH modifier to the ENPINT variable is modified by sub-sector and fuel type for sub-sectors 1-6 and 14-15, and the TPC coefficients are varied by sub-sector and fuel type for sub-sectors 7-13. These LBNL High Efficiency Case parameters are chosen so that energy savings are within +/- 5% of the LIEF energy efficiency savings (See Table A.5.4.) These changes are summarized below.

(1) Changing the RETRATE coefficients

On line 4511, the source code is expanded so that different RETRATES can be used for each of the industrial sub-sectors. See Table A.5.1 below for values used in the EIA AEO98 HI-Tech Case and the LBNL-NEMS HELC Case.

Table A.5.1 Retirement rates in the EIA AEO98 Hi-Tech case and LBNL-HEMS HELC case

Industrial Sub-Sector	RETRATE Value	
	EIA AEO98 Hi-Tech Case	LBNL-NEMS HELC Case
1 Agriculture-Crops	2.0	2.0
2 Agriculture-Other	2.0	2.0
3 Coal Mining	2.0	2.0
4 Oil/Gas Mining	2.0	2.0
5 Metal/Other Mining	2.0	2.0
6 Construction	2.0	2.0
7 Food	2.0	4.0
8 Paper	2.0	2.5
9 Bulk Chemicals	2.0	2.2
10 Glass	2.0	2.0
11 Cement	2.0	2.0
12 Steel	2.0	2.0
13 Aluminum	2.0	3.5
14 Metals Durables	2.0	2.0
15 Other	2.0	2.0

(2) *Changing the HITECH modifiers to the ENPINT variable*

In six locations in the ind.f source code (lines 5333, 5464, 6029, 6202, 6628, and 6993), the HITECH IF Statement is expanded so that varying modifiers can be used for the industrial sub-sectors 1 through 6. See Table A.5.2 below for values used in the EIA AEO98 Hi-Tech Case and the LBNL-NEMS HELC Case.

Table A.5.2 ENPINT modifiers in the EIA AEO98 Hi-Tech case and LBNL-NEMS HELC case

Industrial Sub-Sector	ENPINT Modifier			
	EIA AEO98 Hi-Tech Case		LBNL-NEMS HELC Case	
	Fuels	Elec	Fuels	Elec
1 Agriculture-Crops	-0.0682	-0.0682	-0.190	-0.190
2 Agriculture-Other	-0.0682	-0.0682	-0.200	-0.200
3 Coal Mining	-0.0682	-0.0682	-0.170	-0.170
4 Oil/Gas Mining	-0.0682	-0.0682	-0.200	-0.200
5 Metal/Other Mining	-0.0682	-0.0682	-0.220	-0.220
6 Construction	-0.0682	-0.0682	-0.001	-0.150
14 Metals Durables	-0.0682	-0.0682	-0.130	-0.130
15 Other	-0.0682	-0.682	-0.200	-0.260

(3) *Changing the TPC coefficients*

On line 5640, the source code is expanded so that different TPC sensitivities can be used for electricity and non-electricity processes for each of the industrial sub-sectors. See Table A.5.3 for values used in the EIA AEO98 Hi-Tech Case and the LBNL-NEMS HELC Case.

Table A.5.3 ENPINT modifiers in the EIA Hi-Tech case and LBNL-NEMS HELC case

Industrial Sub-Sector	TPC Parameter			
	EIA AEO98 Hi-Tech Case		LBNL-NEMS HELC Case	
	Fuels	Elec	Fuels	Elec
7 Food	2.0	2.0	4.0	4.0
8 Paper	2.0	2.0	1.8	2.2
9 Bulk Chemicals	2.0	2.0	1.2	3.0
10 Glass	2.0	2.0	1.7	1.5
11 Cement	2.0	2.0	1.7	1.9
12 Steel	2.0	2.0	4.0	1.1
13 Aluminum	2.0	2.0	4.0	3.5

The following table summarizes the energy efficiency savings estimated using the LIEF model and the corresponding savings implemented in the LBNL-NEMS model.

Table A.5.4 Energy efficiency savings predicted by the LIEF model and implemented in the LBNL-NEMS High Efficiency case

Industrial Sub-Sector	LIEF		LBNL-NEMS
	Estimated Energy Savings Percentage (%)	Energy Savings relative to NEMS Baseline Energy Use (TBtu)	High Efficiency Case Energy Savings (1) (TBtu)
<i>Site Electricity</i>			
1 Agriculture-Crops	16%	-15	-15
2 Agriculture-Other	16%	-6	-6
3 Coal Mining	16%	-9	-9
4 Oil/Gas Mining	16%	-24	-24
5 Metal/Other Mining	16%	-21	-19
6 Construction	16%	-16	-16
7 Food	24%	-37	-25
8 Paper	12%	-26	-26
9 Bulk Chemicals	12%	-33	-32
10 Glass	8%	-4	-4
11 Cement	8%	-3	-3
12 Steel	4%	-7	-7
13 Aluminum	12%	-29	-29
14 Metals Durables	16%	-86	-90
15 Other	24%	-172	-164
Total	-	-488	-469
<i>Fuels</i>			
1 Agriculture-Crops	16%	-92	-89
2 Agriculture-Other	16%	-37	-36
3 Coal Mining	16%	-21	-20
4 Oil/Gas Mining	16%	-195	-194
5 Metal/Other Mining	16%	-60	-57
6 Construction	16%	-264	-328
7 Food	16%	-133	-119
8 Paper	12%	-286	-278
9 Bulk Chemicals	12%	-606	-740
10 Glass	8%	-19	-20
11 Cement	8%	-26	-26
12 Steel	8%	-159	-120
13 Aluminum	12%	-4	-4
14 Metals Durables	16%	-129	-122
15 Other	16%	-280	-270
Total	-	-2311	-2423

A.6 Transportation sector

Energy efficiency

The LBNL-NEMS HELC transportation sector assumptions are a replication of the 5-Lab Study HELC Case assumptions. The 5-Lab Study transportation sector analysis used the AEO97 Version of NEMS. We modified the 5-Lab Study input files to account for structural changes in the NEMS model from the AEO97 Version to the AEO98 Version, but otherwise assumptions are consistent between the 5-Lab Study HELC Case and the LBNL-NEMS HELC Case.

The LBNL-NEMS HELC Case makes changes to the horsepower vs. efficiency trade-off in the tran.f source code, the technology and behavior characteristics in the cffuel.v1.3 input file, and technology and behavior characteristics in the trninput input file. These changes are described below:

(1) Changing the horsepower vs. efficiency trade-off in the tran.f source code

The equation on line 1517 of the NEMS tran.f source code shown below

```
ADJHP(ICL,IGP,IFT)=PERFFACT(ICL,IGP)*4.0*
& (((INCOME(YEAR)/INCOME(YEAR-1))**0.9*
& (PRICE(ICL,IGP,YEAR-1,IFT)/PRICE(ICL,IGP,YEAR,IFT))**0.9*
& (FE(ICL,IGP,YEAR,IFT)/FE(ICL,IGP,YEAR-1,IFT))**0.2*
& (FUELCOST(YEAR-1)/FUELCOST(YEAR))**0.2) - 1.0)
```

is replaced with the following equation in the LBNL-NEMS tran.f source code:

```
ADJHP(ICL,IGP,IFT)=PERFFACT(ICL,IGP)*4.0*
& (((INCOME(YEAR)/INCOME(YEAR-1))**0.5*
& (PRICE(ICL,IGP,YEAR-1,IFT)/PRICE(ICL,IGP,YEAR,IFT))**0.5*
& (FE(ICL,IGP,YEAR,IFT)/FE(ICL,IGP,YEAR-1,IFT))**0.1*
& (FUELCOST(YEAR-1)/FUELCOST(YEAR))**0.1) - 1.0)
```

(3) Changing the technology characteristics in the trninput.v1.42 input file:

The AEO98 Reference Case version of the trninput file is modified to mirror the 5-Lab Study HELC version of the trninput file. When necessary, HELC trends are extended from 2015 to 2020 in the AEO98 Version of the file (trninput.v1.42). Otherwise, changes are generally one for one.

The trninput file is a Lotus-123 file. We use Lotus 1 Release 5 for Windows NT to modify the trninput file. In the NEMS model, the nemswk1.f source code is responsible for reading data from lotus (.wk1) binary files. Even though the modified trninput.v1.42 file is saved in the appropriate older Lotus format, the nemswk1 source code is unable to read nine variables from the input file. The nine variables are C1T, C2T, C3T, C4T, COEF\$A, COEF\$B, COEF\$C, T50, and T90. To fix this problem, these variables (none of which are changed in the HELC case) are overwritten with their AEO98 Reference Case values in the READWK1 subroutine in the tran.f source code.

Modifications to the trninput.v1.42 are described below. The purpose of this documentation is to describe which variables in the input file are changed. We do not document the magnitude or direction of changes. For a complete comparison, download the specific files from our ftp server (see beginning of Appendix A for instructions) and use this documentation as a guide through the files.

In the documentation below, descriptions of changes are separated by transportation module, as they are characterized in the trninput file. Specific row numbers are used to refer to the relevant areas of the input file section. The row numbers correspond to the AEO98 version of the input file (trninput.v1.42).

Table A.6.4 Technology parameters* we modified by technology by car and light truck category

Technologies	TECHIDT	Modified Parameters	
		car	light truck
Material Substitution III	4	-	6
Material Substitution IV	5	6	6
Material Substitution V	6	6	6
Drag Reduction IV	9	6	6
Drag Reduction V	10	6	6
CVT	14	2	6
Electronic Transmission II	17	-	6
8C/8V	24	-	6
Engine Friction Reduction II	29	-	6
Engine Friction Reduction III	30	6	6
Engine Friction Reduction IV	31	6	6
VVT I	32	2	6
VVT II	33	2,6	6
DISC**	34	1,2,6	6
Two Stroke	35	6	6
Tires II	43	1,6	2
Tires III	44	1,6	1,6
Tires IV	45	1,6	1,6
ACC II	47	-	6
EPS	48	-	6
4WD Improvements	49	-	6
Drag Reduction VI***	57	1,2,3,4,5,6,7	1,2,3,4,5,6,7
Turbo Direct Injection Diesel***	58	1,2,3,4,5,6,7	1,2,3,4,5,6,7
Hybrid Gasoline***	59	1,2,3,4,5,6,7	1,2,3,4,5,6,7
Hybrid Diesel***	60	1,2,3,4,5,6,7	1,2,3,4,5,6,7
Gasoline Fuel Cell Hybrid***	61	1,2,3,4,5,6,7	1,2,3,4,5,6,7

* See Table A.6.1 for parameter number mapping

** replaces lean burn technology in the AEO98 Reference Case

*** technology added (rather than modified)

Section 2 (rows 231-567)

In this section of the Fuel Economy Model input data, base year and maximum market shares for each of 61 (56 default + 5 new) technologies in seven size classes are listed. Table A.6.5 lists which size class is modified for each technology by marketshare type, and vehicle group.

Table A.6.5 Technology marketshares we modified by marketshare type, vehicle group, and size class

Tech ID	Size Class Modified							
	baseyear marketshare				maximum marketshare			
	vehicle group				vehicle group			
	1	2	3	4	1	2	3	4
front wheel drive	3	-	-	-	2	-	-	-
drag reduction II	3	-	-	-	2	-	-	-
TCLV	3	-	-	-	2	-	-	-
4-speed automatic	3	-	-	-	2	-	-	-
roller cam	-	-	-	-	2	-	-	-
OHC 4	2	-	-	-	2	-	-	-
4C/4V	-	-	-	-	2	-	-	-
engine friction reduction I	-	-	-	-	2	-	-	-
air pump	3	-	-	-	2	-	-	-
DFS	3	-	-	-	2	-	-	-
oil SW-30	3	-	-	-	2	-	-	-
air bags	3	-	-	-	2	-	-	-
ABS	3	-	-	-	2	-	-	-
Drag Reduction VI*	1-7	1-7	1-7	1-7	1-7	1-7	1-7	1-7
Turbo Direct Injection Diesel*	1-7	1-7	1-7	1-7	1-7	1-7	1-7	1-7
Hybrid Gasoline*	1-7	1-7	1-7	1-7	1-7	1-7	1-7	1-7
Hybrid Diesel*	1-7	1-7	1-7	1-7	1-7	1-7	1-7	1-7
Gasoline Fuel Cell Hybrid*	1-7	1-7	1-7	1-7	1-7	1-7	1-7	1-7

* technology added (rather than modified)

Section 3 (rows 688 to 845)

On row 689, the payback period is changed and on row 690, the discount rate is changed.

Section 4 (rows 857 to 1151)

There are no changes in this section of the input data.

Light Duty Vehicle Fleet Module -- (rows 1152 to 1236)

There are no changes in this section of the input data.

Light-Duty Vehicle Stock Module (rows 1237 o 1327)

Section 1 (rows 1237 to 1312)

The degradation factors for cars and light trucks by year (CDG and LTDF) are modified in this section of the data.

Section 2 (rows 1313 to 1327)

There are no changes in this section of the input data.

Freight Transport Module (rows 1407 to 1432)

Section 1 (no longer in trninput file)

The changes to TBETA1 and TBETA2 in the 5-Lab Study trninput file are not recreated in the LBNL-NEMS HELC trninput file because this section of the input data is removed from the AEO98 Version of the trninput file (possibly replaced by the Commercial Light Truck Module).

Section 2 (rows 1421 to 1425)

In this section of the input data, the freight rail efficiency by year (FERAIL) is modified.

Section 3 (1426 to 1432)

In this section of the input data, the freight ship efficiency by year (FESHIP) is modified.

Air Travel Module (rows 1433 to 1463)

In this section of the input data, there are several modifications. The load factor time-series data for domestic and international travel are increased (LFDOM and LFINT). The starting year (TRIGYEAR), cost (TRIGCOST), and incremental efficiency (EFFIMP) improvement parameters for the six generic air travel efficiency technologies are modified. Also, the "rho" times-series data for narrow and wide-body aircraft (RHON and RHOW) are modified.

Miscellaneous Transportation Energy Demand Module (rows 1464 to 1549)

There are no changes in this section of the input data.

APPENDIX B: COMPLETE LIST OF LBNL-NEMS HIGH-EFFICIENCY/LOW CARBON CASES

1	AEO98 Reference Case
2	23 \$/t Carbon Charge Case
3	50 \$/t Carbon Charge Case
4	High Efficiency Case
5	16GW Coal and 0GW Gas-Oil Retirements Case
6	42GW Coal and 0GW Gas-Oil Retirements Case
7	63GW Coal and 0GW Gas-Oil Retirements Case
8	0GW Coal and 100GW Gas-Oil Retirements Case
9	16GW Coal and 100GW Gas-Oil Retirements Case
10	42GW Coal and 100GW Gas-Oil Retirements Case
11	63GW Coal and 100GW Gas-Oil Retirements Case
12	Biomass Cofire Case
13	Industrial Cogen Case
14	Hydro Refurbishment Case
15	Wind Tax Credit Extension Case
16	Supply Side (cofire/cogen/hydro/wind) Case
17	23 \$/t Carbon Charge/High Efficiency Case
18	23 \$/t Carbon Charge 16GW Coal and 100GW Gas-Oil Retirements Case
19	High Efficiency 16GW Coal and 100GW Gas-Oil Retirements Case
20	HELC Case 23\$/tC (0/0)--includes High Efficiency (4) and Supply Side options (16)
21	HELC Case 23\$/tC (16/0)--includes High Efficiency (4) and Supply Side options (16)
22	HELC Case 23\$/tC (42/0)--includes High Efficiency (4) and Supply Side options (16)
23	HELC Case 23\$/tC (63/0)--includes High Efficiency (4) and Supply Side options (16)
24	HELC Case 23\$/tC (0/100)--includes High Efficiency (4) and Supply Side options (16)
25	HELC Case 23\$/tC (16/100)--includes High Efficiency (4) and Supply Side options (16)
26	HELC Case 23\$/tC (42/100)--includes High Efficiency (4) and Supply Side options (16)
27	HELC Case 23\$/tC (63/100)--includes High Efficiency (4) and Supply Side options (16)
28	HELC Case 50\$/tC (0/0)--includes High Efficiency (4) and Supply Side options (16)
29	HELC Case 50\$/tC (16/0)--includes High Efficiency (4) and Supply Side options (16)
30	HELC Case 50\$/tC (42/0)--includes High Efficiency (4) and Supply Side options (16)
31	HELC Case 50\$/tC (63/0)--includes High Efficiency (4) and Supply Side options (16)
32	HELC Case 50\$/tC (0/100)--includes High Efficiency (4) and Supply Side options (16)
33	HELC Case 50\$/tC (16/100)--includes High Efficiency (4) and Supply Side options (16)
34	HELC Case 50\$/tC (42/100)--includes High Efficiency (4) and Supply Side options (16)
35	HELC Case 50\$/tC (63/100)--includes High Efficiency (4) and Supply Side options (16)
36	HELC Case 0\$/tC (0/0)--includes High Efficiency (4) and Supply Side options (16)
37	HELC Case 0\$/tC (16/0)--includes High Efficiency (4) and Supply Side options (16)
38	HELC Case 0\$/tC (42/0)--includes High Efficiency (4) and Supply Side options (16)
39	HELC Case 0\$/tC (63/0)--includes High Efficiency (4) and Supply Side options (16)
40	HELC Case 0\$/tC (0/100)--includes High Efficiency (4) and Supply Side options (16)
41	HELC Case 0\$/tC (16/100)--includes High Efficiency (4) and Supply Side options (16)
42	HELC Case 0\$/tC (42/100)--includes High Efficiency (4) and Supply Side options (16)
43	HELC Case 0\$/tC (63/100)--includes High Efficiency (4) and Supply Side options (16)

APPENDIX C: SUMMARIES OF KEY REVIEW COMMENTS

As described in the preface, this report underwent extensive technical review. We paraphrase the key substantive comments received below, with our responses. We do not include the myriad comments that noted the many places where the initial draft was unclear or inconsistent, because those are not of general interest. We are grateful to the reviewers for all their comments, since they resulted in a vastly improved report.

Comment (1): The paper assumes that the reader is familiar with the NEMS model. We would certainly suggest at least a brief description (and perhaps a flowchart) of how the model works.

Response: In helping our readers better understand the context of our integrated scenario analysis, we expanded the discussion about the NEMS model, including a diagram to illustrate its key components and interactions. In addition, we have given readers more of a context to explain the background of the Five-Lab study that drives many of our scenario assumptions.

Comment (2): The policy relevance of this study is high, perhaps higher than is acknowledged in the introductory discussion. The EU (and most developing countries) is very concerned that the U.S. will attempt to fulfill most of its Kyoto obligation by acquiring carbon allowances from abroad. To prevent this strategy, which the EU regards as contrary to the intent of the Protocol, the EU along with several LDC's inserted into Article 17 the provision that emissions trading "shall be supplemental to domestic actions."

Response: Although we are not in a position to evaluate this statement, we note that the results of our scenario analysis strongly suggest the U.S. economy will benefit from increased domestic technology investments.

Comment (3): We do not believe the Five-Lab energy efficiency potentials are realistic.

Response: Our focus was on creating scenarios that illustrate the economic and environmental opportunities associated with a high-efficiency/low-carbon technology path. Although the American Petroleum Institute and others have written commentaries that are critical of the Five-Lab findings, the resource potential for this path is well documented in a large number of other studies that we reference. Whether one believes these potentials or not, our goal was to learn what we could about such technology-based scenarios using the LBNL-NEMS integrating framework.

The authors believe that a combination of an emissions trading program and a variety of different non-price policies can lead to changes in energy service markets of the magnitude required. These non-price policies include voluntary agreements with industry, cost-effective minimum efficiency standards, ENERGY STAR programs, utility incentive programs funded through "line charges," targeted tax credits, golden carrots, government and industry purchases of high efficiency technologies now on the market, and technology procurement by government and industry for technologies close to commercialization. The program experience over the last two decades solidly demonstrates that these non-price programs work well and have been shown to be cost-effective.

This is especially true with respect to implementing a high-efficiency/low-carbon future. We also believe that the historical record has not been fully understood with respect to the ongoing opportunities to close that efficiency gap. The current generation of Energy Star programs and the various Research and Development initiatives supported by the U.S. Department of Energy all underscore this point.

Comment (9): Why switch in mid-stream to referencing the AMIGA model? What is the pedigree of this model, and what confidence can we place in its conclusions?

Response: Our previous reference to the results found in our AMIGA analysis was unclear. We have attempted to strengthen that discussion. AMIGA shows that model structure matters with respect to anticipated scenario outcomes. We cite the AMIGA analysis to underscore that a combination of policies and price signals can actually accomplish the twin objectives of reducing carbon emissions and maintaining economic activity. As noted in both the reference to AMIGA, and the accompanying footnote, it is a CGE model developed by the Argonne National Laboratory. The model has a substantial documentation that we can provide upon request.

Comment (10): Cost effectiveness of retirements and repowering should be investigated on a regional basis.

Response: This is an excellent point that we didn't have time to explore. We noted that regional fuel prices should be a key area of investigation in the Future Work section.

Comment (12): Many carbon savings options, such as repowering of coal-fired power plants with natural gas, renewables, and advanced efficiency technologies, are not included in the scenarios.

Response: We added a few paragraphs in the Future Work section to describe the ones we feel are missing or need more exploration. We will investigate these in our later work.

Comment (13): It is interesting that your HE/LC case has declining prices and declining demand. This result seems counterintuitive from the perspective of Economics 101.

Response: It is important to understand that the non-price policies posited in our scenarios reduce the barriers to the adoption of efficiency technologies (these technologies are cost effective from society's perspective). These policies are not dependent on energy prices for their effectiveness, and hence can reduce demand for energy use. This reduction in demand will then put downward pressure on prices. There will be some "takeback" due to this decline in prices. As a result, some households and businesses may take back some of the energy savings in the form of increased comfort and slightly higher energy use. However, the empirical research on this topic shows this effect to be small.

The decline in energy prices from implementing these non-price policies is a major benefit to society that is not typically counted in bottom-up analyses of the costs of reducing carbon emissions.

Comment (14): The HE/LC case involves diverting capital from other uses, so that there is an opportunity cost to these investments that is not included in your analysis

Response: The HE/LC case displaces capital intensive supply-side investments with cheaper demand-side investments, and it therefore results in *less* use of capital. If anything, this opportunity cost argument cuts in the opposite direction from the one the commenter intended.

Comment (15): Strengthen the comments on macro effects found in the LBNL-NEMS. That's a weak point in the model so you should be clear on that yourselves.

Response: We agree with this point. Since NEMS does not track either energy efficiency technology investments or energy bill savings with respect to their impact on GDP and personal consumption expenditures, the model may understate the positive impacts of a cost-effective technology path. It is for that reason that we expanded the discussion on the full investment and program transition costs to establish the net positive benefits of scenarios bolstered by the Five-Lab study and similar analysis.

APPENDIX D: KEY OUTPUTS FROM SELECTED MODELING RUNS

The following tables summarize key results from our runs. Each column represents a scenario that combines demand-side and supply side options in different ways. The first two pages show results in 2010, and the second two show results in 2020. The last table shows

Table D-1: Summary of High-Efficiency/Low Carbon Cases

All-Sector Forecast Summary

2010

Page 1 of 2

	AEO98 Ref Case	LBNL-NEMS 23 \$/t C-C Case	LBNL-NEMS High-Eff Case	LBNL-NEMS Coal Retire Case	LBNL-NEMS Gas-Oil Retir Case	LBNL-NEMS SupplySide Case
<i>demand side efficiency measures</i>	-	-	hieff	-	-	-
<i>carbon charge (\$/tC)</i>	-	23	-	-	-	-
<i>coal retirements (GW)</i>	-	-	-	16	-	-
<i>natural gas and oil retirements (GW)</i>	-	-	-	-	100	-
<i>supply-side improvements</i>	-	-	-	-	-	ct/cg/hy/wd
	2010	2010	2010	2010	2010	2010
<i>Primary Energy (Quadrillion Btu)</i>						
Residential	21.6	21.2	20.6	21.5	21.5	21.6
Commercial	16.9	16.6	15.4	16.8	16.8	16.9
Industrial	40.5	40.2	36.6	40.4	40.1	39.5
Transportation	33.1	32.8	29.7	33.1	33.1	33.1
Total	112.2	110.8	102.3	111.7	111.4	111.2
<i>Electricity Sales (TWh)</i>						
Residential	1350	1338	1201	1349	1349	1352
Commercial	1200	1186	1041	1199	1200	1205
Industrial	1282	1314	1106	1283	1267	1143
Transportation	46	46	53	46	46	46
Total	3877	3883	3400	3877	3861	3746
<i>Carbon Emissions by Sector (Mt)</i>						
Residential	338	327	314	333	337	332
Commercial	274	266	245	270	273	269
Industrial	563	552	504	560	558	540
Transportation	628	622	563	628	627	627
Total	1803	1767	1624	1791	1795	1768
Utilities	663	646	577	650	654	621
<i>Carbon Emissions by Source (Mt)</i>						
Petroleum	762	754	687	762	757	760
Natural Gas	424	432	388	428	415	418
Coal	616	580	548	600	622	590
Other	2	1	1	2	2	2
Total	1803	1767	1624	1791	1795	1768
<i>Average Energy Prices to All Users (96\$/MBtu)</i>						
Petroleum Products	8.02	8.31	7.15	7.98	8.04	8.04
Natural Gas	3.70	4.28	3.01	3.75	3.54	3.45
Coal	1.11	1.68	1.08	1.11	1.09	1.11
Electricity	17.32	18.89	16.72	17.39	17.34	17.16
<i>Average Energy Price to Elec Gen (96\$/MBtu)</i>						
Fossil Fuel Average	1.57	2.20	1.30	1.61	1.47	1.46
Petroleum Products	3.84	4.17	3.61	3.81	4.78	4.08
Distillate Fuel	5.33	5.74	4.68	5.33	5.33	5.32
Residual Fuel	3.46	3.86	3.19	3.48	4.34	3.59
Natural Gas	2.84	3.46	1.99	2.91	2.70	2.57
Steam Coal	1.09	1.66	1.06	1.09	1.07	1.09
<i>Energy Consumption (Quadrillion Btu)</i>						
Petroleum Subtotal	44.3	43.9	39.8	44.3	44.1	44.2
Natural Gas	29.6	30.1	27.1	29.9	29.0	29.2
Coal Subtotal	24.0	22.7	21.4	23.4	24.2	23.0
Nuclear Power	6.4	6.4	6.4	6.4	6.4	6.4
Renewable Energy	7.4	7.4	7.2	7.4	7.3	8.0
Electricity Imports	0.3	0.3	0.3	0.3	0.3	0.3
Others	0.1	0.1	0.1	0.1	0.1	0.1
Total	112.2	110.8	102.3	111.7	111.4	111.2
<i>Macroeconomic Indicators</i>						
GDP (billion 1996\$)	10394	10360	10446	10392	10402	10405
Real Consumption	6997	6966	7040	6996	7004	7007
Real Investment	1917	1907	1933	1915	1919	1920
Real Government Spending	1651	1645	1658	1651	1652	1653
Real Exports	2570	2555	2587	2569	2572	2572
Real Imports	2771	2723	2819	2768	2777	2781
Unemployment Rate (%)	5.5	5.6	5.3	5.5	5.5	5.5
Energy Bill (billion 1996\$)	639	683	521	640	634	626
Energy/GDP Ratio (kBtu/1996\$)	10.8	10.7	9.8	10.7	10.7	10.7
Carbon/GDP Ratio (g/1996\$)	173	171	155	172	173	170

Table D-1: Summary of High-Efficiency/Low Carbon Cases
All-Sector Forecast Summary

2010

Page 2 of 2

	LBNL-NEMS	LBNL-NEMS	LBNL-NEMS	LBNL-NEMS	LBNL-NEMS	LBNL-NEMS	LBNL-NEMS	LBNL-NEMS
	CC-Hieff	HE-Ret	CC-Ret	HELC	HELC	HELC	HELC	HELC
	Case	Case	Case	Case	Case	Case	Case	Case
	hieff	hieff	-	hieff	hieff	hieff	hieff	hieff
demand side efficiency measures								
carbon charge (\$/tC)	23	-	23	23	23	23	23	50
coal retirements (GW)	-	16	16	-	16	-	16	16
natural gas and oil retirements (GW)	-	100	100	-	0	100	100	100
supply-side improvements	-	-	-	cf/cg/hy/wd	cf/cg/hy/wd	cf/cg/hy/wd	cf/cg/hy/wd	cf/cg/hy/wd
	2010	2010	2010	2010	2010	2010	2010	2010
Primary Energy (Quadrillion Btu)								
Residential	20.1	20.2	20.9	20.0	19.9	19.7	19.7	19.3
Commercial	15.2	15.1	16.4	15.1	15.0	14.9	14.8	14.6
Industrial	36.4	36.1	39.9	35.6	35.5	35.3	35.3	35.0
Transportation	29.4	29.6	32.8	29.4	29.3	29.3	29.3	29.0
Total	101.1	101.0	109.9	100.0	99.8	99.2	99.1	97.9
Electricity Sales (TWh)								
Residential	1188	1199	1336	1187	1187	1187	1187	1175
Commercial	1033	1041	1185	1034	1034	1034	1034	1025
Industrial	1131	1096	1304	1015	1014	1014	1013	1035
Transportation	52	53	46	52	52	52	52	52
Total	3404	3388	3871	3289	3287	3288	3286	3287
Carbon Emissions by Sector (Mt)								
Residential	305	305	321	294	292	287	286	273
Commercial	239	237	261	229	228	223	222	213
Industrial	496	494	545	472	471	466	466	455
Transportation	557	562	622	556	556	556	556	549
Total	1596	1598	1749	1552	1548	1531	1529	1491
Utilities	566	551	628	515	511	495	492	470
Carbon Emissions by Source (Mt)								
Petroleum	676	684	747	674	675	673	673	665
Natural Gas	390	383	429	389	388	388	386	394
Coal	529	530	572	487	484	469	469	430
Other	1	1	1	1	1	1	1	1
Total	1596	1598	1749	1552	1548	1531	1529	1491
Average Energy Prices to All Users (96\$/MBtu)								
Petroleum Products	7.49	7.15	8.31	7.48	7.48	7.49	7.50	7.92
Natural Gas	3.49	2.93	4.25	3.37	3.36	3.37	3.35	3.95
Coal	1.66	1.06	1.66	1.66	1.66	1.63	1.64	2.33
Electricity	18.20	16.73	19.11	18.21	18.28	18.18	18.24	19.87
Average Energy Price to Elec Gen (96\$/MBtu)								
Fossil Fuel Average	1.88	1.25	2.18	1.82	1.83	1.81	1.81	2.54
Petroleum Products	3.97	4.20	5.16	4.25	4.24	4.63	4.62	5.15
Distillate Fuel	5.11	4.67	5.70	5.11	5.10	5.11	5.10	5.59
Residual Fuel	3.59	3.84	4.68	3.85	3.84	4.25	4.26	4.79
Natural Gas	2.55	1.95	3.52	2.36	2.39	2.40	2.40	3.07
Steam Coal	1.64	1.03	1.63	1.63	1.63	1.61	1.61	2.30
Energy Consumption (Quadrillion Btu)								
Petroleum Subtotal	39.2	39.7	43.5	39.2	39.2	39.1	39.1	38.7
Natural Gas	27.2	26.7	29.9	27.2	27.1	27.1	27.0	27.5
Coal Subtotal	20.7	20.7	22.4	19.1	18.9	18.4	18.3	16.9
Nuclear Power	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4
Renewable Energy	7.2	7.2	7.3	7.8	7.8	7.9	8.0	8.0
Electricity Imports	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.4
Others	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Total	101.1	101.0	109.9	100.0	99.8	99.2	99.1	97.9
Macroeconomic Indicators								
GDP (billion 1996\$)	10417	10451	10362	10420	10421	10421	10423	10386
Real Consumption	7013	7045	6969	7017	7017	7017	7018	6984
Real Investment	1926	1935	1908	1926	1928	1926	1928	1919
Real Government Spending	1652	1659	1647	1653	1653	1653	1653	1648
Real Exports	2572	2588	2556	2573	2575	2575	2575	2558
Real Imports	2775	2824	2727	2779	2781	2781	2782	2729
Unemployment Rate (%)	5.4	5.3	5.6	5.4	5.4	5.4	5.4	5.4
Energy Bill (billion 1996\$)	559	517	683	550	551	549	550	594
Energy/GDP Ratio (kBtu/1996\$)	9.7	9.7	10.6	9.6	9.6	9.5	9.5	9.4
Carbon/GDP Ratio (g/1996\$)	153	153	169	149	149	147	147	144

Table D-2: Summary of High-Efficiency/Low Carbon Cases

All-Sector Forecast Summary

2020

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	AE098 Ref Case	LBNL-NEMS 23 \$/t C-C Case	LBNL-NEMS High-Eff Case	LBNL-NEMS Coal Retire Case	LBNL-NEMS Gas-Oil Retir Case	LBNL-NEMS SupplySide Case
<i>demand side efficiency measures</i>	-	-	hieff	-	-	-
<i>carbon charge (\$/tC)</i>	-	23	-	-	-	-
<i>coal retirements (GW)</i>	-	-	-	16	-	-
<i>natural gas and oil retirements (GW)</i>	-	-	-	-	100	-
<i>supply-side improvements</i>	-	-	-	-	-	cf/cg/hy/wd
	2020	2020	2020	2020	2020	2020
Primary Energy (Quadrillion Btu)						
Residential	23.2	22.8	21.7	23.0	23.1	23.1
Commercial	17.4	17.1	15.5	17.3	17.3	17.4
Industrial	41.6	41.2	34.6	41.4	41.4	40.7
Transportation	36.5	36.1	27.7	36.4	36.4	36.4
Total	118.6	117.2	99.5	118.2	118.3	117.6
Electricity Sales (TWh)						
Residential	1548	1533	1337	1546	1542	1546
Commercial	1304	1286	1090	1303	1301	1308
Industrial	1392	1411	1059	1389	1384	1256
Transportation	64	63	79	64	64	64
Total	4308	4293	3566	4301	4291	4173
Carbon Emissions by Sector (Mt)						
Residential	379	363	344	374	378	370
Commercial	296	283	255	292	295	289
Industrial	589	571	476	585	588	565
Transportation	692	684	526	692	692	691
Total	1956	1901	1601	1942	1952	1915
Carbon Emissions by Source (Mt)						
Petroleum	822	810	637	822	818	822
Natural Gas	474	481	417	475	472	467
Coal	658	608	545	642	659	624
Other	3	3	2	3	3	3
Total	1956	1901	1601	1942	1952	1915
Average Energy Prices to All Users (96\$/MBtu)						
Petroleum Products	8.12	8.42	6.26	8.11	8.12	8.12
Natural Gas	3.86	4.36	2.87	3.90	3.92	3.87
Coal	1.00	1.59	0.98	1.00	1.00	1.01
Electricity	16.01	17.56	15.02	16.08	16.61	16.04
Average Energy Price to Elec Gen (96\$/MBtu)						
Fossil Fuel Average	1.66	2.30	1.31	1.69	1.68	1.67
Petroleum Products	4.21	4.52	3.63	4.13	4.98	4.40
Distillate Fuel	5.64	5.99	4.42	5.63	5.61	5.64
Residual Fuel	3.77	4.15	3.27	3.73	4.47	3.87
Natural Gas	3.15	3.73	2.13	3.21	3.28	3.23
Steam Coal	0.97	1.56	0.95	0.97	0.97	0.98
Energy Consumption (Quadrillion Btu)						
Petroleum Subtotal	47.6	47.0	37.2	47.6	47.5	47.6
Natural Gas	33.1	33.6	29.1	33.2	33.0	32.6
Coal Subtotal	25.6	23.7	21.3	25.0	25.7	24.3
Nuclear Power	4.1	4.1	4.1	4.1	4.1	4.1
Renewable Energy	7.7	8.4	7.4	7.9	7.7	8.6
Electricity Imports	0.3	0.3	0.3	0.3	0.3	0.3
Others	0.2	0.2	0.1	0.2	0.2	0.2
Total	118.6	117.2	99.5	118.2	118.3	117.6
Macroeconomic Indicators						
GDP (billion 1996\$)	12013	11989	12088	12012	12005	12008
Real Consumption	8405	8380	8475	8405	8400	8402
Real Investment	2320	2316	2341	2320	2317	2318
Real Government Spending	1807	1802	1818	1806	1806	1807
Real Exports	3694	3673	3736	3693	3693	3695
Real Imports	4577	4506	4727	4575	4577	4583
Unemployment Rate (%)	5.7	5.6	5.6	5.7	5.7	5.7
Energy Bill (billion 1996\$)	684	727	459	685	691	678
Energy/GDP Ratio (kBtu/1996\$)	9.9	9.8	8.2	9.8	9.9	9.8
Carbon/GDP Ratio (g/1996\$)	163	159	132	162	163	159

Table D-2: Summary of High-Efficiency/Low Carbon Cases
All-Sector Forecast Summary

2020

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	LBNL-NEMS CC-Hieff Case hieff	LBNL-NEMS HE-Ret Case hieff	LBNL-NEMS CC-Ret Case hieff	LBNL-NEMS HELC Case hieff	LBNL-NEMS HELC Case hieff	LBNL-NEMS HELC Case hieff	LBNL-NEMS HELC Case hieff	LBNL-NEMS HELC Case hieff
<i>demand side efficiency measures</i>	23	-	23	23	23	23	23	50
<i>carbon charge (\$/tC)</i>	-	16	16	-	16	-	16	16
<i>coal retirements (GW)</i>	-	100	100	-	0	100	100	100
<i>natural gas and oil retirements (GW)</i>	-	-	-	cf/cg/hy/wd	cf/cg/hy/wd	cf/cg/hy/wd	cf/cg/hy/wd	cf/cg/hy/wd
<i>supply-side improvements</i>	2020	2020	2020	2020	2020	2020	2020	2020
<i>Primary Energy (Quadrillion Btu)</i>								
Residential	21.2	21.4	22.6	21.2	21.1	21.0	20.9	20.4
Commercial	15.2	15.2	16.9	15.1	15.0	15.0	14.9	14.7
Industrial	34.4	34.4	41.0	33.7	33.6	33.6	33.5	33.2
Transportation	27.4	27.7	36.1	27.3	27.3	27.3	27.3	27.0
Total	98.2	98.7	116.6	97.3	97.1	96.9	96.6	95.2
<i>Electricity Sales (TWh)</i>								
Residential	1322	1334	1527	1323	1323	1322	1322	1306
Commercial	1080	1089	1281	1082	1082	1083	1082	1072
Industrial	1089	1058	1411	975	978	979	978	998
Transportation	78	79	63	78	78	78	78	78
Total	3570	3560	4282	3459	3461	3462	3461	3454
<i>Carbon Emissions by Sector (Mt)</i>								
Residential	331	338	361	323	320	319	315	299
Commercial	247	250	281	240	237	237	233	223
Industrial	467	472	570	447	446	444	442	430
Transportation	519	525	684	518	518	517	517	510
Total	1564	1585	1897	1527	1520	1517	1508	1461
<i>Carbon Emissions by Source (Mt)</i>								
Petroleum	626	635	806	624	624	622	622	614
Natural Gas	428	415	485	419	422	422	423	431
Coal	509	534	604	484	473	471	461	415
Other	2	2	3	2	2	2	2	2
Total	1564	1585	1897	1527	1520	1517	1508	1461
<i>Average Energy Prices to All Users (96\$/MBtu)</i>								
Petroleum Products	6.64	6.27	8.41	6.65	6.64	6.64	6.64	7.02
Natural Gas	3.35	2.86	4.50	3.25	3.27	3.33	3.28	3.85
Coal	1.56	0.96	1.57	1.56	1.55	1.54	1.53	2.22
Electricity	16.50	15.16	18.33	16.42	16.44	16.38	16.41	18.13
<i>Average Energy Price to Elec Gen (96\$/MBtu)</i>								
Fossil Fuel Average	1.92	1.29	2.37	1.85	1.87	1.87	1.86	2.58
Petroleum Products	4.03	4.15	5.37	4.16	4.16	4.62	4.62	5.18
Distillate Fuel	4.88	4.43	5.97	4.88	4.86	4.88	4.89	5.42
Residual Fuel	3.71	3.95	4.84	3.85	3.86	4.42	4.42	5.00
Natural Gas	2.68	2.11	3.95	2.53	2.56	2.62	2.56	3.19
Steam Coal	1.53	0.93	1.54	1.53	1.52	1.50	1.50	2.19
<i>Energy Consumption (Quadrillion Btu)</i>								
Petroleum Subtotal	36.6	37.2	46.8	36.5	36.5	36.4	36.5	36.0
Natural Gas	29.9	29.0	33.9	29.2	29.4	29.5	29.5	30.1
Coal Subtotal	19.9	20.8	23.6	18.9	18.5	18.4	18.0	16.3
Nuclear Power	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1
Renewable Energy	7.4	7.3	7.8	8.2	8.1	8.1	8.2	8.4
Electricity Imports	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Others	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.1
Total	98.2	98.7	116.6	97.3	97.1	96.9	96.6	95.2
<i>Macroeconomic Indicators</i>								
GDP (billion 1996\$)	12057	12085	11980	12060	12059	12058	12059	12023
Real Consumption	8445	8474	8374	8448	8448	8446	8448	8412
Real Investment	2334	2340	2313	2335	2334	2334	2334	2327
Real Government Spending	1813	1818	1801	1813	1813	1813	1813	1806
Real Exports	3715	3736	3671	3717	3717	3716	3717	3692
Real Imports	4653	4729	4498	4659	4660	4659	4660	4569
Unemployment Rate (%)	5.6	5.6	5.7	5.6	5.6	5.6	5.6	5.6
Energy Bill (billion 1996\$)	499	460	739	491	491	491	491	532
Energy/GDP Ratio (kBtu/1996\$)	8.1	8.2	9.7	8.1	8.0	8.0	8.0	7.9
Carbon/GDP Ratio (g/1996\$)	130	131	158	127	126	126	125	122

Table D-3: Summary of Fuel Consumption by Sector for Selected Scenarios

	Primary Energy Consumption (Quadrillion Btu)											
	2010					total	2020					total
	electricity (1)	coal	gas	petroleum	renewable (1)		electricity (1)	coal	gas	petroleum	renewable (1)	
AEO98 Reference Case												
Residential	14.0	0.1	5.6	1.3	0.6	21.6	15.2	0.1	6.0	1.3	0.6	23.2
Commercial	12.4	0.1	3.8	0.7	0.0	16.9	12.8	0.1	3.9	0.6	0.0	17.4
Industrial	13.3	2.5	11.7	10.8	2.3	40.5	13.7	2.5	11.8	11.3	2.3	41.6
Transportation	0.5	-	1.2	31.3	0.2	33.1	0.6	-	1.4	34.1	0.3	36.5
Total	40.2	2.7	22.2	44.0	3.1	112.2	42.3	2.6	23.0	47.3	3.3	118.6
23 \$/t Carbon Charge Case												
Residential	13.8	0.1	5.5	1.3	0.6	21.2	15.0	0.1	5.8	1.3	0.6	22.8
Commercial	12.2	0.1	3.7	0.7	0.0	16.6	12.6	0.1	3.8	0.6	0.0	17.1
Industrial	13.5	2.3	11.7	10.5	2.2	40.2	13.8	2.2	12.0	10.9	2.3	41.2
Transportation	0.5	-	1.2	31.0	0.2	32.8	0.6	-	1.4	33.8	0.3	36.1
Total	39.9	2.4	22.1	43.4	3.0	110.8	42.0	2.3	23.0	46.6	3.3	117.2
50 \$/t Carbon Charge Case												
Residential	13.5	0.1	5.4	1.3	0.6	20.8	14.5	0.1	5.7	1.3	0.6	22.2
Commercial	11.9	0.1	3.7	0.7	0.0	16.3	12.1	0.1	3.8	0.6	0.0	16.6
Industrial	13.6	2.2	11.6	10.4	2.2	40.0	13.7	2.0	11.9	10.9	2.3	40.8
Transportation	0.5	-	1.2	30.6	0.2	32.4	0.6	-	1.4	33.3	0.3	35.6
Total	39.4	2.3	21.8	42.9	3.0	109.3	40.9	2.2	22.7	46.1	3.3	115.1
LBNL-NEMS High Efficiency Case												
Residential	12.7	0.1	5.8	1.3	0.6	20.6	13.5	0.1	6.2	1.3	0.7	21.7
Commercial	11.0	0.1	3.6	0.7	0.0	15.4	11.0	0.1	3.7	0.6	0.0	15.4
Industrial	11.7	2.3	10.8	9.7	2.2	36.6	10.7	2.0	10.2	9.5	2.2	34.6
Transportation	0.6	-	1.1	27.9	0.1	29.7	0.8	-	1.1	25.6	0.2	27.7
Total	36.0	2.4	21.3	39.6	2.9	102.3	35.9	2.2	21.2	37.0	3.1	99.4
HELC Case (23 \$/tC)												
Residential	12.0	0.1	5.7	1.3	0.6	19.7	12.8	0.1	6.1	1.3	0.6	20.9
Commercial	10.4	0.1	3.6	0.7	0.0	14.8	10.5	0.1	3.7	0.6	0.0	14.9
Industrial	10.2	2.0	11.6	9.4	2.2	35.3	9.5	1.8	10.9	9.1	2.2	33.5
Transportation	0.5	-	1.0	27.6	0.1	29.3	0.8	-	1.1	25.3	0.2	27.3
Total	33.2	2.1	21.9	39.0	2.9	99.1	33.6	1.9	21.8	36.3	3.0	96.6
HELC Case (50 \$/tC)												
Residential	11.8	0.1	5.5	1.3	0.6	19.2	12.6	0.1	5.9	1.3	0.6	20.4
Commercial	10.3	0.1	3.6	0.7	0.0	14.6	10.3	0.1	3.6	0.6	0.0	14.7
Industrial	10.4	1.9	11.4	9.3	2.1	35.0	9.6	1.6	10.8	9.1	2.2	33.2
Transportation	0.5	-	1.0	27.3	0.1	29.0	0.8	-	1.1	24.9	0.2	27.0
Total	32.9	2.0	21.5	38.5	2.9	97.8	33.2	1.8	21.4	35.9	3.0	95.2

(1) Renewable category includes liquid hydrogen and methanol fuel consumption for the transportation sector.

(2) The primary energy conversion factor for electricity is listed below for each case:

	AEO98 Reference Case	23 \$/t Carbon Charge Case	50 \$/t Carbon Charge Case	High Efficiency Case	HELC Case (23 \$/tC)	HELC Case (50 \$/tC)
conversion factor (kWh _{primary} /kWh _{site})	3.04	3.01	2.98	3.11	2.96	2.93



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COMMENTS:

DRAFT !!!!!**EIA STUDY OF THE KYOTO PROTOCOL**

9/11/98

It is widely known that the Energy Information Administration (EIA) is the premier statistical agency for energy matters. Their ability to collect and present data is second to none, and many public and private sector analysts rely on the price and quantity collected and distributed by EIA. However, a study of the economic effects of the Kyoto Protocol requires analytical skills and economic modeling abilities that are not a main focus of EIA's activities. Therefore, it is not surprising that the analysis has some severe shortcomings. In fact, it might be argued that the analysis presented by EIA incorporates several key assumptions that serve to increase the cost estimates of complying with the Protocol.

Problems with the EIA Analysis

The EIA study does not model the international implications of the Kyoto Protocol because the model used looks only at the United States economy. This leaves out the three flexibility mechanisms (international emissions trading, the Clean Development Mechanism, and joint implementation) that the United States required to be included in the Kyoto agreement. These flexibility mechanisms ensure that the most cost-effective ways to reduce greenhouse gas emissions will be utilized, regardless of where in the world these opportunities are located. Effectively, what the EIA analysis does is compute the cost curve for emissions abatement in the United States alone, and ignores low-cost emissions abatement opportunities available in other countries. The Administration is aware that the United States may have a relatively high cost of reducing emissions domestically, which is why the Administration insisted that flexibility mechanisms such as international emissions trading were included in the Protocol.

The EIA study looks only at carbon dioxide, one of the six major greenhouse gases covered by the Protocol (though carbon dioxide is the most prevalent greenhouse gas). The EIA study also does not incorporate any analysis of "sinks" (activities that capture carbon dioxide emissions, such as tree growing), even though the Protocol allows sink activities to offset greenhouse gas emissions. These omissions ignore the tens of millions of tons of low-cost emissions reductions that are expected to be available through gases other than carbon dioxide and through sinks.

The EIA study assumes that the United States economy (with the exception of the electric utility industry) does not begin preparing for the binding emissions targets under the Kyoto Protocol until 2005, a mere three years before the beginning of the 2008-2012 compliance period. By preventing companies from anticipating the onset of emissions restrictions, the EIA analysis effectively compresses compliance activities into a very short period, raising compliance costs tremendously. This assumption goes against prudent business practice of changing production patterns when there is the anticipation of emissions reduction controls being introduced.

The EIA study uses a macroeconomic model ("macro model") that is designed for relatively

short-term forecasts and emphasizes the costs of short term adjustments the economy must make whenever something in the economy changes. The short-term macroeconomic forecasting model (the DRI model), used by EIA is inappropriate for making forecasts going out a decade or more. A more sensible approach is to base estimates on a general equilibrium-type model, which incorporates the dynamism and flexibility that is the hallmark of the American economy, especially when viewed over periods of a decade or more. (For example, the American economy has adopted the Internet in the past decade, leading to industries and services that could not be dreamed of a decade ago. The class of models used by EIA does not adequately capture the inherent flexibility in the U.S. economy.) A study by the World Resources Institute indicates that this one assumption is often enough to double the estimated costs of meeting a given emissions reduction goal.

The EIA study assumes that consumers and businesses are generally unresponsive to the price changes when it comes to changing their energy consumption habits. Because of this assumption, the modeling requires a very large price signal before energy-reducing investments are made. The degree of price responsiveness is referred to as an "elasticity" by economists. Preliminary analysis indicates that the elasticities used in the EIA analysis, particularly for long-run choices, are very small compared to the prevailing estimates in the economic literature. In addition, the EIA analysis does not foresee much increase in the use of natural gas without a sharp price increase. A more moderate choice of demand and supply elasticities would reduce the estimated permit prices and reduce the economic costs estimated by EIA.

The EIA study takes a dim view on the role technology can play in meeting the greenhouse gas emissions targets under the Kyoto Protocol. In particular, the EIA analysis does not incorporate very much in the way of efficiency improvements in the industrial, buildings, and transportation sectors. In part, this is because EIA constrains itself by assuming that policies do not change over time. That is, even with projected high prices for energy, Federal and State governments *take no action whatsoever* to design and implement policies to encourage the use of energy efficient or clean energy technologies. Given the many options available such as efficiency standards, tax incentives, technology demonstrations, additional R&D, etc., it is inconceivable that no policy actions would be taken. Ignoring these policy possibilities is tantamount to assuming that the Protocol will be implemented in as costly a way as possible.

The EIA study is substantially pessimistic in terms of the potential of both technology and market innovation. While technology is assumed to gradually improve over time in the EIA analysis, there is no direct effect of the substantially higher fuel prices on the availability of more advanced technology or more innovative uses of technology. Indeed, certain classes of equipment, such as a range of miscellaneous commercial appliances, barely improve their efficiency despite a large potential to do so. Because of the relative technology pessimism, only about one fourth of the carbon dioxide emissions reductions projected by EIA come from the "demand side" (i.e., buildings, industry and transportation), while three fourths of the reductions are from the electric utility sector. These latter reductions are achieved largely through the retirement of coal plants, generally a very expensive way to reduce emissions. This assumption imparts an upward bias into the EIA study.

In particular, various programs the Administration is engaged in -- electricity restructuring, PNGV, R&D for renewables, appliance standards, EnergyStar buildings -- all will have substantial effects over the next decade, making it less costly for the U.S. to meet its emissions target. Studies put out by the Department's National Laboratories (the so-called Five Lab and Eleven Lab studies) indicate there are many viable technology pathways to reduce greenhouse gas emissions at low cost. The Department has a goal of getting many of these technologies widely deployed in the marketplace, but these technologies do not show up in the EIA analysis.

The Administration's Approach

The Administration estimated the economic costs of meeting the Kyoto Protocol target by looking at the Protocol itself and trying to model all its important features -- the inclusion of 6 different greenhouse gases, the ability to average emissions over the 2008-2012 period to meet the target, the existence of flexibility mechanisms such as international emissions trading and the Clean Development Mechanism that will help reduce costs, and the fact that countries around the world will be looking for the most cost-effective ways to reduce greenhouse gas emissions. When all of these elements is incorporated into a comprehensive analysis, the cost of meeting the Protocol targets is shown to be quite modest.

The Administration's illustrative analysis of the Kyoto Protocol estimates that the United States will be able to meet its emissions reduction commitment under the Protocol using the international emissions trading system included in the Protocol at a permit price of \$14-23 dollars per ton of carbon equivalent. The cost in terms of GDP is less than 0.1 percent per year in reduced output. Under this analysis, the estimated permit price is the global cost of emissions permits -- all countries can buy permits at \$14-23 per ton, and there are enough available permits for all countries to meet their Protocol commitments. This is a key element of the analysis, because climate change is a global problem and studies that do not attempt to solve this globally (such as the EIA study) miss out on the potential for large amounts of low-cost greenhouse gas abatement opportunities in other countries.

Summary

Attempts to model the Kyoto Protocol should feature the key elements of the Protocol -- the international flexibility mechanisms, the potential to search worldwide for low-cost abatement opportunities, and the ability to trade-off between various gases and sinks. Moreover, the analysis should take into account the vibrant and dynamic nature of the American (and global) economy, where investments can flow between sectors in response to price signals. Finally, the analysis should take into account the decade or so of lead time to prepare a path for gradually shifting energy use in order to meet the Kyoto Protocol goals. The Administration's analysis does take these elements into account and shows that the cost of meeting the Kyoto Protocol is likely to be modest. The EIA analysis does not take these elements into account and estimates the cost to be quite high. The difference indicates why the Administration fought so hard to make sure the various flexibility elements were included in the Protocol.

As Dr. Janet Yellen has said "If we do it dumb, it could cost a lot, but if we do it smart, it will

cost much less and indeed, could produce benefits over the long run." We believe that the Administration will succeed in making the Kyoto Protocol the "smart way" to reduce greenhouse gas emissions at modest cost and that the Administration's analysis is the "smart way" to perform the necessary economic cost analysis.

Postscript

An interesting point made in the EIA study is that, despite the extraordinarily high permit prices, there is no long-term harm to the overall U.S. economy. This shows that the U.S. economy can take a sharp hit from higher energy prices, but still right itself and grow at a vigorous pace once it adjusts to the higher prices. The Administration, however, believes that the permit prices (and the energy price changes) will be much smaller under the Kyoto Protocol, and the effect on the economy even smaller than estimated by EIA.

FAX

Date: Monday, September 14, 1998

Time: 11:45:00 AM

3 Pages

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Comments:

Good morning, Joe:

Even as we speed toward the finish of our analysis, I thought perhaps this two-pager might be useful with respect to the EIA Kyoto analysis. Let me know if you have questions. I be sure to provide you with our full report later this week.

Best regards,

Skip

Comparing the EIA Analysis on the Impact of Kyoto and the EPA/LBNL-NEMS Integrated Scenario Analysis

Working Notes

September 14, 1998

The EPA Office of Atmospheric Program (OAP) contracted with the Lawrence Berkeley National Laboratory (LBNL) to modify the AEO98 version of the National Energy Modeling System (NEMS) to analyze the technology and policy assumptions of the Five-Lab Study within an integrated macroeconomic context. The EPA/LBNL studied two cases: (1) a high efficiency/low carbon (HELC) case with a price of \$23 per metric ton; and (2) a HELC case with a carbon price of \$50 per metric ton. All prices are in 1996 dollars.

For comparison to the EIA Kyoto analysis, the EPA/LBNL preliminary results indicate that the HELC \$50/tonne scenario would reduce carbon emissions to 1491 MtC by 2010 (11 percent above 1990 levels) and 1461 MtC by 2020 (9 percent above 1990 levels). By comparison, the EIA 1990+9% scenario requires a cost \$163/t while the 1990+9% high technology case requires a carbon price of \$110/t. Moreover, the EIA suggests a significant GDP penalty — on the order of \$200 billion for the +9% case (compared to a reference case projection of \$10.372 billion in 2010). The EPA/LBNL results, on the other hand, range from a small but net benefit of \$29 billion by 2010, to a small loss of \$8 billion in 2010 that changes to a positive \$10 billion benefit in 2020. In other words, the EPA/LBNL scenarios appears to have a negligible impact on GDP while achieving significant reductions in domestic carbon emissions. The technology path provides the important difference between the two different studies.

Based upon the EPA/LBNL analysis, the following comments may be appropriate with respect to the limited technology path reviewed by EIA.

The NEMS model is guided by: (1) behavioral rules that severely limit future technology choices; (2) very low elasticities that are unresponsive to new or changing consumer/producer preferences; and (3) an incomplete set of technology choices that are unaffected by a significantly changed price regime. The result is a model that, by definition, will find carbon reductions only at very high carbon prices with large economic penalties.

The almost glacial response of the NEMS model to both technology availability and choices, as well as changing consumer preferences is strongly suggested by the very high permit prices that persist in the years 2005-2020. For example, despite a \$300 permit price, NEMS shows almost no change in the use of industrial cogeneration compared to the reference case. If we examine the history of fossil fuel production prices which peaked in 1981 at about \$4.16/MMBtu (in 1992 dollars), we find that by 1996 they had fallen to \$1.69/MMBtu. This is a nearly 60 percent decline that is made possible, in part, by increased efficiency and changed institutional arrangements.

The NEMS model appears biased in that a reduction in energy use tends to lower the productivity of other factors in the production process. Hence, a reduction of energy use would penalize the economy. This seems to assume that all productivity gains are energy using. But the evidence points in the opposite direction: that is, investments in energy efficiency improvements can actually stimulate an overall gain in total factor productivity.

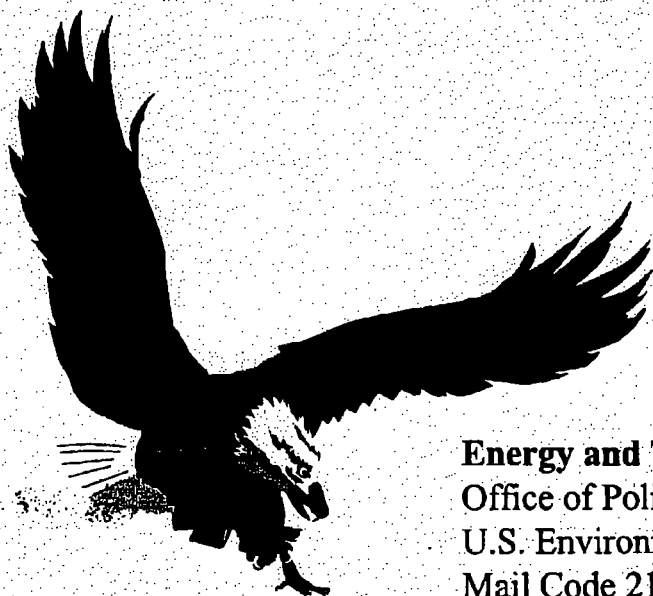
The DRI equation for potential GDP may further bias the macroeconomic results. In previous DRI documentation, it is set forth as the follow function:

Potential GDP = $f(\text{LaborNonNrg}, \text{CapitalNonNrg}, \text{Nrg}, \text{NrgDemand}, \text{NrgProduction})$

The end result is that if energy consumption is reduced — whether by an investment-led strategy or by a price shock — lower energy consumption tends to reduce potential GDP. But if, in fact, an investment-led strategy generates a net energy bill savings, both investment and consumption would increase. A more appropriate formulation of potential GDP would show a small increase in this measure of economic well-being. And if there are other productivity gains beyond energy bill savings (such as increased throughput and reduced material consumption in the production process), then potential GDP should benefit even further.

Although it makes sense to reflect the purchase of international permits as a cost to the US economy, EIA overstates the cost in two ways. First, there is every indication that international permits will be considerably cheaper than the marginal costs represented in the EIA analysis. Second, the marginal cost of the last permit does not equal the average cost of all permits that are purchased. Preliminary analysis suggests that the average cost will be about half of the marginal cost.

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7

Comments:

Comments on EIA report: Chapter 3 - Residential Demand & Commercial Demand

EIA uses the Residential and Commercial Demand Modules (RDM) to generate disaggregated forecasts of energy demand in the residential and commercial sectors for the period 1993 through 2020 by housing and fuel type, Census Division, and end-use service. EIA also uses it as a policy tool to assess the impacts of changes in energy markets building and equipment technologies, and regulatory initiatives that affect the residential and commercial sector.

General Description of Residential Demand Module

- The RDM is a housing and equipment stock model. The stock of households and corresponding energy consuming equipment is tracked for each year of the forecast period.
- Within the RDM, households do not explicitly respond to economic changes over time, or with foresight, nor do households seek to optimize welfare over time.
- Instead, consumers base their fuel and equipment choices on performance at the point of use (the way in which the particular piece of equipment will be used, i.e., space conditioning, water heating, lighting, etc). Decisions are based on cost and performance characteristics of the available technologies, mandated efficiency standards, and energy prices.
 - ◆ Technologies are characterized by their cost, efficiency, dates of availability, minimum and maximum life expectancies, and the relative weights of choice criterion – installed cost and operating cost. The ratio of installed cost to the operation cost gives an estimate of the “hurdle rate” used to evaluate the consumer’s energy efficiency choice. Increasing the weight on the installed cost increases the hurdle rate.
 - ◆ Hurdle rates for residential equipment range from 15% for space heating technologies to more than a 100% for some water heating applications. The “hurdle rate” is the empirically based rate required to simulate actual purchases.

Technology Choice

- NEMS simulates technology choices based on the consumers’ evaluation of certain equipment attributes (such as installed cost and operating cost), with the choice of a particular unit expressed as a probability of the consumer choosing that unit. This probability is empirically estimated and reflects observed trends in the home appliance market.

Elasticities

- Residential energy price elasticities range from -0.24 to -0.28 in the short run, depending on fuel type, to -0.33 to -0.51 in the longer term. The elasticities were derived through a series of simulations that only varied one energy price at a time, beginning in 2000. The elasticities reflect both the demand for energy services and the penetration rate of more efficient technologies.

General description of the Commercial Demand Module (CDM)

- The NEMS Commercial Sector Demand Module is a simulation tool based upon economic engineering relationships that models commercial sector energy demand at the nin Census Division level of detail for eleven distinct categories of commercial buildings. Commercial equipment selections are performed for the major fuels of electricity, natural gas, and distillate fuel, and for the major energy services.
- The market segment level of detail is modeled using a constrained life-cycle cost minimization algorithm that considers commercial sector consumer behavior and time preference premiums.
- The EIA's analysis assumes myopic foresight with respect to energy prices in the commercial sector, using only currently known energy-prices in the annualized cost calculations of the technology selection algorithm. However, the model is *capable* of adaptive foresight and perfect foresight.
- The prime determinants of energy consumption in the CDM are floorspace, building location, age, and the composition of end-use services.

Technology Choice

- The level of efficiency available to commercial consumers and the rate at which more efficient equipment is purchases limits the degree to which energy-efficiency equipment can affect energy consumption.
- The purchasing behavior of the commercial sector is represented by distributing floorspace over a variety of hurdle rates. Rates of return on investment in energy efficiency are required to meet or exceed the hurdle rate. Floorspace is distributed over hurdle rates that range from a low of about 18% to rates high enough to cause choices to be made solely by minimizing the costs of installed equipment (i.e. future potential energy cost savings are ignored).
- However, the hurdle rates in the commercial sector are not fixed: as fuel prices increase, the nonfinancial portion of the hurdle rate in the distribution decreases.

Why are the Residential and Commercial Demand Modules not well suited to analyzing climate policy?

1. Lack of foresight

- A credible climate policy announced sufficiently in advance would affect household energy investment decisions because:
 - 1) Rational households would use information about the coming policy to adapt their energy investment decisions in advance.

2. High "hurdle rates"

- High hurdle rates push down the energy price elasticities in the model by slowing the turnover of less efficient capital with more efficient capital. In some cases the hurdle rates have been set sufficiently high such that increases in energy prices will not induce consumers to make technology/equipment changes regardless of the future energy cost savings.

- Among the reasons often cited for the relatively high hurdle rates in the NEMS framework are uncertainty about future energy prices and future technologies, lack of information about technologies and energy savings, additional costs of adoption not included in the standard calculations, relatively short tenure of residential home ownership, hesitancy to replace functional equipment, and market barriers. It is uncertain how some of these factors would respond to the energy price increases associated with the stabilization of greenhouse-gas emissions. Additionally, there exist policy levers with the potential to decrease the hurdle rates.

Comments on EIA Analysis Chapter 6: Assessment of Economic Impacts

EIA uses the DRI Model of the U.S. Economy to analyze the domestic economic impacts of meeting the Kyoto Protocol targets. The DRI model has been used in several similar analyses, and has been reviewed by a number of well-known economists. In general, the reviewers did not believe that the DRI model was well suited for analyzing climate change policies, primarily because of its structure.

General Description of the DRI Model

- The DRI model is a macroeconomic model of the U.S. economy designed primarily to examine short-term cyclical changes and disequilibrium effects in the economy.
- Within the DRI model, agents do not explicitly respond to economic changes efficiently or with foresight, nor do they seek to optimize welfare over time. This is a key difference between CGE and macro models. (This is also the primary criticism of the model from economists involved in climate change analysis.)
- Instead, decisions by firms and households are driven primarily by a set of macroeconomic indicators — interest rates, inflation, unemployment, and income. Behavioral responses to changes in key economic variables are estimated based on historical data.
 - Consumer sentiment about spending is modeled as a function of recent changes in unemployment, income, interest rates and inflation.
 - Inflation expectations (which influence financial conditions) and market strength expectations (influencing inventory and capital spending decisions) are modeled as functions of recent *rates* of increase in prices and spending.
- With respect to interest rates, inflation and unemployment, agents' expectations of the future are based on the recent past. These variables are key drivers of overall economic activity ("actual GDP").

Long-run Growth

- Long-run economic growth (called "potential GDP" in the DRI model) is determined through a Cobb-Douglas production function that includes labor, business fixed capital, energy and total factor productivity (determined by the stock of research and development capital and trends in technological change).

Unemployment

- The unemployment rate has both a full-employment component (the "natural rate of unemployment") and a cyclical component. Cyclical unemployment is determined in the model by the gap between actual and potential GDP. If actual output is 1% below potential output, cyclical unemployment rises by 0.43 percentage points (based on Okun's Law).

Monetary Policy

- Monetary policy is determined by a reaction function model that uses coefficients estimated over historical data.
- Because monetary policy is one of the key determinants of interest rates, different Fed responses can lead to significantly different estimates of economic effects in the model.

Why are macroeconomic models not well suited to analyzing climate change policy?

1. Lack of foresight

- Economists argue that climate policies announced sufficiently in advance would have minimal cyclical effects on the economy because:
 - 1) Rational households and firms, incorporating the information about the coming policy, would be able to adapt in advance of its implementation; and
 - 2) Inflationary impacts on prices would also be fully anticipated, and would not discourage consumer spending and business production and investment in the same way as an unanticipated energy price shock;
- The DRI Model, lacking forward-looking expectations, treats energy price increases due to climate policy as a shock, most likely overstating the adjustment costs.

2. Lack of intertemporal optimizing behavior

- The DRI model uses reduced form representations of past behavior to predict future production, investment and consumption decisions.
- These representations are problematic because they cannot incorporate how market signals alter the character of the reduced-form response in each sector, nor can they adequately capture structural changes in the economy due to climate policies.
- These errors are likely to become greater further into the forecast, making macroeconomic models particularly unsuitable for medium- to long-term analysis.

(Ray Kopp, RFF)

3. Use of fixed input-output coefficients

- DRI uses a fixed-coefficient input-output (I-O) model to estimate the economic impacts at the industry level. (DRI's own I-O model includes 247 sectors. DRI has also developed an I-O model specifically for EIA which includes 45 sectors).
- Projections of energy and other intermediate inputs are fixed in proportion to the output of each industry. Coefficients for inputs may change over time in the model based on historical trends, but they do not respond to changes in prices.
 - For example, the amount of energy used to produce a ton of steel in the model will decrease over time based on historical trends, but the model cannot predict energy efficiency improvements in steel production that might result from changes in energy prices.
- The I-O model will likely give a distorted view of adjustment behavior at the sectoral level, and these errors will become greater over time.

Comments on Electricity Supply

Competition between coal and natural gas in this sector is one of the most important drivers of the results in this analysis. The sector supplies most of the emissions reductions, and the **coal-gas competition is the single most important emissions reduction mechanism**. This is demonstrated by the carbon emissions tables (Table B18). Total US emissions in 2010 range from baseline levels of 1790.6 MMTC to 1243.4 MMTC in the 1990-7% case. This is a range of 547.2 MMTC. Emissions from utility coal use range from 550.4 MMTC in the reference case to 94.8 MMTC in the 1990-7% case, a range of 455.6 MMTC. Thus **displacing coal accounts for roughly 80% of the full range of emissions reductions** between these two cases.

Not all of the coal use is displaced by natural gas. Lower energy demand and renewable energy also play a role. Coal-fired electric generation falls from 2075 bKWh in the reference case (2010) to 385 bKWh in the 1990-7% case. Of this 1690 bKWh difference, 840 bKWh is made up for by increased natural gas use. 640 bKWh reflects decreased demand. 115 bKWh comes from increased nuclear generation and 93 bKWh from renewable energy. Demand responses are discussed elsewhere.

It is unclear why such a high carbon tax is required to back out these levels of coal generation. It is probable that constraints in the NEMS model's dispatch submodule are preventing gas-fired generation from taking the place of coal. Documentation of this submodule was last produced in 1997, for the AEO 1997. Substantial modifications have taken place since then, both for AEO98 and for this analysis.

Table 18 on page 76 of the EIA report offers some perspective on this problem. Without taking into account changes in wellhead gas and minemouth coal prices, the 'break even' point where a new gas plant operating at 70% capacity would be able to overtake a coal plant also operating at 70% capacity appears to fall in the range of \$100-150/ton carbon tax. Several dynamic factors complicate this simplistic exercise. First, the costs in Table 18 are only average costs. The least expensive coal plants would require a higher carbon tax to be pushed aside. Second, increasing demand for natural gas increases the wellhead gas price. This factor adds about 30% to the cost of gas in the most extreme case, which translates into about 20% in final operating cost for a new gas plant. However, in the EIA analysis minemouth coal prices also increase, by about the same amount. Finally, as the coal plants are pushed out of the dispatch order their capacity factors decline, from 76% in the reference case to 26% in the 1990 case and 17% in the 1990-7% case.

Hence the relevant comparison on Table 18 is between a new combined-cycle gas plant at 70% capacity factor versus an existing coal plant at 30% capacity factor (or less). Even adjusting the gas plant's operating cost to account for the wellhead price increase, **the 'break even' point for the gas-coal competition appears to be in the \$50-100/ton range.**

Severe constraints must be affecting the dispatch submodule of NEMS in this analysis. Take the difference between the two most extreme cases—1990-3% and 1990-7%. Installed capacity of coal and natural gas is virtually identical. This indicates that the capacity planning submodule has built enough gas capacity to meet the 1990-3% constraint, and no more is required to meet the 1990-7% constraint. The difference in the carbon constraint is about 100 MMTC in 2010. Meeting this constraint, with little change in the capital stock, entails dispatching more gas and less coal. The incremental carbon tax required is another \$100/ton. **This large increase in cost**

shows how difficult it is for the NEMS model to shift fuel usage, even when required power plants are in place. At such high tax levels, estimating the operating cost of gas and coal plants indicates that the **gas plants could operate at a cost of over \$0.01/kWh less than the coal plants** (on average). This kind of economic advantage is another indication of constraints acting to prevent natural gas entering the electric sector.

Another possible reason for these results is the NEMS model's design, which includes the concept of '**market-sharing**'. As the carbon constraint increases, the share of each carbon-reducing mechanism in the electric sector remains consistent. Demand, natural gas, nuclear power and renewable energy all change together. Yet in other analyses, one emissions reduction mechanism often plays a dominant or even exclusive role over a range of carbon tax levels, until other mechanisms become cost-effective.

More questions need to be answered to determine exactly why the carbon tax needs to be so high in the electric utility sector. Each region is considered separately in the dispatch submodule, and detailed information about each unit type's performance is contained in the subroutines. A critical question involves **the distribution of costs among coal units**. How cheap are the cheapest units? Similarly, it would be useful to know what constraints affect utility gas use, since the model documentation shows that **gas is not available in some regions and seasons** (it is reserved for residential use, a relic of the regulatory system in place when NEMS was built).

Baseline natural gas costs are also higher in the this version of NEMS. Since the AEO97, estimates of 2010 wellhead prices have risen from \$2.06 to \$2.33 per MCF, in constant (1996) dollars. Delivered utility gas increases even more, from \$2.37 per MBtu to \$2.82. **These baseline prices are on the high end of the forecast range**, as noted in AEO98 (Table 22, page 84). Four other forecasts are presented (although for 2015 and 2020), and EIA is the highest in all cases (both years, wellhead and delivered utility). It is unclear how much this affects the results, but given the importance of natural gas in climate change policy, this factor needs to be kept in mind.

Talking Points on EIA's Analysis of Implementation of the Kyoto Protocol

September 1998

The Energy Information Administration's (EIA) recent analysis of the Kyoto Protocol is flawed. In modeling implementation of the Protocol, EIA fails to take into account the Protocol's flexibility mechanisms and incorrectly assumes that most businesses will fail to take action to address climate change until 2005 or later. In contrast, the Administration's economic analysis of the Protocol, released in July, demonstrates that with effective market mechanisms, meaningful developing country participation, and a realistic ramp up period, the costs of meeting the Kyoto target should be modest.

In addition, the Administration determined that taking action to address global warming amounts to an insurance policy against a serious threat; that there are significant opportunities for low-cost reductions both at home and abroad; and that the benefits of averting climate change could be very large.

The EIA Analysis Omits the Kyoto Protocol's Flexibility

- **The EIA analysis fails to model international trading.** EIA's model is not capable of modeling international emissions trading, even though this is a critical feature in reducing the cost of compliance for the United States and other countries. By contrast, the Administration explicitly modeled international trading, as has every modeling team participating in the exercise assessing Kyoto conducted under Stanford's Energy Modeling Forum -- which includes virtually all of the leading energy economic modelers in the world. These models have demonstrated that international trading among industrialized countries could lower costs of emissions reductions by as much as half.

EIA does attempt to include scenarios which assume an amount of domestic reductions intended to mirror the level of domestic reductions implied in the model used by the Administration. However, these EIA scenarios still overstate the cost of permits because they fail to take into account the way that an international market, bidding to a single international permit price, lowers cost.

- **The EIA analysis does not account for all six categories of greenhouse gases.** This study assumes that the United States would achieve its target only through carbon dioxide reductions, even though all six major types of greenhouse gases are covered by the Protocol. In fact, the Kyoto agreement covers all six major greenhouse gases, and permits countries to achieve their targets through reductions made in any of these gases. This flexibility allows countries and companies to make reductions in the most cost-effective manner possible, reducing the cost of compliance.

EIA Assumes Firms Take Little or No Action to Address Climate Change before 2005

- **EIA assumes most firms do not anticipate climate change policies.** In EIA's study, most businesses do not take action to address climate change until 2005, and therefore

only have a short time until the 2008-2012 budget window to reduce emissions. Studies have demonstrated that the amount of lead time a company takes has dramatic economic implications. For example with EIA's model, a 5-year "ramp-up" (starting in 2005) would result in economic costs 65% greater than that associated with a 10-year "ramp-up" (starting in 2000). Thus, EIA's assumption that many businesses would fail to plan for the future results in higher projected costs.

- Already businesses are taking action to address climate change. For example, on September 18, British Petroleum announced their plan to reduce emissions of greenhouse gases worldwide by 10% below 1990 levels by the year 2010 and, in July, United Technologies, a \$25 billion company that produces high-tech systems, announced their plan to reduce energy consumption by 25% by the year 2007. In addition, many other companies in the manufacturing and energy production sectors are starting to develop long-term plans to reduce greenhouse gas emissions.

The EIA Analysis Does Not Include Policy Elements That Will Lower Costs

- In the Administration's analysis, additional elements of policy were recognized as having the potential to significantly decrease the costs of compliance and increase the amount of reductions that might be accomplished at home. These policies were not factored into the illustrative model the Administration cited, but were qualitatively taken into account in reaching the conclusion that the United States could meet its Kyoto target for a relatively modest cost. The EIA analysis, however, ignores elements such as forestry activities (covered under the Kyoto Protocol) and the Administration's electricity restructuring proposal, which could significantly lower compliance costs.

Initial Review of EIA's *Impacts of Kyoto Protocol*

Several major problems:

- Very low consumer price responsiveness => very high prices necessary to meet targets
- Very little anticipation: end-users respond to current prices, not anticipated prices
- Very little time to upgrade capital stock in anticipation: policy is announced in 2005
- Carbon only; no other greenhouse gases
- Poor treatment of international permit trading
- Poor treatment of international trade/finance issues
- Poor treatment of potential GDP
- High-cost revenue recycling mechanisms

OPTIONAL FORM 99 (7-90)

FAX TRANSMITTAL

of pages ► 1

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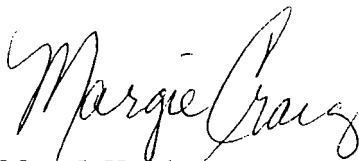
Mr. Joe Aldy
White House Task Force on Climate Change
734 Jackson Place, N.W.
Washington, D.C. 20503

Dear Mr. Aldy:

Enclosed is a copy of EIA's draft report entitled, "Impacts of the Kyoto Protocol on U.S. Energy Markets and Economic Activity" that was requested by Congressmen Sensenbrenner and Brown. The report is not expected to be officially released until the end of the month when it will be formally printed and released at a Congressional hearing. Until then it should be used only for your own information.

If you have any questions, please call me on 202-586-2222.

Sincerely,


for Mary J. Hutzler
Director, Office of Integrated Analysis
and Forecasting
Energy Information Administration

Enclosure



Printed with soy ink on recycled paper

Impacts of the Kyoto Protocol on U.S. Energy Markets and Economic Activity

**— DRAFT REPORT—
September 8, 1998**

NOT FOR QUOTATION OR CITATION

Energy Information Administration
Office of Integrated Analysis and Forecasting
U.S. Department of Energy
Washington, DC 20585

This report was prepared by the Energy Information Administration, the independent statistical and analytical agency within the Department of Energy. The information contained herein should be attributed to the Energy Information Administration and should not be construed as advocating or reflecting any policy position of the Department of Energy or of any other organization.

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Preface

From December 1 through 11, 1997, more than 160 nations met in Kyoto, Japan, to negotiate binding limitations on greenhouse gases for the developed nations, pursuant to the objectives of the Framework Convention on Climate Change signed on May 4, 1992. The outcome of the meeting was the Kyoto Protocol, in which the developed nations agreed to limit their greenhouse gas emissions, relative to the levels emitted in 1990. The United States agreed to reduce emissions from 1990 levels by 7 percent during the period 2008 to 2012.

The analysis in this report was undertaken at the request of the Committee on Science of the U.S. House of Representatives. In its request, the Committee asked the Energy Information Administration (EIA) to analyze the Kyoto Protocol, "focusing on U.S. energy use and prices and the economy in the 2008-2012 time frame," as noted in the first letter in Appendix D. The Committee specified that EIA consider several cases for energy-related carbon reductions in its analysis, with sensitivities evaluating some key uncertainties: U.S. economic growth, the cost and performance of energy-using technologies, and the possible construction of new nuclear power plants.

The energy projections and analysis in this report were conducted using the National Energy Modeling System (NEMS), an energy-economy model of U.S. energy markets designed, developed, and maintained by EIA. NEMS is used each year to provide the projections in the *Annual Energy Outlook* (AEO). In its second letter, in Appendix D, the Committee requested that the analysis use the same general methodologies and assumptions underlying the *Annual Energy Outlook 1998* (AEO98), published in December 1997; however, some minor modifications were made to allow greater flexibility in NEMS in response to higher energy prices and to incorporate some methodologies that were formerly represented offline. These differences are outlined in Appendix A. The macroeconomic analysis used the Data Resources, Inc. (DRI) Macroeconomic Model of the U.S. Economy, which is also used for the economic analysis in the AEO.

Chapter 1 of this report provides background discussion of the Kyoto Protocol and the framework and methodology of the analysis. Chapter 2 summarizes the energy market results from the various carbon reduction cases. Chapters 3, 4, and 5 analyze in more detail the issues and results for the end-use demand sectors, the electricity

generation sector, and the fossil fuel supply markets, respectively. Chapter 6 provides the results of EIA's analysis of the macroeconomic impacts of carbon reduction under different monetary and fiscal policy assumptions. Chapter 7 compares the results of this study with those from other studies of the costs of carbon reduction, with accompanying tables in Appendix C. Appendix B includes the detailed energy market results from the carbon reduction cases.

Within its Independent Expert Review Program, EIA arranged for leading experts in the fields of energy and economic analysis to review earlier versions of this analysis and provide comment. The assistance of the following reviewers in preparing the report is gratefully acknowledged:

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The legislation that established EIA in 1977 vested the organization with an element of statutory independence. EIA does not take positions on policy questions. It is the responsibility of EIA to provide timely, high-quality information and to perform objective, credible analyses in support of the deliberations of both public and private decisionmakers. This report does not purport to represent the official position of the U.S. Department of Energy or the Administration.

Other EIA reports on the topic of greenhouse gases include the following annual reports:

- *Annual Energy Outlook 1998*, published in December 1997, with projections of domestic energy carbon emissions through 2020
- *International Energy Outlook 1998*, published in April 1998, with projections of international energy carbon emissions through 2020

- *Emissions of Greenhouse Gases in the United States 1996*, published in October 1997, with an inventory of all domestic greenhouse gas emissions
- *Mitigating Greenhouse Gas Emissions: Voluntary Reporting*, published in October 1997, reporting voluntary actions in 1995 to reduce greenhouse gases in the United States
- *Greenhouse Gases, Global Climate Change, and Energy*, an information brochure on greenhouse gases.

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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 Framework Convention on Climate Change was signed by more than 160 countries in Rio de Janeiro, Brazil, on May 4, 1992. 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 countries²—relative to their 1990 emissions levels. The targets range from an 8-percent reduction for the European Union 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 in meeting the commitment, but they are limited to afforestation, reforestation, and deforestation since 1990. Emissions trading

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 is an Annex I nation but did not commit to a quantifiable emissions target.

among the Annex I countries is also allowed. According to estimates presented by the Energy Information 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

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

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

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

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

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

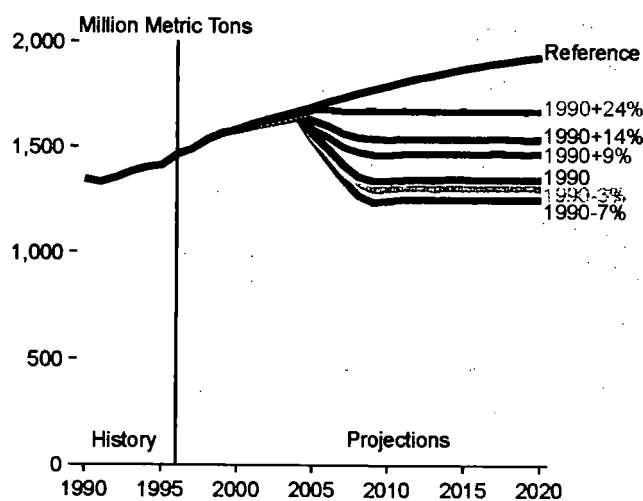
based on the reference case from AEO98, there are small differences between this case and AEO98, in order to permit additional flexibility in response to higher energy prices or to include certain analyses previously done offline directly within the modeling framework, such as nuclear plant life extension 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

⁸Energy 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	Reference	2010					
			1990 +24%	1990 +14%	1990 +9%	1990	1990 -3%	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

^aThe carbon revenues do not include fees on the nonsequestered portion of petrochemical feedstocks, nonpurchased refinery fuels, or industrial other petroleum.

^bCarbon 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

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

Variable	1996	Reference	2020					
			1990 +24%	1990 +14%	1990 +9%	1990	1990 -3%	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

^aThe carbon revenues do not include fees on the nonsequestered portion of petrochemical feedstocks, nonpurchased refinery fuels, or industrial other petroleum.

^bCarbon 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.

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 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

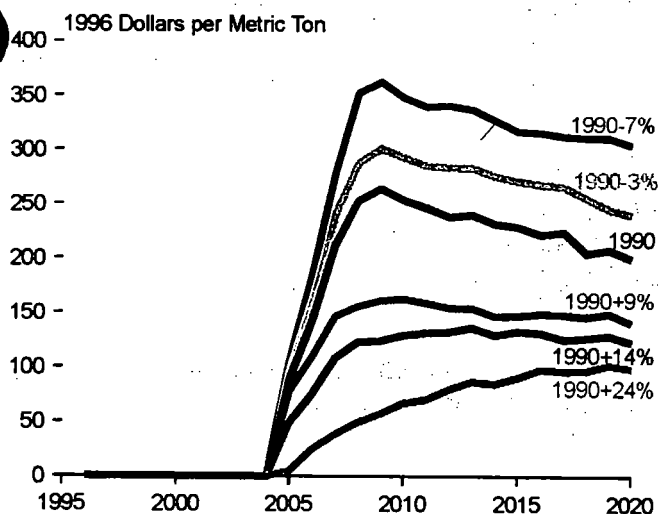
dramatically increase the use of renewables in the more stringent reduction cases, particularly biomass and wind energy systems, which become more economical with higher carbon prices.

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

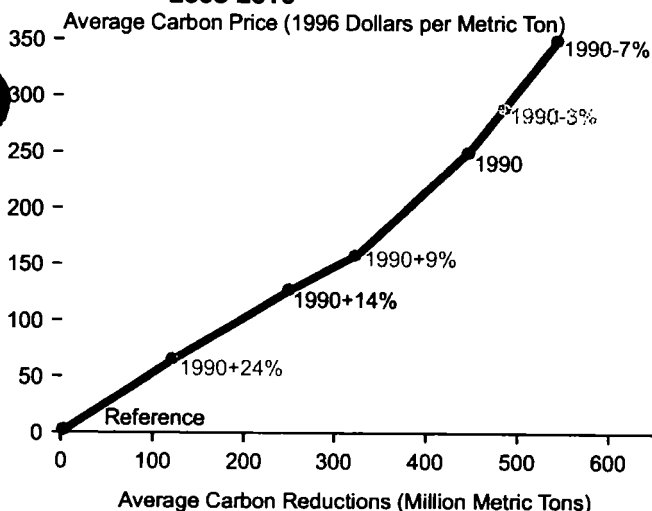
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Figure ES2. Projections of Carbon Prices, 1996-2020



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.

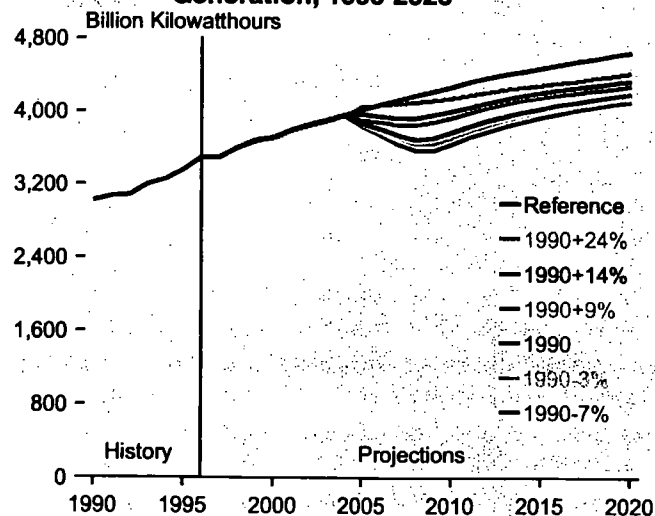
Figure ES3. Average Projected Carbon Prices and Annual Carbon Emission Reductions, 2008-2010



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.

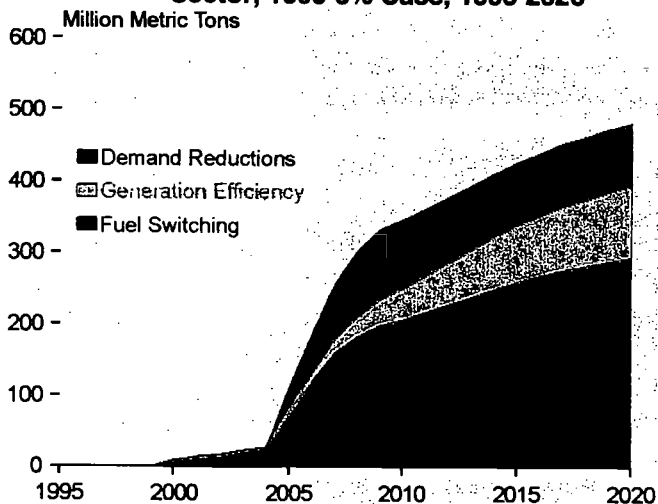
carbon prices (Figure ES7). Higher electricity prices reflect the increased costs of fossil fuels for generation and the incremental cost of additional investments, although the increase is mitigated by generation from renewables and nuclear power, because their fuel prices are not affected by carbon 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.

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.

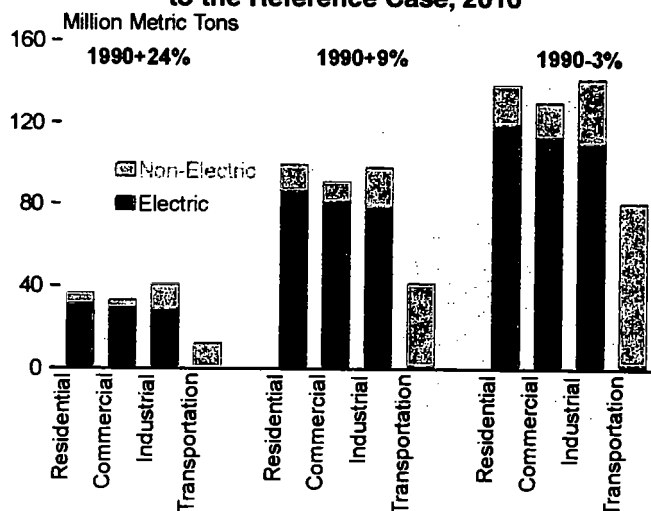
Figure ES5. Projected Reductions in Carbon Emissions From the Electricity Supply Sector, 1990-3% Case, 1996-2020



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

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 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.

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.

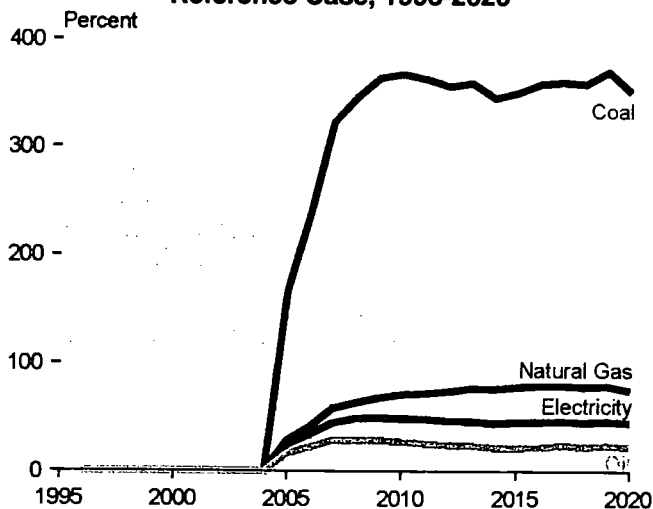
Source: Office of Integrated Analysis and Forecasting, National Energy Modeling System runs KYBASE.D080398A, FD24ABV.D080398B, FD09ABV.D080398B, and FD03BLW.D080398B.

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 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

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.

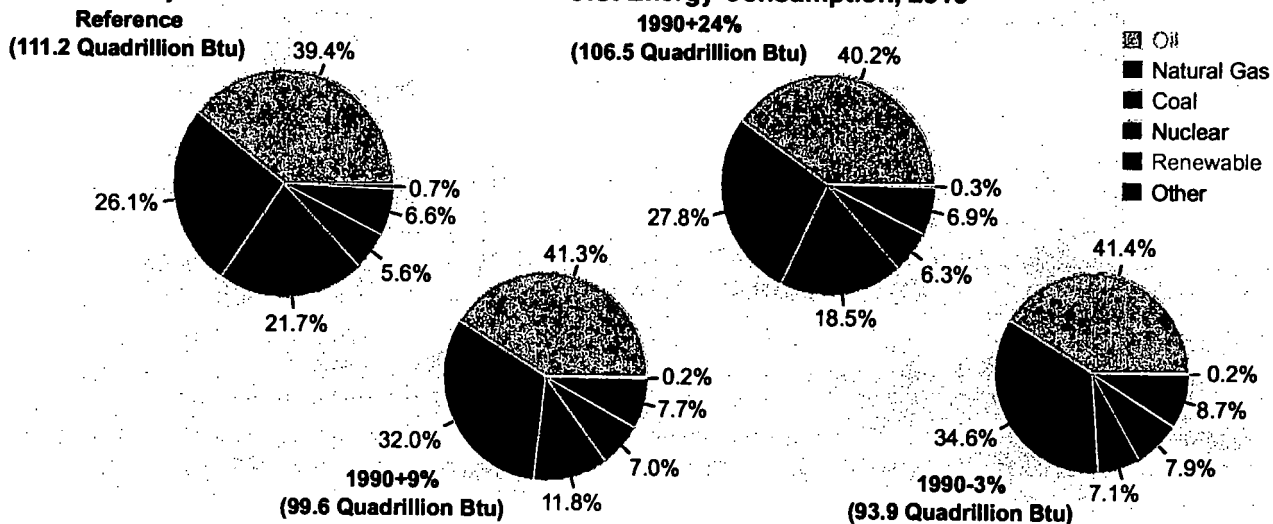
percent, primarily as the result of reduced travel and the purchase of more efficient vehicles. The relatively low carbon reductions for transportation result from the continued dominance of petroleum, although some increase in market share is projected for alternative-fuel vehicles. Improvements in 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). 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

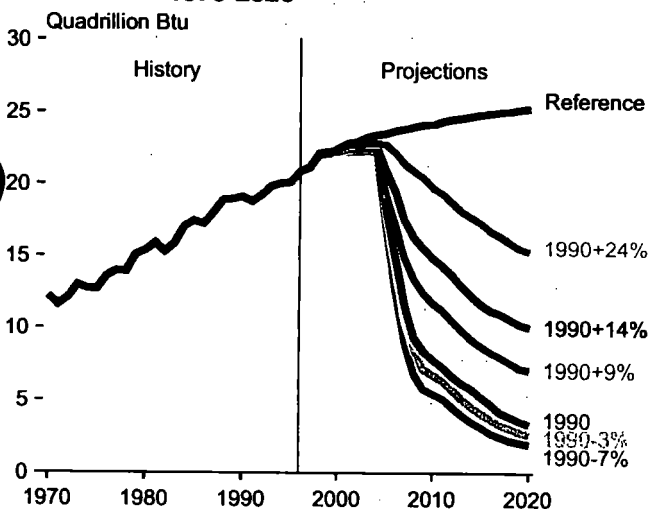
Figure ES8. Projections of Fuel Shares of Total U.S. Energy Consumption, 2010



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.

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.

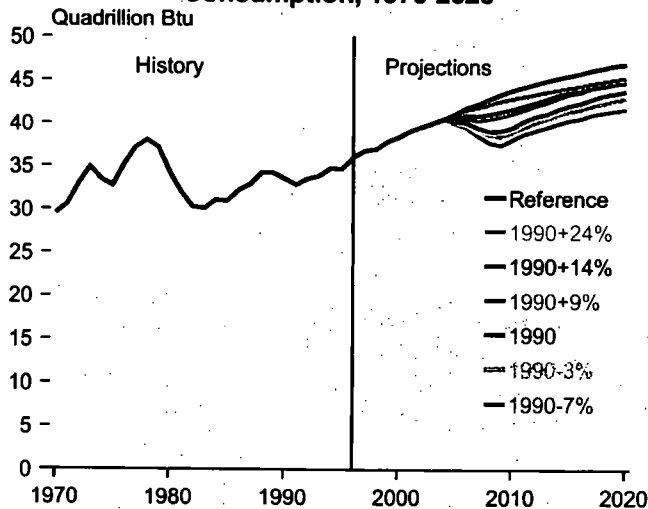
for industrial steam coal and metallurgical coal is also reduced because of a shift to natural gas in industrial boilers and a reduction in industrial output. Coal exports are also lower in the carbon reduction cases, by between 21 and 32 percent, due to lower demand for coal in the Annex I nations.

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

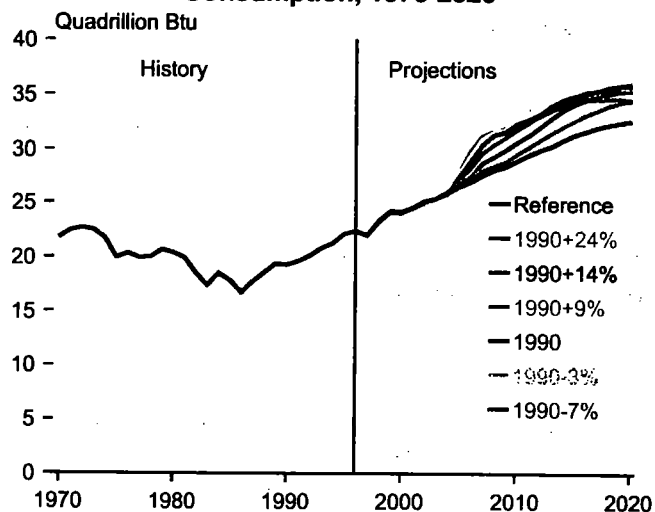
Petroleum consumption is lower in all the carbon reduction cases than in the reference case, by between 2 and 13 percent (Figure ES10). Because most of the petroleum is used for transportation, between 68 and 82 percent of the total reduction is in the transportation sector, as travel and freight requirements are reduced and higher-efficiency vehicles are used. Because of lower petroleum demand in the United States and in

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



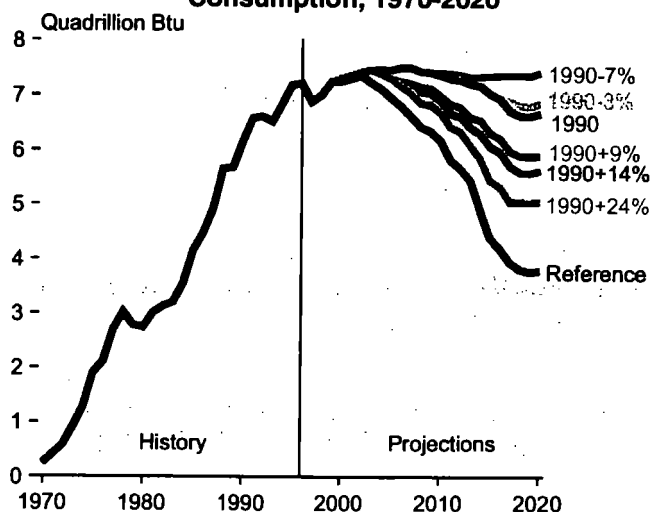
Sources: **History:** Energy Information Administration, *Annual Energy Review* 1997, DOE/EIA-0384(97) (Washington, DC, July 1998). **Projections:** Office of Integrated Analysis and Forecasting, National Energy Modeling System runs KYBASE.D080398A, FD24ABV.D080398B, FD1998.D080398B, FD09ABV.D080398B,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

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 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.

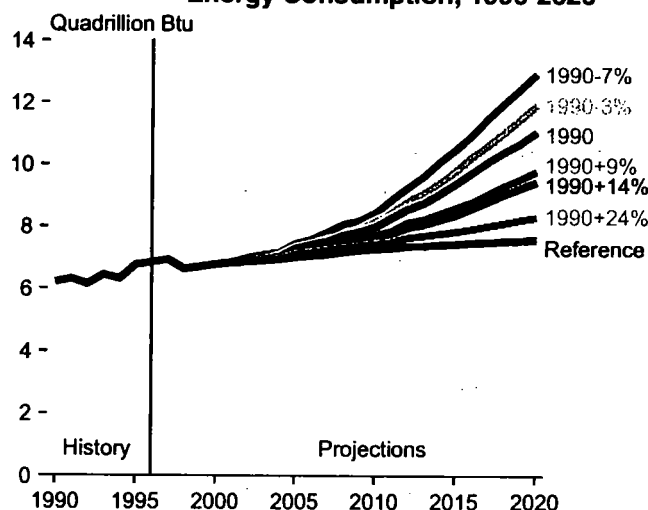
Nuclear power, which produces no carbon emissions, increases with carbon reduction targets by between 8 and 20 percent in 2010, relative to the reference case (Figure ES12). Although no new nuclear plants are

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.

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.

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.

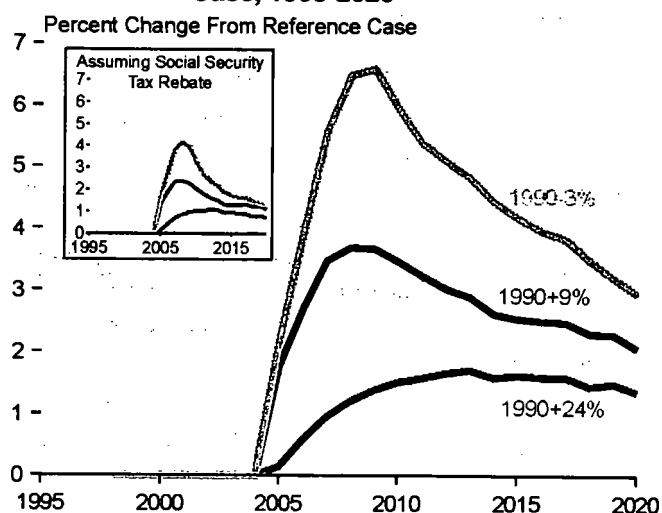
As a direct consequence of the carbon price, aggregate energy prices in the U.S. economy are expected to rise. One way to measure this effect is to look at the percentage change in prices in the economy. For example, in the 1990+9% case, energy prices are 56 percent higher than the reference case projection 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

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		Value of Purchased International Permits (Billion 1992 Dollars)
				1996 Dollars per Metric Ton	1992 Dollars per Metric Ton	
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.

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.

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

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

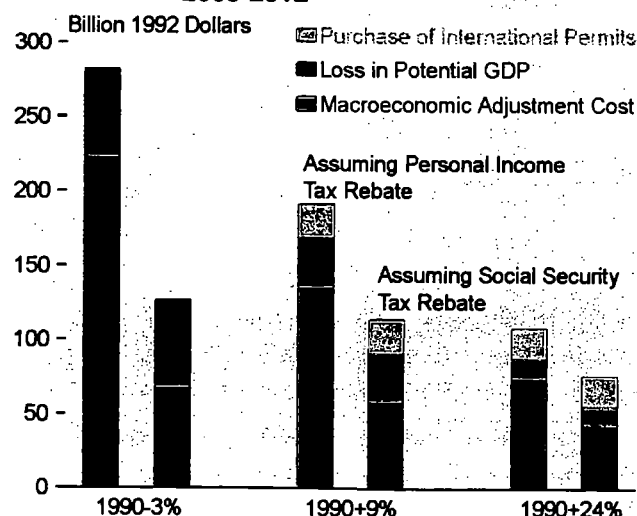
Note: Loss in potential GDP plus the macroeconomic adjustment cost equals the loss in actual GDP. The actual GDP loss plus purchases of international permits equals the total cost to the economy.

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

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 economy, 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 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

Figure ES15. Total Projected 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						
			Refer- ence	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

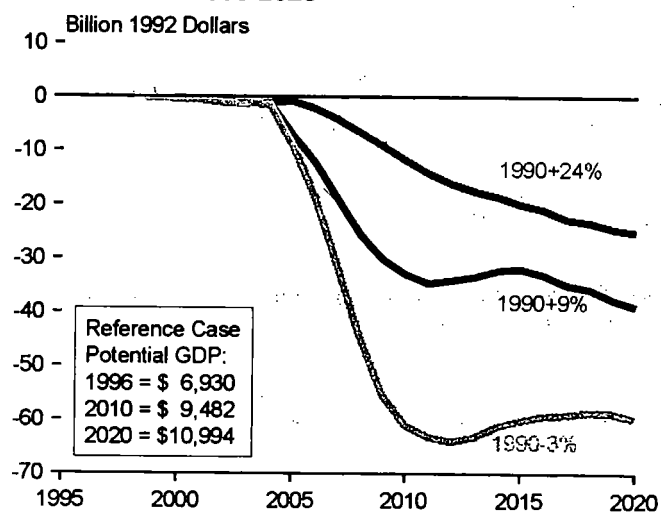
Source: Simulations of the Data Resources, Inc. (DRI) Macroeconomic Model of the U.S. Economy.

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

Variable	1996	2005 Reference	2020						
			Refer- ence	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.

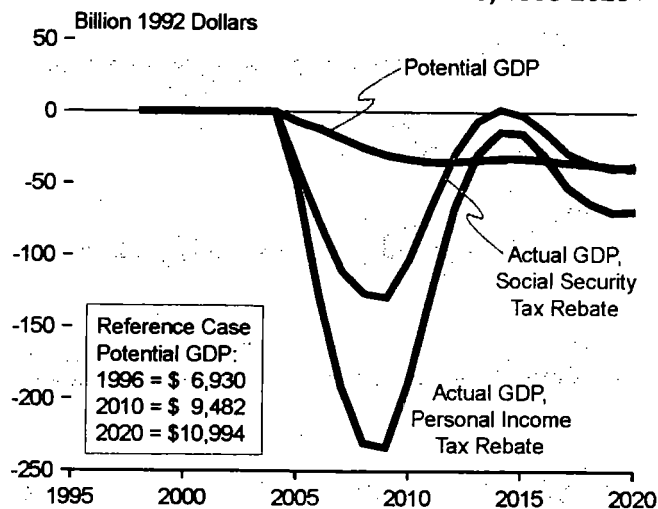
Source: Simulations of the Data Resources, Inc. (DRI) Macroeconomic Model of the U.S. Economy.

"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 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

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



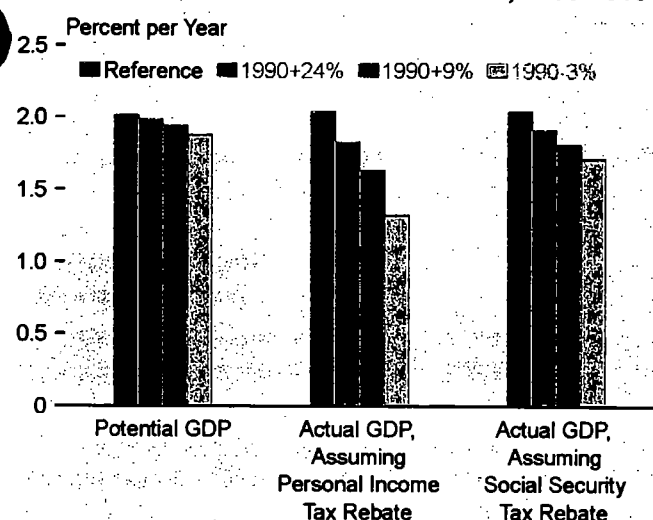
Source: Simulations of the Data Resources, Inc. (DRI) Macroeconomic Model of the U.S. Economy.

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.

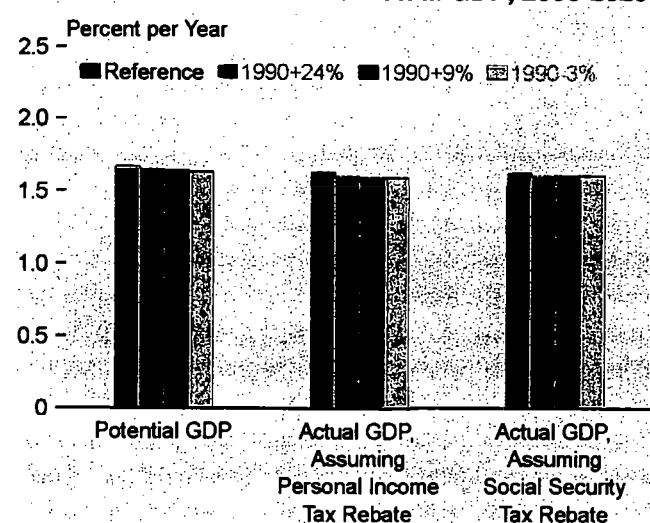
Figure ES17 shows the projected impacts on both actual and potential GDP for the two hypothetical fiscal policies (income tax and social security tax cuts) in the 1990+9% case. The figure indicates that, in the 2008 to 2012 period, the short-run cyclical impact on actual GDP is larger than the long-run 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.

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.

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

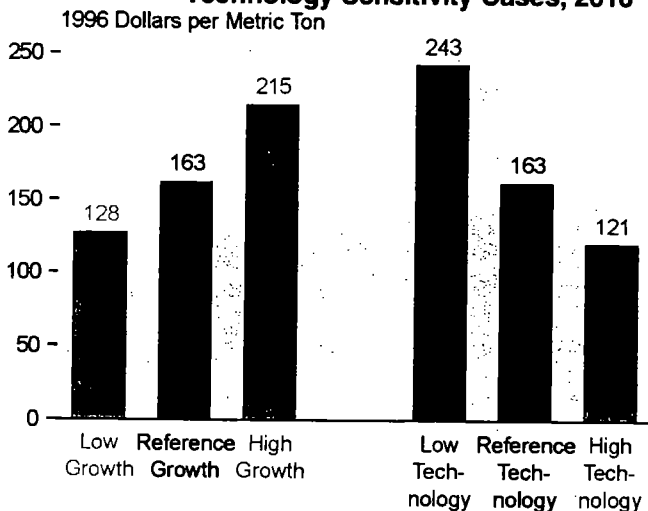
emissions over the next 20 years, including higher and lower economic growth, faster and slower availability and rates of improvement in technology, and the construction of new nuclear power plants. The sensitivity cases illustrate how such factors influence the results of the carbon reduction cases. 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 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,

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.

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.

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.

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 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.

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 tech-

nology 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

⁹The 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.

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

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

²Greenhouse 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.

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

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

⁵Energy 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 Framework Convention on Climate Change was signed by more than 160 countries at the Earth Summit in Rio de Janeiro, Brazil, on May 4, 1992.

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 emissions⁷ 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

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

⁷Carbon 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.

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

⁹Energy 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 countries¹¹ range from an 8-percent reduction for the European Union (EU) 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

¹⁰The text of the Kyoto Protocol is available at web site www.cop3.de.

¹¹Australia, 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 is an Annex I nation but did not commit to a quantifiable emissions target.

¹²Hydrofluorocarbons 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 emissions from Annex I nations. Signature by the United States would need to be followed by Senate 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 (SO₂) 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 SO₂, 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 SO₂ trading program is credited with reducing the overall cost of compliance by allowing reductions to be made in the most cost-effective manner.

Unlike SO₂, 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 SO₂ trading plan for several reasons. The largest sources of SO₂ 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 SO₂ 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

¹³See 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 proposed to encourage the use of renewable fuels for electricity generation, such as those in the Electric System Public Benefits Protection Act of 1997, the 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 gases 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.

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

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

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

¹⁷See 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

¹⁸The 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

^aFuel 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, meas-

ured 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 SO₂ 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 SO₂ 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 SO₂ 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.

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

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

²¹A.E. Smith, J. Platt, and A.D. Ellerman, "The Cost of Reducing SO₂," *Public Utilities Fortnightly* (May 15, 1998).

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.

2. Summary of Energy Market Results

This chapter summarizes the energy market results of the carbon reduction and sensitivity cases evaluating the effects of the Kyoto Protocol in the National Energy Modeling System (NEMS). The first set of cases examine the impacts of six carbon emissions reduction targets, relative to a reference case without the Kyoto Protocol, as described in Chapter 1. The remaining cases examine the sensitivity of those results to variations in key assumptions—the macroeconomic growth rate, the rate of technological progress, and the role of nuclear power. More detailed analyses of the energy market results are presented in Chapters 3, 4, and 5. The macroeconomic results are described in Chapter 6. Although the results of the carbon reduction cases are consistent with the assumptions made, the projected impacts are subject to considerable uncertainty—particularly with the more stringent carbon reduction targets—because the cases reflect significant changes in energy markets.

Carbon Reduction Cases

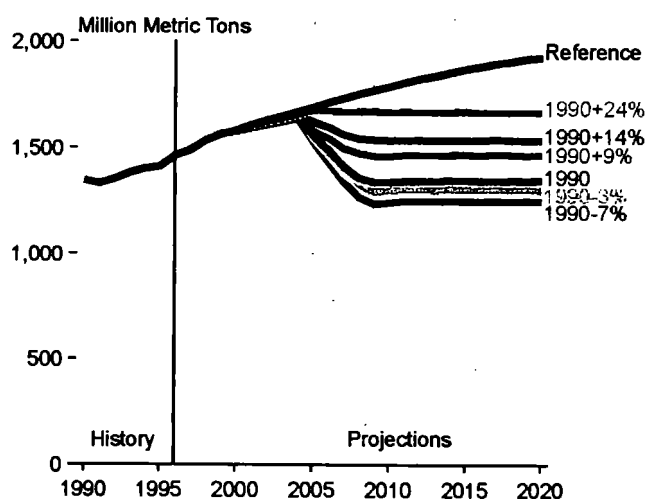
Carbon Prices

Under the Kyoto Protocol, the United States is committed to reducing greenhouse gas emissions to 7 percent below 1990 levels in the period 2008 through 2012. The reduction in energy-related carbon emissions that the United States must achieve to comply with the greenhouse gas reduction target in the Protocol depends on the level of emissions offsets credited for sinks, reductions in other greenhouse gases, international permit trading, joint implementation, and the Clean Development Mechanism (CDM). A set of six cases examines a range of carbon emissions reduction targets, ranging from 7 percent below 1990 levels, an average of 1,250 million metric tons during the period 2008 to 2012, to 24 percent above 1990 levels, or an average of 1,670 million metric tons. The most stringent case assumes that the target of reducing greenhouse gases to 7 percent below 1990 levels is the domestic goal for energy-related carbon emissions, with no offsets from sinks, offsets, international trade, the CDM, or compensating changes in other greenhouse gases.

The six carbon reduction cases are compared against a reference case similar to the one published in the *Annual Energy Outlook 1998* (AEO98) (Figure 1). The Protocol indicates that the greenhouse gas reductions must be

achieved on average in each of the years between 2008 and 2012, and the targets are assumed to hold on average for that period. At the specification of the Committee, the targets were held constant after 2012 through the forecast horizon of 2020. To provide energy markets time to adjust, mandatory carbon reduction targets were phased in beginning in 2005, the year when the Protocol indicates that progress toward compliance must be demonstrated.

Figure 1. 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.

In order to reduce carbon emissions, demand for energy services must be reduced, more efficient energy-consuming technologies used, or less carbon-intensive fuels consumed. Thus, to constrain the overall level of carbon emissions to a given target, a price on carbon emissions is included in the delivered price of fuels. The carbon price is equivalent to the cost of a carbon permit under a market-based program within the United States to regulate the overall level of carbon emissions. In such a program, the purchase of fossil fuels would require the exchange of carbon permits, and a market for carbon permits would operate to allocate the overall supply of permits among U.S. energy consumers. More restrictive carbon targets would lead to higher market-clearing prices for carbon.

In analyzing the carbon emissions reduction targets, the carbon prices are incorporated as an added cost of consuming energy; that is, as an increase in the delivered price of energy. The added cost is in direct proportion to the carbon permit price and the carbon content of the fuel consumed. As a result, energy consumers face higher energy costs—both for the fossil fuels they consume directly, such as gasoline, and for the indirect use of fossil energy used to generate electricity. The higher energy costs also affect the cost of producing goods and services throughout the economy and, as a result, have macroeconomic effects beyond the impacts on the energy sector.

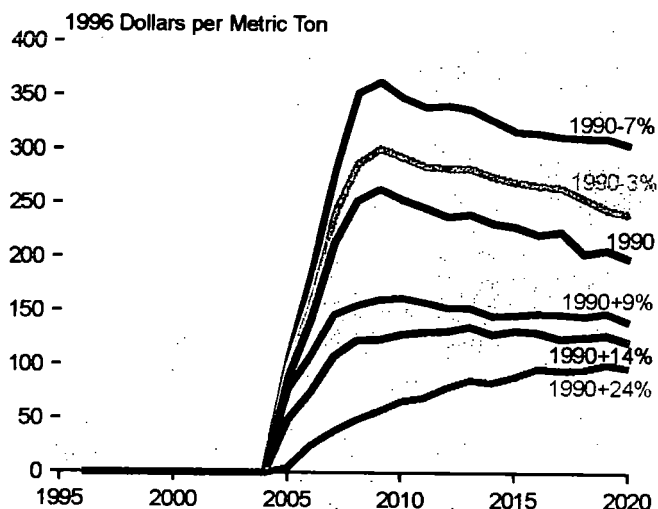
As indicated in Figure 1, some carbon reductions occur before 2005, based on anticipatory behavior, primarily as a result of forward-looking capacity planning decisions assumed in the electricity industry. For the electricity industry, where fossil fuel purchases are a predominant operating cost, planners are assumed to incorporate future fuel costs in their economic evaluation of generating plant alternatives.²² As a result, some capacity choices reflected in the reference case before 2005 are altered in the carbon reduction cases based on carbon prices beginning in 2005, thus lowering carbon emissions before the assumed start of carbon permit trading.

Table 2 presents a summary of the key results in 2010 and 2020 for the reference case, the 24-percent-above-1990 (1990+24%) case, the 9-percent-above-1990 (1990+9%) case, and the 3-percent-below-1990 (1990-3%) case. Tables of the complete results for all the carbon reduction cases are included in Appendix B.

Figure 2 depicts the estimated carbon prices, in constant 1996 dollars, necessary to achieve the carbon emissions reduction targets. Generally, the highest permit price occurs early on in the commitment period. The carbon price declines over time as cumulative investments in more energy-efficient and lower-carbon equipment, particularly in the electricity generation industry, tend to reduce the marginal cost of compliance in later years.

For most of the cases, the trend of carbon prices includes some relatively minor year-to-year fluctuations. Also, particularly in the more stringent reduction cases, the carbon price generally peaks in 2008, the first year of the commitment period, because of the 3-year phase-in period. A longer adjustment period might reduce the price; however, early reductions do not count toward the required reductions in the commitment period. In some cases, 1- to 2-year declines in prices occur as

Figure 2. 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.

electricity generators complete construction of low-carbon replacement plants. The new plants allow generators to shift from coal to lower-carbon energy sources, reducing their need to purchase carbon permits and holding down carbon prices. Because the additions of replacement capacity occur in discrete amounts, the year-to-year changes in carbon prices can be somewhat uneven. The short-term fluctuations in projected carbon prices are consistent with, but probably understate, the degree of short-term price movements that would be expected in a market for carbon permits.

The carbon prices from 2008 to 2012 average \$159 per metric ton in the 1990+9% case, which represents a carbon reduction averaging 325 million metric tons a year relative to the reference case (Figure 3). In the more stringent 1990-3% case, the average carbon price from 2008 to 2012 is \$290 per metric ton, achieving an average annual carbon reduction during that period of 485 million metric tons. In the 1990+24% case, carbon prices average \$65 per metric ton in the compliance period, with average carbon reductions of 122 million metric tons.

Carbon prices decline in most of the cases after 2012, despite continued growth in the demand for energy as the carbon target is held constant. While increased energy demand would be expected to exert upward pressure on carbon prices over time, downward pressure results from the cumulative effect of investments to improve energy efficiency and switch to lower-carbon energy sources. These long-lived

²²The modeling approach assumes perfect foresight of carbon prices for capacity planning in the electricity industry. Perfect foresight, in this context, means that the carbon prices that are anticipated during planning are later realized. An algorithm solves for the path of carbon prices in which anticipated and realized carbon prices are approximately the same, while ensuring that the carbon prices clear the carbon permit market each year. In the end-use demand sectors, foresight is assumed not to have a material influence on energy equipment decisions, and such decisions are modeled on the basis of prices in effect at the time of the decision.

Table 2. Summary Comparison: Reference, 1990+24%, 1990+9%, and 1990-3% Cases, 2010 and 2020

Summary Indicators	1996	2010				2020			
		Refer- ence	1990 +24%	1990 +9%	1990 -3%	Refer- ence	1990 +24%	1990 +9%	1990 -3%
Carbon Price (1996 Dollars per Metric Ton)	NA	NA	67	163	294	NA	99	141	240
Delivered Energy Price (1996 Dollars per Million Btu)									
Coal	1.32	1.12	2.82	5.24	8.57	1.01	3.50	4.57	7.18
Natural Gas	4.13	3.76	4.71	6.45	8.49	3.96	5.69	6.95	8.30
Motor Gasoline	9.89	10.11	11.23	12.53	14.49	10.00	11.45	12.04	13.48
Jet Fuel	5.52	5.62	6.69	8.15	10.24	5.76	7.32	8.01	9.66
Distillate Fuel	7.84	7.81	8.91	10.50	12.71	7.67	9.21	9.79	11.49
Electricity	20.19	17.22	20.92	25.70	30.68	16.31	21.44	23.77	26.10
Primary Energy Use (Quadrillion Btu)									
Natural Gas	22.60	28.97	29.57	31.82	32.49	32.65	34.50	36.02	35.39
Petroleum	36.01	43.82	42.83	41.12	38.89	46.88	45.25	44.78	42.94
Coal	20.90	24.14	19.70	11.68	6.72	25.27	15.28	7.06	2.59
Nuclear	7.20	6.17	6.68	6.98	7.36	3.80	5.06	5.90	6.86
Renewable	6.91	7.27	7.44	7.72	8.23	7.59	8.29	9.77	11.91
Other ^a	0.39	0.80	0.25	0.25	0.23	0.83	0.26	0.26	0.25
Total	94.01	111.18	106.48	99.57	93.93	117.02	108.64	103.79	99.94
Electricity Sales (Billion Kilowatthours)	3,098	3,865	3,696	3,492	3,286	4,240	3,972	3,837	3,718
Carbon Emissions by Fuel (Million Metric Tons)									
Natural Gas	318	415	424	456	466	468	495	517	507
Petroleum	621	752	735	704	660	805	777	767	727
Coal	524	621	506	299	172	652	393	181	66
Total	1,463	1,791	1,668	1,462	1,300	1,929	1,668	1,468	1,303
Carbon Emissions by Sector (Million Metric Tons)									
Residential	286	337	301	238	199	375	291	224	181
Commercial	230	277	244	186	147	299	225	168	130
Industrial	476	559	519	462	418	582	505	449	405
Transportation	471	617	605	576	536	673	647	626	588
Total	1,463	1,791	1,668	1,462	1,300	1,929	1,668	1,468	1,303
Electricity Generation	517	657	567	409	312	726	519	351	246
Carbon Reductions by Sector (Million Metric Tons)									
Residential	NA	NA	37	99	139	NA	85	151	195
Commercial	NA	NA	33	91	130	NA	73	131	169
Industrial	NA	NA	41	98	141	NA	77	133	177
Transportation	NA	NA	12	41	81	NA	26	47	85
Total	NA	NA	123	329	491	NA	261	461	625
Electricity Generation	NA	NA	90	248	345	NA	207	375	481
Electricity Generation as Percent of Total	NA	NA	74	75	70	NA	79	81	77
Energy Fuel Expenditures (Billion 1996 Dollars)	560	637	726	834	952	674	807	862	945
Energy Intensity (Thousand Btu per 1992 Dollar of GDP)	13.57	11.80	11.42	10.78	10.33	10.78	10.05	9.62	9.27
Carbon Intensity (Kilograms per Million Btu)	15.6	16.1	15.7	14.7	13.8	16.5	15.4	14.1	13.0

^aIncludes net electricity imports, methanol, and liquid hydrogen.

NA = not applicable.

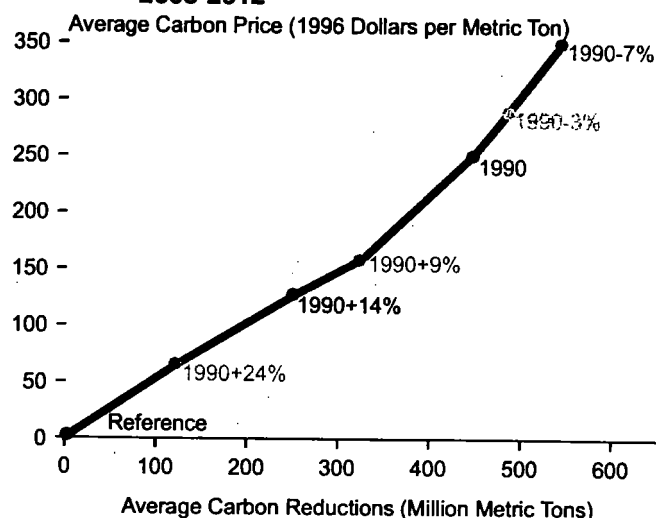
Note: Totals may not equal sum of components due to independent rounding.

Sources: 1996: Energy Information Administration, *Annual Energy Outlook 1998*, DOE/EIA-0383(98) (Washington, DC, December 1997). Projections: Office of Integrated Analysis and Forecasting, National Energy Modeling System runs KYBASE.D080398A, FD24ABV.D080398B, FD09ABV.D080398B, and FD03BLW.D080398B.

Investments tend to reduce the demand for carbon permits over an extended period of time, outweighing the opposing effect of moderate growth in energy demand.

Thus, although high carbon prices must be sustained over several years to induce such investments, carbon prices eventually moderate.

Figure 3. Average Annual Carbon Emission Reductions and Projected Carbon Prices, 2008-2012



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.

Energy Prices

With the carbon prices included in the delivered cost of energy, the prices under the various carbon targets rise significantly above the reference case. Figures 4, 5, and 6 show the average delivered prices of coal, natural gas, petroleum, and electricity in the 1990+24%, the 1990+9% and the 1990-3% cases, respectively. In percentage terms, coal prices are most affected by the carbon prices, with the delivered price of coal in the 1990+9% case increasing 346 to 358 percent above the reference case price in the 2008 to 2012 period (Figure 7). Natural gas prices in the 1990+9% case increase 64 to 74 percent above the reference case prices, and oil prices increase by 25 to 29 percent. Electricity prices, reflecting the higher costs of fossil fuels used for generation, as well as the incremental cost of additional plant investments to reduce carbon emissions by replacing coal-fired plants, increase to 47 to 49 percent above the reference case level.

Compared with the changes in coal and natural gas prices, the average increase in electricity prices is relatively low. Larger amounts of electricity would be generated from renewable and nuclear power, for which fuel costs are unaffected by carbon prices. In addition, cost-of-service electricity pricing is assumed for most of the country, so that fuel costs would be only a partial determinant of electricity prices. Nonfuel operating and

maintenance costs and capital equipment costs have a larger role in setting electricity prices under cost-of-service pricing. In regions where electricity prices are assumed to be set competitively on the basis of marginal costs (California, New York, and New England), carbon prices would have a more significant influence on electricity prices, particularly when coal-fired plants are the marginal generators. On the other hand, those regions are less dependent on coal than are many other areas of the country.

The pattern of projected delivered energy prices matches the trend for carbon prices, especially in the more restrictive carbon reduction cases. In these cases, the carbon prices become a dominant component of the delivered cost of fossil energy; however, market forces continue to play a role in energy prices, especially for petroleum products. The reduced demand for oil under the various carbon reduction targets tends to reduce world oil prices. World oil prices are projected to fall as demand is reduced in the United States and in other developed countries that are committed to reducing emissions under the Kyoto Protocol. In 2010, world oil prices are projected to be about \$20.00 per barrel in the 1990+24% case, \$18.70 in the 1990+9% case, and \$17.80 in the 1990-3% case, as compared with \$20.80 per barrel in the reference case. With lower world oil prices, the change in delivered petroleum product prices with the various carbon prices is not as high as for natural gas prices, despite the higher carbon content of petroleum.²³

In contrast to petroleum, coal prices are unlikely to be moderated by competitive forces. Much of the demand for coal by electricity generators is eliminated in the carbon reduction cases, particularly with the more stringent targets. Coal consumption for other uses, including industrial steam coal and metallurgical coal, is also reduced but on a smaller percentage basis than for electricity generation. Although coal produced for export is also lower in the carbon reduction cases due to lower demand in the Annex I nations, the change is relatively small in comparison with the reductions in production for domestic use. Coal exports, projected at 113 million short tons in 2010 in the reference case, are 89 million short tons in 2010 in the 1990+24% and 1990+9% cases and 76 million short tons in the 1990-3% case. Because the industrial and export coal markets are served primarily by eastern coal producers, eastern production declines less in the carbon reduction cases than does production from western mines, which primarily serve the electricity generation market. Thus, while regional minemouth prices generally decline in the carbon reduction cases relative to the reference case, the national

²³ A related factor influencing the effect of carbon prices on gasoline demand is that the price of gasoline already includes Federal and State excise taxes averaging 37 cents per gallon in 1996, equivalent to a carbon permit price of \$155 per metric ton. When additional carbon permit prices are included in the delivered price of gasoline, the percentage increase in price is not as high as it would be if gasoline were untaxed initially. In turn, the percentage change in gasoline demand due to the carbon price is not as high as it would be if gasoline were not already taxed.

Figure 4. Average Delivered Prices for Energy Fuels in the 1990+24% Case, 1996-2020

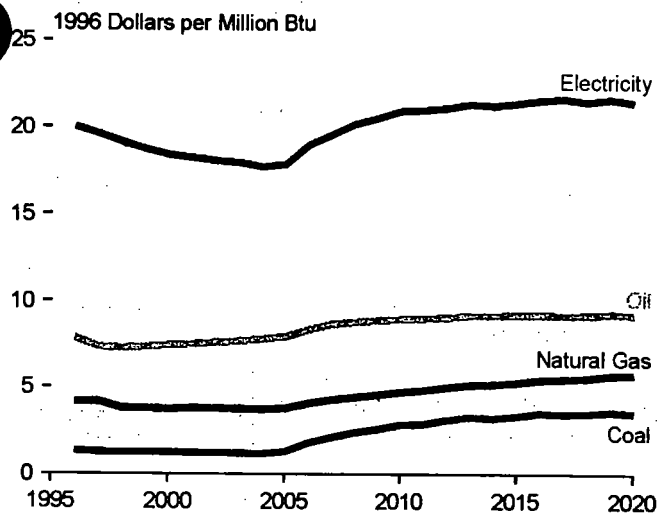
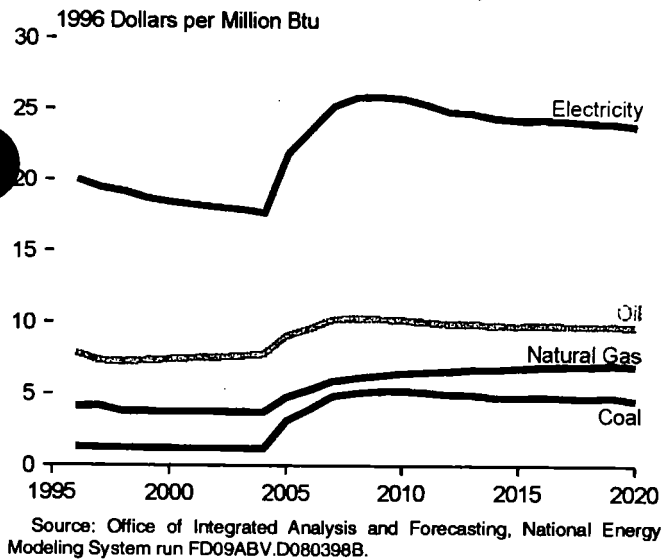


Figure 5. Average Delivered Prices for Energy Fuels in the 1990+9% Case, 1996-2020



average minemouth price increases because of the shift in share to the higher-priced coal mined in the East. Western coal production is also discouraged by higher rail transportation costs and reduced incentive for the development of new mines.

Natural gas demand is higher in the carbon reduction cases relative to the reference case primarily because of higher use in the electricity generation sector, offsetting reductions in the end-use demand sectors. As a result, the average wellhead price of natural gas, excluding any carbon price, is higher relative to the reference case in all the carbon reduction cases. The higher wellhead prices are an indication that greater reliance on natural gas under the Kyoto Protocol could benefit some domestic energy producers.

Figure 6. Average Delivered Prices for Energy Fuels in the 1990-3% Case, 1996-2020

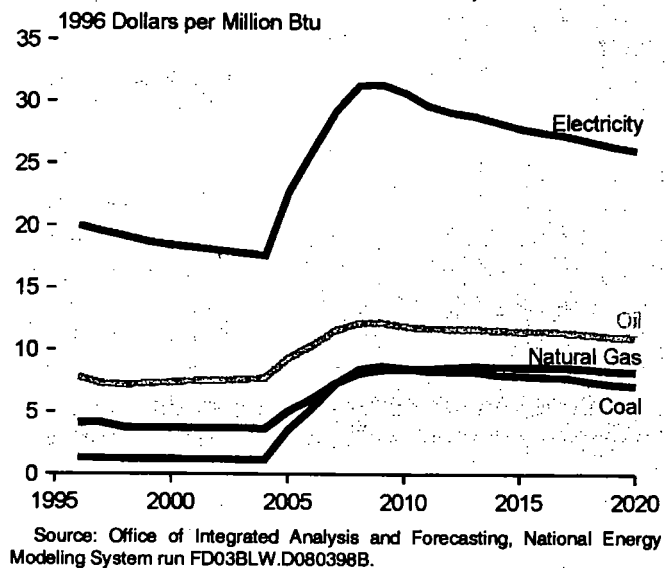
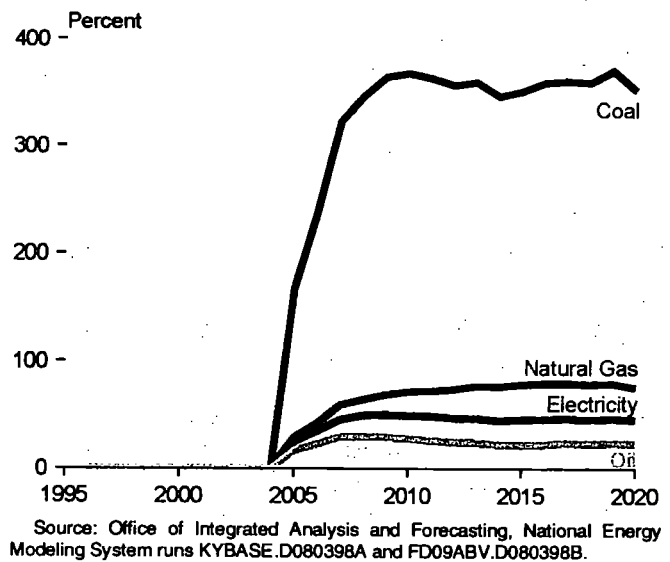


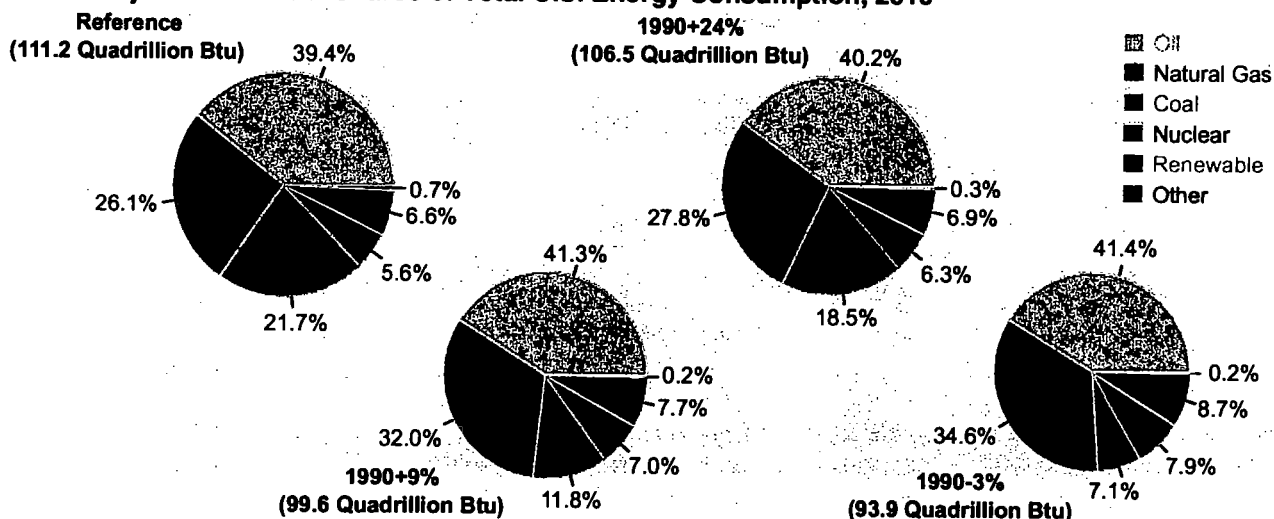
Figure 7. Projected Changes in Average Delivered Prices for Energy Fuels in the 1990+9% Case Relative to the Reference Case, 1996-2020



Impacts by Fuel

To meet the required carbon emissions reductions, the mix of energy fuels consumed would change dramatically from that projected in the reference case (Figure 8). Relative price changes cause a reduction in coal and petroleum use, coupled with greater reliance on natural gas, renewable energy, and nuclear power (see Figures 9 through 13). Coal, with its high carbon content and relatively low end-use efficiency, is severely curtailed in the more stringent cases, replaced by more use of natural gas, renewable fuels, and nuclear power in electricity generation. Coal's share of generation is reduced from 52 percent in 1996 to 42 percent, 26 percent, and 15 percent in 2010 in the 1990+24%, 1990+9%, and 1990-3% cases. By 2020, coal is nearly

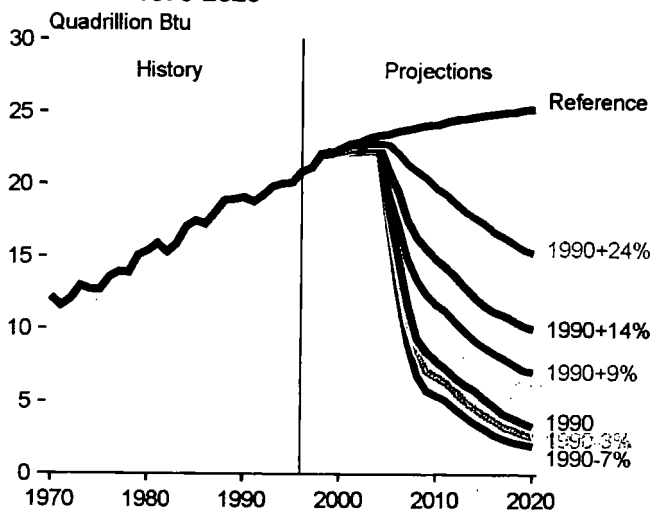
Figure 8. Projections of Fuel Shares of Total U.S. Energy Consumption, 2010



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.

Figure 9. Projections of U.S. Coal Consumption, 1970-2020

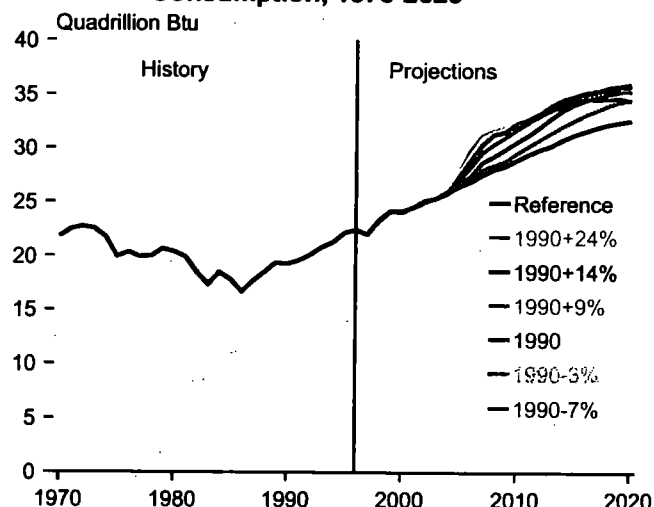


Sources: **History:** Energy Information Administration, *Annual Energy Review* 1997, DOE/EIA-0384(97) (Washington, DC, July 1998). **Projections:** Office of Integrated Analysis and Forecasting, National Energy Modeling System runs KYBASE.D080398A, FD24ABV.D080398B, FD1998.D080398B, FD09ABV.D080398B,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

eliminated from electricity generation in the 1990-3% case (Figure 9). Some reduction in coal use, compared with the reference case, occurs before the start of the carbon permit program in 2005. These changes occur as the result of anticipatory behavior in the electricity industry, where capacity planning decisions in advance of 2005 are affected by the prospects of carbon prices in the future.

Natural gas consumption is higher than in the reference case, as greater use of natural gas in the generation sector outweighs the reductions in the residential, commercial, and industrial sectors (Figure 10). In those cases with less stringent carbon reduction targets, and correspondingly lower carbon prices, generators find it more economical to substitute natural gas for coal than

Figure 10. Projections of U.S. Natural Gas Consumption, 1970-2020

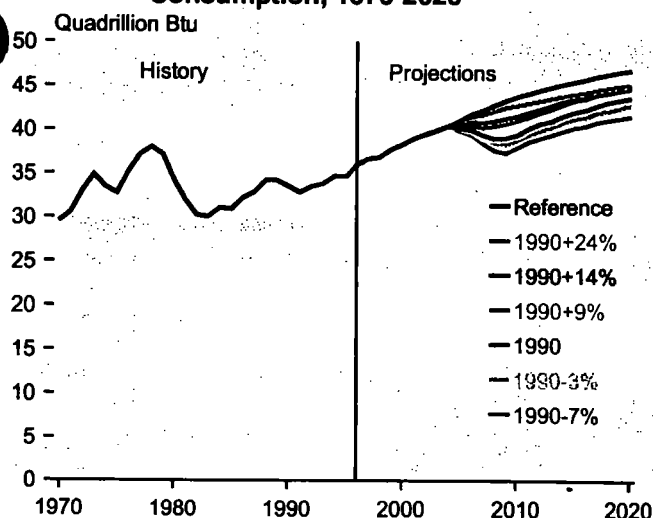


Sources: **History:** Energy Information Administration, *Annual Energy Review* 1997, DOE/EIA-0384(97) (Washington, DC, July 1998). **Projections:** Office of Integrated Analysis and Forecasting, National Energy Modeling System runs KYBASE.D080398A, FD24ABV.D080398B, FD1998.D080398B, FD09ABV.D080398B,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

to invest in renewable technologies. In the more stringent cases, with high carbon prices, increasing use of renewable fuels eventually leads to reductions in the demand for natural gas by generators. This pattern is reflected in Figure 10, as natural gas consumption in the more stringent cases falls below that in the less stringent cases toward the end of the forecast period. In the earlier portion of the forecast, the rapid growth of natural gas use exerts pressure on suppliers and distributors to increase production and pipeline capacity. The ability of the gas industry to respond to higher demand growth is discussed in Chapter 5.

Petroleum, used primarily for transportation, is lower in all the carbon reduction cases (Figure 11). Motor

Figure 11. Projections of U.S. Petroleum Consumption, 1970-2020



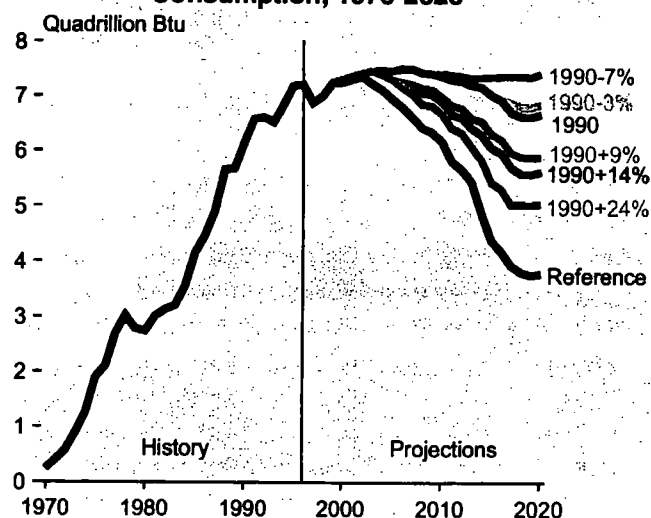
Sources: **History:** Energy Information Administration, *Annual Energy Review 1997*, DOE/EIA-0384(97) (Washington, DC, July 1998). **Projections:** Office of Integrated Analysis and Forecasting, National Energy Modeling System runs KYBASE.D080398A, FD24ABV.D080398B, FD1998.D080398B, FD09ABV.D080398B,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

gasoline demand, accounting for 43 percent of total petroleum consumption in 1996, is lower by 15 percent in 2010 in the 1990-3% case, by 8 percent in the 1990+9% case, and by 3 percent in the 1990+24% case than in the reference case. Consumers respond to higher gasoline prices by reducing miles driven and purchasing more efficient vehicles.

Nuclear power, which produces no carbon emissions, becomes more attractive under carbon reduction targets. While no new nuclear plants are allowed 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 reference case, approximately half of the nuclear capacity now in operation is expected to be retired by 2020, reducing U.S. nuclear capacity by 53 gigawatts between 1996 and 2020. Much of that capacity would be life-extended in the carbon reduction cases (15 gigawatts, 26 gigawatts, and 38 gigawatts in the 1990+24%, 1990+9%, and 1990-3% cases, respectively). As a result, the use of nuclear power for electricity generation is projected to be higher in all three cases than in the reference case (Figure 12).

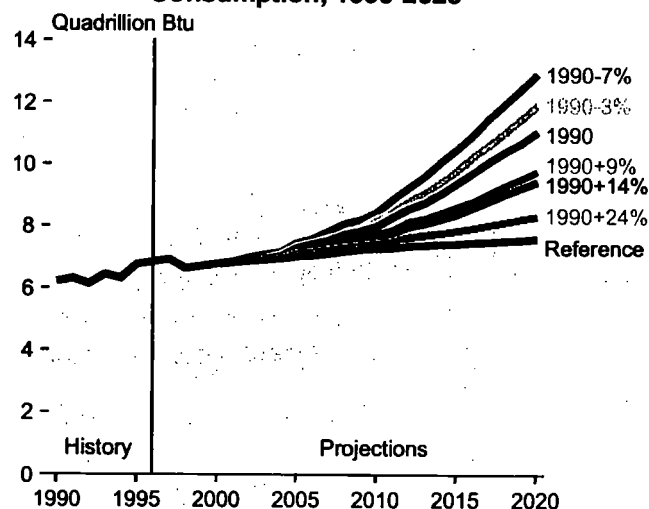
Consumption of renewable energy, which results in no net carbon emissions, is projected to be higher with carbon reduction targets (Figure 13). Most of the increase is in electricity generation, primarily with additions to wind energy systems and an increase in the use of biomass (wood, switchgrass, and refuse). The share of generation supplied by renewables increases from 9 percent in 2020 in the reference case to 11 percent, 15 percent, and 20 percent in the 1990+24%, 1990+9%, and 1990-3% cases, respectively. Most of the increase in renewable generation occurs after the 2008-2012

Figure 12. 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 13. Projections of U.S. Renewable Energy Consumption, 1990-2020

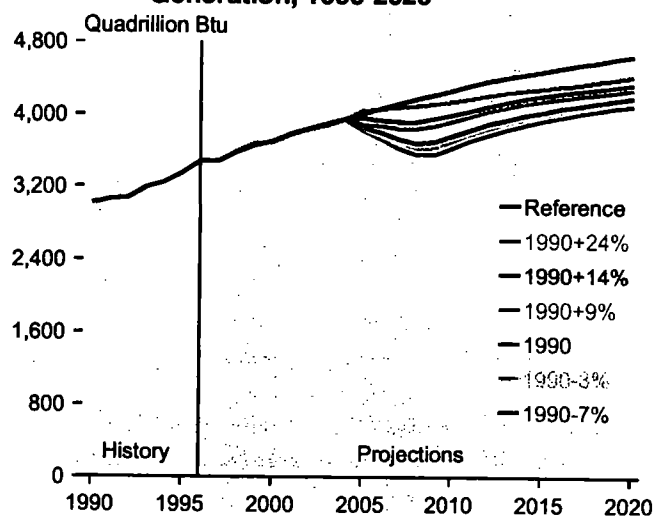


Sources: **History:** Energy Information Administration, *Annual Energy Review 1997*, DOE/EIA-0384(97) (Washington, DC, July 1998). **Projections:** Office of Integrated Analysis and Forecasting, National Energy Modeling System runs KYBASE.D080398A, FD24ABV.D080398B, FD1998.D080398B, FD09ABV.D080398B,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

compliance period, reflecting a relatively prolonged period of market penetration as renewable technology costs and performance improve over time.

Electricity generation, which accounted for 35 percent of energy-related carbon emissions in 1996, is also significantly lower across all the cases (Figure 14). In the 1990-3% case, electricity sales in 2010 are 15 percent below the reference case projection, with percentage reductions of about 13 percent occurring in the residential and industrial sectors and about 19 percent in the commercial sector. The relative changes in electricity

Figure 14. Projections of U.S. Electricity Generation, 1990-2020

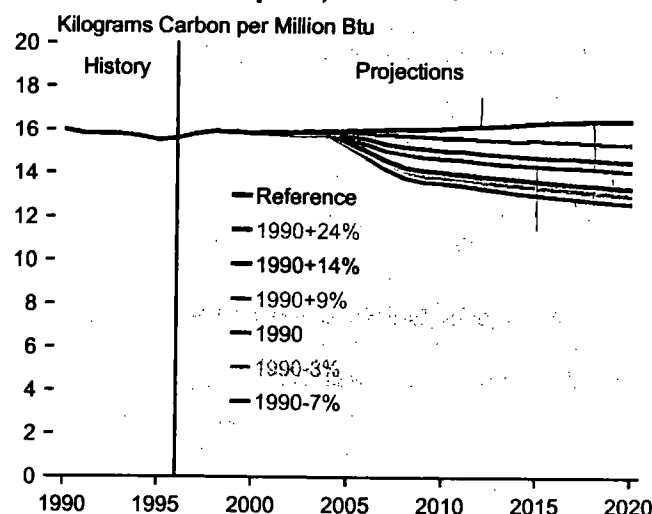


Sources: History: Energy Information Administration, *Annual Energy Review 1997*, DOE/EIA-0384(97) (Washington, DC, July 1998). Projections: Office of Integrated Analysis and Forecasting, National Energy Modeling System runs KYBASE.D080398A, FD24ABV.D080398B, FD1998.D080398B, FD09ABV.D080398B, FD1990.D080398B,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

sales by sector are similar in the 1990+9% and 1990+24% cases, but the overall percentage reductions are smaller (9 percent and 4 percent). One factor mitigating the response of electricity demand to higher electricity prices in these sectors is the relative change in energy prices. For example, the percentage changes in electricity prices, relative to the reference case, are smaller than the changes in natural gas prices. With a smaller percentage price increase, electricity becomes relatively attractive in those end uses where it competes with natural gas, such as home heating.

As the results have indicated, reductions in carbon emissions are also met through substitution away from carbon-intensive fuels, not just through energy efficiency improvements and reductions in energy services. The degree to which this occurs is indicated by the change in aggregate carbon intensity of energy use, or carbon emissions per unit of energy consumption. For example, natural gas has a carbon intensity at full combustion of 14.5 kilograms per million Btu, whereas coal averages about 25.7; thus, switching from coal to natural gas tends to reduce carbon intensity. Aggregate carbon intensity declined from 16 kilograms per million Btu in 1990 to 15.6 in 1996, but it is projected to increase in the reference case after 2000, reaching a level of 16.1 kilograms per million Btu by 2010 (Figure 15), even though energy intensity continues to decline. In the carbon reduction cases, carbon intensity begins to decline with the phase-in of the carbon targets. By 2010, carbon intensity declines to 15.7 kilograms per million Btu in the 1990+24% case, 14.7 in the 1990+9% case, and 13.8 in the 1990-3% case.

Figure 15. Projections of U.S. Carbon Emissions per Unit of Primary Energy Consumption, 1990-2020



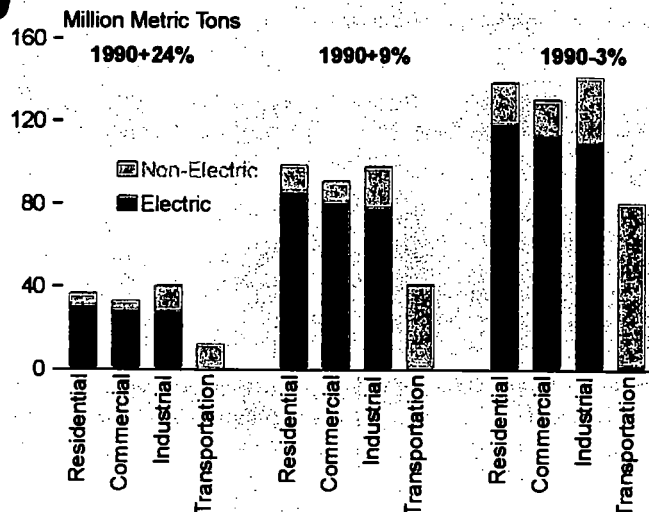
Source: Office of Integrated Analysis and Forecasting, National Energy Modeling System runs KYBASE.D080398A, FD24ABV.D080398B, FD1998.D080398B, FD09ABV.D080398B, FD1990.D080398B, FD03BLW.D080398B, and FD07BLW.D080398B.

Sectoral Impacts

Energy demand across each of the end-use sectors—residential, commercial, industrial, and transportation—will respond to different degrees to the incentives imposed by a carbon permit price. In all sectors, however, consumers will have greater incentive to conserve energy, switch to lower-carbon energy sources, and invest in more energy-efficient technologies.

Figure 16 illustrates the contribution of each sector toward meeting the carbon reduction goals in 2010 under three of the cases. The residential and industrial sectors (including electricity losses) account for the greatest carbon reduction, and transportation accounts for the least. As shown in Figure 16, most of the carbon reductions for the four end-use sectors occur in electricity, stemming from both reduced electricity demand and the use of more efficient, less carbon-intensive sources of generation. Reductions in carbon emissions from electricity generation account for about 75 percent of the total carbon reductions in both the 1990+24% and 1990+9% cases in 2010, and for about 70 percent in the 1990-3% case. A variety of factors contribute to the central role played by the electricity sector in meeting the carbon reduction targets: the industry's current dependence on coal; the availability and economics of technologies to switch from coal to less carbon-intensive energy sources; and the comparative economics of fossil-fuel switching in other sectors, particularly at lower carbon prices. As discussed in more detail in Chapter 3, the extent to which end-use energy consumers respond to prices is often limited by institutional factors.

Figure 16. Projected Reductions in Carbon Emissions by End-Use Sector Relative to the Reference Case, 2010



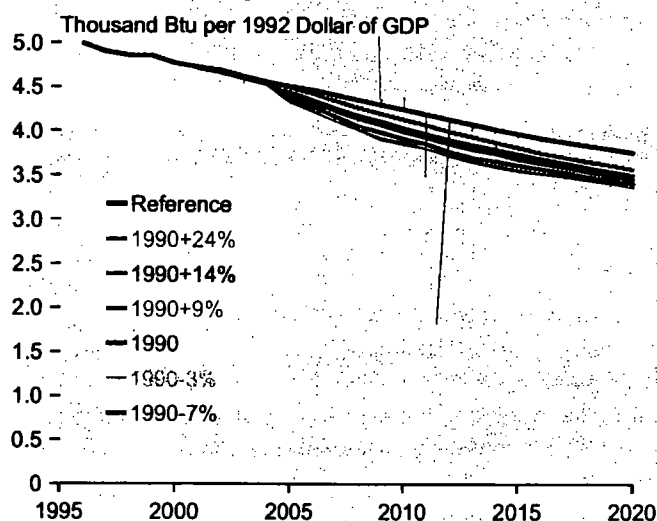
Note: Electricity emissions are from the fuels used to generate electricity and are attributed to the sectors relative to their shares of total electricity consumption.

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

In the industrial sector, some of the carbon reductions can be attributed to reductions in manufacturing output that result from the impact of higher energy prices on the economy. In addition, industrial firms respond by replacing productive capacity faster, investing in more efficient technology, and switching to less carbon-intensive fuels. Improvements in efficiency are indicated by reductions in energy intensity, as measured by the energy use per dollar of gross domestic product (GDP). In 2010, industrial energy intensity is reduced from 4.2 million Btu per dollar of GDP in the reference case to 4.1 million Btu per dollar in the 1990+24% case, 4.0 million Btu per dollar in the 1990+9% case, and 3.9 million Btu per dollar in the 1990-3% case (Figure 17). Taking into account fuel switching and efficiency improvements, carbon emissions per unit of GDP in 2010 for the industrial sector are reduced from 60 kilograms per thousand dollars of GDP in the reference case to 55, 50, and 46 kilograms per thousand dollars of GDP in the 1990+24%, 1990+9%, and 1990-3% cases, respectively.

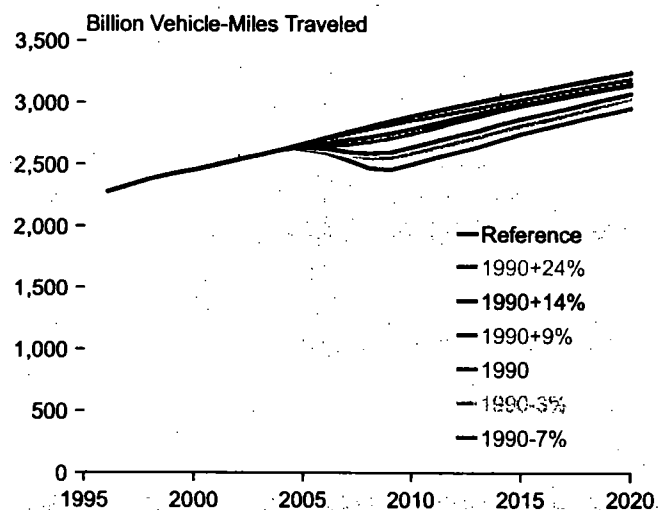
Carbon reductions in the transportation sector occur primarily as the result of reduced travel and the purchase of more efficient vehicles in response to higher energy prices. Compared with the reference case, light-duty vehicle travel (cars, vans, pickup trucks, and sport-utility vehicles) in 2010 is lower by 1 percent in the 1990+24% case, by 5 percent in the 1990+9% case, and by 11 percent in the 1990-3% case (Figure 18). At the same time, more efficient cars and light trucks are purchased, raising overall fleet efficiency (Figure 19). In 2010, the average fuel efficiency for the light-duty vehicle fleet is 20.7, 21.2, and 21.5 miles per gallon in the 1990+24%,

Figure 17. Projections of U.S. Industrial Energy Intensity, 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 18. Projections of U.S. Light-Duty Vehicle Travel, 1996-2020

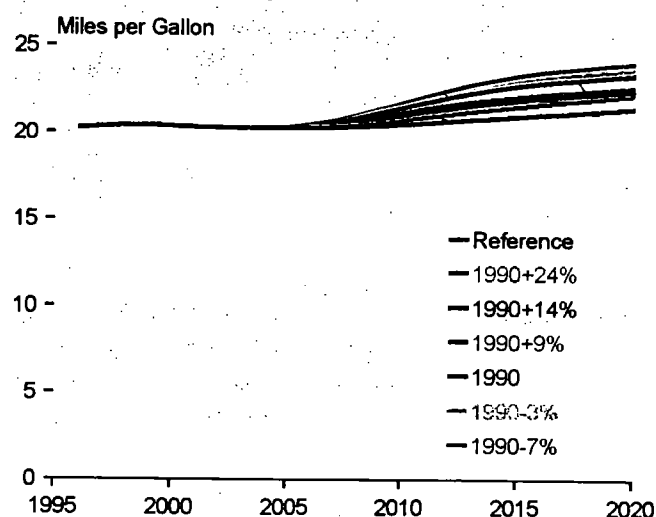


Source: Office of Integrated Analysis and Forecasting, National Energy Modeling System runs KYBASE.D080398A, FD24ABV.D080398B, FD1998.D080398B, FD09ABV.D080398B, FD1990.D080398B, FD03BLW.D080398B, and FD07BLW.D080398B.

1990+9%, and 1990-3% cases, respectively, compared with 20.5 miles per gallon in the reference case. The results of those increases are reductions of 3 percent, 8 percent, and 15 percent, respectively, from the reference case level of motor gasoline demand in 2010 (Figure 20). Travel reductions and efficiency improvements also occur in the air and freight sectors, further reducing carbon emissions. Overall, transportation energy consumption in 2010 is lower by 2 percent in the 1990+24% case, by 6 percent in the 1990+9% case, and by 12 percent in the 1990-3% case, than in the reference case.

In the residential and commercial sectors, higher energy prices encourage investments in more efficient equipment and building shells and also reduce the

Figure 19. Projections of Average Fuel Efficiency for the Light-Duty Vehicle Fleet, 1996-2020

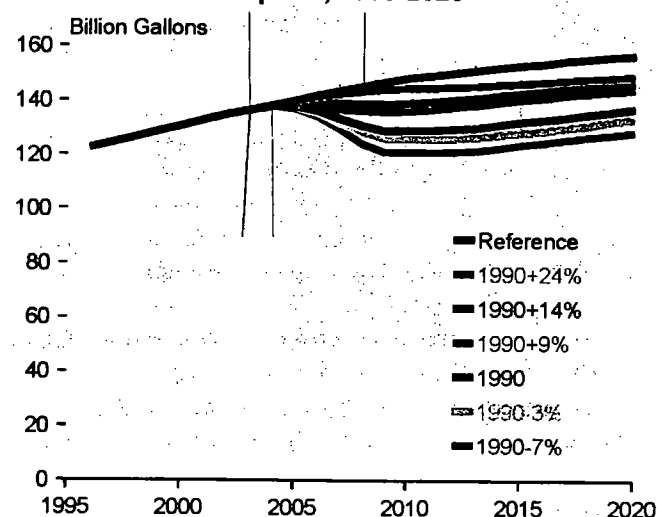


Source: Office of Integrated Analysis and Forecasting, National Energy Modeling System runs KYBASE.D080398A, FD24ABV.D080398B, FD1998.D080398B, FD09ABV.D080398B, FD1990.D080398B, FD03BLW.D080398B, and FD07BLW.D080398B.

demand for energy services. In the residential sector, delivered energy use per household in 2010 drops by 4 percent in the 1990+24% case, 10 percent in the 1990+9% case, and 15 percent in the 1990-3% case compared with the reference case. Energy consumption for space conditioning accounts for 59 to 62 percent of the change in the three cases. Those energy services for which appliance efficiency standards are already in place, such as for refrigerators and freezers, are not expected to change greatly in the carbon reduction cases, because the standards reflect very efficient technology that already reduces fuel consumption substantially in the reference case. The fastest-growing segment of residential electricity consumption, categorized as miscellaneous and including a variety of appliances such as computers and VCRs, accounted for approximately 22 percent of residential electricity consumption in 1996. Relative to the reference case, miscellaneous electricity consumption per household is lower by 5 percent in 2010 in the 1990+24% case, by 10 percent in the 1990+9% case, and by 14 percent in the 1990-3% case.

The energy demand response is somewhat stronger in the commercial than in the residential sector. Overall, delivered energy use per square foot of commercial floorspace in 2010 drops by 5 percent in the 1990+24% case, 13 percent in the 1990+9% case, and 21 percent in the 1990-3% case. As in the residential sector, significant energy reductions are projected for heating, cooling, and ventilation (29 to 31 percent of the change in the three cases); however, more than half the energy reduction comes from more efficient lighting and office equipment and in the category of miscellaneous electricity uses,

Figure 20. Projections of U.S. Motor Gasoline Consumption, 1996-2020



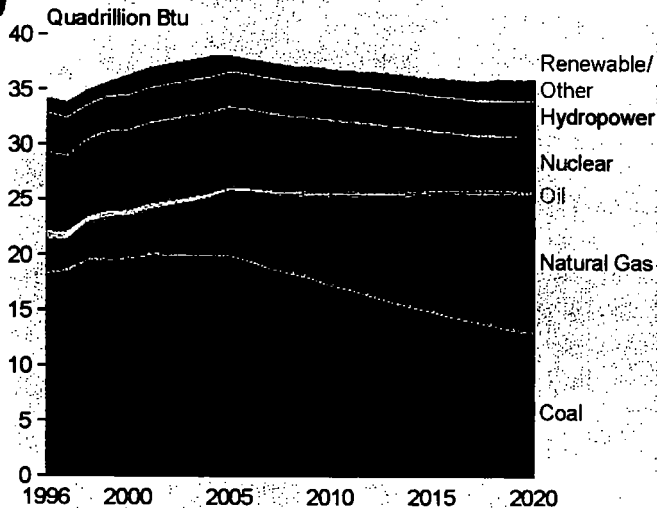
Source: Office of Integrated Analysis and Forecasting, National Energy Modeling System runs KYBASE.D080398A, FD24ABV.D080398B, FD1998.D080398B, FD09ABV.D080398B, FD1990.D080398B, FD03BLW.D080398B, and FD07BLW.D080398B.

including such appliances as vending machines and telecommunications equipment.

The electricity generation sector is expected to respond strongly to the incentives imposed by a carbon price. Generation from coal, which currently accounts for more than half of all electricity, drops significantly as the cost of coal to generators increases by factors of 3 to 8 times the reference case level in 2010. To replace coal plants, generators build natural-gas-fired combined-cycle plants, extend the life of existing nuclear plants, and dramatically increase the use of renewables, particularly biomass and wind energy systems, which become economical once a carbon price is imposed. These changes, coupled with the expected reduction in electricity demand, result in carbon emissions of 567 million metric tons in the 1990+24% case, 409 million metric tons in the 1990+9% case, and 312 million metric tons in the 1990-3% case. In comparison, actual 1990 emissions in the electricity generation sector are estimated at 477 million metric tons. The issues related to plant capacity changes in the electricity industry are discussed in detail in Chapter 4.

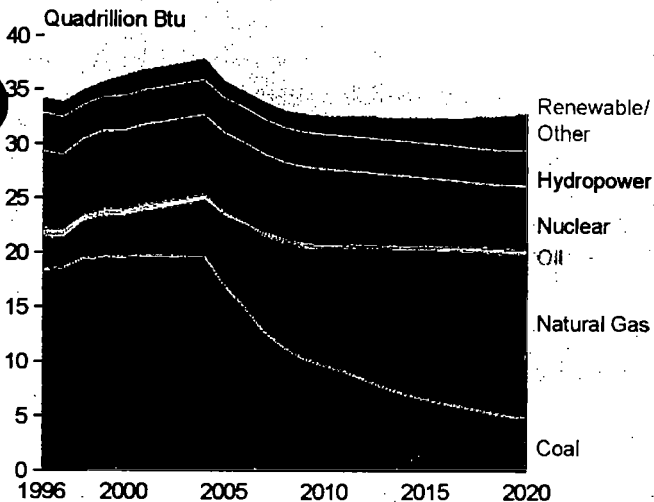
The mix of fuels used for electricity generation is projected to change rapidly as new plants come on line (Figures 21, 22, and 23). In the aggregate, cumulative investments by generators to reduce carbon emissions tend to bring down the carbon price over time. A slowdown in most new plant additions occurs at the end of the initial compliance period in 2012, but the growth in renewable capacity continues throughout the forecast horizon.

Figure 21. Projected Fuel Use for Electricity Generation by Fuel in the 1990+24% Case, 1996-2020



Source: Office of Integrated Analysis and Forecasting, National Energy Modeling System run FD24ABV.D080398B.

Figure 22. Projected Fuel Use for Electricity Generation by Fuel in the 1990+9% Case, 1996-2020

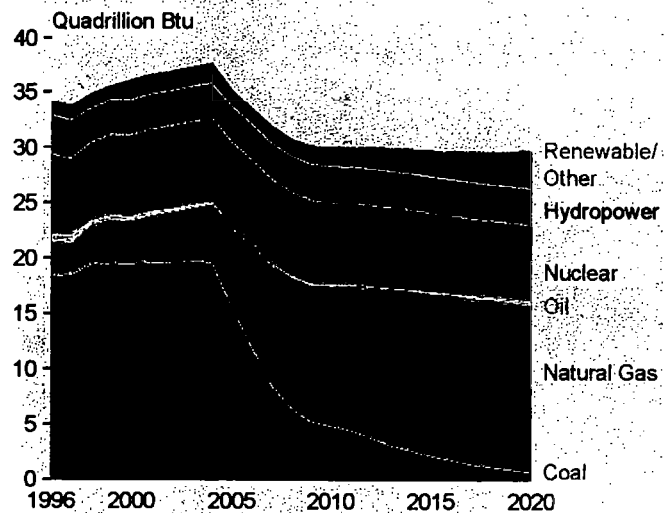


Source: Office of Integrated Analysis and Forecasting, National Energy Modeling System run FD09ABV.D080398B.

Sensitivity Cases

Among the sources of uncertainty in the effects of carbon mitigation policies over the next 20 years are the assumed rate of economic growth, the speed of adoption of advanced technologies, and the role of nuclear power. A series of sensitivity cases illustrate how these factors influence the results of the carbon reduction cases. The sensitivity cases were analyzed against the 1990+9% case. The nuclear power sensitivity case was analyzed against the 1990-3% case, because new nuclear power plants were found to be economical only with the higher carbon prices in that case.

Figure 23. Projected Fuel Use for Electricity Generation by Fuel in the 1990-3% Case, 1996-2020



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

Because each of the sensitivity cases 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 aggregate energy consumption, but rather on the carbon prices required to meet the emissions target. For example, in the high technology case, with an emissions reduction target of 9 percent above 1990 levels, projected carbon emissions during the compliance period are the same as in the corresponding reference technology case (1990+9%) with emissions at the same level. What differs is the cost of meeting the target, as reflected in the required carbon price or in expenditures for energy services. As a result, the carbon price and energy expenditures are the primary measures by which the sensitivity cases are compared in this report, in contrast to the presentation of similar sensitivities in *AEO98*. Because the technology sensitivities in the *AEO* typically are run with energy prices and macroeconomic assumptions held constant and without any target for carbon emissions, sensitivities are normally compared on the basis of levels of energy consumption.

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. In *AEO98*, the high economic growth case includes higher 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 from 1996 to 2020, compared with a growth rate of 1.9 percent a year in the reference case. With higher macroeconomic growth, energy demand grows more rapidly, as higher manufacturing output and higher income increase the demand for energy services. In *AEO98*, total energy consumption

in the high economic growth case is 117 quadrillion Btu in 2010, compared with 112 quadrillion Btu in the reference case. Carbon emissions are 80 million metric tons, or 4 percent, higher than the reference case level of 1,803 million metric tons.

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 AEO98 low economic growth case between 1996 and 2020. With lower economic growth, energy consumption in 2010 is reduced from 112 quadrillion Btu to 107 quadrillion Btu, and carbon emissions are 90 million metric tons, or 5 percent, lower than in the reference case. Thus, the effect of higher or lower macroeconomic growth can have a significant impact on the ease or difficulty of meeting the carbon targets.

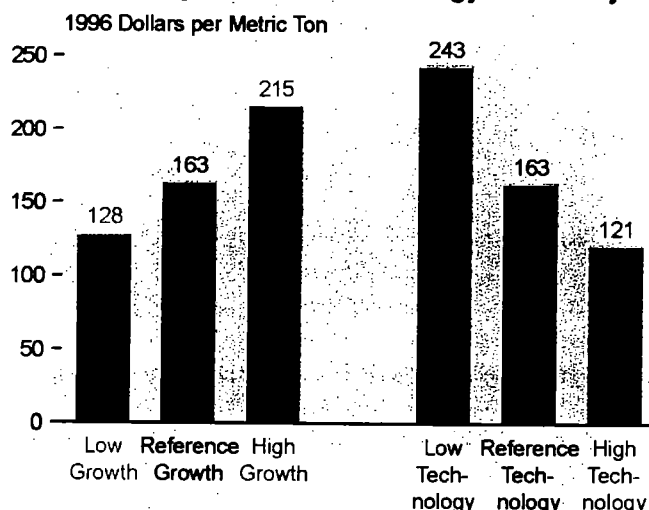
To reflect the uncertainty of potential economic growth, high and low economic growth sensitivity cases were analyzed against the 1990+9% case, using the same higher and lower economic growth assumptions as in AEO98. With higher economic growth, the industrial output and energy service demand are higher. As a result, carbon prices must be correspondingly higher to attain a given carbon emissions target. With low economic growth, the effects are reversed, leading to lower carbon prices. In addition to industrial output, some of the most important economic drivers in NEMS are disposable personal income, housing stock, housing size, commercial floorspace, industrial output, light-duty vehicle sales, and travel.

Figure 24 shows the effect of the high and low macroeconomic growth assumptions on the projections for 2010 in the 1990+9% case. The carbon price in 2010 is \$215 per metric ton in the high economic growth case, or \$52 per metric ton higher than the price of \$163 per metric ton in the 1990+9% case with reference economic growth. In the low economic growth case, the carbon permit price in 2010 is \$128 per metric ton or \$35 per metric ton lower than in the 1990+9% case.

The higher carbon prices necessary to achieve the carbon reductions with higher economic growth will tend to moderate the growth rates of the economy as a whole and the economic drivers in the energy system. Despite this price effect, total energy consumption in 2010 is higher with higher economic growth, by 2.2 quadrillion Btu relative to the 1990+9% with reference economic growth. Similarly, the lower economic growth assumption results in lower carbon prices, which offset a portion of the projected reduction in energy consumption that would otherwise be expected when economic growth slows. Lower economic growth lowers total energy consumption by 2.2 quadrillion Btu.

To meet a carbon reduction target with higher economic growth and energy consumption, there is a shift to less

Figure 24. Projected Carbon Prices in the 1990+9% High and Low Economic Growth and High and Low Technology Sensitivity



Source: Office of Integrated Analysis and Forecasting, National Energy Modeling System runs FD09ABV.D080398B, LMAC09.D080698A, HMA09.D080598A, FREEZE09.D080798A, and HITECH09.D080698A.

carbon-intensive fuels and higher energy efficiency; however, economic growth affects energy consumption in the industrial and transportation sectors more significantly than in the other end-use sectors. With higher economic growth, renewable energy and natural gas consumption is higher, primarily for generation but also in the industrial sector. Coal use for generation is lower, and more nuclear capacity is life-extended as a result of the higher carbon prices. Petroleum consumption is also higher with higher economic growth, in both the transportation and industrial sectors. As shares of total energy consumption, natural gas and renewables are higher with higher economic growth, coal is lower, and nuclear and petroleum remain approximately the same. Opposite trends for fuel consumption and fuel shares are seen when lower economic growth is assumed.

Total energy intensity is lower in the high economic growth case, partially offsetting the changes in energy consumption caused by the different growth assumptions. There are three reasons for the improvement in energy intensity. First, although demand for energy services is higher with higher economic growth, there is greater opportunity to turn over and improve the stock of energy-using technologies. In the AEO98 cases, aggregate energy efficiency in the high economic growth case decreases at a rate of 1.0 percent a year through 2020, compared with 0.9 percent in the reference case and 0.8 percent in the low economic growth case. Second, with higher carbon prices, additional efficiency improvements are induced by higher energy prices. Finally, the higher energy prices lead to some reductions in energy service demand, moderating the impacts of higher economic growth. In the 1990+9% carbon reduction case, aggregate energy intensity declines at an average annual rate of 1.6 percent through 2010. In the 1990+9% high

economic growth sensitivity case, the annual decline increases to 1.9 percent. In the 1990+9% low economic growth case, the decline in energy intensity slows to 1.3 percent per year.

Technological Progress

The assumed rate of development and penetration of energy-using technology has 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 AEO98 reference case already assumes continued improvement in both energy consumption and production technologies, slower technological development is also possible.

To examine the influence of technology improvement, two sensitivity cases were analyzed relative to the 1990+9% case. The high technology case includes more optimistic assumptions on the costs, efficiencies, market potential, and year of availability for the more advanced generating and end-use technologies, assuming increased research and development activity. This sensitivity case also assumes a carbon sequestration technology for coal- and natural-gas-fired electricity generation, which would capture the carbon dioxide emitted during fuel combustion and store it in underground aquifers; however, use of the technology is not projected to be economical relative to other technologies within the time frame of this sensitivity case because of high operating costs and storage difficulties. The low technology case assumes that all future equipment choices are made from the end-use and generation equipment available in 1998, with building shell and industrial plant efficiencies frozen at 1998 levels.

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 reduced. Conversely, slower technology improvement requires higher carbon prices (Figure 24). In the 1990+9% case with high technology assumptions, the carbon price in 2010 is \$121 per metric ton—\$42 per metric ton lower than the price of \$163 per metric ton in the 1990+9% case with reference technology assumptions. With the low technology assumptions, the projected carbon price is \$243 per metric ton in 2010.

Total energy consumption in 2010 is lower by 2.1 quadrillion Btu in the high technology case, about 2 percent below the projection in the 1990+9% case, and average energy prices, including carbon prices, are 10 percent lower. As a result, direct expenditures on energy are 13 percent lower in the high technology case. Demand 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 1990+9% case. With the high technology assumptions in the generation sector, coupled with the lower carbon permit price, coal use for generation is 3.8 quadrillion Btu higher than the 9.7 quadrillion Btu level associated with reference technology assumptions.

In the low technology case, the converse trends prevail. In 2010, total consumption is higher by 1.5 quadrillion Btu with the low technology assumptions, and energy expenditures are 17 percent higher. Industrial and transportation demand is higher, and residential and commercial demand lower, suggesting that industry and transportation are more sensitive to technology changes than to price changes, and that 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, with more natural gas, nuclear power, and renewables used to meet the carbon reduction targets.

Nuclear Power

In the AEO98 reference case, nuclear generation declines significantly, because 52 percent of the total nuclear capacity available in 1996 is expected to be retired by 2020. A number of units are 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. In the carbon reduction cases, life extension of the plants can occur, if economical, and there is an increasing incentive to invest in nuclear plant refurbishment with higher carbon prices; however, no construction of new nuclear power plants is assumed, given continuing high capital investment costs and institutional constraints associated with nuclear power.

A nuclear power sensitivity case was developed to examine the potential contribution of new nuclear plant construction to carbon emissions reductions, assuming that new nuclear capacity would be built when it was economically competitive with other generating technologies. In the nuclear power sensitivity case, electricity generators were assumed to add nuclear power plants when it became economical to do so. In addition, the reference case assumptions about higher costs incurred for the first few advanced nuclear plants were relaxed by reducing the premium in costs for the first phase of new nuclear plant additions.

In the 1990+9% case, even with the nuclear power sensitivity assumptions, nuclear plants are not competitive with fossil and renewable plants. In the 1990-3% case, however, when the new nuclear assumptions are used, 1 gigawatt of new nuclear capacity is added by 2010, and

41 gigawatts, representing about 68 new plants of 600 megawatts each, are added by 2020. (In a trial case in which first-generation cost premiums were left unchanged, only 3 gigawatts of nuclear capacity was added.) The availability of this no-carbon capacity offsets about 25 million metric tons of carbon emissions from additional natural gas plants in 2020; on the other hand, more coal is used, because the projected carbon prices are lower. Most of the impact from the new nuclear plants comes after the commitment period of 2008 through 2012. As a result, 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 the 1990-3% case, total energy consumption is about the same in 2010 with new nuclear plants allowed and higher by about 1.8 quadrillion Btu in 2020. Somewhat lower energy prices induce higher consumption in all sectors, and the greater availability of carbon-free nuclear generation allows the carbon reduction target to be met with higher end-use consumption.

3. End-Use Energy Demand

Background

This chapter provides in-depth analyses of the carbon emissions reduction cases for the four end-use demand sectors—residential, commercial, industrial, and transportation. Additional analyses are included for a number of alternative cases, including low and high technology sensitivity cases, which have the most direct impacts on energy end use.

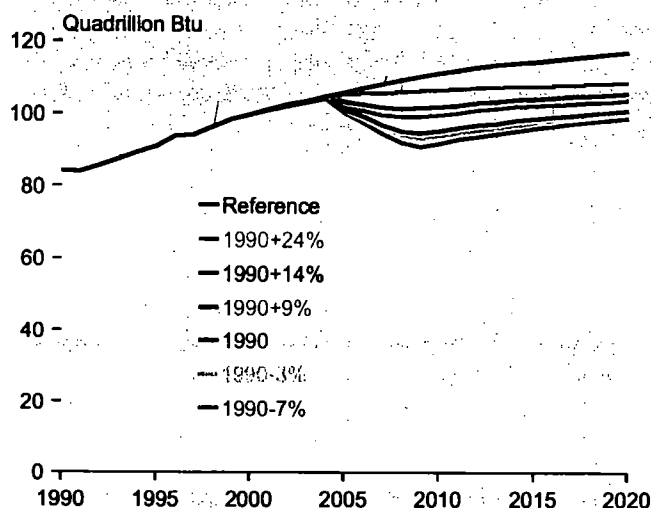
Primary and Delivered Energy Consumption

In each of the reduction cases, carbon emissions are reduced through a combination of switching to carbon-free or lower-carbon fuels, reductions in energy services, and increased energy efficiency. The latter two options lower total energy consumption (Figure 25).

Electricity generation typically consumes about three times as much energy, on the basis of British thermal units (Btu), as is contained in the electricity delivered to final consumers. In *AEO98*, total delivered energy consumption in 1996 is estimated at 70.4 quadrillion Btu, compared with total primary energy consumption of 94.0 quadrillion Btu (Table 3). The difference comes from electricity-related generation and transmission losses and, consequently, is relatively small for the transportation sector, where little electricity is consumed. Although the delivered price of electricity per Btu generally is more than three times the delivered price of other energy sources, the convenience and efficiency of electricity use outweigh the price difference for many applications.

Because consumers base their fuel and equipment choices on performance at the point of use, the analysis of end-use energy consumption presented in this chapter focuses on energy delivered to final consumers. When consumers choose to purchase a particular type of

Figure 25. Projections of Primary 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, FD07BLW.D080398B.

energy-consuming equipment or to use a particular fuel, their decisions are based on the cost and performance characteristics of the technology, mandated efficiency standards, and energy prices. End-use energy prices include all the direct costs of providing energy to the point of use.

The distinction between end-use and primary energy consumption is an important one for the evaluation of efficiency standards and other energy policies. Reducing electricity demand through the use of more efficient technologies reduces primary energy consumption by a factor of three. In addition, although electricity at its point of use produces no carbon emissions, reductions in electricity use produce savings in emissions from the fuels used for its generation.

Table 3. Primary and End-Use Energy Consumption by Sector, 1996

Sector	End-Use Consumption		Primary Consumption	
	Quadrillion Btu	Percent of Total	Quadrillion Btu	Percent of Total
Residential	11.1	16	19.4	21
Commercial	7.5	11	15.0	16
Industrial	27.1	38	34.8	37
Transportation	24.7	35	24.9	26
Total	70.4	100	94.0	100

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

Integrated Energy Market Analysis

The analysis in this report is a fully integrated analysis of U.S. energy markets, representing the interactions of energy supply, demand, and prices across all fuels and sectors. For example, initiatives to lower energy consumption may lower the prices of the energy supplied, causing some offsetting increase in energy consumption. An integrated market analysis can capture such feedback effects, which may be missed in an analysis that focuses on end-use demand for energy without accounting for impacts on energy prices.

The Energy Information Administration's *Annual Energy Outlook 1998* (AEO98), includes results from a number of alternative sensitivity cases in addition to its reference case projections. Sensitivity cases generally are designed by varying key assumptions in one of the demand, conversion, or supply modules of the National Energy Modeling System (NEMS), in order to isolate the impacts of the revised assumptions. For example, the high technology sensitivity cases for the end-use demand sectors in AEO98 do not include any feedback effects from energy prices, and energy consumption in each sector is lower than in the reference case solely due to the revised assumptions about technology costs and efficiencies. The sensitivity cases described in this report, in contrast, were combined into an integrated analysis. As a result, lower energy consumption in the high technology case leads to lower energy prices, which in turn produce some offsetting increases in consumption.

Carbon emission reduction targets and carbon prices further complicate the integrated market analysis. In the high technology sensitivity cases presented in this chapter, the carbon reduction targets are the same as those in the comparable cases that use the AEO98 reference case technology assumptions. For example, the 9-percent-above-1990 (1990+9%) case and the 1990+9% high technology sensitivity case have the same carbon emissions target. The effect of the high technology assumptions is to lower the projected carbon price that would be required to achieve the same level of carbon emissions, which also reduces the delivered price of fuel. With lower carbon prices, adverse impacts on the macroeconomy and on energy markets are moderated. Assuming that the technological advances posited in the high technology cases for the various end-use sectors could in fact be achieved, energy consumption levels would not necessarily be lower in each sector. Rather, the carbon price

would be lower, and it would be less costly to achieve a given emissions reduction target.

Residential Demand

Background

As the largest electricity-consuming sector in the United States, households were responsible for 20 percent of all carbon emissions produced in 1996, of which 63 percent was directly attributable to the fuels used to generate electricity for the sector. Electricity is a necessity for all households, and with electricity use per household growing at 1.5 percent per year since 1990, the projected increase in residential sector electricity consumption has become a central issue in the debate over carbon stabilization and meeting the goals of the Kyoto Protocol.

The number of occupied households is the most important factor in determining the amount of energy consumed in the residential sector. All else being equal, more households mean more total use of energy-related services. From 1980 to 1996, the number of U.S. households grew at a rate of 1.4 percent per year, and residential electricity consumption grew by 2.6 percent per year. In the reference case, the number of households is projected to grow by 1.1 percent per year through 2010, and residential electricity consumption is projected to grow by 1.6 percent per year. Strong growth in the South, which features all-electric homes more prominently than do other areas of the country, and the advent of many new electrical devices for the home have significantly contributed to high electricity growth since 1980. Although these trends are projected to continue through 2010, efficiency improvements—due in part to recent Federal appliance standards, utility demand-side management programs, building codes, and nonregulatory programs (e.g., Energy Star)—should dampen electricity growth somewhat as residential appliances are replaced with newer, more efficient models.

Within the residential sector, all of the major end-uses (heating, cooling, lighting, etc.) are represented by a variety of technologies that provide necessary services. Technologies are characterized by their cost, efficiency, dates of availability, minimum and maximum life expectancies, and the relative weights of the choice criteria—installed cost and operating cost. The ratio of the weight of installed cost to that of operation cost gives an estimate of the “hurdle rate” used to evaluate the energy

efficiency choice.²⁴ When more emphasis is placed on installed cost, the hurdle rate is higher. The hurdle rates for residential equipment range from 15 percent for space heating technologies to more than 100 percent for some water heating applications. The range in part reflects differences in the way consumers purchase the two technologies. In the case of water heaters, for example, purchases tend to occur at the time of equipment failure, which tends to restrict the choice to equipment readily available from the plumber. Space conditioning equipment, on the other hand, is not used all year round, allowing some latitude in terms of timing the replacement of an older unit. It is assumed that residential consumers expect future energy prices to remain at the current level at the time of purchase when calculating the future operating cost of a particular technology.

Technological advances and availability play a large role in determining future energy savings and carbon emission reductions. Even in today's marketplace, there exist many efficient technologies that could substantially reduce energy consumption and carbon emissions, however the relatively high initial cost of these technologies restricts their widespread penetration. Over time, the costs of more advanced technologies are assumed to fall as the technology matures, one example being natural gas condensing water heaters. In addition, technologies that are not available today but are nearing commercialization are assumed to become available in the future. Three technology menus are used in the analysis below: a reference technology menu, a high technology menu (reflecting more aggressive research and development), and a "frozen" menu limited to equipment available today. In all cases, the menu options and characteristics are fixed. In the high technology sensitivity case, for example, the cost of a condensing natural gas water heater is assumed to fall by almost 75 percent by 2005, relative to the reference case, and a natural gas heat pump water heater becomes available for purchase, by 2005.

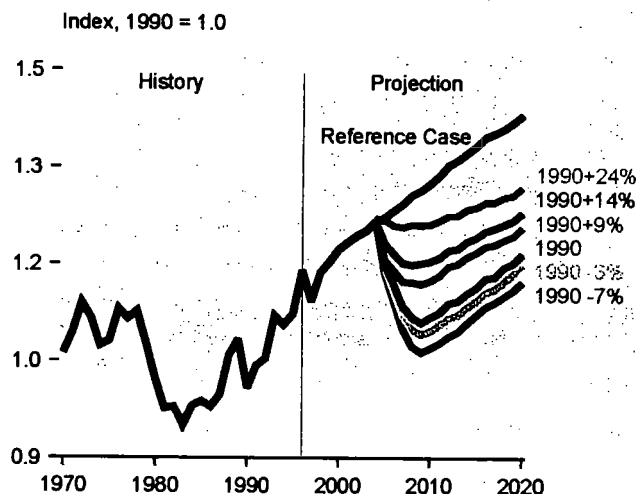
In response to energy price changes, residential elasticities, defined as the percent change in energy consumed with a 1-percent change in price, range from -0.24 to -0.28 in the short run, depending on the fuel type, to -0.33 to -0.51 in the longer term. The elasticities reported here are derived from NEMS by a series of simulations with only one energy price varying at a time, beginning in 2000.²⁵ These price elasticities reflect changes in both the

demand for energy services and the penetration rate of more efficient technologies. In the absence of energy price changes, energy intensity, as defined as delivered energy consumption per household, declines at an average rate of 0.5 percent per year through 2010. This non-price-induced intensity improvement reflects the efficiency gain brought about by ongoing stock turnover, equipment standards, new housing stock, and the future availability of new technologies.

Energy consumption, including the combustion of various fossil fuels, is the major source of U.S. carbon emissions. Energy use in the residential sector is greatly affected by year-to-year variations in seasonal temperatures, particularly in the winter, as illustrated by the decline in delivered energy use in 1990 (Figure 26), which was one of the warmest winters on record. The projections in this analysis assume normal seasonal temperatures over the 1996-2020 forecast period.

In the 3-percent-below-1990 (1990-3%) carbon reduction case, which assumes an emissions target of 3 percent below 1990 levels for the United States, a sharp drop in residential energy use is projected between 2005, when

Figure 26. Index of Residential Sector Delivered Energy Consumption, 1970-2020

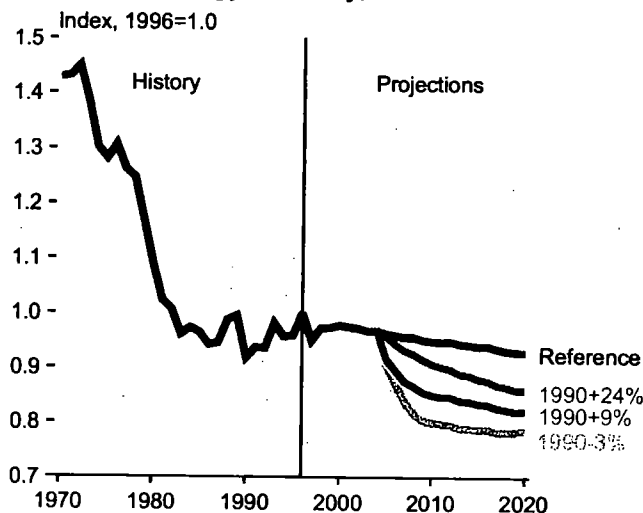


Sources: **History:** Energy Information Administration, *State Energy Data Report 1995*, DOE/EIA-0214(95) (Washington, DC, December 1997). **Projections:** Office of Integrated Analysis and Forecasting, National Energy Modeling System runs KYBASE.D080398A, FD24ABV.D080398B, FD1998.D080398B, FD09ABV.D080398B, FD1990.D080398B, FD03BLW.D080398B, FD07BLW.D080398B.

²⁴The "hurdle rate" for evaluating energy efficiency investments has also been referred to as the "implicit discount rate" (i.e., the empirically based rate required to simulate actual purchases—the one implicitly used). These rates are often much higher than would be expected if financial considerations alone were their source. Among the reasons often cited for relatively high apparent hurdle rates are uncertainty about future energy prices and future technologies, lack of information about technologies and energy savings, additional costs of adoption not included in the calculations, relatively short tenure of residential home ownership, hesitancy to replace working equipment, attributes other than energy efficiency that may be more important to consumers, limited availability of investment funds, renter/owner incentive differences, and builder incentives to minimize construction costs. For a good discussion of potential market barriers and the economics of energy efficiency decisions, see Jaffe and Stavins, "Energy Efficiency Investments and Public Policy," *The Energy Journal*, Vol. 15, No. 2 (1994), pp. 43-65.

the target is implemented, and 2010 (Figure 26). However, the projected decline is nearly identical to that seen historically from 1978 to 1983, in terms of both consumption and intensity (Figure 27). Housing starts, a major predictor of residential energy use, fell from 2.02 million units in 1978 to 1.062 million in 1982.²⁶ The drop in housing starts was tied directly to mortgage rates, which increased from 9.6 percent in 1978 to over 16 percent in 1981-1982. In addition, real energy prices to the residential sector increased by 87 percent from 1978 to 1982, similar to the 82-percent real price increase projected in the 1990-3% case. In the carbon reduction cases, delivered energy consumption in the residential sector never reaches its 1990 level, which has been used as a benchmark in setting carbon reduction targets. Given the uncertainty regarding technology and consumer behavior in a high-price energy world, additional sensitivities are examined here to analyze the effects of variations in the level of optimism associated with assumptions about both technology advances and consumer responsiveness.

Figure 27. Index of Residential Sector Delivered Energy Intensity, 1970-2020



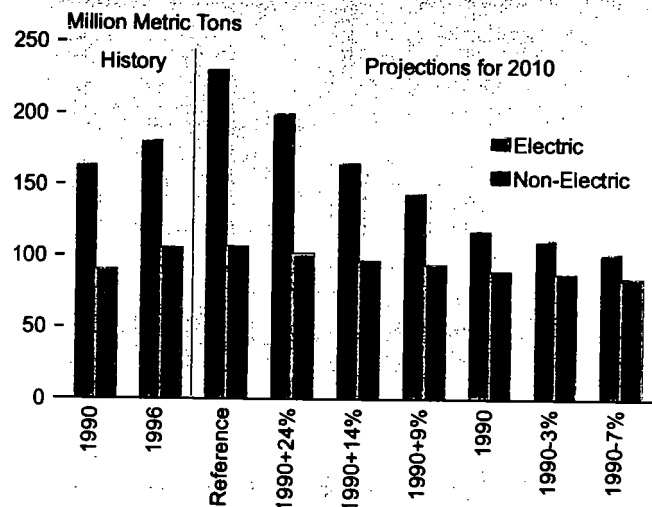
Sources: History: Energy Information Administration, *State Energy Data Report 1995*, DOE/EIA-0214(95) (Washington, DC, December 1997) and Data Resources Incorporated. Projections: Office of Integrated Analysis and Forecasting, National Energy Modeling System runs KYBASE.D080398A, FD24ABV.D080398B, FD09ABV.D080398B, FD03BLW.D080398B.

Carbon Reduction Cases

Carbon emissions associated with electricity generation are the largest component of emissions from the residential sector, in terms of both the levels and projected growth in the reference case, and in terms of the projected declines in the carbon reduction cases. In the reference case, which does not include the Kyoto Protocol, 98 percent of the projected increase in residential sector carbon emissions by 2010 results from increasing electricity use and the fuels used for

electricity generation. In the 1990+9% case, 87 percent of the sector's decline in carbon emissions is related to reduced electricity demand and changes in electricity generation (Figure 28). The following discussion focuses on the results of three carbon reduction cases—1990-3%, 1990+9%, and 24-percent-above-1990 (1990+24%)—in which carbon emissions, averaged across all energy sectors, reach targeted levels relative to 1990 in the 2008-2012 period.

Figure 28. Residential Sector Carbon Emissions, 1990, 1996, and 2010



Note: Electricity emissions are from the fossil fuels used to generate the electricity used in this sector.

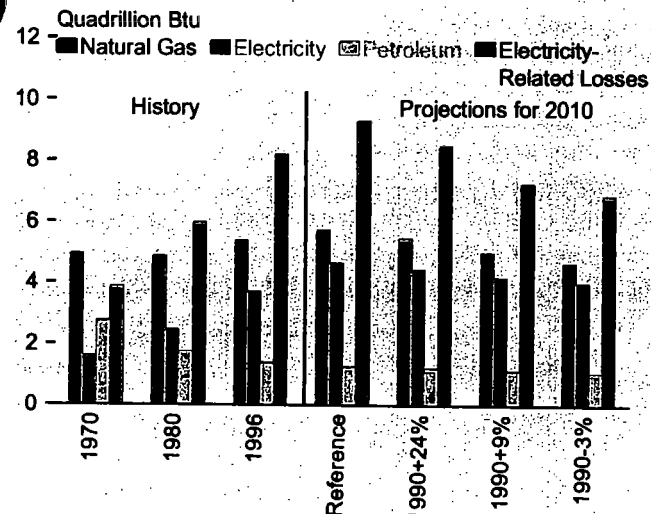
Sources: History: Energy Information Administration, *Emissions of Greenhouse Gases in the United States 1996*, DOE/EIA-0573(96) (Washington, DC, October 1997). Projections: Office of Integrated Analysis and Forecasting, National Energy Modeling System runs KYBASE.D080398A, FD24ABV.D080398B, FD1998.D080398B,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

Although the use of electricity contributes most to the projected growth in emissions in the residential sector, natural gas consumption, which emits relatively low levels of carbon per Btu burned compared with coal (the major fuel used to generate electricity), is projected to remain the most important fuel in the sector as measured by delivered energy. Figure 29 shows delivered energy consumption by major fuel as well as the losses associated with electricity generation. On a delivered basis, natural gas use is projected to decrease the most in the three carbon reduction cases by 2010. Relative to the projected level of consumption in the reference case in 2010, delivered energy consumption is projected to be 10 percent lower in the 1990+9% case and electricity-related losses 22 percent lower. Of the 2.0 quadrillion Btu savings in electricity-related losses in 2010 in the 1990+9% case, 43 percent (0.9 quadrillion Btu) can be attributed to reduced electricity demand in the residential sector. The remaining 1.1 quadrillion Btu (57 percent) of the savings in electricity-related losses comes from efficiency gains and/or fuel switching for

²⁵The long-run elasticities reflect the effects of altered prices after 20 years for the last year of the forecast, 2020.

²⁶U.S. Bureau of the Census, *Construction Reports*, series C20.

Figure 29. Delivered Energy Consumption in the Residential Sector by Major Fuel, 1970, 1980, 1996, and 2010



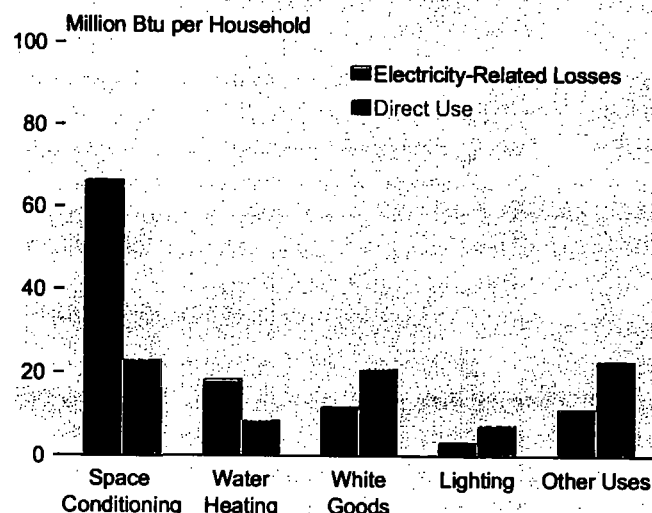
Sources: **History:** Energy Information Administration, *State Energy Data Report 1995*, DOE/EIA-0214(95) (Washington, DC, December 1997). **Projections:** Office of Integrated Analysis and Forecasting, National Energy Modeling System runs KYBASE.D080398A, FD24ABV.D080398B, FD09ABV.D080398B, FD03BLW.D080398B.

electricity generation. Thus, changes in electricity supply, absent any major technological or behavioral changes in residential end use over the next 12 years, are the key to controlling carbon emissions for the residential sector.

Energy is used in the residential sector to provide a number of different services, which vary in end-use intensity (energy consumption per household) (Figure 30). Space conditioning (which includes heating, cooling, and ventilation) is clearly the most energy-intensive end use in the sector, and it accounts for most of the direct use of fossil fuels. "White goods" (which include refrigerators, freezers, dishwashers, clothes washers and dryers, and stoves), lighting, and other uses are almost entirely powered by electricity and, therefore, are responsible for most of the electricity-related losses.

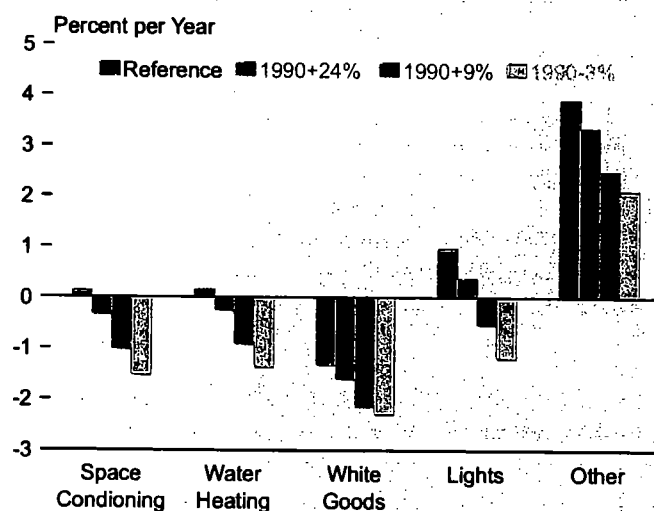
In the reference case, most of the projected growth in residential energy consumption between 1996 and 2010 comes from increasing use of miscellaneous electric devices, such as personal computers and home security systems (Figure 31). The rate at which energy consumption changes over time depends on factors such as equipment turnover rates, ability to control unit operation (thermostatic controls), energy prices, household size (people per house), housing unit size (square feet), and the efficiency of newly purchased appliances. Stock turnover can provide drastic reductions in energy intensity, even without future gains in appliance efficiency. On average, a new

Figure 30. Residential Sector Energy Use per Household, 1996



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

Figure 31. Average Projected Annual Growth in Residential Sector Energy Consumption by End Use, 1996-2010



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

refrigerator purchased in 1995 used 62 percent less electricity than one purchased 20 years earlier.²⁷ Conversely, slow stock turnover can limit the role of energy efficiency gains in the future. Equipment purchased in the 1990s that lasts 20 years or more will not be eligible for replacement until after 2010.

With the exception of white goods, increases in total energy consumption for all the major residential energy services are projected from 1996 to 2010 in the reference case. The negative growth in total energy consumption for white goods results from a decline in energy use for

²⁷ Association of Home Appliance Manufacturers, *Fact Book 1996*.

refrigeration, as aggressive Federal efficiency standards²⁸ taking effect in 1993 and 2001 reduce the amount of energy needed to provide the same level of service. In the carbon reduction cases, increasing energy prices act to reduce the growth in energy consumption for all major services relative to their growth in the reference case. In the absence of mandatory standards, residential consumers traditionally have been reluctant to purchase highly efficient appliances. However, faced with the higher energy prices projected in the carbon reduction cases, it is expected that consumers will respond by purchasing more efficient appliances (Table 4). The extent of consumer response and its impact on average equipment efficiencies would also depend on the purchase price of the new equipment (the initial investment required).

Table 4. Change in Projected Average Efficiencies of Newly Purchased Residential Equipment in Carbon Reduction Cases Relative to the Reference Case, 2010 (Percent)

Technology	1990+24%	1990+9%	1990-3%
Air-Source Heat Pump	1.3	3.6	5.7
Electric Water Heater	0.3	2.4	13.6
Natural Gas Water Heater	1.1	3.7	4.8
Building Shell	1.0	3.3	5.5

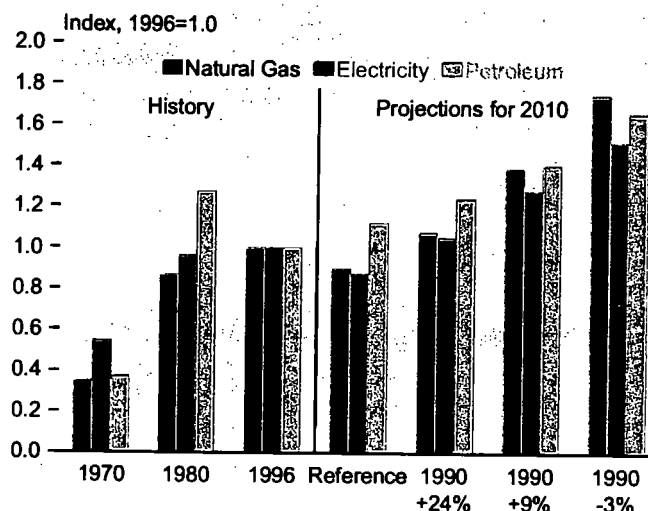
Sources: Office of Integrated Analysis and Forecasting, National Energy Modeling System runs KYBASE.D080398A, FD24ABV.D080398B, FD09ABV.D080398B, and FD03BLW.D080398B.

In the reference case, the real (inflation-adjusted) prices of electricity and natural gas to residential consumers are projected to decline between 1996 and 2010 (Figure 32), by 8 and 10 percent, respectively. The outlook for prices in the carbon reduction cases, however, is much different. Without major changes in energy policy, technology, or consumer response, prices to the residential sector are expected to be as much as 94 percent higher in 2010 in the 1990-3% case. In response to the higher prices, total residential energy consumption is projected to decline by more than 20 percent by 2010 in the 1990-3% case.

The factors that contribute to lower consumption include behavioral responses, such as adjusting the thermostat or turning off the lights when leaving the room, and, to a lesser extent, the acquisition of more efficient appliances. The rate of improvement in average appliance efficiency is constrained by the rate of stock turnover. For example, it is not uncommon for major energy-using appliances, such as furnaces, to last for 30 years or more. More immediate responses to higher

energy prices can be achieved through retrofits to improve the thermal efficiency of building shells. During the energy price shocks of the 1970s, for example, homeowners increased insulation levels substantially,²⁹ with the immediate effect of conserving energy and lowering energy bills. The potential for similar improvement between 1996 and 2010 is reduced, given the improvements already made.

Figure 32. Index of Residential Sector Energy Prices, 1970, 1980, 1996, and 2010



Sources: **History:** Energy Information Administration, *State Energy Price and Expenditure Report 1994*, DOE/EIA-0376(94) (Washington, DC, June 1997). **Projections:** Office of Integrated Analysis and Forecasting, National Energy Modeling System runs KYBASE.D080398A, FD24ABV.D080398B, FD09ABV.D080398B, FD03BLW.D080398B.

Sensitivity Cases

High and Low Technology. Technology improvements over time can take the form of increased efficiency, decreased cost, or both. To examine the effects of assumptions about the rate at which technologies will improve in the future, two sets of sensitivity cases were analyzed. The low technology sensitivity cases assume that none of the improvements assumed in the reference case will occur. In other words, future technologies are assumed to be "frozen" at their 1998 cost and efficiency levels. Technological improvement occurs in this case as older units are retired and are replaced with 1998 technologies. Engineering technology experts were consulted to develop the high technology case, which assumes more rapid advances than those in the reference case, due to research and development (Table 5).³⁰ In the high technology case, for example, the efficiency of the best available natural gas water heater is assumed to improve by 63 percent over the 1998 level by 2015, and the cost is assumed to decline by 15 percent,

²⁸These standards represent updates to previous standards authorized by the National Appliance Energy Conservation Act of 1987.

²⁹U.S. Department of Energy, *Progress in Residential Retrofit*, Based on Owens-Corning Marketing Research.

³⁰Energy Information Administration, *Technology Forecast Updates—Residential and Commercial Building Technologies*, Draft Report (Arthur D. Little, Inc., June 1998).

Renewables and Dispersed Electricity Generation

Dispersed renewable energy use in the residential sector includes wood, solar thermal, geothermal energy, photovoltaic cells, and fuel cells.^a Wood is used as a main or secondary heating source in some households. Geothermal energy is used to power ground-source heat pumps, which exchange energy with below-ground earth or water, extracting heat in the winter and delivering heat to the earth (and cooling the building) in the summer. Solar thermal energy is used mainly to heat water for swimming pools and household use. Photovoltaics provide small-scale electricity generation, often in remote locations, using semiconductors to transform sunlight directly into electricity, which may be used for a variety of functions, such as water pumps or remote lighting systems. Fuel cells convert liquid fossil fuels into electricity through electrochemical processes.

The share and quantity of wood as a primary heating fuel in the residential sector has been falling for nearly two decades. In 1982, 6.7 percent of all U.S. households heated with wood, but its share fell to 3.2 percent in 1993. The aggregate quantity of wood consumed as primary heating in households has fallen as well, from 28.7 million cords in 1982 to 12.6 million cords in 1993.^b The decline has resulted in part from local laws restricting wood burning. In addition, the convenience of natural gas heating and the decline in real oil and gas prices over the past decade have led many households to choose gas or oil over wood.

While wood has declined as a primary residential heat source, its use as a backup or secondary heat source has not. Wood use as a secondary heat source increased from 16 percent of households in 1980 to 20 percent in 1993, suggesting that wood stoves are being kept as backup heating systems. If the prices of other fuels rise significantly, however, the use of wood as a primary household heating fuel may well increase. In the reference case for this analysis, wood energy use is projected to be 0.61 quadrillion Btu in 2010. In the most stringent carbon reduction case (7 percent below 1990 levels), higher energy prices lead to wood use of 0.63 quadrillion Btu in 2010, increasing to 0.67 quadrillion Btu in 2020.

The market for solar energy systems has undergone substantial changes over the past three decades, largely as a result of the introduction, removal, and subsequent reintroduction of Federal energy tax credits for photovoltaic cells and solar thermal collection systems. With the introduction of a Federal tax credit in 1978, shipments of

solar thermal collectors to the residential and commercial sectors nearly doubled to 10 million square feet from 5.8 million square feet in 1976. The annual growth in shipments averaged 8 percent per year until 1985, when the tax credits were repealed. Subsequently, shipments fell sharply from 19.1 million square feet in 1985 to 9.1 million in 1986. The energy tax credit was reintroduced for the commercial sector in 1986, followed by a small increase in shipments, but since 1991 there has been little growth in the industry. Residential sales of solar thermal systems are not expected to increase substantially in the reference case, given current tax policy and projected declines in real energy prices.

Domestic shipments in the photovoltaic market (including both dispersed and grid-connected system) have grown significantly since the 1980s, but they also were affected by the repeal of the tax credit. From 10,717 peak kilowatts shipped in 1983, shipments were down to 3,224 peak kilowatts in 1986 after the tax credit repeal, a 32-percent average annual decline.^c The market recovered somewhat in the next decade, with 1992 shipments reaching 5,760 peak kilowatts. Since then, the industry has been developing steadily, particularly after 1992, with 23-percent average annual growth to 13,016 peak kilowatts shipped in 1996.

Fuel cells have the potential for future integration into both grid-connected and off-grid applications in every sector. When their cogenerative capabilities are used, capturing excess heat from the chemical reaction for space and water heating, fuel cell efficiencies can rise to two or three times those of typical energy combustion plants, emitting only half the amount of carbon dioxide per unit of useful energy obtained.^d

To date, fuel cells have not been used extensively. With their relatively recent development and only one major manufacturer worldwide, there are only 160 medium-sized (200-kilowatt) units in use.^e Smaller units have been tested in the space program and in the automobile industry, but the first unit designed for the residential market was not built until 1998. Fuel cells are a promising technology for the residential sector, but their current high costs do not favor extensive market penetration. Costs can be expected to fall as production volumes increase, and depending on the timing and extent of the cost reductions, fuel cells could become an important source of dispersed electricity generation.

^aDispersed renewable energy is the direct use of power from a renewable energy system such as a photovoltaic array, disconnected from the electric power grid. The production and sale of electricity from utilities using renewable energy fuels are not included.

^bEnergy Information Administration, *Housing Characteristics 1980*, DOE/EIA-0312 (Washington, DC, June 1982), p. 101; *Housing Characteristics 1982*, DOE/EIA-0314(82) (Washington, DC, August 1984), pp. 47-98; and *Household Energy Consumption and Expenditures 1993*, EIA/DOE-0321(93) (Washington, DC, October 1995), pp. 37-62.

^cEnergy Information Administration, *Renewable Energy Annual 1997*, Vol. 1, DOE/EIA-0603(97/1) (Washington, DC, February 1998), p. 19.

^dWhen byproduct heat is used, average total efficiency of the system increases to approximately 80 percent, significantly more than a standard coal-fired utility plant, which operates at around 30 percent efficiency. Source: U.S. Department of Energy, Office of Fossil Energy, Technology Center, *Climate Change Fuel Cell Program*, NG001.1197M.

^eFred Kemp, Manager of Government Programs, International Fuel Cells (South Windsor, CT), personal communication, August 1998.

Table 5. Cost and Efficiency Indexes of Best Available Technologies for Selected Residential Appliances, 2015
(1998 Values = 1.00)

Technology	Cost			Efficiency		
	1990+9% Low Technology	1990+9%	1990+9% High Technology	1990+9% Low Technology	1990+9%	1990+9% High Technology
Air-Source Heat Pump	1.00	0.99	0.98	1.00	1.09	1.18
Ground-Source Heat Pump.....	1.00	0.86	0.56	1.00	1.05	1.08
Natural Gas Heat Pump	1.00	0.81	0.75	1.00	1.00	1.00
Natural Gas Water Heater.....	1.00	0.76	0.85	1.00	1.00	1.63
Solar Water Heater	1.00	1.00	0.73	1.00	1.00	1.67
Electric Water Heater	1.00	1.00	0.73	1.00	1.04	1.17

Source: Office of Integrated Analysis and Forecasting, National Energy Modeling System runs FREEZE09.D080798A, FD09ABV.D080398B, and HITECH09.D080698A, computed from *Technology Forecast Updates—Residential and Commercial Building Technologies*, Draft Report (Arthur D. Little, Inc., June 1998).

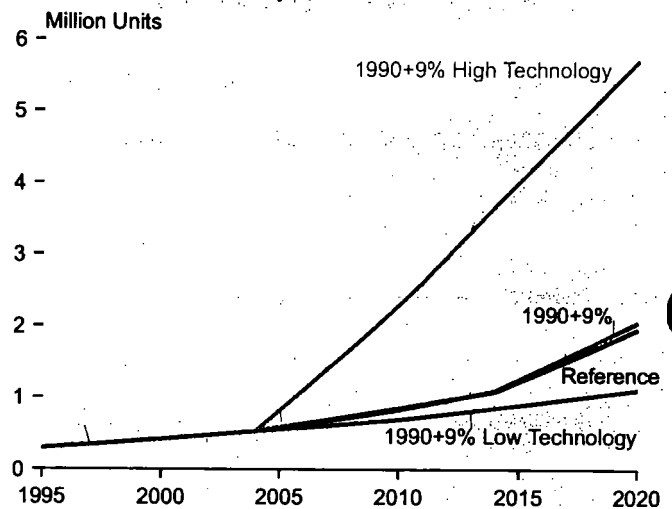
while ground-source heat pumps, which do not realize much gain in efficiency, are assumed to decline in cost by 44 percent in the high technology case by 2015.

Ground-source heat pumps, which draw stored heat from the ground beneath the frost line, provide an efficient and comfortable (in terms of delivered heat) alternative to the more common air-source heat pumps. The cost of the unit and the placement of the ground loop have been major barriers to wide market acceptance, however. Different levels of stocks of ground-source heat pumps are projected in the reference case, the 1990+9% carbon reduction case, and the 1990+9% case low and high technology cases (Figure 33). Given that significant market acceptance is seen only in the high technology case, it can be concluded that the costs associated with the technology restrict its acceptance. Space heating technologies, in general, have the lowest hurdle rates (15 percent) of all residential appliances, primarily because of the large energy costs of home heating, relative to other energy-using services.

Figure 34 shows that improvements in technology can indeed dampen the impact carbon restrictions have on residential energy prices. Given the amount of time needed for technology to penetrate the market, one would expect that over a longer period of time, the prices in the high technology sensitivity would fall relative to the other cases. After 2008, prices in the high technology sensitivity begin to fall, as reduced energy demand caused by more efficient technology penetrating the market begin to make an impact. Relative to the price in the 1990+9% case, the composite real residential energy price in 2010 is 11 percent less in the high technology case. Conversely, if technology were frozen at the level available in 1998, 2010 prices are expected to be 17 percent higher than the 1990+9% case, indicating that energy efficiency plays a significant role in the cases with reference technology assumptions.

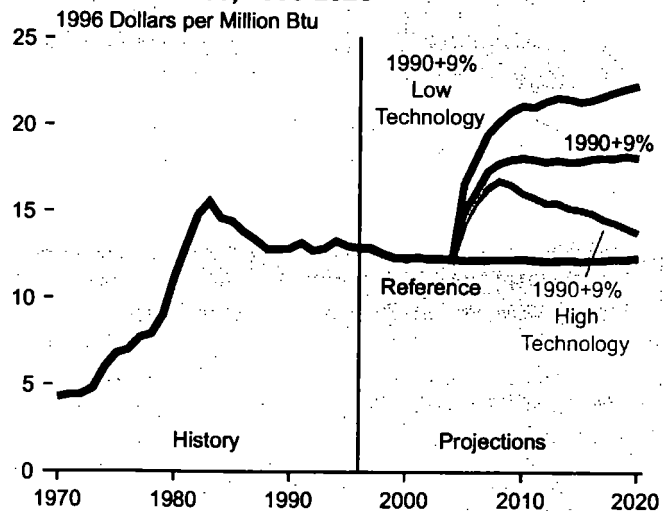
Energy fuel expenditures are a good indication of the success that technological advancement achieves in

Figure 33. Projected Stocks of Ground-Source Heat Pumps, 1995-2020



Source: Office of Integrated Analysis and Forecasting, National Energy Modeling System runs KYBASE.D080398A, FREEZE09.D080798A, FD09ABV.D080398B, and HITECH09.D080698A.

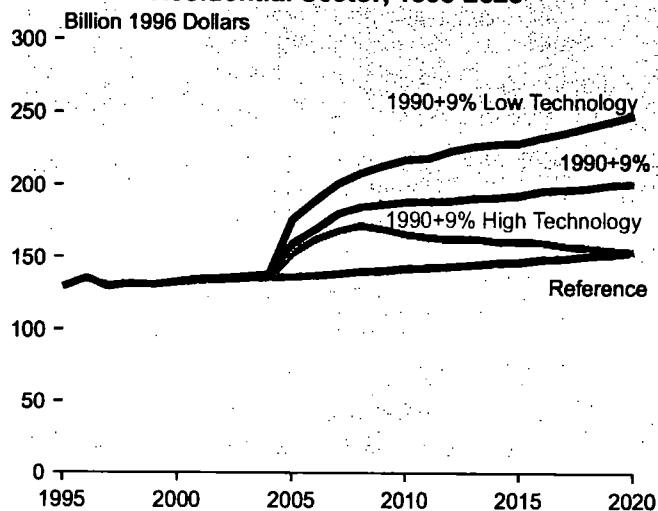
Figure 34. Average Residential Sector Energy Prices, 1995-2020



Sources: **History:** Energy Information Administration, *State Energy Price and Expenditure Report 1994*, DOE/EIA-0376(94) (Washington, DC, June 1997). **Projections:** Office of Integrated Analysis and Forecasting, National Energy Modeling System runs KYBASE.D080398A, FREEZE09.D080798A, FD09ABV.D080398B, HITECH09.D080698A.

lessening the impact on the consumer in a carbon-restricted environment. Figure 35 details residential sector energy expenditures for the 1990+9% case and technology sensitivities. For the high technology sensitivity, energy expenditures in 2020 are 23 percent less than those realized in the 1990+9% case, saving consumers over \$440 billion from 2008 to 2020.

Figure 35. Projected Energy Expenditures in the Residential Sector, 1995-2020



Source: Office of Integrated Analysis and Forecasting, National Energy Modeling System runs KYBASE.D080398A, FREEZE09.D080798A, FD09ABV.D080398B, and HITECH09.D080698A.

Increased Consumer Response. Residential energy consumers have traditionally been reluctant to invest in energy efficiency, even with ample financial benefits. Many market barriers tend to create what are known as high hurdle rates for consumer investments in energy efficiency. As of 1993, 35 percent of all homes were occupied by renters,³¹ most of whom were responsible for paying energy bills but not for purchasing major energy-consuming appliances. Such households tend to buy the least expensive equipment on the market, which also tends to be the least energy-efficient. The same reasoning can be applied to many newly constructed homes as well, because the builders, not the occupants, are tasked with equipping them with most of the major energy-using appliances. Other barriers include equipment availability (e.g., whether plumbing contractors have high-efficiency water heaters available when they make service calls) and lack of information.

To examine the effects that lower hurdle rates could have on both energy prices and expenditures in the carbon reduction cases, and at the same time differentiate those effects from the effects of technological advances,

an increased consumer response sensitivity case was analyzed. This sensitivity case includes assumptions of lower discount rates, higher short-run elasticities of demand, greater inclination to change fuels when purchasing equipment, and lower growth in miscellaneous electricity use.³²

Impacts of Increased Consumer Response and Advanced Technology. In order to gauge the impact of assumptions regarding technological advancement and consumer behavior with respect to delivered energy consumption, sensitivity cases were analyzed relative to the 1990+9% case where delivered energy prices were the same across all cases. These cases serve to isolate the impact of each of the key variables separately, and to understand the impact of implementing the sensitivities simultaneously. This section evaluates the relative impact that each of these concepts could have on future energy intensity at a price level realized in the 1990+9% case.

Changes in technological development and the value residential consumers place on energy related issues can significantly affect the pattern of energy consumption—and carbon emissions—in the future. The availability of high-efficiency technologies in itself does not guarantee increased energy efficiency. Without the willingness of consumers to purchase the more efficient products, which usually cost significantly more, technology may not have much of an impact on future energy consumption patterns. Conversely, in a world where energy conservation was of paramount concern to energy consumers, yet at the same time high-efficiency products were unavailable, future energy consumption patterns would probably not be greatly affected either.

Given the detailed nature regarding technological development and consumer choice with regards to different technologies, it is important to analyze the results at the technology level, as well as the overall level. With nearly 40 million households (38 percent) using electric water heaters in 1995, and given the relatively high intensity associated with using electric water heaters, the projected impact of increased energy efficiency can have a large impact on future electricity use for this service. Electric resistance water heaters have traditionally exhibited slow growth in energy efficiency. In fact, the highest efficiency unit available today is not likely to see any efficiency improvement due to thermal limits and diminishing returns on controlling heat loss.³³ This implies that future gains in efficiency for electric water

³¹Energy Information Administration, *Housing Characteristics 1993*.

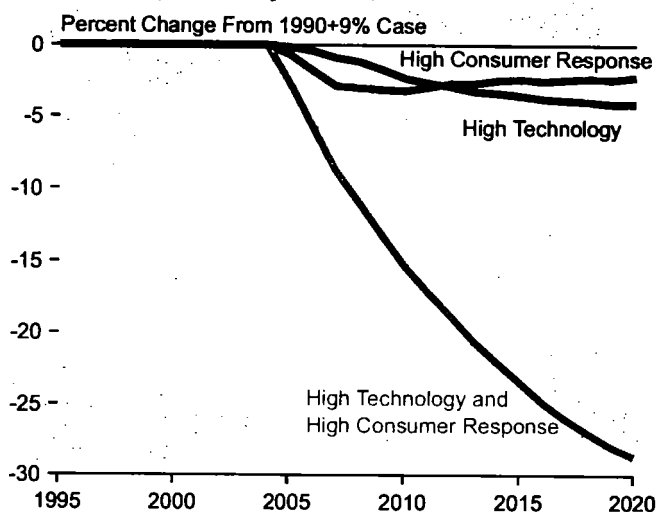
³²Assumptions include lowering hurdle rates to 15 percent real, increasing the price sensitivity parameters to switch fuels, increasing short-run price elasticities from -0.25 to -0.40, and decreasing miscellaneous electricity penetration.

³³Energy Information Administration, *Technology Forecast Updates—Residential and Commercial Building Technologies*, Draft Report (Arthur D. Little, Inc., June 1998).

heating must be achieved through the increased penetration of electric air-source heat pump water heaters, which achieve higher efficiency levels by extracting heat from the air surrounding the unit. The current cost of this technology, however, is several times that of a traditional resistance unit, and coupled with observed implicit discount rates of over 100 percent, has led to very limited market penetration.

Assumptions regarding technological advances, through improved performance and reduced cost, as well as changes in consumer behavior, can significantly affect the market penetration of emerging technologies. Figure 36 details the relative importance of varying assumptions regarding technological advances and consumer behavior with respect to the intensity of the electric water heating end use.³⁴ Relative to the 1990+9% case, intensity drops faster when assumptions regarding consumer behavior are changed, as compared to changes in technology characteristics. Over time, however, the intensity decline in the technology case outpaces that projected for the behavior case as more and more equipment is purchased at higher efficiency levels. Combining both sets of assumptions, that is, changing both technology characteristics and consumer behavior together, results in over a 25 percent decline in energy intensity for electric water heating over time. This indicates that a combination of both technology and consumer behavior changes can bring about large declines in energy intensity for this service, all else equal.

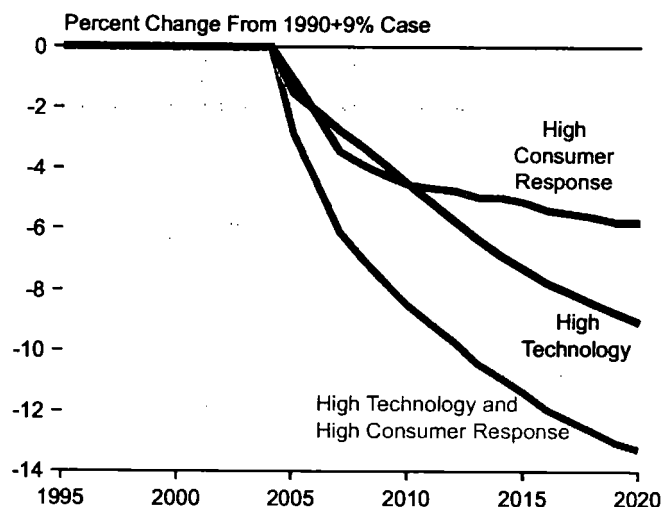
Figure 36. Changes From Reference Case Projections of Energy Intensity for Residential Water Heating in Three Sensitivity Cases, 1995-2020



Source: Office of Integrated Analysis and Forecasting, National Energy Modeling System runs FD09ABV.D080398B, KYTECH.D081098C, KYBHAVE.D081098D, and KYBOTH.D081098A.

Overall annual energy consumption per household, or energy intensity, for these sensitivity cases follows the general pattern described for electric water heating. Again, technology advances exhibit a greater potential for energy intensity decline in the long run (Figure 37), but the combination of the two cases yields roughly half of the intensity decline projected for electric water heating. This is due to the fact that all other major technologies exhibit much lower observed hurdle rates and less range in terms of high-efficiency products. For example, natural gas furnaces, the largest energy consuming product class in terms of delivered energy in the U.S., has already matured in terms of product efficiency, and at the same time hurdle rates are at 15 percent.

Figure 37. Changes From Reference Case Projections of Residential Energy Consumption in Three Sensitivity Cases, 1995-2020



Source: Office of Integrated Analysis and Forecasting, National Energy Modeling System runs FD09ABV.D080398B, KYTECH.D081098C, KYBHAVE.D081098D, and KYBOTH.D081098A.

Commercial Demand

Background

The commercial sector consists of businesses and other organizations that provide services. Stores, restaurants, hospitals, and hotels are included, as well as a wide range of facilities that would not be considered "commercial" in a traditional economic sense, such as public schools, correctional institutions, and fraternal organizations. In the commercial sector, energy is consumed mainly in buildings, and relatively small amounts are used for services, including street lights and water supply.

³⁴Intensity here is the average annual consumption of electricity for water heating in homes with electric water heaters.

The commercial sector is currently the smallest of the four demand sectors in terms of energy use, accounting for 11 percent of delivered energy demand in 1996. The commercial sector is also responsible for fewer carbon emissions than the other sectors, emitting 230 million metric tons, or 16 percent of total U.S. carbon emissions, in 1996. The sector has a larger share of emissions than its share of energy use because of the importance of commercial electricity use. The emissions associated with electricity-related losses are included in the calculation of emissions from electricity use.

Several factors determine energy use and, consequently, carbon emissions in the commercial sector. One of the most important is floorspace. Building location, age, and type of activity also affect commercial energy use. Currently, total commercial floorspace in the United States exceeds the area of the State of Delaware and amounts to about 200 square feet for every U.S. resident. Mercantile (retail and wholesale stores) and service businesses are the most common type of commercial buildings, and offices and warehouses are also common.³⁵

Because of the relatively long lives of buildings, the characteristics of the stock of commercial floorspace change slowly. Over half of the commercial buildings in the United States were built before 1970, and the reference case used for this analysis projects that total commercial floorspace will grow at about the same rate as population, 0.8 percent annually, through 2020. This limits the effects that new, more efficient building practices can achieve in the near term, but as time passes and building stock "turnover" occurs, current and future building practices will have a greater effect on commercial energy use.

The composition of end-use services is another determinant of the amount of energy consumed and the type of fuel used. The majority of energy use in the commercial sector is for lighting, space heating, cooling, and water heating. In addition, the proliferation of new electrical devices, including telecommunications equipment, personal computers, and other office equipment, is spurring growth in electricity use. Electricity use currently accounts for 45 percent of delivered energy consumption in the sector, and that share is projected to grow to about 48 percent by 2010 in the reference case.

Consideration of end-use services leads to another determining factor in commercial energy consumption—the effects of turnover and change in end-use technologies. The stock of installed equipment changes with normal turnover as old, worn-out equipment is replaced and new buildings are outfitted with newer versions of equipment that tend to be more energy-efficient. Equip-

ment with even greater energy efficiency is expected to be available to commercial consumers in the future. Energy prices have both short-term and long-term effects on commercial energy use. Fuel prices influence energy demand in the short run by affecting the use of installed equipment and in the long run by affecting the stock of installed equipment.

Legislated efficiency standards also affect energy use, by imposing a minimum level of efficiency for purchases of several types of equipment used in the commercial sector. Two mandates currently affect commercial appliances: the National Energy Policy Act of 1992 (P.L. 102-486, Title II, Subtitle C, Section 342), which specifically targets larger-scale commercial equipment and fluorescent lighting, and the National Appliance Energy Conservation Amendments (NAECA), which affect commercial buildings that install smaller residential-style equipment. Examples include standards for heat pumps, air conditioning units, boilers, furnaces, water heating equipment, and fluorescent lighting.

Effects of Technology Availability and Choice

The degree to which energy-efficient equipment can affect energy consumption, and in turn carbon emissions, in the commercial sector is limited by the level of efficiency available to commercial consumers and the rate at which more efficient equipment is purchased. Technologies for all the major end uses (lighting, heating, cooling, water heating, etc.) are defined by their installed cost, operating cost, efficiency, average useful life, and first and last dates of availability. These parameters are considered, along with fuel prices at the time of purchase, in the selection of technologies that provide end-use services. Commercial consumers are not assumed to anticipate any future changes in fuel prices when choosing equipment. The commercial sector encompasses a wide variety of buildings, and not all consumers will have the same requirements and priorities when purchasing equipment. Major assumptions that take these differences in behavior into account and affect commercial technology choices are described below.

In making the tradeoffs between equipment cost and equipment efficiency, the purchase behavior of the commercial sector is represented by distributing floorspace over a variety of hurdle rates. Rates of return on investments in energy efficiency (referred to in financial parlance as "internal rates of return") are required to meet or exceed the hurdle rate. Floorspace is distributed over hurdle rates that range from a low of about 18 percent to rates high enough to cause choices to be made solely by

³⁵General characteristics of the commercial sector provided in the above paragraphs are from Energy Information Administration, *A Look at Commercial Buildings in 1995: Characteristics, Energy Consumption, and Energy Expenditures*, DOE/EIA-0318(95) (Washington, DC, September 1998).

minimizing the costs of installed equipment (i.e., future potential energy cost savings are ignored at the highest hurdle rate).³⁶ The distribution of hurdle rates used in all the cases for this analysis is not static: as fuel prices increase, the nonfinancial portion of each hurdle rate in the distribution decreases.³⁷

For a proportion of commercial consumers, it is assumed that newly purchased equipment will use the same fuel as the equipment it replaces. This proportion varies by building type and by type of purchase—whether it is for new construction, to replace worn-out equipment, or to replace equipment that is economically obsolete. Purchases for new construction are assumed to show the greatest flexibility of fuel choice, while purchases for replacement equipment have the least flexibility. For example, when space heating equipment in large office buildings is replaced, 8 percent of the purchasers are assumed to consider all available equipment using any fuel or technology, while 92 percent select only from technologies that use the same fuel as the equipment being replaced. The proportions used are consistent with data from EIA's Commercial Buildings Energy Consumption Survey and from published literature.³⁸ Considerations such as owner versus developer financing, past experience, ease of installation, and fuel availability all play a role in fuel choice. This assumption also accounts for some of the factors that influence technology choices but cannot be measured. For example, a hospital adding a new wing has an economic incentive to use the same fuel that is used in the existing building.

The availability and costs of advanced technologies affect the degree to which they can contribute to future energy savings and carbon emission reductions. Many efficient technologies currently available to commercial consumers could significantly reduce energy consumption; however, their high purchase costs and the current low level of fuel prices have limited their penetration to date. As more advanced technologies mature over time, their costs are expected to decline (compact fluorescent lighting is an example). New technologies, beyond those available today, may also enter the market in the future. For example, the high technology sensitivity case, described below, assumes that by 2005 a triple-effect absorption natural-gas-fired commercial chiller will be widely available, and that "typical" heat pump water heaters will cost 18 percent less than assumed in the reference case.

The combination of technology and behavior assumptions determines the commercial-sector price elasticity for each of the major fuels—that is, how commercial-sector demand projections are affected by changes in energy prices. Specifically, the commercial-sector price elasticity for a particular fuel is the percent change in demand for that fuel in response to a 1-percent change in its delivered price. In the reference case, short-run price elasticities for fuel use in the commercial sector are -0.34 for electricity, -0.39 for natural gas, and -0.39 for distillate fuel oil. Long-term price elasticities in the reference case are higher, reflecting changes in both the use of existing equipment and the adoption rates for more efficient equipment: -0.36 for electricity, -0.44 for natural gas, and -0.45 for distillate fuel oil.³⁹ The similarity of the short-run and long-run elasticities for electricity has two main causes. First, electric equipment becomes more efficient even with the reference case assumptions, thus reducing opportunities for further reductions when prices are higher. For example, electric lighting efficiency in the reference case increases on average by 0.6 percent per year from 1996 through 2020. Electric space cooling and ventilation improve on average by 1.1 and 0.7 percent per year, respectively, over the same period. Second, miscellaneous electric end uses capture a growing share of commercial electricity consumption and exhibit the same response in the long run as in the short run. Building codes, equipment standards, and improvements in technology costs and performance contribute to reduced energy intensity in the commercial sector (i.e., annual energy consumption per square foot of floorspace) even in the absence of price changes. With constant real energy prices, energy intensity declines on average by 0.1 percent per year through 2010.

Carbon Reduction Cases

In the 1990-3% case, commercial sector energy use in 2010 is projected to be below the 1996 level (Figure 38), and carbon emissions attributable to the commercial sector are projected to be 29 percent below their 1990 levels (Figure 39), despite 1-percent annual growth in commercial floorspace from 1996 to 2010. Projected fuel prices in 2010 in the 1990-3% case are more than twice as high as the reference case projection, and they are higher in real terms than they have been in any year since 1980 (Figure 40). As a result, energy consumption in 2010 is 22 percent lower in the 1990-3% case than in the reference

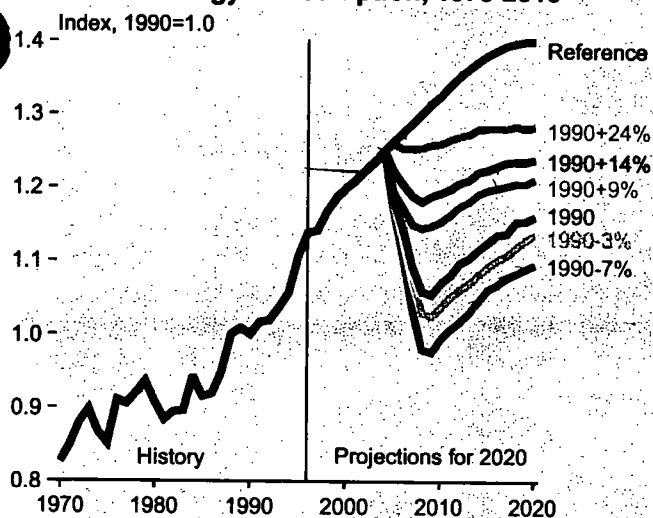
³⁶The hurdle rates consist of both financial and nonfinancial components, as described for the residential sector.

³⁷For the purposes of this study, the financial portion of the hurdle rates is considered to be 15 percent in real terms.

³⁸Current assumptions use an analysis of data from EIA's 1992 commercial buildings survey. Sources for data on consumer behavior are listed on page A-18 of Energy Information Administration, *Model Documentation Report: Commercial Sector Demand Module of the National Energy Modeling System*, DOE/EIA-M066(98) (Washington, DC, January 1998).

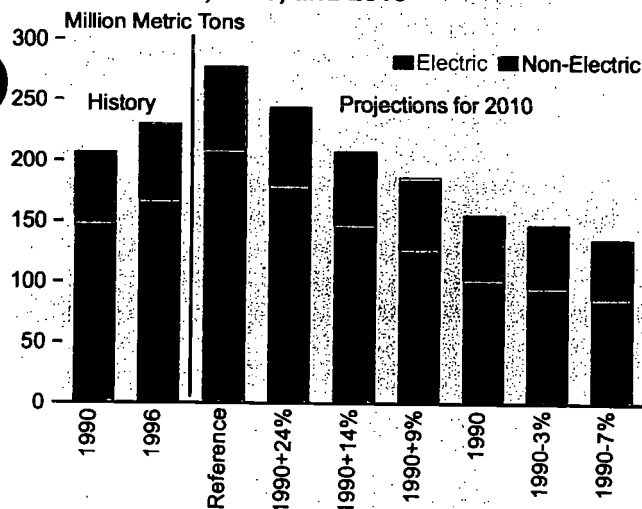
³⁹As in the residential model, the long-run elasticities are for 2020 and represent the effects after 20 years of altered price regimes.

Figure 38. Index of Commercial Sector Delivered Energy Consumption, 1970-2010



Sources: **History:** Energy Information Administration, *State Energy Data Report 1995*, DOE/EIA-0214(95) (Washington, DC, December 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, FD07BLW.D080398B.

Figure 39. Commercial Sector Carbon Emissions, 1990, 1996, and 2010

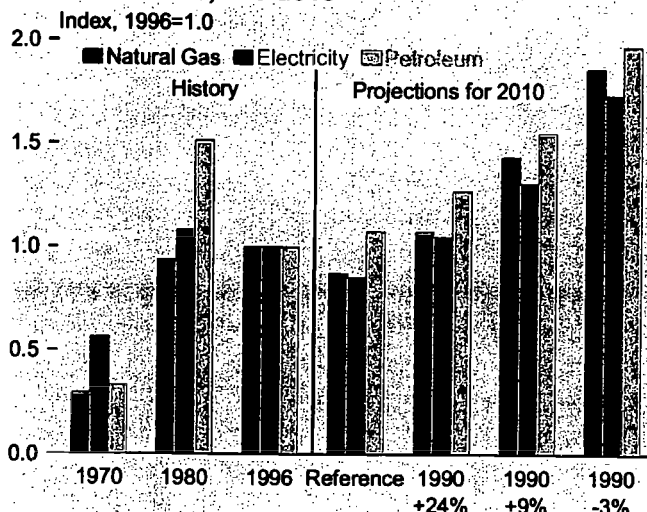


Note: Electricity emissions are from the fossil fuels used to generate the electricity used in this sector.

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, FD07BLW.D080398B.

case, and expenditures for energy purchases are 52 percent higher. Energy consumption starts to increase again later in the 1990-3% case, as demand reductions lead to a decline in fuel prices. Energy consumption in the 1990+24% and 1990+9% cases does not rebound as much, because prices do not fall at the rate seen in the 1990-3% case.

Figure 40. Real Prices for Delivered Energy in the Commercial Sector by Fuel, 1970, 1980, 1996, and 2010

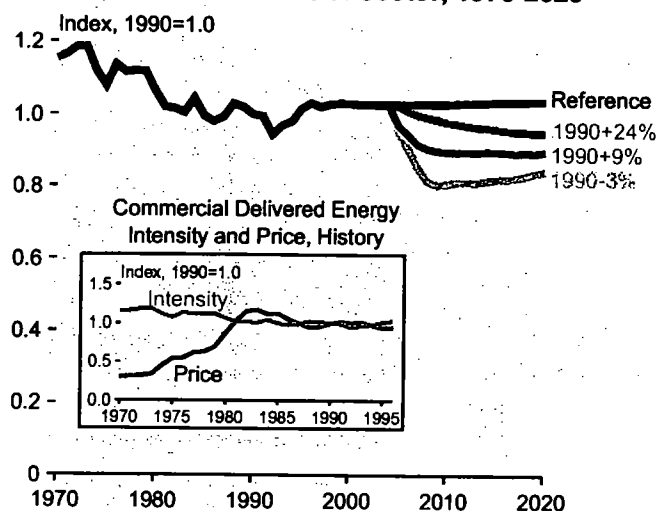


Sources: **History:** Energy Information Administration, *State Energy Price and Expenditure Report 1994*, DOE/EIA-0376(94) (Washington, DC, June 1997). **Projections:** Office of Integrated Analysis and Forecasting, National Energy Modeling System runs KYBASE.D080398A, FD24ABV.D080398B, FD09ABV.D080398B, FD03BLW.D080398B.

Floorspace expansion in the commercial sector will lead to growth in energy consumption if other factors remain the same. Figure 41 removes the effects of floorspace growth by presenting commercial energy intensity in terms of delivered energy consumption per square foot of commercial floorspace. Although total energy consumption continued to increase when energy prices were rising from 1970 through 1982, commercial energy intensity declined by about 12 percent. Delivered energy intensity in the reference case is projected to remain essentially flat throughout the forecast. Projected commercial sector growth is offset by the availability and continued development of energy-efficient technologies, existing equipment efficiency standards, and voluntary programs such as those for the Climate Change Action Plan. In the carbon reduction cases, with higher energy prices, the energy intensities projected for 2010 are below the 1996 level. The projections for commercial delivered energy intensity in 2010 in the 1990+24%, 1990+9%, and 1990-3% cases are 5 percent, 13 percent, and 21 percent below the reference case projection, respectively.

When energy prices rise, consumers are expected to reduce energy use by purchasing more efficient equipment and by altering the way they use energy-consuming equipment. In addition to buying more efficient boilers and chillers, commercial customers in the 1990-3% case are expected to choose more heat pumps, heat pump water heaters, and efficient lighting technologies than they would in the reference case (Table 6). The same trends toward purchasing efficient technologies and monitoring energy use are projected in the 1990+9% case and in the 1990+24% case, but to a lesser degree than projected for the 1990-3% case.

Figure 41. Index of Delivered Energy Intensity in the Commercial Sector, 1970-2020



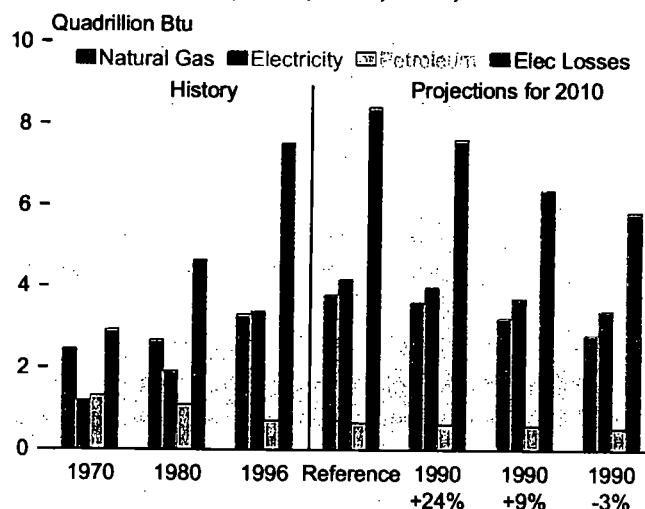
Sources: **History:** Energy Information Administration (EIA), *State Energy Data Report 1995*, DOE/EIA-0214(95) (Washington, DC, December 1997); EIA, *State Energy Price and Expenditure Report 1994*, DOE/EIA-0376(94) (Washington, DC, June 1997); and EIA, *Commercial Buildings Energy Consumption Survey 1992 Public Use Data*. **Projections:** Office of Integrated Analysis and Forecasting, National Energy Modeling System runs KYBASE.D080398A, FD24ABV.D080398B, FD09ABV.D080398B, FD03BLW.D080398B.

The adoption of more efficient technologies reflects the reaction to rising fuel prices and a change in the way commercial consumers are expected to look at purchase decisions involving energy efficiency if carbon emissions are severely limited. Most commercial consumers give some consideration to fuel costs when buying equipment. A significant increase in fuel prices is expected to cause consumers to give energy costs greater weight in the purchase decision, by seeking out more information about energy efficiency options and by accepting a longer time period to recoup the additional initial investment typically required to obtain greater energy efficiency. While taking client comfort and employees' working conditions into consideration, commercial energy consumers would also be expected to turn thermostats down (up) a few degrees during cooler (warmer) weather and to be more conscientious about turning off lights and office equipment not in use.

The vast majority of the projected commercial sector reductions in carbon emissions in the carbon reduction cases are related to electricity use (see Figure 39). Two factors contribute to electricity-related carbon savings: reductions in the level of carbon emitted during the generation of a given amount of electricity (as discussed in Chapter 4), and reductions in electricity consumption. The projections for delivered electricity consumption in the commercial sector in 2010 for the 1990-3% and 1990+9% cases are 19 percent and 12 percent lower, respectively, than the reference case projection (Figure 42), and the 1990+24% case is 5 percent lower.

Historically, steady growth in electricity consumption has been seen in the commercial sector during times of both rising and falling prices. The growth has resulted in part from expansion in the sector and, more importantly, from an increasing number of end uses for electricity (i.e., increasing electricity intensity). The reference case projects further growth in electricity use between 1996 and 2010. In the 1990-3% case, however,

Figure 42. Delivered Energy Use and Electricity-Related Losses in the Commercial Sector, 1970, 1980, 1996, and 2010



Sources: **History:** Energy Information Administration, *State Energy Data Report 1995*, DOE/EIA-0214(95) (Washington, DC, December 1997). **Projections:** Office of Integrated Analysis and Forecasting, National Energy Modeling System runs KYBASE.D080398A, FD24ABV.D080398B, FD09ABV.D080398B, FD03BLW.D080398B.

Table 6. Change in Projected Penetration Rates for Selected Technologies in the Commercial Sector Relative to the Reference Case, 2010 (Percent)

Technology	1990+24%	1990+9%	1990-3%
High-Efficiency Boiler	19	97	205
Air-Source Heat Pump	2	9	10
Ground-Source Heat Pump	0	27	150
High-Efficiency Chiller	4	18	23
Heat Pump Water Heater	29	102	167
Compact Fluorescent Lights	6	14	24
Electronic Ballast Fluorescent Lights With Reflectors or Controls	14	26	32

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

the electricity consumption projected for 2010 falls to 1996 levels. The growth in commercial sector electricity intensity is projected to slow in the reference case for the same reasons that apply to energy intensity, and further reductions are expected in the carbon reduction cases.

The projected share of total end-use energy services that each major fuel provides to the commercial sector in 2010 is fairly stable across the different carbon reduction cases, and each fuel's share of energy consumption within specific end uses (space heating, cooling, water heating, etc.) shows little change. Electricity does increase slightly in share, however—up to 2 percentage points in 2010 in the 1990-3% and 7-percent-below-1990 (1990-7%) cases relative to the reference case.

Because the carbon prices required to meet emissions reduction targets cause a greater percentage increase in natural gas prices than electricity prices relative to those in the reference case, commercial consumers are expected to curtail their use of equipment powered by natural gas more than their use of electrical equipment. In addition, because of its critical nature, the usage pattern of existing commercial refrigeration equipment is not assumed to change in response to price changes, limiting projected reductions in electricity use for refrigeration to those caused by potential earlier retirements and purchases of more efficient equipment when prices are higher.

Finally, the fastest-growing commercial end uses, under reference case assumptions, include office equipment and miscellaneous devices powered by electricity (e.g., telecommunications equipment, medical imaging equipment, ATM machines), which are continuing to penetrate the commercial sector. Although electricity consumption for these end uses would be responsive to the price signals resulting from emissions reduction efforts, their growth still is expected to be faster than growth in the end uses that consume fossil fuels (primarily space heating and water heating).

The expected effects of carbon emission reduction efforts on the average efficiencies of equipment stocks in the commercial sector are exemplified by the projections for natural-gas-fired space heating equipment. In the reference case, the average efficiency of natural gas space heating systems in the commercial sector is projected to increase by 0.6 percent per year through 2010, and gas heating equipment purchased in 2005 is projected to be about 6.4 percent more efficient than the average system in use at that time. The 1990+24% case projects the same level of efficiency improvement and purchased efficiency. With 2010 natural gas prices expected to be near 1996 levels in this case (see Figure 40), there is little incentive for purchasers to invest

additional capital in more efficient gas heating systems. In the 1990+9% case, however, the projected higher gas prices yield a projected 0.7-percent annual increase in average stock efficiency and an average efficiency for new equipment purchases in 2005 that is 7.2 percent higher than the stock average. Similarly, in the 1990-3% case, the average stock efficiency for gas heaters in the commercial sector increases by 0.8 percent per year, and new gas heating systems are 7.5 percent more efficient, on average, than the stock average in 2005. Heating systems typically are purchased only for new construction, for major renovations, or when an existing system needs to be replaced. Once in place, they typically last over 20 years. Therefore, the energy savings realized from purchases of more efficient equipment take time to accumulate.

Sensitivity Cases

Sensitivity case assumptions were developed for the 1990+9% case, to examine uncertainties about technology development in the commercial sector. Similar assumptions were developed for each of the demand sectors, and results were derived from integrated model runs requiring the entire U.S. energy system, not the commercial demand sector individually, to meet the specified emission reduction goals. Much different results might be expected if only commercial sector assumptions were modified and/or only the commercial sector was required to meet a specific emissions target, independent from other demand sectors and utilities.

The low technology sensitivity case assumes that all future equipment purchases will be made only from the equipment available to commercial consumers in 1998, and that commercial building shell efficiencies will remain at 1998 levels. Alternatively, the high technology sensitivity assumptions were developed by engineering technology experts, considering the potential impact on technology given increased research and development into more advanced technologies.⁴⁰ The high technology sensitivity case includes technologies with higher efficiencies and/or lower costs than those assumed to be available in the reference case.

The projected carbon prices and fuel prices in the different sensitivity cases (Table 7) reflect the possible impacts that changes in the level of technological progress, across all sectors, may have on the fuel costs required for the United States to meet a specific emissions level. Different actions expected in the residential, commercial, industrial, transportation, and electricity generation sectors all contribute to meeting the emissions target. The combination of these actions results in the projected carbon prices, as each sector is

⁴⁰Energy Information Administration, *Technology Forecast Updates—Residential and Commercial Building Technologies*, Draft Report (Arthur D. Little, Inc., June 1998).

Photovoltaics and Fuel Cells

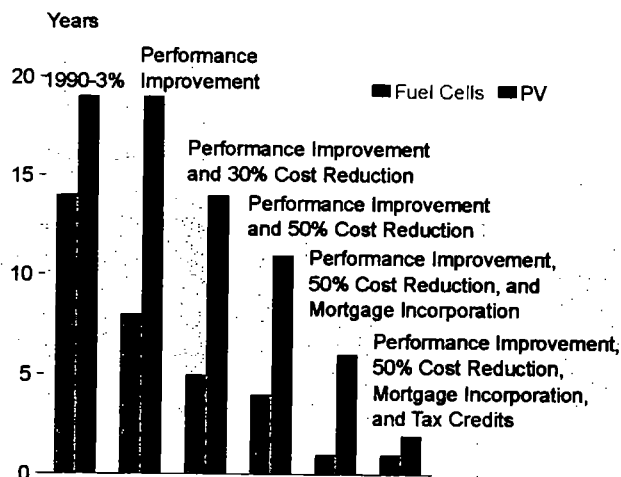
In every carbon reduction case considered in this report, neither photovoltaics nor fuel cells are projected to gain significant market penetration, because of their high costs. With payback periods of more than 20 years, the success of these technologies seems largely dependent on reducing production costs and increasing efficiency (which would result in further cost reductions for the consumer). Federal financial assistance would also play a role in their success.

Currently, electricity from photovoltaics and fuel cells is approximately 1.4 to 5.8 times the price to consumers of electricity from utility grids. Average prices in 1998 were 79 mills per kilowatt for utility power, 112 mills for phosphoric acid fuel cells (with no cogeneration), and 461 mills for photovoltaic systems. To increase the market penetration rates of the alternative technologies, their costs would have to be more competitive.

Photovoltaic and fuel cell technologies are examined here on the basis of their potential for further market penetration in 2010 for the 1990-3% case and in sensitivity cases assuming cost reductions (30 to 50 percent), performance improvements (50 percent for fuel cells and 70 percent for photovoltaics), and Federal subsidies and credits. Payback periods are calculated for the regions where these technologies are most likely to penetrate.

The effects of various private and government-assisted financing plans, such as rolling the cost of the alternative technology into a mortgage plan, tax credits, and depreciation, are summarized in the chart below. The first pair of bars shows the projected payback periods in 2010 for the 1990-3% case with current technology performance and costs. The other projections incorporate performance improvements of 50 percent for fuel cells and 70 percent for photovoltaics, as well as the cumulative effects of various methods for reducing the payback periods. The second set of bars shows the effects of the assumed performance improvement. The third includes a 30-percent production cost reduction, the fourth includes a

Projected Payback Periods for Photovoltaic and Fuel Cell Purchases Under Different Assumptions, 2010



Source: Energy Information Administration, Office of Integrated Analysis and Forecasting.

50-percent cost reduction, the fifth includes the incorporation of capital costs into a mortgage plan, and the sixth includes a tax credit for photovoltaics and depreciation adjustments for businesses. It is important to note that the substantial cost reductions and improvements in efficiency (50 percent for fuel cells, 70 percent for photovoltaics) are merely arbitrary assumptions and are not calculated projections for future costs and efficiencies. These assumptions are not included in the carbon reduction cases or sensitivity cases presented in this report.

Under the most favorable assumptions shown in the graph, payback periods could be reduced to less than 1 year for fuel cells and 2 years for photovoltaics. Although penetration levels are hard to predict from payback periods, it can generally be assumed for the commercial and residential sectors that paybacks within 3 to 4 years would be needed for significant penetration. In the National Appliance Energy Conservation Act, the Federal efficiency payback standard for appliances is 3 years or less for investments to be non-burdensome to the consumer. Although some utilities may have payback periods on their plants of 20 years, building consumers are more likely to spend their money for efficient technologies elsewhere if payback periods are over 4 years. To achieve 3- to 4-year paybacks, both the current performance and the costs of these alternatives would have to be improved by the levels shown here; however, the likelihood of such substantial improvements in the next two decades is small.

Production costs for photovoltaic modules have fallen from \$100 per watt to \$4 per watt over the past three decades, an 11-percent annual decline, but since 1990 they have declined by an annual average of only 3.9 percent.^a To meet the cost reduction assumptions in these scenarios, the production costs for photovoltaic cells and modules would have to decline at an average annual rate of 5.6 percent through 2010.

The energy production efficiency of photovoltaic modules has also improved, to approximately 12 percent today from 9 percent in 1980.^b Reaching the goal of 70 percent improvement in performance, as assumed for this sensitivity analysis, would require an efficiency level of 20 percent in 2010. Since 1980, the rate of improvement in performance for photovoltaics has been less than 2 percent annually, whereas a 4.3-percent annual rate would be needed to achieve a 70-percent improvement by 2010, and that improvement would also have to be accompanied by cost improvements to achieve a 3- to 4-year payback period. Fuel cells have been on the market for only a short time, and historical information is not available. Neither technology appears to be on course to accomplish such a goal during the period of this analysis, however, and thus extensive market penetration is not probable for either photovoltaics or fuel cells.

^aEnergy Information Administration, *Solar Collector Manufacturing Activity 1991*, DOE/EIA-0174(91), p. 18; and P. Maycock, "Photovoltaic Energy Conversion: PV Technology, Cost, Products, Markets, and Systems—Forecast 2010," ASES Conference (Albuquerque, NM, June 1998).

^bPaul Maycock, PV Energy, personal communication, August 1998.

Table 7. Projected Carbon Prices and Average Fuel Prices for the Commercial Sector in Technology Sensitivity Cases, 2010

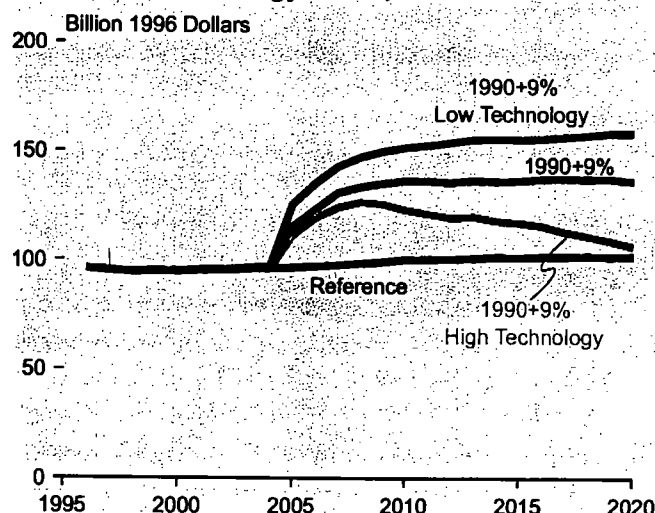
Analysis Case	Carbon Price (1996 Dollars per Metric Ton)	Average Fuel Price (1996 Dollars per Million Btu)
Reference	—	11.51
1990+9%	163	17.99
1990+9% Low Technology	243	21.66
1990+9% High Technology	121	15.75

Source: Office of Integrated Analysis and Forecasting, National Energy Modeling System runs KYBASE.D080398A, FREEZE09.D080798A, FD09ABV.D080398B, and HITECH09.D080698A.

expected to reduce demand in a way suitable to that particular sector.

Among the technology cases the highest carbon prices, and thus the highest fuel prices, in 2010 are projected in the 1990+9% low technology sensitivity case. Due to the lack of technological progress in all sectors, higher fuel prices are required to achieve the demand reductions needed to reach the emissions target. The projected price of fuel to the commercial sector is 20 percent higher in the low technology case than in the 1990+9% case, resulting in 7 percent less commercial energy use. Commercial expenditures for fuel are also expected to be highest under these conditions (Figure 43). Fewer options for increased efficiency limit the potential for energy savings in the low technology case. The average efficiency of the equipment stock in this case continues to improve as normal turnover takes place and older equipment is replaced, but the most energy-efficient equipment available for purchase in 2010 or 2020 is what is available today (Table 8).

Figure 43. Projected Fuel Expenditures in the Commercial Sector in Low and High Technology Cases, 1996-2020



Source: Office of Integrated Analysis and Forecasting, National Energy Modeling System runs KYBASE.D080398A, FREEZE09.D080798A, FD09ABV.D080398B, and HITECH09.D080698A.

In the 1990+9% high technology sensitivity case, advanced technologies are expected to penetrate the market in all sectors over time as normal stock turnover results in the replacement of older, less efficient equipment. Projected technological advances throughout the energy market result in a carbon price in 2010 that is 25 percent lower than that projected in the 1990+9% case (see Table 7). In turn, the expected commercial fuel price in 2010 is 12 percent lower than in the 1990+9% case, resulting in 4 percent more energy consumption. Even though more advanced technologies are available in the high technology case, with less price incentive, commercial consumers are not as likely to purchase more costly equipment. For technologies such as commercial natural gas water heaters, where high

Table 8. Projected Highest Available and Average Efficiencies for Newly Purchased Equipment in the Commercial Sector, 2015

Technology	1998	1990+9% Low Technology	1990+9%	1990+9% High Technology
Highest Available Efficiency^a				
Air-Source Heat Pump	2.70	2.70	2.93	3.22
Natural Gas Chillers and Air Conditioners	3.52	3.52	3.81	4.40
Heat Pump Water Heater	2.00	2.00	2.50	2.80
Natural Gas Water Heater	0.91	0.91	0.91	0.91
Average Purchased Efficiency^a				
Electric Space Heating	1.10	1.13	1.13	1.11
Natural Gas Space Cooling	1.32	1.73	1.62	1.59
Electric Water Heating	0.95	1.03	1.00	0.98
Natural Gas Water Heating	0.79	0.82	0.82	0.84

^aThe efficiencies shown (Btu of output divided by Btu of input) generally are seasonal efficiencies or include some measure of losses incurred during normal use.

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

technology assumptions specify lower costs in 2015 for the most efficient equipment, as compared with the reference case technology assumptions, more consumers are expected to adopt the efficient technology (see Table 8). The projected reduction in energy demand in other sectors causes commercial fuel prices to decline in the later years of the forecast, lowering commercial expenditures for fuel (Figure 43).

Industrial Demand

Background

The industrial sector includes agriculture, mining, construction, and manufacturing activities. The sector consumes energy as an input to processes that produce the goods that are familiar to consumers, such as cars and computers. The industrial sector also produces a wide range of basic materials, such as cement and steel, that are used to produce goods for final consumption. Energy is an especially important input to the production processes of industries that produce basic materials. Typically, the industries that are energy-intensive are also capital-intensive. Industries within the sector compete among themselves and with foreign producers for sales to consumers. Consequently, variations in input prices can have significant competitive impacts. The most significant determinant of industrial energy consumption is demand for final output.

Although energy is an important factor of production, it is not large in terms of annual manufacturing expenditures. In 1995, for example, purchased energy expenditures were 2.3 percent of annual manufacturing outlays.⁴¹ Technology usually plays a minor role in the pattern of energy consumption, because technology tends to be used to produce new and improved final products rather than to reduce energy consumption; however, when new investments are undertaken to introduce improved production technology, steps to increase energy efficiency also are undertaken. Overall, energy prices and technological breakthroughs tend to have a rather small impact on industrial energy consumption.⁴²

The influence of energy prices on industrial energy consumption is modeled in terms of the efficiency of use of existing capital, the efficiency of new capital additions, and the mix of fuels used. This analysis uses "technology bundles" to characterize technological change in the energy-intensive industries. This approach is dictated by the number and complexity of processes used in the industrial sector and the absence of systematic cost and performance data for the components. These bundles are defined for each production process step (e.g., coke ovens) for five of the industries and for end use (e.g., refrigeration) in two of the industries. The process-step industries in the NEMS model are pulp and paper, glass, cement, steel, and aluminum.⁴³ The industries for which technology bundles are defined by end use are food and bulk chemicals.

The rate at which the average industrial energy intensity declines is determined primarily by the rate and timing of additions to manufacturing capacity. The rate and timing of additions are functions of retirement rates and industry growth rates. Typical retirement rates range from 1 percent to 3 percent annually. The current model also allows retirement rates and the energy intensity of new additions to vary as a function of price. Price elasticity of demand, which indicates the responsiveness of energy consumption to changes in energy prices, is not an explicit assumption in the model; however, the typical 20-year price elasticity ranges between -0.2 and -0.3, which indicates that a 1-percent price increase would reduce demand by 0.2 to 0.3 percent. Because the reference case approximates a constant price regime, the reference case results do not differ greatly from a situation in which all prices are held constant.

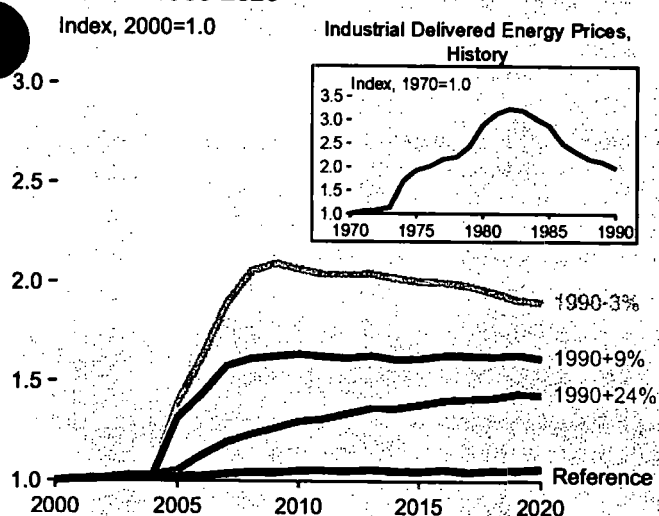
In 1996, the industrial sector's consumption of 34.6 quadrillion Btu accounted for more than one-third of all U.S. energy consumption. The associated emissions of 476 million metric tons of carbon accounted for one-third of all U.S. carbon emissions. In 1996, although industrial energy prices were more than 50 percent lower than in 1980 (Figure 44), delivered energy consumption was only 13 percent higher than in 1980. Industrial output increased by more than 30 percent over that period. As a result, energy intensity (thousand Btu consumed per dollar of output) fell by 20 percent.

⁴¹Calculated from U.S. Department of Commerce, *1995 Annual Survey of Manufactures*, pp. 1-7 and 1-36.

⁴²For a variety of views, see Boyd et al., "Separating the Changing Composition of U.S. Manufacturing Production from Energy Efficiency Improvements: A Divisia Index Approach," *The Energy Journal*, Vol. 8, No. 2 (1987); Doblin, "Declining Energy Intensity in the U.S. Manufacturing Sector," *The Energy Journal*, Vol. 9, No. 2 (1988); Howarth, "Energy Use in U.S. Manufacturing: The Impacts of the Energy Shocks on Sectoral Output, Industry Structure, and Energy Intensity," *The Journal of Energy and Development*, Vol. 14, No. 2 (1991); Jacard, Nyober, and Fogwill, "How Big is the Electricity Conservation Potential in Industry?" *The Energy Journal*, Vol. 14, No. 2 (1993); Steinmeyer, "Energy Use in Manufacturing," in Hollander, ed., *The Energy-Environmental Connection* (Island Press, 1992), Chapter 10; and U.S. Department of Energy, *Comprehensive National Energy Strategy* (Washington, DC, April 1998), pp. 13-14.

⁴³The refining industry is modeled separately in the Petroleum Market Module of NEMS.

Figure 44. Index of Industrial Sector Energy Prices, 2000-2020



Sources: History: Energy Information Administration, *State Energy Price and Expenditure Report 1993*; DOE/EIA-0376(93) (Washington, DC, December 1995). Projections: Office of Integrated Analysis and Forecasting, National Energy Modeling System runs KYBASE.D080398A, FD24ABV.D080398B, FD09ABV.D080398B, and FD03BLW.D080398B.

Most of the drop in energy intensity in the U.S. industrial sector occurred between 1980 and 1985, when prices for both energy and capital inputs were rising and the ability of U.S. manufacturers to compete internationally was deteriorating. The recessions of 1980 and 1981-1982 forced many less efficient plants to close, many permanently. Particularly hard hit were the primary metals industries and motor vehicle manufacturing. Output of the U.S. steel industry has never recovered to the levels of the late 1970s. Manufacturing profits did not return to the levels attained in 1981 until 1988.⁴⁴ Energy prices certainly played a role in shaping these changes in the industrial sector, but general economic conditions, recession, record high interest rates, and reduced ability of key industries to compete in international markets were more important determinants of change.⁴⁵

In the reference case, industrial energy prices are projected to increase very slightly or fall through 2010. For example, the price of natural gas is projected to increase by 0.5 percent, and the price of electricity is projected to fall by 16 percent. From 1996 to 2010, industrial output is projected to grow by 39 percent and energy consumption by only 16 percent. Industrial intensity falls by 17 percent during the same period, approximating the intensity decline between 1980 and 1996. The factors that are expected to produce the rapid decline in industrial energy intensity despite moderate changes in energy

prices include a relative shift from energy-intensive to less energy-intensive industries; replacement of existing equipment with less energy-intensive equipment as existing capacity is retired; adoption of improved and less energy-intensive technologies; and the pressures of international competition.

Carbon Reduction Cases

In the carbon reduction cases, the combined effect of reduced demand for U.S. industrial output and higher energy prices produces lower energy consumption than in the reference case. Compared with the reference case in 2010, industrial output is \$69 billion (1 percent) lower in the 1990+24% case, \$157 billion (3 percent) lower in the 1990+9% case, and \$308 billion (6 percent) lower in the 1990-3% case (see Table 29 in Chapter 6).

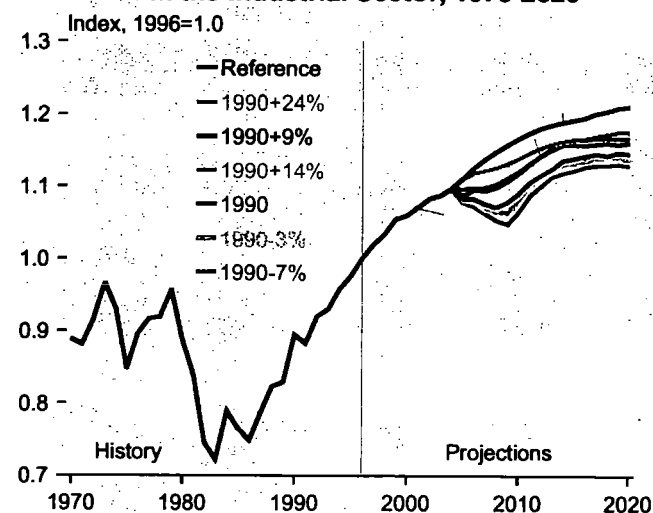
Compared with the reference case, average energy prices in the industrial sector in 2010 are projected to be 22 percent higher in the 1990+24% case, 55 percent higher in the 1990+9% case, and 95 percent higher in the 1990-3% case. In comparison, the industrial sector's average energy price increased by almost 189 percent from 1970 to 1980. Prices of all fuels are projected to be higher in the carbon reduction cases, with coal prices 135 percent higher than the reference case in 2010 in the 1990+24% case and natural gas prices 33 percent higher. The projected price increase for coal is attributable solely to the projected carbon price, whereas the carbon price and higher demand contribute about equally to the increase for natural gas. In the 1990+9% case, natural gas and coal prices are projected to be 93 percent and 328 percent higher, respectively, than in the reference case, and in the 1990-3% case they are 162 percent and 589 percent higher.

Lower projections of industrial output and higher projected energy prices reduce the projections for delivered energy consumption in the industrial sector by 0.7 quadrillion Btu (2 percent) in the 1990+24% case, by 1.3 quadrillion Btu (4 percent) in the 1990+9% case, and by 2.3 quadrillion Btu (7 percent) in the 1990-3% case in 2010 relative to the reference case (Figure 45). In the 1970-1980 period, industrial consumption was unchanged even though prices increased by 189 percent. Year-to-year industrial energy consumption began to fall in 1980, and the decline accelerated when general economic conditions began to deteriorate during the 1980 and 1981-1982 recessions. Energy consumption reached its minimum in 1983, even though prices had begun to decline. These events reinforce the concept that while energy prices do play a role in industrial energy

⁴⁴Council of the Economic Advisers, *Economic Report of the President* (Washington, DC, February 1995), p. 381.

⁴⁵For example, see Boyd and Karlson, "Impact of Energy Prices on Technology Choice in the U.S. Steel Industry," *The Energy Journal*, Vol. 14, No. 2 (1993). More general discussion can be found in Berndt and Wood, "Energy Price Shocks and Productivity Growth: A Survey," in Gordon et al., eds., *Energy: Markets and Regulation* (Cambridge, MA: MIT Press, 1987); and Berndt, "Energy Use, Technical Progress and Productivity Growth: A Survey of Economic Issues," *Journal of Productivity Analysis*, Vol. 2 (1990).

Figure 45. Index of Delivered Energy Consumption in the Industrial Sector, 1970-2020



Sources: **History:** Energy Information Administration, *State Energy Data Report 1995*, DOE/EIA-0214(96) (Washington, DC, December 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.

consumption, general and industry-specific economic conditions also play an important role.

Coal consumption is projected to drop sharply in the carbon reduction cases, given its extreme price disadvantage. In the 1990+24% case, coal consumption in 2010 is lower by 422 trillion Btu (16 percent) than in the reference case; in the 1990+9% case it is 737 trillion Btu (28 percent) lower; and in the 1990-3% case it is about 1 quadrillion Btu (36 percent) lower. The projected reductions in coal consumption are predominantly due to projected reductions in boiler fuel use.

The industrial sector consumes coal mainly as a boiler fuel and for production of coke in the iron and steel industry. For example, 75 percent of manufacturing consumption of steam coal was used in boilers in 1994.⁴⁶ Coal-fired boilers have substantially higher capital costs than do gas-fired boilers, because of their materials handling requirements. For large steam loads, however, coal's price advantage over natural gas offsets its capital cost disadvantage. But in the carbon reduction cases, coal suffers from both a capital cost and a fuel cost disadvantage. As a result, a substantial amount of boiler fuel use switches from coal to natural gas and petroleum products.

The projected reduction in total steam coal consumption in the industrial sector in 2010 (including for uses other than boiler fuel) in the 1990-3% case relative to the reference case is more than 50 percent. Still, the reduction is less severe than that projected for the electric utility

sector. Electricity generators, in addition to switching to natural gas, also have the available options of nuclear power and renewable energy sources.

Consumption of metallurgical coal, which is used to produce coke for iron and steel production, also is reduced sharply in the carbon reduction cases. The reduction has several causes: substitution of natural gas in production processes, replacement of domestic coke production with coke imports, replacement of some coke-based steelmaking capacity with electricity-based capacity, and reduced production of domestic steel.

In the carbon reduction cases, natural gas consumption is subject to two countervailing effects. The effect of generally higher energy prices, and consequent lower levels of industrial activity, is to reduce natural gas consumption. On the other hand, natural gas prices do not increase by as much as the prices of competing fuels. As noted above, this results in relatively greater use of natural gas as a boiler fuel. The carbon reduction cases also induce additional cogeneration using natural gas, which increases natural gas consumption and reduces requirements for other boiler fuels.

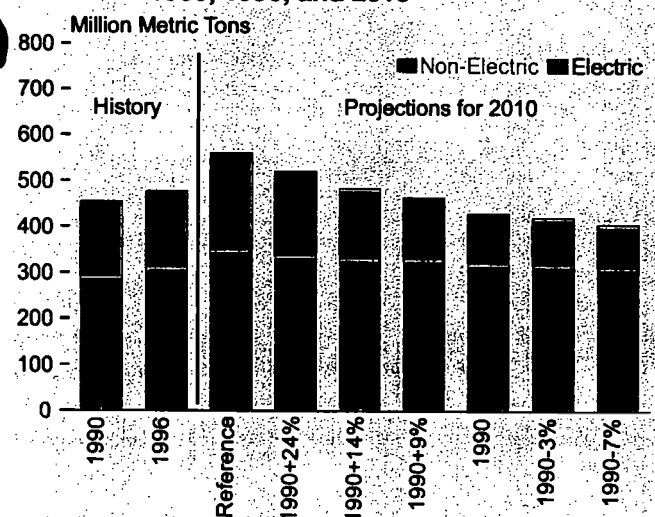
In the 1990+24% and 1990+9% cases, natural gas consumption is projected to increase slightly, because the impact of increased boiler fuel use outweighs the reduction caused by lower industrial output. In the 1990-3% case, natural gas consumption is unchanged from the reference case in 2010. Here, the drop in industrial output and the substitution for other boiler fuels have offsetting effects.

In the reference case, industrial carbon emissions are projected to be 83 million metric tons higher in 2010 than they were in 1996 (Figure 46). Emissions attributable to increased electricity consumption account for more than half the increase. In contrast, electricity-based emissions account for more than 70 percent of the emissions reductions in the carbon cases. For example, in the 1990+9% case, electricity-based carbon emissions in 2010 are 79 million metric tons lower than in the reference case. A reduction of 19 million metric tons in carbon emissions from the combustion of fossil fuels brings industrial sector emissions to approximately their 1990 level. Carbon emissions in the 1990-3% case fall to 418 million metric tons, 58 million tons below the 1996 level and 35 million tons below the 1990 level. Again, electricity-based emissions account for three-fourths of the reduction from projected levels in the reference case.

Part of the reduction in electricity-based carbon emissions for the industrial sector is due to lower electricity consumption in the carbon reduction cases

⁴⁶Energy Information Administration, *Manufacturing Consumption of Energy 1994*, DOE/EIA-0512(94) (Washington, DC, December 1997), p. 168.

Figure 46. Industrial Sector Carbon Emissions, 1990, 1996, and 2010



Note: Electricity emissions are from the fossil fuels used to generate the electricity used in this sector.

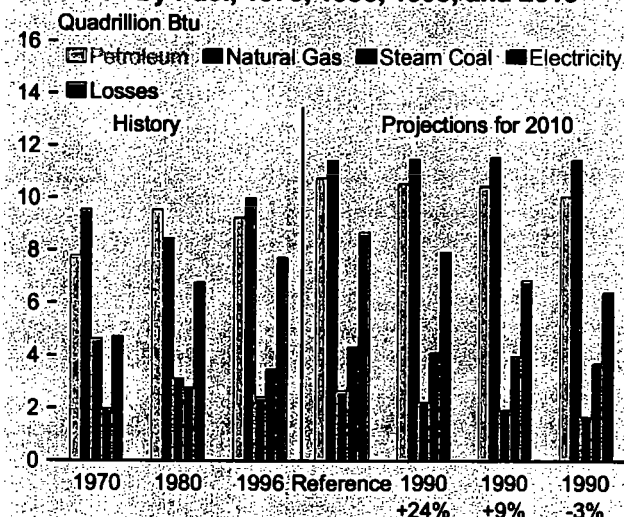
Sources: History: Energy Information Administration, *Emissions of Greenhouse Gases in the United States 1996*, DOE/EIA-0573(96) (Washington, DC, October 1997). Projections: Office of Integrated Analysis and Forecasting, National Energy Modeling System runs KYBASE.D080398A, FD24ABV.D080398B, FD1998.D080398B,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

(Figure 47). A larger part of the reduction results from sharply lower carbon intensity of electricity production. In the reference case, approximately 16.5 million metric tons of carbon are emitted in the production of 1 quadrillion Btu of delivered electrical energy, as compared with only 12.6 million metric tons in the 1990+9% case and only 10.2 million metric tons in the 1990-3% case (38 percent less than in the reference case).

Industrial energy intensity fell by 17 percent between 1980 and 1996. In 1996, approximately 7,100 Btu of energy was required to produce a dollar's worth of industrial output. In the reference case energy intensity continues to fall, and in 2010 it is projected that only 5,900 Btu will be required for each dollar of industrial output. The impact of the carbon reduction cases on industrial energy intensity results from opposing effects. The effect of higher energy prices is to reduce energy intensity, whereas reduced or falling output growth limits the amount of new, less energy-intensive capital equipment that will be added to the existing stock, thereby retarding the rate of decline in energy intensity. Additional structural shifts in the composition of industrial output further reduce energy intensity. (Fuel switching contributes to reduced carbon but does not affect energy intensity.)

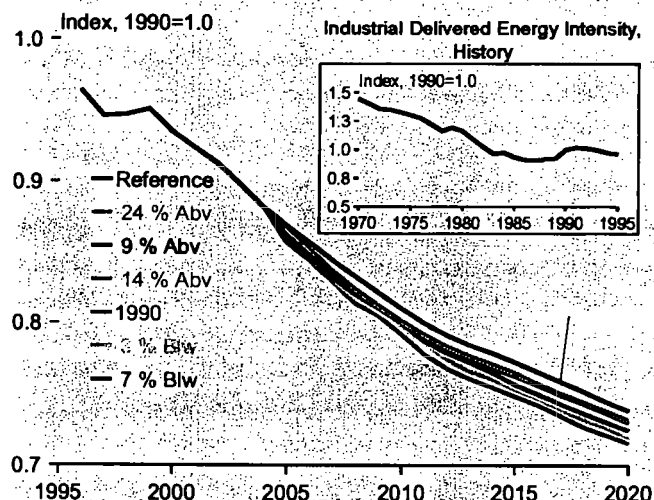
The projected rate of decline in industrial energy intensity is smaller in the more stringent carbon reduction cases (Figure 48). Some process steps in the energy-intensive industries approach the minimum level of energy intensity assumed to be practically achievable. In addition, in the more stringent carbon reduction cases, industrial output is more severely

Figure 47. Industrial Sector Energy Consumption by Fuel, 1970, 1980, 1996, and 2010



Sources: History: Energy Information Administration, *State Energy Data Report 1995*, DOE/EIA-0214(96) (Washington, DC, December 1997). Projections: Office of Integrated Analysis and Forecasting, National Energy Modeling System runs KYBASE.D080398A, FD24ABV.D080398B, FD09ABV.D080398B, and FD03BLW.D080398B.

Figure 48. Projected Energy Intensity in the Industrial Sector, 1995-2020

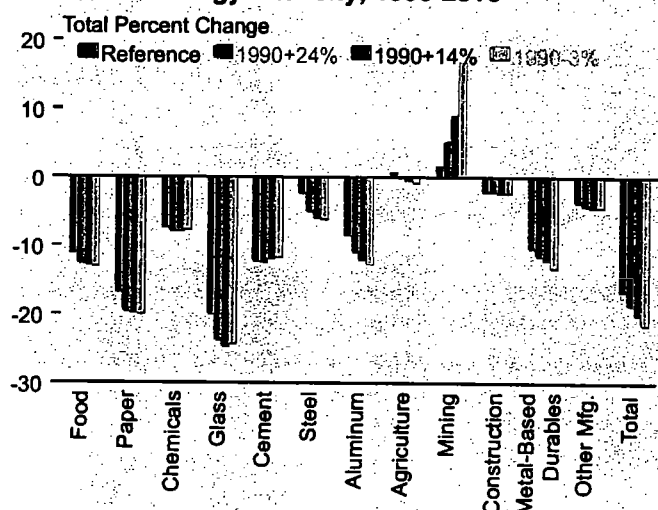


Sources: History: Consumption: Energy Information Administration, *State Energy Data Report 1995*, DOE/EIA-0214(96) (Washington, DC, December 1997). Output: Constructed by Standard & Poor's DRI from U.S. Department of Commerce, "Benchmark Input-Output Accounts for the U.S. Economy, 1992: Make, Use, and Supplementary Tables," Survey of Current Business, November 1997, and predecessor benchmark tables. 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.

reduced, resulting in smaller incentives for the addition of new, less energy-intensive capital equipment. The changes in energy intensity for the industrial subsectors (Figure 49) indicate that slower growth in output can lead to less pronounced declines in energy intensity in the more stringent carbon reduction cases.

The change in aggregate industrial energy intensity can be decomposed into two effects. One is the change in energy intensity that results from a change in the composition of industrial output. For example, if the

Figure 49. Projected Change in Industrial Sector Energy Intensity, 1996-2010

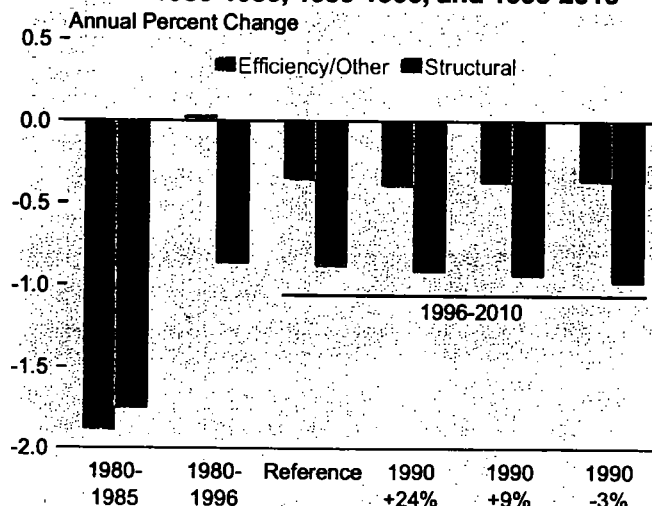


Source: Office of Integrated Analysis and Forecasting, National Energy Modeling System runs KYBASE.D080398A, FD24ABV.D080398B, FD09ABV.D080398B, and FD03BLW.D080398B.

output of the most energy-intensive industries grows more slowly than other parts of the industrial sector, aggregate energy intensity will fall even though no individual industry's energy intensity has changed. This is the "structural" effect. The other is increased energy efficiency and shifts toward less energy-intensive products in individual industries (the "efficiency/other" effect). The relative contributions of these two effects to the reduction in aggregate industrial intensity have varied substantially over time (Figure 50).⁴⁷ For example, between 1980 and 1985, when aggregate industrial intensity fell by 3.6 percent annually, the structural and efficiency/other effects made equal contributions to the decline. Over a longer period, from 1980 to 1996, the structural effects dominated the reduction in aggregate industrial energy intensity. Similarly, in the projections, the structural and efficiency/other effects can be decomposed. About two-thirds of the projected reduction in aggregate industrial intensity is attributable to the structural effect, which is slightly larger in the carbon reduction cases than in the reference case.

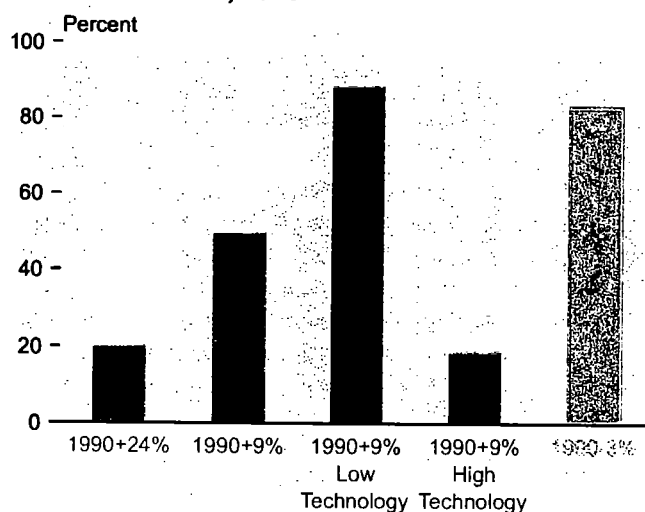
Total expenditures for energy purchases in the industrial sector are projected to be \$121 billion in 2010 in the reference case. In the carbon reduction cases, the effects of higher energy prices are reduced by fuel switching and reduced consumption. Nevertheless, energy expenditures in 2010 are projected to be \$24 billion (20 percent) higher in the 1990+24% case and \$60 billion (50 percent) higher in the 1990+9% case than in the reference case,

Figure 50. Structural and Efficiency/Other Effects on Industrial Energy Intensity, 1980-1985, 1980-1996, and 1996-2010



Sources: **History:** Consumption: U.S. Department of Commerce, National Technical Information Service, National Energy Accounts, PB89-187918 (Springfield, VA, February 1989). Output: Constructed by Standard & Poor's DRI from U.S. Department of Commerce, "Benchmark Input-Output Accounts for the U.S. Economy, 1992: Make, Use, and Supplementary Tables," Survey of Current Business, November 1997; and predecessor benchmark tables. **Projections:** Office of Integrated Analysis and Forecasting, National Energy Modeling System runs KYBASE.D080398A, FD24ABV.D080398B, FD09ABV.D080398B, and FD03BLW.D080398B.

Figure 51. Change From Projected Reference Case Energy Expenditures in the Industrial Sector for Alternative Carbon Reduction Cases, 2010



Source: Office of Integrated Analysis and Forecasting, National Energy Modeling System runs KYBASE.D080398A, FD24ABV.D080398B, FD09ABV.D080398B, FREEZE09.D080798A, HITECH09.D080698A, and FD03BLW.D080398B.

and in the 1990-3% case they are projected to be even higher—\$101 billion (83 percent) higher than in the reference case at \$222 billion (Figure 51).

⁴⁷ The decomposition is done with the Divisia index. For an explanation of the calculation of the index, see Boyd et al., "Separating the Changing Composition of U.S. Manufacturing Production from Energy Efficiency Improvements: A Divisia Index Approach," *The Energy Journal*, Vol. 8, No. 2 (1987). Alternative decomposition methods are discussed in Greening et al., "Comparison of Six Decomposition Methods: Application of Aggregate Energy Intensity for Manufacturing in Ten OECD Countries," *Energy Economics*, Vol. 19 (1997). Note that using different time periods or subsector aggregations may also yield different results.

Sensitivity Cases

The projections of industrial sector energy expenditures in the carbon reduction cases are based on the reference case assumptions about technology improvements and likely industrial response. Expenditures would be much higher if technology improvements occurred at a slower rate than in the reference case. On the other hand, a more optimistic technology outlook would reduce energy expenditures.

To span the technology alternatives, low and high technology sensitivity cases, based on the 1990+9% carbon reduction case, were analyzed. The low technology case

assumes that no additional technology changes (as reflected in energy intensity) will occur after 1998. Normal turnover of capital, however, would result in some decline in energy intensity as old equipment is replaced with currently available equipment with lower energy intensity. The high technology case assumes an aggressive private and Federal commitment to energy-related research and development, which results in successful commercialization of energy-saving technologies.⁴⁸

As noted earlier, the analysis uses technology bundles to characterize technological change in the energy-intensive industries. This approach is illustrated in Table 9. For example, the energy intensity of the

Table 9. Projected Energy Intensities for Industrial Process Steps and End Uses

Industry/Process Step or End Use	1990+9% Low Technology	1990+9%	1990+9% High Technology
Food	1.00	0.89	0.79
Direct Fuel	1.00	0.88	0.79
Hot Water/Steam	1.00	0.89	0.79
Refrigeration	1.00	0.90	0.79
Other Electric	1.00	0.90	0.79
Pulp and Paper	1.00	0.78	0.64
Paper Making	1.00	0.77	0.62
Bleaching	1.00	0.86	0.78
Waste Fiber Pulping	1.00	0.94	0.87
Mechanical Pulping	1.00	0.92	0.96
Semi-Chemical	1.00	0.86	0.91
Kraft, Sulfite, misc.	1.00	0.78	0.61
Wood Preparation	1.00	0.95	0.92
Bulk Chemicals	1.00	0.95	0.85
Electrolytic	1.00	0.91	0.83
Other Electric	1.00	0.90	0.83
Direct Fuel	1.00	0.88	0.83
Steam/Hot Water	1.00	0.89	0.83
Feedstocks	1.00	0.99	0.87
Glass	1.00	0.73	0.59
Post-Forming	1.00	0.91	0.94
Forming	1.00	0.89	0.88
Melting/Refining	1.00	0.63	0.41
Batch Preparation	1.00	0.96	0.99
Cement	1.00	0.85	0.77
Finish Grinding	1.00	0.82	0.72
Dry Process	1.00	0.83	0.66
Wet Process	1.00	0.93	0.97
Steel	1.00	0.81	0.50
Cold Rolling	1.00	0.56	0.33
Hot Rolling	1.00	0.65	0.37
Ingot Casting/Primary Rolling	1.00	1.00	1.00
Continuous Casting	1.00	1.08	1.06
Blast Furnace/Basic Oxygen Furnace	1.00	1.10	0.50
Electric Arc Furnace	1.00	1.00	0.62
Coke Oven	1.00	1.00	0.98
Primary Aluminum	1.00	0.87	0.71

Notes: The energy intensity for the low technology case is defined as 1.0. The 1990+9% case and high technology case energy intensities are dexed against the energy intensity for the low technology case. The intensities are not additive within an industry.

Source: The high technology sensitivity case is based in part on an analysis prepared by Arthur D. Little, Inc., *Aggressive Technology Strategy for the NEMS Model* (1998).

⁴⁸The high technology sensitivity case is based in part on an analysis prepared by Arthur D. Little, Inc., *Aggressive Technology Strategy for the NEMS Model* (1998).

Cogeneration Systems

In every carbon reduction case considered in this report, neither photovoltaics nor fuel cells are projected to gain significant market penetration, because of their high costs. With payback periods of more than 20 years, the success of these technologies seems largely dependent on reducing production costs and increasing efficiency (which would result in further cost reductions for the consumer). Federal financial assistance would also play a role in their success.

A key issue facing power producers and their customers is whether the types of cogeneration systems currently used in the United States will be extended to include district energy systems and advanced turbine systems (ATS). Cogeneration systems, also called combined heat and power systems, simultaneously produce heat in the form of hot air or steam and power in the form of electricity by a single thermodynamic process, usually steam boilers or gas turbines, reducing the energy losses that occur when process steam and electricity are produced independently. Thus, cogeneration systems could play a significant role in reducing U.S. greenhouse gas emissions.

In 1996, electric utilities used more than 21 quadrillion Btu of energy from the combustion of coal, natural gas, and oil to produce the equivalent of only 7 quadrillion Btu of electricity available at the plant gate, representing a conversion loss of 67 percent.^a Consequently, unused waste heat at utility plants accounted for 346 million metric tons or nearly 24 percent of U.S. carbon emissions in 1996. Additional losses on the order of 7 percent are incurred during transmission and distribution of electricity to customers.^b Because cogeneration systems capture and use a significant portion of the waste heat energy, they are nearly twice as efficient as conventional power plants in extracting usable energy. About 6 percent of total U.S. generating capacity includes some type of cogeneration system, in such diverse industries as manufacturing, mining, and refining.^c

Some energy analysts believe that there is even greater potential to increase the penetration of cogeneration systems and reduce carbon emissions by wide-scale construction of district energy systems.^d District energy systems distribute chilled water, steam, or hot water to buildings to provide air conditioning, space heating, domestic hot water, and industrial process energy. About 5,800 district energy systems are installed in the United States, serving more than 8 percent of commercial floor-space—primarily military bases, universities, hospitals, downtown areas, and other group buildings.^d

The greatest growth potential for district energy systems is in the area of utility-financed cooling systems for downtown areas where there is a large amount of commercial floorspace located in a relatively small area; however,

significant hurdles must be overcome if the potential is to be realized. Siting one or more power and steam generators in an area already dense with buildings could prove to be a challenge, as could the installation, maintenance, and repair of lines to carry steam and hot or chilled water supplies in cities with under-street congestion of existing gas, water, sewage, and electricity lines. Also, construction costs for district energy systems are about one-third higher than those for conventional generating technologies.

Although it is possible that fuel cost savings over the life of a district energy plant could offset its higher initial construction cost, electricity producers might be reluctant to invest significant capital during a period of regulatory reform. Even after the current restructuring process in U.S. electricity markets is completed, the risk of nonrecovery of capital for capital-intensive technologies in a competitive environment will make finding investors in such projects a challenge. Moreover, the development of a district energy system involves the coordinated effort of local and State governments, investors, and the community as a whole, together with the subsequent legal, financial, and environmental issues that arise with the inclusion of many and diverse stakeholders.

Another technology that some energy analysts believe could significantly reduce greenhouse gas emissions is the next-generation, very-high-efficiency ATS. These turbines are expected to operate, at minimum, 5 to 10 percent more efficiently than steam boilers and to cost less than \$350 per kilowatt-hour when used as a simple-cycle turbine.^e Their small size (5 megawatts) and short construction and delivery schedule (18 months) result in relatively smaller capital outlays and faster capital recovery, which are expected to give them an economic advantage over large central-station turbines.

Commercialization of ATS turbines is not expected until 2001, and penetration is expected to occur first where there is a need to satisfy internal power and steam requirements at industrial and large commercial establishments. But large-scale penetration of the ATS technology as envisioned by its advocates depends on the development of a significant niche market for this cogeneration system—a market characterized as having a small, but not constant, demand for steam. ATS in electric-only mode may not be competitive with other primary power technologies, and a constant demand for steam could be satisfied more economically by conventional gas and combined-cycle steam boilers.^f Consequently, the competitiveness of ATS with other generating technologies depends on locating markets with an optimal demand for steam during part of the day and maximum demand for electricity for the remainder of the day, even during off-peak periods. Few, if any, power markets would meet such stringent criteria.

^aEnergy Information Administration, *Annual Energy Review 1996*, DOE/EIA-0384(96) (Washington, DC, July 1997).

^bInterlaboratory Working Group on Energy-Efficient and Low-Carbon Technologies, "Scenarios of U.S. Carbon Reductions," BNL-40533, ORNL/CON-444 (September 1997).

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

^dSee web site www.energy.rochester.edu/us/climate/abstract.htm, "District Energy in U.S. Climate Change Strategy."

paper-making process step in the pulp and paper industry is 19 percent lower in the 1990+9% case than in the low technology sensitivity case. For the same process step, energy intensity is 36 percent lower in the high technology case than in the low technology case. For some process steps where the change in intensity is very small, the higher energy prices in the 1990+9% case lead to a slightly lower intensity than in the high technology case, where energy prices are lower. (The technology cases were modeled across all sectors simultaneously. The resulting lower consumption in the high technology case also resulted in lower prices.)

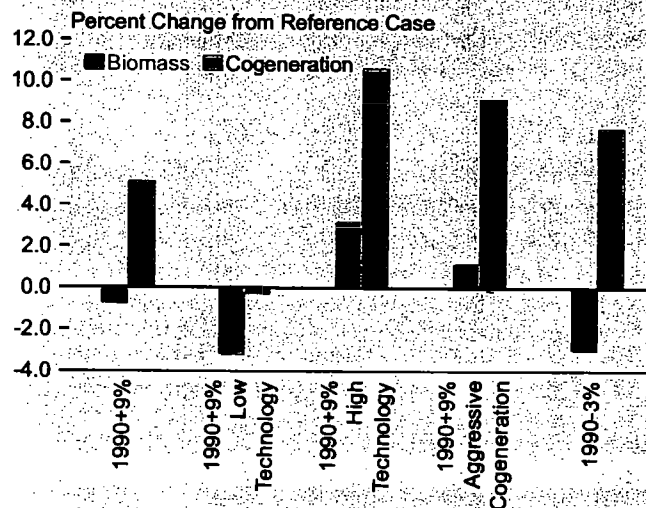
In the 1990+9% low technology case, industrial energy expenditures in 2010 are projected to be nearly double those in the 1990+9% carbon reduction case and \$110 billion higher than those in the reference case. In the high technology sensitivity case, energy expenditures are projected to be only \$23 billion higher than in the reference case, which has no carbon reductions, in 2010. The high technology case reduces, but does not eliminate, the impact of higher energy prices, producing \$37 billion in savings attributable to the assumed technology advances (Figure 51).

Another sensitivity case for the 1990+9% carbon reduction case was implemented to examine the impacts of alternative assumptions about the use of cogeneration and biomass for electricity generation. These assumptions reflect the possibility that natural gas cogeneration and biomass could be used more extensively than projected in the other cases. Natural-gas-fired cogeneration is posited to be a function of two economic factors. One is demand for process steam, with higher demand leading to more cogeneration. (In the carbon reduction cases, industrial steam demand is reduced because the requirements for process steam fall when industrial output falls.) The other is the spread between electricity and natural gas prices, with a higher price difference leading to more gas-fired cogeneration. The assumption used here is that natural-gas-fired cogeneration is more responsive to increasing prices.

Industrial biomass consumption is dominated by activities in the pulp and paper industry, where biomass residue and pulping liquor are used to supply more than half the industry's energy requirements. Consumption of biomass residue and pulping liquor is a function of the industry's output. Consequently, biomass consumption tends to fall in the carbon reduction cases, because industrial output is projected to be lower. The 1990+9% aggressive cogeneration/biomass sensitivity case assumes that the reduction in biomass consumption will be attenuated by additional biomass recovery and utilization. Additional biomass recovery also leads to an increase in cogeneration from biomass, which further reduces the requirements for other fossil fuels.

The aggressive cogeneration/biomass case results in a 9-percent increase (20 billion kilowatthours) in the level of gas-fired cogeneration in 2010 relative to the reference case (Figure 52). This is smaller than the change seen in the high technology sensitivity case, because industrial output is lower in the aggressive cogeneration/biomass sensitivity than in the high technology case. (Industrial output is lower in the aggressive cogeneration case than in the high technology case, because the projected energy prices are higher in the aggressive cogeneration case.) Biomass consumption in 2010 is projected to be 1.2 percent (27 trillion Btu) higher in the aggressive cogeneration/biomass sensitivity case than in the reference case (Figure 52). As with cogeneration, this increase is slightly less than the change seen in the high technology sensitivity case, again because of the lower industrial output projected in the aggressive cogeneration/biomass case. Projected energy expenditures in the industrial sector in 2010 in this sensitivity case are \$15 billion less than in the 1990+9% case. It should be noted that neither the cost nor the likelihood of achieving the assumed changes in the high technology or aggressive cogeneration/biomass sensitivity case has been evaluated. Instead, the experiments were an attempt to span the range of possible outcomes.

Figure 52. Natural-Gas-Fired Cogeneration and Biomass Consumption in the Industrial Sector in Alternative Carbon Reduction Cases, 2010



Source: Office of Integrated Analysis and Forecasting, National Energy Modeling System runs KYBASE.D080398A, FD09ABV.D080398B, FREEZE09.D080798A, HITECH09.D080698A, BEHAVE09.D080498A, and FD03BLW.D080398B.

Industrial Composition

Because non-Annex I countries are not required to reduce emissions under the Kyoto Protocol, their energy prices are likely to be lower than those in the Annex I countries, including the United States. As a result, more energy-intensive industries could migrate from areas with high energy costs, and those that remain could lose markets to lower-cost foreign competition. Energy-intensive industries also may face reduced demand as consumers shift their consumption patterns to less energy-intensive goods and services. There are several counter arguments to this hypothesis: the relatively small share of energy expenditures in annual manufacturing expenditures makes the impact of differential energy prices relatively unimportant; energy prices are not important determinants of international trade or capital flows, which implies that U.S. energy-intensive industries are not likely to be seriously affected by an energy price disadvantage; and a large number of business opportunities related to climate change mitigation will become available both domestically and in non-Annex I countries. Needless to say, there are widely divergent points of view about the likelihood of significant industrial migration and the extent of adverse impacts on U.S. industry.^a An analysis of the change in industrial composition, which would require an analysis of all the relative costs of manufacturing inputs, of which energy costs are only one, monetary issues, and international trade issues, is beyond the scope of this report.

One published study has attempted to evaluate the potential effects of differential changes in international energy prices on the U.S. industrial sector. The study was conducted by Argonne National Laboratory in a workshop format (see Argonne National Laboratory, *The Impact of High Energy Price Cases on Energy-Intensive Sectors: Perspectives from Industry Workshops* (July 1997)). Industry-specific discussion papers circulated to workshop participants contained analyses that examined impacts for each individual industry, assuming no price changes for other

industries or markets. The industries affected and the percentage reductions in projected industrial output in the reference case were as follows: bulk chemicals, 28.5; aluminum, 13.7; pulp and paper, 10.2; steel, 30.5; and cement, 38.2.

A second study was conducted at EIA's request by Charles River Associates (CRA),^b using a more general approach. Explicit linkages to international trade were a fundamental part of the modeling framework for the study, which was conducted under assumptions similar to those of the 1990+14% carbon reduction case in this analysis. The industries affected and the percentage reductions from reference case output projections were as follows: total chemicals, 3.9; nonferrous metals, 1.5; pulp and paper plus printing, 0.7; steel, 1.4; and nonmetallic minerals, 1.4. The percentage output reductions from the comparable NEMS case (1990+14%) are about double the CRA values: nonferrous metals, 4.4; pulp and paper plus printing, 2.0; steel, 3.1; and nonmetallic minerals, 3.5. The exception is total chemicals for which the NEMS results project a slightly smaller reduction of 3.5 percent. The projections from NEMS, which estimates only domestic output reductions, and from CRA, which treated both international capital flows and domestic output reductions, are significantly lower than those from the Argonne National Laboratory study.

In view of the above results, it is difficult to distinguish the effects of reduced output from those that could result from industrial migration abroad in response to differences in international energy prices. There are many analytical complexities in the assessment of potential effects of carbon reductions on industrial output. A complete analysis of the issue would require consideration of all input costs, including infrastructure and locational advantages, monetary issues, and trade issues. Significant additional research would be required to examine the differential impacts of climate change policies on the United States and other countries.

^aThe following authors provide a sample of the breadth of disagreement in this area: American Petroleum Institute, *Impacts of Market-Based Greenhouse Gas Emission Reduction Policies on U.S. Manufacturing Competitiveness*, January 1998; American Automobile Manufacturers Association, *Economic Implications of the Adoption of Limits on Carbon Emissions from Industrialized Countries*, November 1997; Argonne National Laboratory, *The Impact of High Energy Price Cases on Energy-Intensive Sectors: Perspectives from Industry Workshops*, July 1997; Matthewson, et al., *The Economic Implications for Canada and the United States of International Climate Change Policies*, 1997 Canadian Energy Research Institute Environment-Energy Modeling Forum, October 1997; Repetto, et al., *U.S. Competitiveness is Not at Risk in the Climate Negotiations*, (World Resources Institute, October 1997); and WEFA, Inc., *Global Warming: The High Cost of the Kyoto Protocol*, National and State Impacts, 1998.

^bCharles River Associates, *Report to the Energy Information Administration* (August 1998).

Transportation Demand

Background

In terms of primary energy use in 1996, transportation sector carbon emissions, which almost equaled industrial carbon emission levels, were the second highest among the end-use demand sectors. Nearly 33 percent of all carbon emissions and 78 percent of carbon emissions from petroleum consumption originate from the transportation sector. In the reference case, carbon emissions from transportation are projected to grow at an average annual rate of 1.9 percent to 2010, compared with 1.4 percent for the commercial sector and 1.2 percent for both the residential and industrial sectors. In addition, transportation is the only sector with increasing carbon emissions projected for the period from 2010 to 2020 in the carbon reduction cases. Therefore, if there are no specific initiatives to reduce carbon emissions in the transportation sector, especially beyond 2010, increasing pressure may have to be exerted in the other sectors in order to reach and then maintain 2010 carbon emissions targets beyond 2010.

Consumers select light-duty vehicles (cars, vans, pickup trucks, and sport utility vehicles) based on a number of attributes: size, horsepower, price, and cost of driving; weighting these attributes by their personal preferences. This analysis uses past experience to determine the weights that each of these attributes have in terms of consumer preferences for conventional vehicles. Technologies are represented by component (e.g., front wheel drive, electronic transmission type) with each technology component defined by a date of introduction, a cost, and a weight that indicates its impact on efficiency and horsepower. The vehicles are categorized by the 12 size classes for cars and light trucks defined by the Environmental Protection Agency and includes 2 conventional engine technologies, and 14 alternative fuel vehicle engine technologies. Technologies penetrate based on both their cost-effectiveness and by consumer preference based on past experience with similar technologies in the automotive industry. Consumers are assumed to consider only current energy prices when evaluating technologies. However, it is assumed that the automobile industry requires 3 years for minor technology makeovers and 5 years for major redesigns, estimating future fuel prices based on their rate of growth in the past 3 to 5 years. Therefore, manufacturers consider whether future fuel prices will enable their technologies to be cost-effective from a consumer standpoint.

Penetration of alternative-fuel vehicles is based on four consumer criteria—vehicle price, cost of driving per mile, vehicle range, and availability of refueling stations. Each of these attributes is weighted according to consumer surveys and expected changes over the forecast period as a result of technological improvements, larger

scales of production, the availability and cost of fuel-saving technologies, and the availability of alternative-fuel refueling stations as more alternative-fuel vehicles penetrate the market. Production levels for alternative-fuel vehicles are constrained by the lead time to switch production to a particular technology and the availability of technologies in each size class.

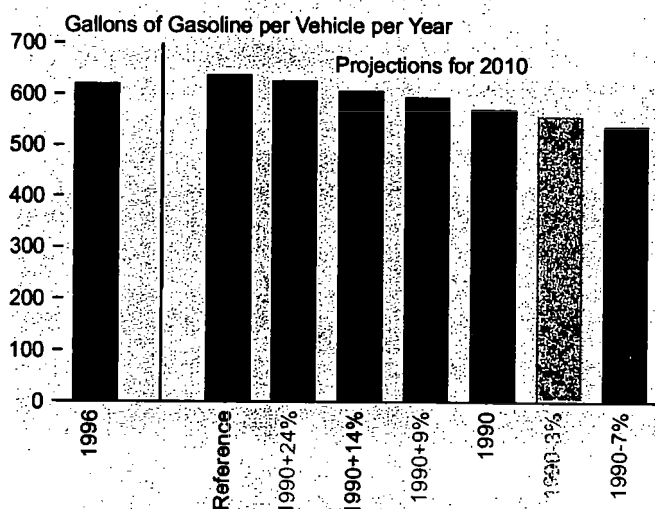
Depending on per capita income, fuel prices, and fuel economy, consumers may switch to either smaller size classes or smaller vehicles with lower horsepower requirements within a size class. The trend in vehicle sales toward or away from light trucks (vans, sport utility vehicles, and pickups) is determined by fuel prices. Vehicle travel is determined by the cost of driving per mile and per capita income. For flex-fuel or bi-fuel alternative-fuel vehicles, the percentage use of each fuel is based on the price differential between gasoline and the alternative fuel.

Responding to changes in fuel prices, gasoline has a 2-year demand elasticity of -0.25 and a 20-year elasticity of -0.45. In the long term, consumers are expected to alter their purchasing patterns and manufacturers to incorporate more fuel-saving technologies. Because fuel use for freight trucks and trains depends primarily on requirements for freight movement as a result of economic activity and the slow turnover of the stock, distillate fuel has lower 2-year and 20-year price elasticities, at -0.09 and -0.13, respectively. In addition to fuel prices, business and personal air travel also depend on gross domestic product (GDP) and per capita income, respectively, and have very slow rates of stock turnover. Jet fuel has 2-year and 20-year elasticities of -0.12 and -0.15.

Energy intensity in the transportation sector is defined as energy use (in terms of gallons of gasoline) per vehicle per year. In the reference case, transportation energy intensity in 2010 is projected to be about 635 gallons of gasoline per vehicle, or about 53 gallons per month (Figure 53). Energy intensity in the 1990+24% case is lower than in the reference case but only by 12 gallons of gasoline per car per month. In the 1990+9% case, the projected energy intensity in 2010 is almost 53 gallons lower—equivalent to 1 month's use of gasoline. In the 1990-3% and 1990-7% cases, the corresponding reductions in gasoline consumption in 2010 are equivalent to nearly 1.5 and 2 months of gasoline use, respectively.

In the absence of fuel price changes, transportation energy intensity will change in response to stock turnover, technology availability, and income effects (Table 10). Because 1998 prices are lower than those projected for 2010 in the reference case, vehicle-miles traveled would be higher and fuel efficiency lower than in the reference case if the 1998 price level continued. Constant 1998 fuel prices would slightly increase air

Figure 53. Light-Duty Vehicle Energy Intensity, 1996 and 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.

Table 10. Projected Average Transportation Energy Intensities by Mode of Travel, 2010

(Million Btu per Vehicle per Year)

Travel Mode	1998 Average	Reference	Constant 1998 Prices
Light-Duty Vehicles	78.4	79.5	80.9
Freight Truck	699.5	787.7	787.7
Aircraft	486,100	517,100	521,900

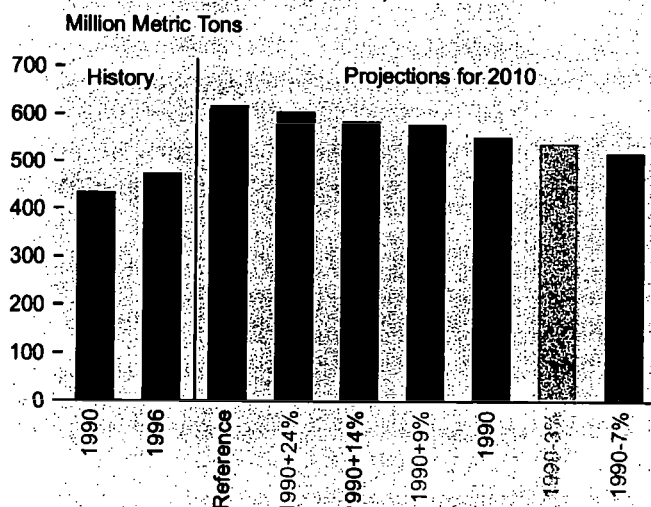
Source: Office of Integrated Analysis and Forecasting, National Energy Modeling System run KYBASE.D080398A.

travel, but aircraft efficiency levels would not decline relative to those in the reference case. More air travel would necessitate higher aircraft stock levels in 2010, but the increase would be more than offset by higher levels of travel per plane. Freight truck fuel intensity would not change with constant prices, because freight travel is determined primarily by economic activity rather than fuel prices. The slightly lower fuel prices in the constant price case would not be enough to lower the fuel economy of freight trucks relative to their projected fuel economy in the reference case.

Carbon Reduction Cases

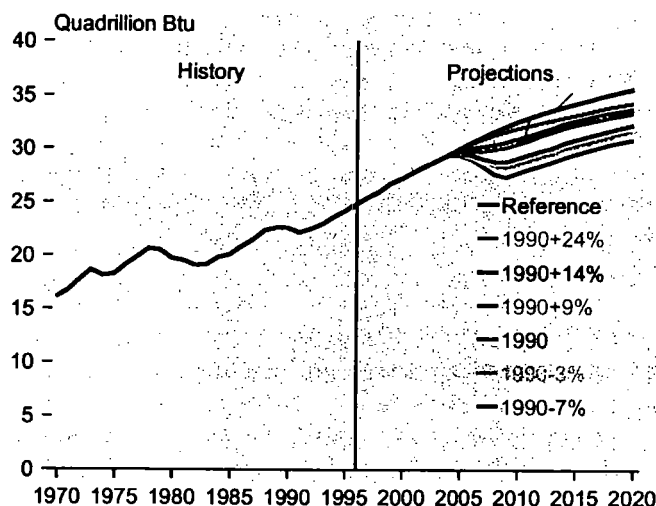
The transportation sector is the only sector that does not reach 1990 carbon emissions levels by 2010 in any of the carbon reduction cases (Figure 54). In the reference case, energy demand in the transportation sector is projected to exceed 1990 levels by approximately 10.7 quadrillion Btu in 2010, a 49-percent increase (Figure 55). The corresponding increases are 9.4 quadrillion Btu in the 1990+24% case, 8.6 quadrillion Btu in the 1990+9% case, and 6.6 quadrillion Btu in the 1990-3% case.

Figure 54. Carbon Emissions in the Transportation Sector, 1990, 1996, and 2010



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.

Figure 55. Fuel Consumption in the Transportation Sector, 1970-2020



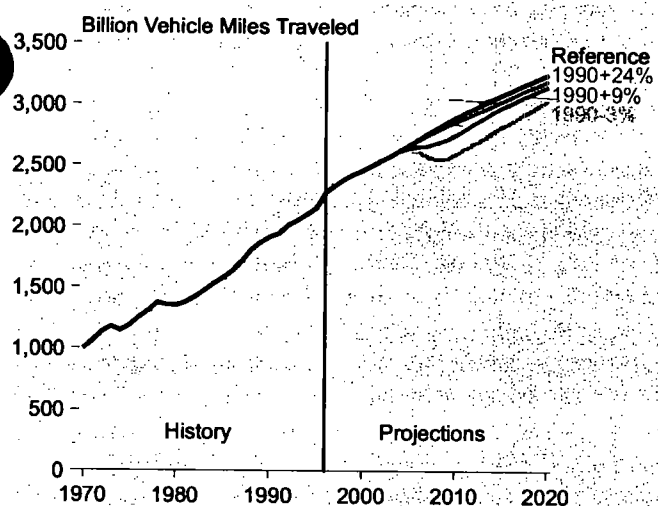
Sources: **History:** Energy Information Administration, *State Energy Data Report 1995*, DOE/EIA-0214(96) (Washington, DC, December 1997). **Projections:** Office of Integrated Analysis and Forecasting, National Energy Modeling System runs KYBASE.D080398A, FD24ABV.D080398B, FD1998.D080398B, FD09ABV.D080398B, FD1990.D080398B, FD03BLW.D080398B, and FD07BLW.D080398B.

Relative to the reference case, only 14 percent of the projected reduction in total energy demand for all sectors in 2010 occurs in the transportation sector in the 1990+24% case, 19 percent in the 1990+9% case, and 24 percent in the 1990-3% case. In the 1990-3% case, the reduction in carbon emissions from all sectors in 2010 is approximately 492 million metric tons, of which 18 percent comes from the transportation sector.

Light-Duty Vehicles

Travel Demand. Light-duty vehicle travel (cars, pickup trucks, vans, and sport utility vehicles) in 2010 is projected to be 1.3 percent lower than in the reference case in the 1990+24% case, 5.2 percent lower in the 1990+9% case, and 11.2 percent lower in the 1990-3% case (Figure 56). Declines in light-duty vehicle travel have been seen historically in 1973-1974 (2.7 percent) and 1979-1980 (1.6 percent). In the 1990+24% and 1990+9% cases, the levels of light-duty vehicle travel rise between 2005 and 2008, they are projected to decline by an average of 1.2 percent per year over the same period in the 1990-3% case (comparable to the rate of decline from 1979 to 1980). In 1973-1974 and 1979-1980, disposable per capita income was declining, at 0.7-percent and 0.3-percent annual rates, respectively. Those historical declines in income per capita, combined with rising fuel prices, further reduced vehicle travel. In contrast, from 2005 to 2008 income per capita is projected to rise at an average annual rate of 0.8 percent, more than twice the projected rate in the reference case, partially offsetting the reductions in travel that are expected to accompany higher fuel prices.

Figure 56. Light-Duty Vehicle Travel, 1970-2020



Sources: History: U.S. Department of Transportation, Federal Highway Administration, *Highway Statistics*, various years, (Washington, DC). Projections: Office of Integrated Analysis and Forecasting, National Energy Modeling System runs KYBASE.D080398A, FD24ABV.D080398B, FD09ABV.D080398B, FD03BLW.D080398B.

Slowing growth in vehicle-miles traveled is projected even in the reference case, for several reasons. First, as the "baby boomers" age, they are expected to drive less (although they probably will drive more than previous generations of the same age group).⁴⁹ Second, as more women have entered the workforce over the past three

decades, resulting in more two-income households, female drivers have logged more vehicle-miles of travel; however, that growth will eventually slow as the vehicle-miles traveled by women approaches that of men. Finally, consumers have been keeping their vehicles longer than in past decades, and older cars tend to be driven less than newer cars. A countervailing trend is the recent growth in purchases of light trucks, which are driven 4.7 percent more per year than cars. In the carbon reduction cases, a reversal of this trend back to car sales as a result of higher fuel prices is expected, leading to slower growth in vehicle-miles traveled.

After 2010, vehicle-miles of travel, total fuel use, and total carbon emissions for light-duty vehicles are projected to begin rising again in the 1990-3% case and to continue on an upward path through 2020, paralleling the trends in the reference, 1990+24%, and 1990+9% cases for the later years of the forecast. There are three reasons for the continued growth in vehicle-miles traveled after 2012. First, carbon prices are projected to decline in most cases after 2010. Second, lower demand for gasoline is projected to result in lower refining costs, lower world oil prices, and lower gasoline prices. Finally, increases in disposable income after 2012—particularly after 2015, when the U.S. average disposable income in the 1990+24%, 1990+9%, and 1990-3% cases is expected to exceed that projected in the reference case as the economy rebounds from the initial response to carbon reduction efforts—lead to more rapid increases in light-duty vehicle travel from 2012 through 2020.

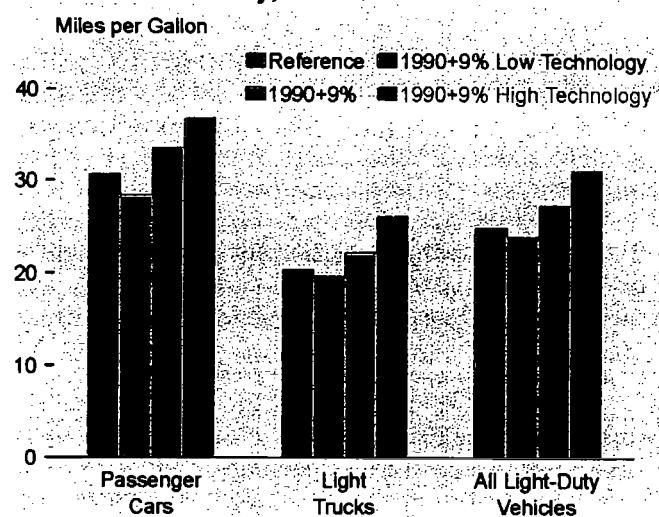
Increased telecommuting, which is assumed to reduce vehicle-miles traveled by 0.13 percent in 2000 according to the Climate Change Action Plan,⁵⁰ is also assumed in all the cases for this analysis, resulting in fuel savings of 21.6 trillion Btu in 2000. The 0.13-percent reduction is assumed to continue throughout the projections, so that as vehicle-miles traveled increase over time, the savings from telecommuting increase proportionately.

Fuel Efficiency. In the carbon reduction cases, the fuel economy of newly purchased light-duty vehicles in 2010 is expected to be higher than projected in the reference case. Higher fuel prices are expected to encourage the development of advanced fuel-saving technologies, as well as changes in consumer purchasing patterns. For example, average fuel efficiency for all new light-duty vehicles in 2010, projected to be just under 25 miles per gallon in the reference case, surpasses 27 miles per gallon in the 1990+9% case (Figure 57), and even higher levels might be achieved with more rapid advances in technology, as described in the discussion of sensitivity

⁴⁹Federal Highway Administration, *National Personal Travel Survey: 1990 NPTS Databook*, Vol. I (Washington, DC, November 1993), p. 3-18.

⁵⁰U.S. Department of Energy, Office of Policy, Planning, and Program Evaluation, *The Climate Change Action Plan: Technical Supplement* (Washington, DC, March 1994).

Figure 57. Projected New Car and Light Truck Fuel Economy, 2010



Source: Office of Integrated Analysis and Forecasting, National Energy Modeling System runs KYBASE.D080398A, FREEZE09.D080798A, FD09ABV.D080398B, and HITECH09.D080698A.

cases below. The projections of new vehicle fuel efficiency in the reference, 1990+24%, 1990+9%, and 1990-3% cases in 2010 are as follows: for cars, 30.6, 32.0, 33.6, and 35.6 miles per gallon; and for light trucks, 20.4, 21.2, 22.1, and 23.3 miles per gallon.

In the past, a 4.3-percent average annual increase in new car fuel efficiency was achieved by automobile manufacturers from 1976 to 1988. Thus, the projected increases of 0.9 percent per year from 1996 to 2010 in the 1990+24% case, 1.3 percent per year in the 1990+9% case, and 1.7 percent per year in the 1990-3% case appear to be possible. On the other hand, those historical improvement rates resulted from the introduction of fuel-saving technologies that involved radical changes in structural design and were relatively inexpensive to implement. For example, space and size reductions resulting from downsizing to front wheel drive designs actually reduced costs while also permitting the spatial redesign of engine compartments, but further downsizing and weight reductions may be difficult to achieve, because they could eliminate larger vehicles from the marketplace and, possibly, increase the safety concerns associated with smaller light-weight vehicles. Diminishing returns to scale have limited the potential for future fuel savings, because many of the least expensive options have already been implemented.

Light trucks have not achieved fuel efficiency improvements equivalent to those for automobiles, because consumers have sought higher horsepower for personal use (particularly in sport utility vehicles), hauling (pickup trucks), and commercial applications (standard vans). Historically, the highest average annual growth rate in fuel efficiency for new light trucks was 2.9 percent per year from 1976 to 1986. In contrast, light truck fuel econ-

omy is projected to grow by only 0.1 percent annually in the 1990+24% case, 0.4 percent annually in the 1990+9% case and 0.8 percent annually in the 1990-3% case between 2000 and 2010. Lower growth rates occur for light trucks in the carbon reduction cases than historically because of the difference described above regarding inexpensive and one time technological improvements.

Among the 55 fuel-saving technologies that are assumed to be available to manufacturers of light-duty vehicles in the reference and carbon reduction cases, the most significant market penetration is expected for drag reduction, continuously variable transmissions, electronic transmission controls, cylinder friction reduction technologies, advances in low-rolling-resistance tires, variable valve timing, and accessory control units (Table 11). Aerodynamic improvements (drag reduction) have already been implemented on many vehicles, but further market penetration may be possible, especially in the larger size classes. Continuously variable transmissions match the gear ratio in a continuous manner over the wide spectrum of gear ratios demanded by the engine, rather than having a discrete number of gears. Electronic transmission controls assist the transmission by matching more precisely the gear to be used with a given engine load. Cylinder friction reduction technologies, such as low-friction pistons and rings, lower the thermal and mechanical losses of the engine. Low-rolling-resistance tires limit energy losses from friction between tires and road surfaces. Variable valve timing improves the thermal efficiency of an engine by precisely timing when the ignition sparks within the cylinder. Electronic controls and electric motors for accessory drives on vehicles (cooling fan, water pump, alternator, power steering and windows) could improve fuel economy by reducing engine loads.

Changes in consumer purchasing patterns also are expected to contribute to the fuel economy improvements for light-duty vehicles in the carbon reduction cases. For that to happen, however, trends in consumer choices over the past decade would have to be reversed. With low fuel prices and high disposable income per capita, average fuel economy has been flat from 1990 to 1996. Consumer purchases have tended toward larger cars and light trucks, especially sport utility vehicles, and there has been a growing preference for light trucks over cars. Similarly, within each size class, consumers have tended to purchase cars and light trucks that are larger and have more horsepower.

In 1996, compact cars accounted for 45 percent of new automobile sales, an increase from 34 percent in 1990; however, the subcompact share of new car sales fell from a high of 26 percent in 1991 to 19 percent in 1996. Small pickup trucks, which captured 25 percent of the

Table 11. Projected Penetration of Selected Technologies for Domestic Compact Cars, 2010
(Percent of New Sales)

Technology	Reference	1990+9%	1990+9% High Technology
Drag Reduction (I)	52	73	63
Drag Reduction (II)	14	19	17
Continuously Variable Transmission	48	54	49
Electronic Transmission Controls (I)	21	26	23
Electronic Transmission Controls (II)	22	28	24
Cylinder Friction Reduction (I)	46	65	56
Cylinder Friction Reduction (II)	7	9	8
Low-Rolling-Resistance Tires (I)	46	67	57
Low-Rolling-Resistance Tires (II)	22	30	26
Variable Valve Timing	79	82	52
Accessory Control Units (I)	24	33	28
Accessory Control Units (II)	21	27	24

Source: Office of Integrated Analysis and Forecasting, National Energy Modeling System runs KYBASE.D080398A, FD09ABV.D080398B, and HITECH09.D080698A.

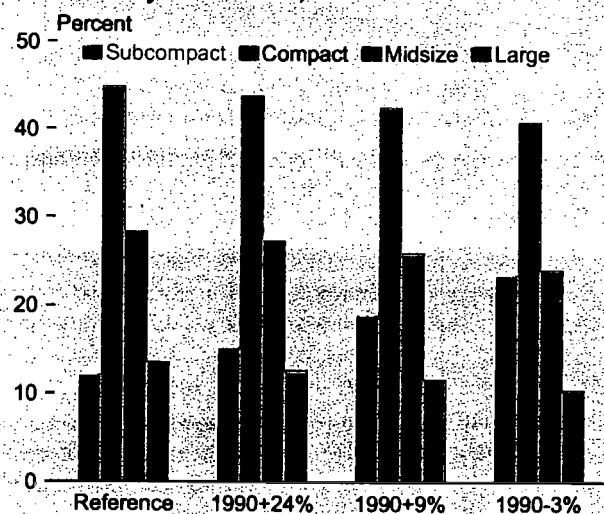
market for new light trucks in 1990, reached a low of 19 percent in 1996. Concurrently, standard and compact sport utility vehicles, which had only a 20-percent share of the light truck market in 1990, had a 45-percent share in 1996. The average fuel economy of small pickup trucks is 26.3 miles per gallon, as compared with 21.3 miles per gallon for small utility trucks and 18.1 miles per gallon for large sport utility vehicles, which are now growing in share at a much faster pace than even small utility trucks. Sales of large sport utility vehicles increased from 3.3 percent of all new light truck sales in 1991 to a high of 10.3 percent in 1996. In addition, sales of small vans, which currently have an average fuel economy rating of about 22.7 miles per gallon, are being displaced by sales of small and large sport utility vehicles. With a large supply of sport utility vehicles available to consumers and a lack of station wagons designed from sedan autos, which have a much higher fuel efficiency rating, the fuel economy options for new vehicle buyers are becoming limited.

With higher fuel prices in the carbon reduction cases in 2010 than in the reference case, it is projected that size class shares will return to near 1976 levels. The subcompact share of new car sales in 2010 is projected to be 15 percent in the 1990+24% case, 19 percent in the 1990+9% case, and 24 percent in the 1990-3% case, compared with 12 percent in the reference case (Figure 58). Similar trends are projected for all size classes in the carbon reduction cases, as consumers move their vehicle purchases down to lower size classes and sales of compact, mid-size, and large cars are reduced. Although shifting vehicle lines back to production of smaller cars would require major changes in production facilities, the lead time associated with those changes has narrowed from about 4 years to 2 years.

Since 1990, the growth in light trucks sales at the expense of car sales, and the growth in sales of standard and compact sport utility vehicles and minivans at the expense of station wagons has slowed the rate of improvement in

efficiency for new light-duty vehicles. Light truck sales shares have grown from about 37 percent of all light-duty vehicle sales in 1990 to 43 percent in 1997, with a net loss on average of more than 8 miles per gallon between new cars and light trucks. In 2010, light trucks sales are projected to be 46.1 percent of light-duty vehicle sales in the 1990+24% case, 44.4 percent in the 1990+9% case, and 42.5 percent in the 1990-3% case, compared with 47 percent in the reference case. Reversing the trend back toward cars and away from truck purchases will not be costless, however. Vehicle manufacturers reap much higher profits from sales of light trucks than from car sales. In addition, consumers may have difficulty finding fuel-efficient vehicles suitable for larger families with the disappearance of many station wagons from the new car market.

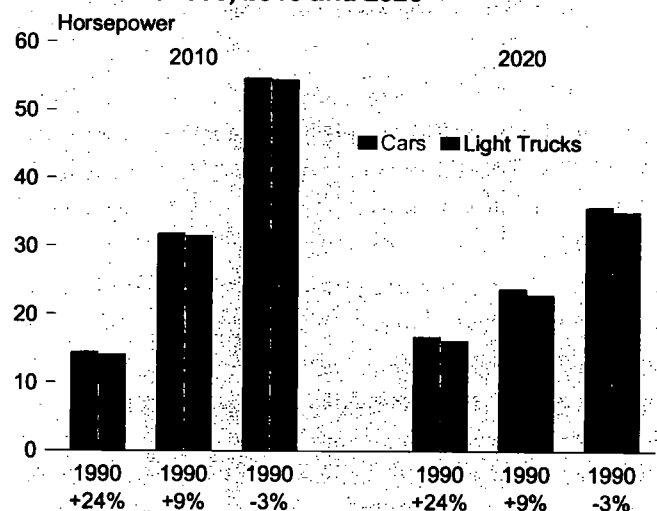
Figure 58. Projected Shares of Automobile Sales by Size Class, 2010



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

Horsepower. Growth rates in new vehicle horsepower in the light-duty vehicle market are currently at their highest historical levels. From 1990 to 1997, new vehicle horsepower increased at annual rates of 3.2 percent for cars and 4.3 percent for light trucks. Between 1996 and 2010, horsepower for both cars and light trucks is projected to increase at an annual rate of 2.4 percent in the reference case, as a result of high per capita incomes and low fuel prices. The higher fuel prices in the carbon reduction cases are projected to lower the growth rate of horsepower for cars to 1.9 percent between 1996 to 2010 in the 1990+24% case, 1.2 percent in the 1990+9% case, and 0.3 percent in the 1990-3% case (Figure 59).

Figure 59. Projected Reductions From Reference Case Projections of Car and Light Truck Horsepower in the Carbon Reduction Cases, 2010 and 2020

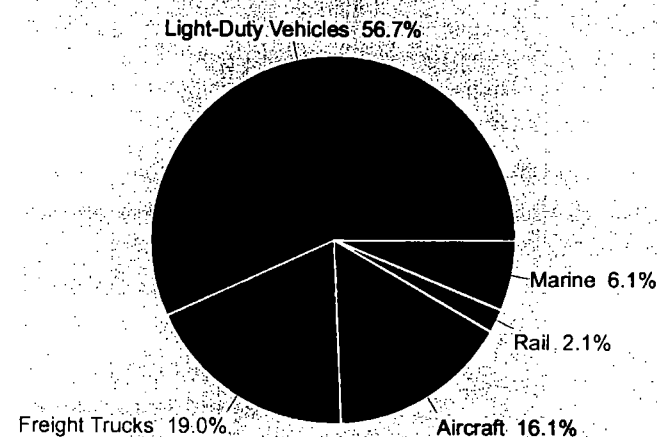


Source: Office of Integrated Analysis and Forecasting, National Energy Modeling System runs KYBASE.D080398A, FD24ABV.D080398B, FD09ABV.D080398B, and FD03BLW.D080398B.

Fuel Consumption. Reductions in fuel use by light-duty vehicles (cars, pickup trucks, vans, and sport utility vehicles) are projected to account for more than two-thirds of the reduction in transportation energy consumption in 2010 in the carbon reduction cases relative to the reference case projections. In the reference case, light-duty vehicles are responsible for 57 percent of all transportation use in 2010 (Figure 60). The difference in gasoline consumption by light-duty vehicles (Figure 61) results from both a decline in vehicle-miles traveled and an increase in new car and light truck efficiency in response to higher gasoline prices and lower levels of disposable income. As fuel-saving technologies penetrate the light-duty vehicle market, higher fuel efficiencies lower the cost of driving per mile, which increases vehicle travel, offsetting some of the fuel savings.⁵¹ The

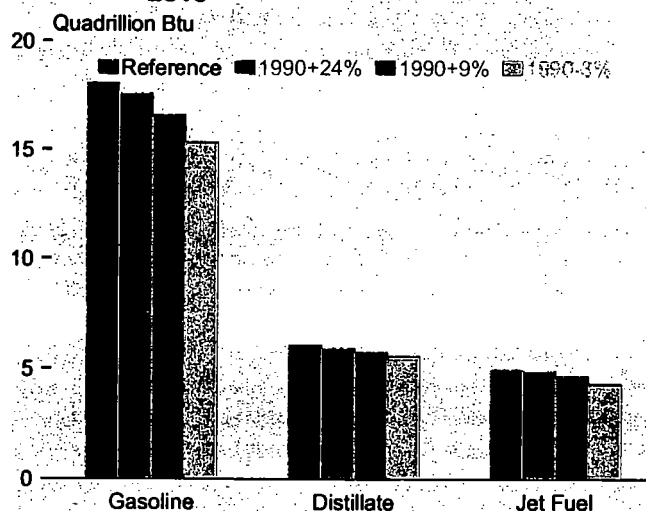
increase in fuel efficiency also reduced the demand for gasoline, leading to lower gasoline prices than would otherwise have occurred. Gasoline prices in real 1996 dollars in 2010 are projected to be 14 cents per gallon higher in the 1990+24% case than in the reference case, 30 cents per gallon higher in the 1990+9% case, and 55 cents per gallon higher in the 1990-3% case. Comparable increases in gasoline prices were last seen during the oil crisis of 1973-1974 (33 cents a gallon in 1996 dollars) and during the oil embargo of 1979-1980 (47 cents a gallon).

Figure 60. Projected Fuel Consumption in the Transportation Sector by Mode in the Reference Case, 2010



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

Figure 61. Projected Fuel Consumption in the Transportation Sector by Fuel Type, 2010



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

⁵¹This secondary effect has been estimated at about 10 to 12 percent. See L.A. Greening and D.L. Greene "Energy Use, Technical Efficiency, and the Rebound Effect: A Review of the Literature," draft report prepared for the Office of Policy Analysis and International Affairs, U.S. Department of Energy (Washington, DC, November 6, 1997).

Air Travel

Personal, business, and international air travel are expected to decline in response to higher jet fuel prices and higher ticket prices in the carbon reduction cases, as compared with the reference case, from 2005 through 2015. The projected levels of air travel in 2010 are 1.4 percent lower in the 1990+24% case than in the reference case, 7.4 percent lower in the 1990+9% case, and 16.0 percent lower in the 1990-3% case. Higher fuel prices in 2010 are projected to increase ticket prices by 5 percent, 13 percent, and 23 percent in the 1990+24% case, 1990+9% and 1990-3% cases, respectively, over the reference case prices. Lower merchandise exports (0.9 percent lower in the 1990+24% case, 2.5 percent in the 1990+9% case, and 4.9 percent in the 1990-3% case than in the reference case) have comparable effects on dedicated air freight travel.

Between 2005 and 2008, air travel is projected to decline by 1.2 percent annually in the 1990-3% case as a result of a 19-percent average annual increase in jet fuel prices. In comparison, air travel declined by 2.2 percent from 1980 to 1981, when jet fuel prices increase by 49 percent. Similar to light-duty vehicles, differences in the responses to higher fuel prices between history and the carbon reduction cases can be explained by comparing growth rates in income levels. Income during 2005 to 2008 is expected to increase by 0.8 percent annually in the carbon reduction cases, however from 1980 to 1981 income was rising even faster at 2.3 percent per year, which mitigated the decline in air travel.

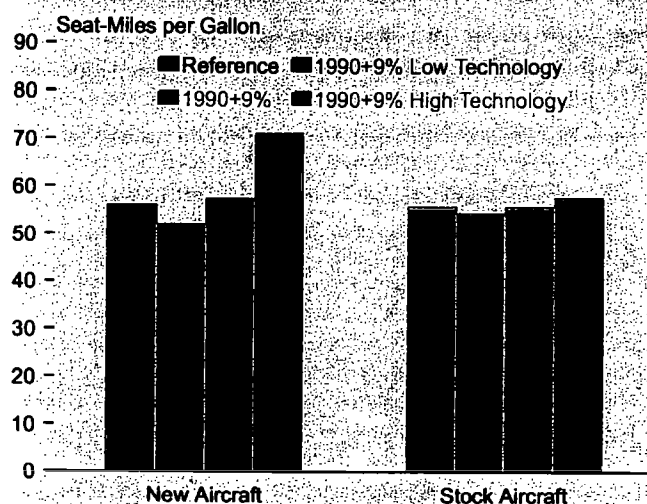
In 2010, the projected use of jet fuel is lower by 1.4 percent in the 1990+24% case than in the reference case, by 6.6 percent in the 1990+9% case, and by 14.2 percent in the 1990-3% case (Figure 61). Jet fuel prices are projected to be 15 cents per gallon higher than in the reference case in 2010 in the 1990+24% case, 34 cents per gallon higher in the 1990+9% case, and 63 cents per gallon higher in the 1990-3% case.

Only relatively minor changes in the average fuel efficiency of new aircraft are expected to result from the imposition of carbon reduction targets. For example, in the 1990+9% case, new aircraft fuel efficiency is projected to improve at an annual rate of just 0.9 percent between 1996 and 2010, compared with the 0.7-percent rate projected in the reference case. As a result, the average efficiencies projected for the entire U.S. stock of aircraft are nearly the same in the two cases (Figure 62).

Less air travel is expected in the carbon reduction cases than in the reference case, leading to slower rates of aircraft stock turnover, which in turn limit the penetration of new aircraft into the aircraft stock. Higher fuel prices and lower air travel in the carbon reduction cases lower the demand for wide-body aircraft, which have higher efficiencies in terms of seat-miles per gallon than do

narrow-body aircraft. In addition, near-term aircraft technologies that can improve fuel efficiency are limited, and they are not expected to be cost-effective even in the 1990-3% case. Among the six advanced aircraft technologies available by 2010, only weight-reducing materials and ultra-high-bypass engines, which are currently in use, are expected to penetrate the market (Table 12); and only the ultra-high-bypass engine technology is projected to achieve significant penetration (more than 90 percent) by 2010, and then only in the 1990-3% case or the high technology sensitivity case described below.

Figure 62. Projected New and Stock Aircraft Fuel Efficiency, 2010



Source: Office of Integrated Analysis and Forecasting, National Energy Modeling System runs KYBASE.D080398A, FREEZE09.D080798A, FD09ABV.

Table 12. Projected Penetration for Selected Advanced Technologies for Aircraft, 2010
(Percent of New Sales)

Technology	Reference	1990+9%	1990+9% High Technology
Ultra-High-Bypass Engines	9	90	77
Weight-Reducing Materials	85	85	96
Advanced Aerodynamics	0	0	96
Thermodynamics	0	0	56

Source: Office of Integrated Analysis and Forecasting, National Energy Modeling System runs KYBASE.D080398A, FD09ABV.D080398B, and HITECH09.D080698A.

Freight Trucks, Rail, and Shipping

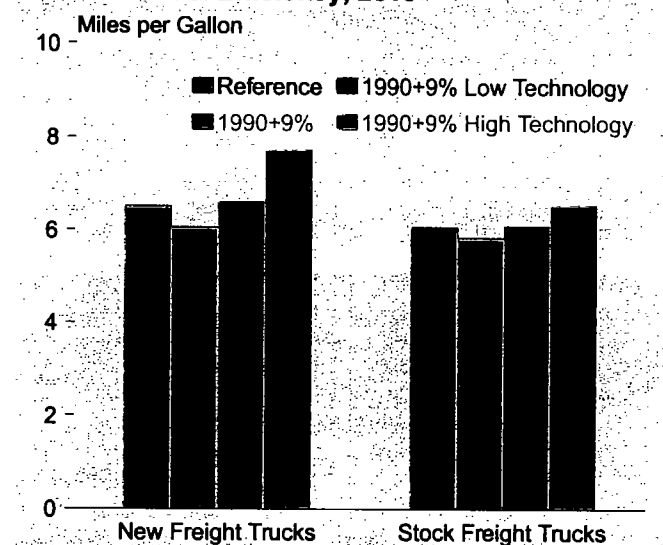
The projected demand for distillate fuel, used primarily for freight trucks and rail, is also lower in the carbon reduction cases than in the reference case in 2010—by 2 percent in the 1990+24% case, by 4.9 percent in the 1990+9% case, and by 8.3 percent in the 1990-3% case (see Figure 61). Distillate fuel prices are projected to be

15 cents per gallon higher in the 1990+24% case, 37 cents per gallon higher in the 1990+9% case and 68 cents higher in the 1990-3% case. These increases are larger than those projected for gasoline because of the higher carbon content of distillate fuel.

Higher fuel prices do not result in as much change in travel and efficiency for freight trucks and rail as they do for light-duty vehicles. Because of the slow turnover in the stock of freight trucks and rail and the high power requirements of the engines used to move freight, fuel savings are limited. The main source of reductions in distillate fuel use is the response to overall lower economic activity and demand for goods by 2010 in the carbon reduction cases, leading to lower freight travel for both trucks and rail. Lower demand for goods in the 1990+24%, 1990+9% and 1990-3% cases results in levels of freight truck travel that are 1.3 percent, 2.4 percent and 4.9 percent lower, respectively, in 2010 than projected in the reference case. Declines in coal consumption and production also lead to further cuts in rail travel as described below.

The potential for improvement in fuel economy for freight trucks is also limited. In the reference case, the fuel efficiency of new freight trucks is projected to increase by only 0.6 percent per year between 1996 and 2010. Even with higher distillate fuel prices in the 1990-3% case, the efficiency for new freight trucks improves at an annual rate of only 0.8 percent. As a result of the lower demand for goods and slower turnover in the stock of freight trucks projected in the 1990+9% case relative to the reference case, there is almost no difference in the projected average stock efficiencies for the two cases in 2010 (Figure 63).

Figure 63. Projected New and Stock Freight Truck Fuel Efficiency, 2010



Source: Office of Integrated Analysis and Forecasting, National Energy Modeling System runs KYBASE.D080398A, FREEZE09.D080798A, FD09ABV.D080398B, and HITECH09.D080698A.

The number of advanced technologies available for freight trucks is relatively small. Those with the greatest potential are advanced aerodynamics, the turbo-compound diesel engine, and the LE-55 heat engine, with expected marginal fuel efficiency improvements of approximately 25, 10, and 17 percent, respectively (Table 13). In all the carbon reduction cases, the advanced aerodynamics technology is projected to achieve the greatest efficiency improvements and highest penetration rates for both medium- and heavy-duty trucks. The turbo-compound diesel engine and the LE-55 heat engine do not penetrate the market until after 2010, except in the high technology sensitivity cases.

Table 13. Projected Penetration of Selected Technologies for Freight Trucks, 2010 (Percent of New Sales)

Technology	Reference	1990+9%	1990+9% High Technology
Medium Trucks			
Improved Tires and Lubricants	0	0	0
Electronic Engine Controls	0	0	5
Advanced Drag Reduction	23	34	45
Turbo Compound Diesel	0	2	8
LE-55 Heat Engine	0	0	13
Heavy Trucks			
Improved Tires and Lubricants	0	3	98
Electronic Engine Controls	0	4	98
Advanced Drag Reduction	100	100	100
Turbo Compound Diesel	1	1	35
LE-55 Heat Engine	0	0	10

Source: Office of Integrated Analysis and Forecasting, National Energy Modeling System runs KYBASE.D080398A, FD09ABV.D080398B, and HITECH09.D080698A.

In percentage terms, the projections for rail and ship freight travel in 2010 show the sharpest reductions relative to the reference case in the carbon reduction cases. Rail freight travel is 9 percent, 23 percent, and 32 percent lower in 2010 in the 1990+24%, 1990+9%, and 1990-3% cases than in the reference case. Since more than 40 percent of rail travel is for coal transportation, the lower rail travel in the carbon reduction cases is primarily due to the projected reductions in coal production of 20 percent, 52 percent, and 71 percent in the 1990+24%, 1990+9%, and 1990-3% cases relative to the reference case. Domestic freight travel by ship is projected to be 3 percent, 6 percent, and 10 percent lower in the three cases than in the reference case. Domestic shipping is not expected to be affected as adversely by the decline in coal production as is rail traffic; however, with lower demand for goods and industrial production

in the carbon reduction cases, domestic shipping is also projected to be lower.

Like freight truck and rail travel, shipping is affected more by the impacts of carbon prices on travel and shipping requirements than by the direct impacts of higher fuel costs. High-carbon residual fuel has the largest projected price increases of all the transportation fuels, with increments of 19 cents per gallon in the 1990+24% case, 46 cents in the 1990+9% case, and 84 cents—almost 100 percent—in the 1990-3% case relative to the prices projected for 2010 in the reference case.

Approximately 15 to 17 percent of the drop in total fuel consumption in 2010 in the carbon reduction cases is attributed to aircraft, 6 to 7 percent to freight trucks, 4 to 6 percent to rail engines, and 1 percent to marine engines. The relative energy consumption shares for the major transportation modes and fuels do not vary significantly across the cases (Table 14).

Table 14. Projected Fuel Consumption Shares in the Transportation Sector by Fuel and Travel Mode, 2010
(Percent of Total)

Projection	Reference	1990 +24%	1990 +9%	1990 -3%
Fuel				
Gasoline	58	58	57	56
Distillate	19	19	20	21
Jet Fuel	16	16	16	16
Residual	4	4	4	5
Alternative Fuels	3	3	3	3
Travel Mode				
Light-Duty Vehicles	57	56	56	55
Freight Trucks	17	19	20	20
Aircraft	16	16	16	16
Rail	2	2	2	2
Marine	6	6	6	7

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

Both freight rail and domestic shipping efficiencies are projected to remain at reference case levels in the carbon reduction cases. Stock turnover will virtually cease, because rail ton-miles traveled are lower by 32 percent in 2010 in the 1990-3% case than in the reference case, and domestic shipping travel is 10 percent lower. Also, with the loss in revenue associated with the projected lower levels of travel, efficiency improvements will be difficult to achieve.

Alternative-Fuel Vehicles

According to consumer surveys, alternative-fuel vehicle sales are dependent on vehicle price, the cost of driving per mile, vehicle range, fuel availability, and commercial availability. In 2010, alternative-fuel vehicle sales as a

percent of light-duty vehicle sales are projected to increase to 11.98 percent in the 1990+24% case, 12.07 percent in the 1990+9% case, and 12.10 percent in the 1990-3% case from 11.91 percent in the reference case. The projected market shares for alternative-fuel vehicles are higher in the carbon reduction cases primarily because higher fuel prices would encourage consumers to take advantage of the higher fuel efficiencies and lower costs of driving projected for some alternative-fuel vehicles relative to gasoline vehicles. In addition, as the fuel efficiency of alternative-fuel vehicles improves, their driving range will increase.

Although alternative-fuel vehicle sales increase in percentage terms relative to the reference case in 2010, the actual number of alternative-fuel vehicles sold is expected to be smaller in the carbon reduction cases as a result of projected declines in light-duty vehicle sales overall. In the reference case alternative-fuel vehicle sales are projected to be approximately 1.79 million vehicles in 2010, whereas sales range between 1.68 and 1.75 million vehicles in the 1990+24%, 1990+9%, and 1990-3% cases. Similar results are projected for alternative-fuel consumption as a percentage of total transportation fuel use in 2010. Although the projected cost of driving per mile is lower for some alternative-fuel vehicles than for gasoline vehicles in some of the carbon reduction cases, it would still be more costly to drive an alternative-fuel vehicle than a gasoline vehicle. The purchase prices for most alternative-fuel vehicles still would be higher than those for conventional gasoline-powered vehicles, and additional driving costs would be incurred as the result of lower vehicle range and limited availability of fuel. Also, with higher projected fuel prices, vehicle-miles traveled are expected to be reduced for all vehicles, including those that use alternative fuels. Finally, the higher efficiencies of alternative-fuel vehicles would lower their total fuel consumption.

Sensitivity Cases

To examine the effects of technology improvements on energy use and prices, two sensitivity cases were analyzed for the transportation sector. The 1990+9% low technology sensitivity case was designed to hold average new vehicle fuel efficiencies at their 1998 levels throughout the forecast period. The implication is that stock turnover and travel reductions would have to compensate for the lack of fuel efficiency improvements in order to meet the carbon reduction targets. The 1990+9% high technology sensitivity case was designed to illustrate the effects of advanced fuel-saving technologies on transportation fuel efficiency, fuel consumption, and carbon emissions. This sensitivity case generally assumes that the costs of new technologies will be reduced, the marginal fuel efficiency benefits will be

Mass Transit and Carpooling

An issue for the transportation sector is whether the ratification of the Kyoto Protocol by the United States will lead to increased use of mass transit and carpooling. Automobile transportation is a major contributor to air pollution and greenhouse emissions, and a cutback in this area would be desirable. U.S. transportation patterns make this unlikely, however, in spite of the fact that the carbon reduction cases in this analysis project higher gasoline prices and lower levels of vehicle-miles traveled.

The United States consumes far more energy per capita for transportation than any other developed country, with U.S. passenger travel dominated by the automobile. In 1990, about 86 percent of passenger-miles were accounted for by automobiles, and mass transit accounted for less than 4 percent. The U.S. mass transit system includes buses, light rail, commuter rail, trolleys, subways, and an array of services such as van pools, subsidized taxis, dial-a-ride services, and shared minibus and van rides. Most cities of over 20,000 population have bus systems, and buses on established routes with set schedules account for over half of all public transit passenger trips. About 70 percent of all public transit trips in 1990, however, were in the 10 cities with rapid rail systems; 41 percent were in New York City and its suburbs.^a More recent statistics show that, as of 1995, mass transit accounted for only 0.8 percent of total fuel consumption in the transportation sector.^b

One reason for the low usage of mass transit in the United States and the concentration of use in major cities is urban development that has decreased the importance of historic central business districts (CBDs). Peak trips in general, and work trips in particular, have become diffuse in both origin and destination and thus not easily served by mass transit. In 1980 only 9 percent of the workers in urban areas and only 3 percent of workers living outside the central city were employed in the CBDs.^c (In Europe, where population densities are much higher, access to the workplace is much easier.) Other factors that work against mass transit in the United States are a past history of low gasoline prices, rising income levels, increasing numbers of women in the workforce with needs to drop off and pick up children at child care facilities, a move toward less standardization of work hours, and premiums placed on personal independence and time saved by driving rather than making use of mass transit. The same factors affect the use of carpooling.

Available statistics support the contention that the lower levels of vehicle-miles traveled associated with the carbon reduction cases do not necessarily imply increased use of mass transit. According to the American Public Transit Association, all forms of mass transit in terms of passenger-miles decline during periods of high fuel prices.^d Transit rail passenger-miles, which include light and heavy rail travel, declined by nearly 10 percent from 1973 to 1974 and by 5 percent from 1979 to 1981, even though real gasoline prices concurrently rose by 28 percent during both periods. Similar trends occurred in commuter rail, which experienced declines of almost 8 percent from 1980 to 1982. Between 1979 and 1982, transit bus passenger-miles declined by 7 percent and intercity bus travel by 1 percent, while real gasoline prices increased by 15 percent. A counter example is the period from 1973 to 1974, when transit bus use rose by 11 percent, and intercity bus passenger-miles increased by 5 percent. That period was unique, however, because gasoline was often either unavailable or required waits of up to several hours in gas station lines.

Carpooling trends, according to the U.S. Census Bureau, have declined from approximately 20 percent of the workforce in 1980 to just over 13 percent in 1990.^e The National Personal Transportation Survey has reported similar trends in vehicle occupancy rates, which indicate that from 1977 through 1990, vehicle occupancy rates have declined in commuting to and from work, from 1.30 to 1.14 person-miles per vehicle mile.^f These occupancy rates correspond to about one-third of total vehicle-miles traveled.

Because travelers do not take into account such externalities as reducing greenhouse gas emissions when making their transportation decisions, and past gasoline price increases do not seem to have had an impact, it is unlikely that mass transit and carpooling will increase in the United States without policy intervention factors such as higher gasoline taxes and urban and transportation planning that facilitates access to workplaces. There are differing opinions as to the role these factors could play in shaping travel patterns. If history, geography, income, and demographics are the primary determinants of travel patterns, policy may play only a minor role in changing energy use; but if instruments of public policy are primary travel determinants, then there is a large potential for policy to reduce energy use^g and alter mass transit and carpooling patterns.

^aU.S. Congress, Office of Technology Assessment, *Saving Energy in U.S. Transportation*, OTA-ETI-589 (Washington, DC, July 1994), pp. 5-6.

^bS. Davis, *Transportation Energy Databook No. 17*, prepared for the Office of Transportation Technologies, U.S. Department of Energy (Oak Ridge, TN: Oak Ridge National Laboratory, August 1997), p. 2-12.

^cU.S. Congress, Office of Technology Assessment, *Saving Energy in U.S. Transportation*, OTA-ETI-589 (Washington, DC, July 1994), pp. 5-6.

^dAmerican Public Transit Association, *1994-1995 Transit Fact Book* (Washington, DC, February 1995), pp. 106-107.

^eS. Davis, *Transportation Energy Databook No. 17*, prepared for the Office of Transportation Technologies, U.S. Department of Energy (data provided by the Journey-to-Work and Migration Statistics Branch, Population Division, U.S. Bureau of the Census) (Oak Ridge, TN: Oak Ridge National Laboratory, August 1997), p. 2-12.

^fFederal Highway Administration, *National Personal Travel Survey: 1990 NPTS Databook*, Vol. II, Chapter 7 (Washington, DC, November 1993).

^gU.S. Congress, Office of Technology Assessment, *Saving Energy in U.S. Transportation*, OTA-ETI-589 (Washington, DC, July 1994), pp. 5-6.

higher, and the advanced technologies will be commercially available at earlier dates than in the reference case or the carbon reduction cases.⁵²

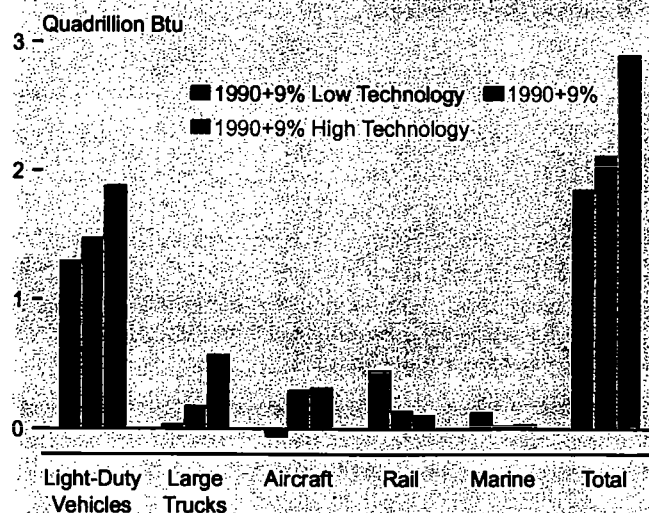
Higher projected carbon prices in the low technology sensitivity case lead to higher prices for all transportation fuels. In 2010, average fuel prices in the transportation sector are projected to be 14 percent higher in the 1990+9% low technology case than in the 1990+9% case. Gasoline prices are projected to be about 19 cents per gallon higher, jet fuel prices 21 cents per gallon higher, distillate fuel prices 22 cents per gallon higher, and residual fuel prices 26 cents per gallon higher.

Both fuel efficiency and travel are lower in the low technology case than in the 1990+9% case. Higher fuel prices would affect travel both directly and through their secondary impacts on the general levels of macroeconomic activity, disposable income, and freight movement. Of all travel modes, vehicle-miles traveled by light-duty vehicles are the most responsive to the higher fuel prices in the 1990+9% low technology case, with a 5.1-percent reduction from the projected level in the 1990+9% case in 2010. Air travel is reduced by a similar percentage, 5.5 percent, whereas smaller reductions are projected for freight, rail, and domestic shipping travel (0.8 percent, 3.1 percent, and 0.9 percent, respectively). Total projected fuel consumption in 2010 is higher in the low technology case than in the 1990+9% case, because fuel efficiency does not improve as rapidly.

With lower carbon prices and lower fuel prices in the 1990+9% high technology sensitivity case, more travel is expected than in the 1990+9% case. Despite the higher travel projection, however, more rapid improvements in new vehicle and stock fuel efficiencies result in lower fuel consumption in the high technology case, with higher fuel efficiencies outweighing the projected increases in vehicle-miles traveled that result from lower projected fuel prices. Average transportation fuel prices in 2010 are 9.6 percent lower in the 1990+9% high technology sensitivity case than in the 1990+9% case. Gasoline prices are projected to be 14 cents per gallon lower in 2010, jet fuel prices 13 cents per gallon lower, distillate fuel prices 14 cents per gallon lower, and residual fuel prices 16 cents per gallon lower.

Comparing across the travel modes, light-duty vehicles hold the greatest potential for reducing fuel consumption and carbon emissions with more rapid technology advances (Figure 64). Not only do light-duty vehicles

Figure 64. Projected Reductions From Reference Case Projections of Transportation



Source: Office of Integrated Analysis and Forecasting, National Energy Modeling System runs KYBASE.D080398A, FREEZE09.D080798A, FD09ABV.D080398B, and HITECH09.D080698A.

consume more fuel in total than the other vehicle types (more than 56 percent of all transportation fuel use in 1996), they also have the greatest potential for advanced technology penetration. In the 1990+9% high technology sensitivity case, light-duty vehicles are projected to account for 65 percent of the reduction in transportation fuel use relative to the 1990+9% case, compared with 20 percent for trucks, 11 percent for aircraft, 4 percent for rail, and 1 percent for marine.

Fuel-saving technologies for conventional light-duty vehicles in the high technology case are assumed to have approximately 50 percent lower marginal technology costs and 30 percent higher marginal fuel efficiency improvements than those for gasoline vehicles. All conventional technologies achieve lower sales penetration rates in the high technology case than in the 1990+9% case, due to lower fuel prices (Table 11); however, because the marginal fuel efficiencies are also higher than in the 1990+9% case, the total fuel efficiency improvement is larger in the high technology case.

With lower marginal costs and earlier introduction dates in the high technology sensitivity, most new aircraft technologies reach significantly higher penetration rates than in the 1990+9% case with reference technology (Table 12). The penetration rate for ultra-high-bypass engines is lower in the high technology case, because they are partially displaced by advanced thermodynamic engines. Substantial fuel efficiency improvements

⁵²High technology assumptions were derived from the following sources: light-duty vehicle conventional technology attributes from J. DeCicco and M. Ross, *An Updated Assessment of the Near-Term Potential for Improving Automotive Fuel Economy*, American Council for an Energy-Efficient Economy (Washington, DC, November 1993); light-duty alternative fuel vehicle cost and performance attributes from U.S. Department of Energy, Office of Transportation Technologies, *Program Analysis Methodology: Final Report—Quality Metrics 98 Revised* (Washington, DC, April 1997); freight trucks from U.S. Department of Energy, Office of Transportation Technologies, *OHVT Technology Roadmap* (Washington, DC, October 1997), and conversations with Frank Stodolsky, Argonne National Laboratory, and Mr. Suski, American Trucking Association; air from conversations with Glenn M. Smith, National Aeronautics and Space Administration.

result from the penetration of weight-reducing materials, advanced aerodynamics, and advanced thermodynamic engines, which can potentially achieve efficiency improvements of 15 percent, 18 percent, and 20 percent, respectively.

Fuel efficiency for new freight trucks rises by more than 1 mile per gallon by 2010 in the high technology case relative to the 1990+9% case, primarily because of the penetration of the turbo compound diesel, LE-55 heat engine, improved tires and lubricants, and electronic engine controls on heavy-duty trucks (Table 13). Both advanced engine technologies—the turbo compound diesel and LE-55 heat engine—are diesel technologies, which improve fuel economy by 10 percent and 23 percent, respectively.

The high technology case assumes that the U.S. Department of Energy Office of Transportation Technologies program goals⁵³ for alternative-fuel vehicle cost and performance improvements will be met. Generally these program goals include a reduction of 50 to 66 percent in the marginal price difference between comparable gasoline vehicles and electric or electric hybrid vehicles, and a 75-percent reduction in the difference for fuel cell vehicles. Fuel efficiency improvements are assumed to be 230 to 300 percent greater for electric and electric hybrid vehicles and 250 percent greater for fuel cell vehicles than for gasoline vehicles. These fuel efficiency improvements are also assumed to result in travel ranges that are 57 percent greater for electric hybrid vehicles and 20 percent greater for fuel cell vehicles than the range for similar sized gasoline vehicles. Total alternative-fuel vehicle sales in the 1990+9% high technology case in 2010 are projected to make up almost 19 percent of all light-duty vehicle sales, compared with just over 11 percent in both the reference and 1990+9% cases. The projected shares for different alternative-fuel vehicle types are shown in Table 15.

In order for alternative-fuel vehicles to displace large quantities of gasoline use, they must penetrate the market early enough to replace gasoline vehicles and then sustain high sales volumes. Displacement of gasoline may be limited, however, because the vast majority of the projected increase in alternative-fuel vehicle sales consists of alcohol flexible-fuel vehicles, which are expected to have only slightly higher fuel efficiencies than gasoline vehicles. They will also use only 15-percent blends of E85 and M85 and will more frequently be consuming gasoline than the alternative fuel.

Table 15. Projected Alternative-Fuel Vehicle Shares of New Light-Duty Vehicle Sales by Type in the High Technology Cases, 2010
(Percent)

Vehicle Type	Sales Share
Flex-Fuel Methanol and Ethanol	9.1
Dedicated Methanol and Ethanol	2.1
Electric	1.2
Hybrid Electric/Gasoline	1.3
Hybrid Electric/Diesel	1.6
Bi-Fuel CNG and LPG	1.0
Dedicated CNG and LPG	2.5
Fuel Cell Gasoline	0.02
Fuel Cell Methanol	0.01
Diesel Direct Injection	2.1

CNG = compressed natural gas. LPG = liquefied petroleum gas (propane).

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

For alternative-fuel vehicles to maintain a larger share of the vehicle market, they will need to have lower costs, higher performance, and earlier availability dates than projected in this analysis. Simultaneously, higher fuel prices will be needed to send market signals to both consumers and vehicle producers. The high technology case indicates both of these points: fuel-saving technology becomes available and is purchased in 2005, but its advantage is quickly offset by reductions in gasoline consumption, which lead to lower gasoline prices. Consequently, as fuel prices begin to decline after 2008, consumers tend to demand higher performance and larger vehicles, and manufacturers respond by designing and producing larger, more profitable models, such as sport utility vehicles.

⁵³U.S. Department of Energy, Office of Transportation Technologies, *Program Analysis Methodology: Final Report—Quality Metrics 98* (Washington, DC, April 16, 1997).