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.

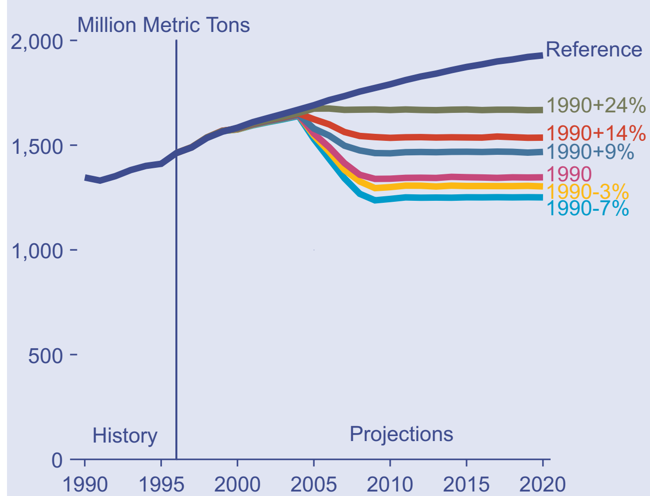
Carbon Reduction Cases

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.

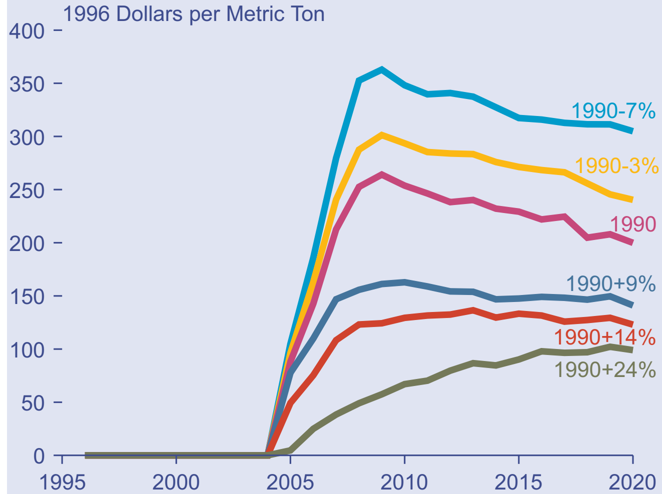
As indicated in Figure 1, some carbon reductions occur before 2005, based on anticipatory behavior, primarily as a result of forward-looking capacity planning decisions assumed in the electricity industry. For the electricity industry, where fossil fuel purchases are a predominant operating cost, planners 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

[22] The 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.

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.

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

Summary Indicators	1996	2010 Reference	2010 1990 +24%	2010 1990 +9%	2010 1990 -3%	2020 Reference	2020 1990 +24%	2020 1990 +9%	2020 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**

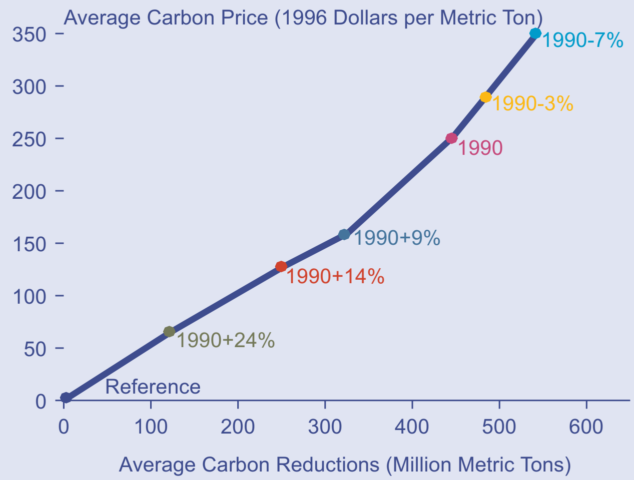
[a]Includes net electricity imports, methanol, and liquid hydrogen.

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.

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 368 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 50 percent above the reference case level.

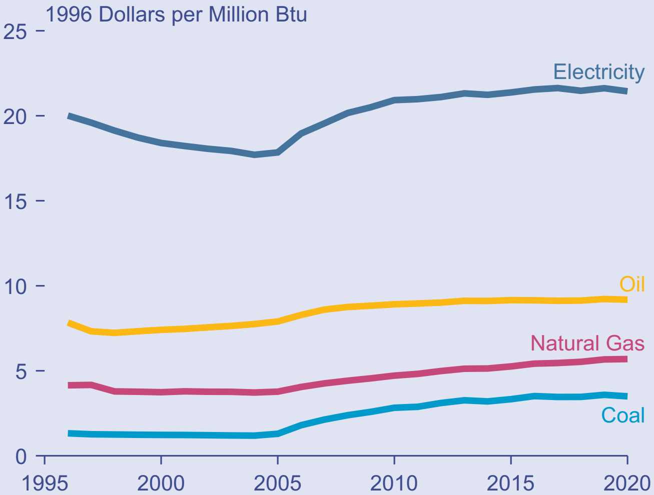
Compared with the changes in coal and natural gas prices, the average increase in electricity prices is relatively low. Larger amounts of electricity would be generated from renewable and nuclear power, for which fuel costs are unaffected by carbon prices. In addition, cost-of-service electricity pricing 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

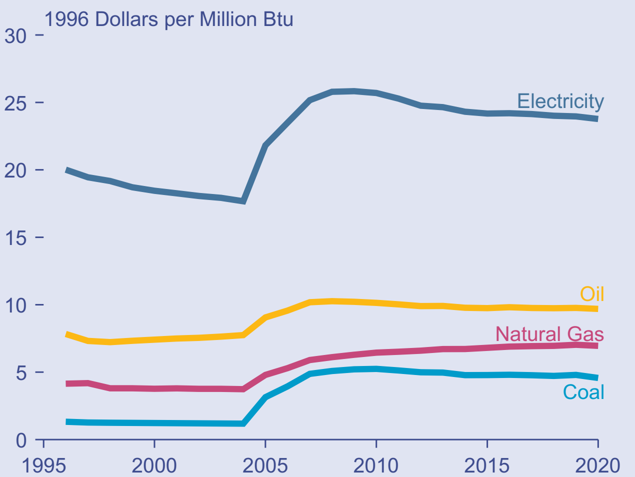
[23] A related factor influencing the effect of carbon prices on gasoline demand is that the price of gasoline already includes Federal and State excise taxes averaging 37 cents per gallon in 1996, equivalent to a carbon permit price of $155 per metric ton. When additional carbon permit prices are included 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



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

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

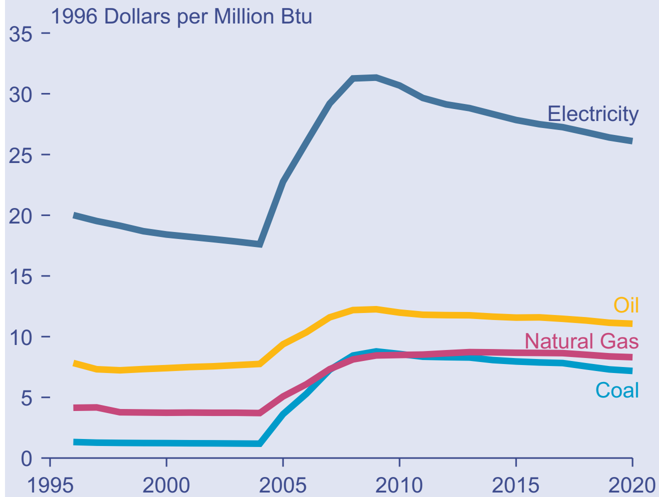


Source: Office of Integrated Analysis and Forecasting, National Energy Modeling System run FD09ABV.D080398B.

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.

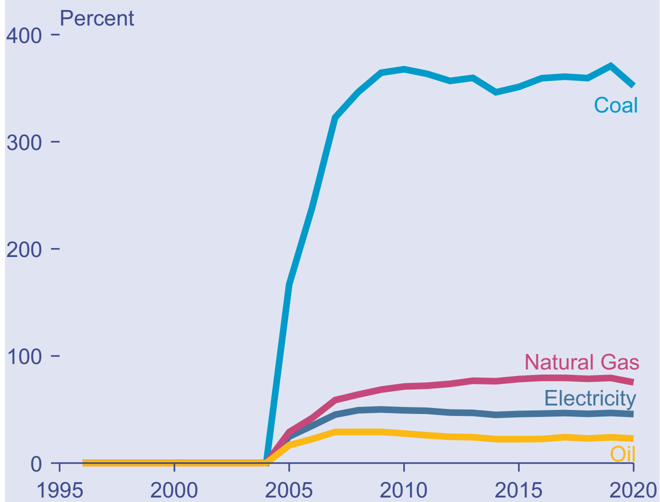
Natural gas demand is higher in the carbon reduction cases relative to the reference case primarily because of higher use in the electricity generation sector, offsetting reductions in the end-use demand sectors. As a result, the average wellhead price of natural gas, excluding any carbon price, is higher 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



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

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

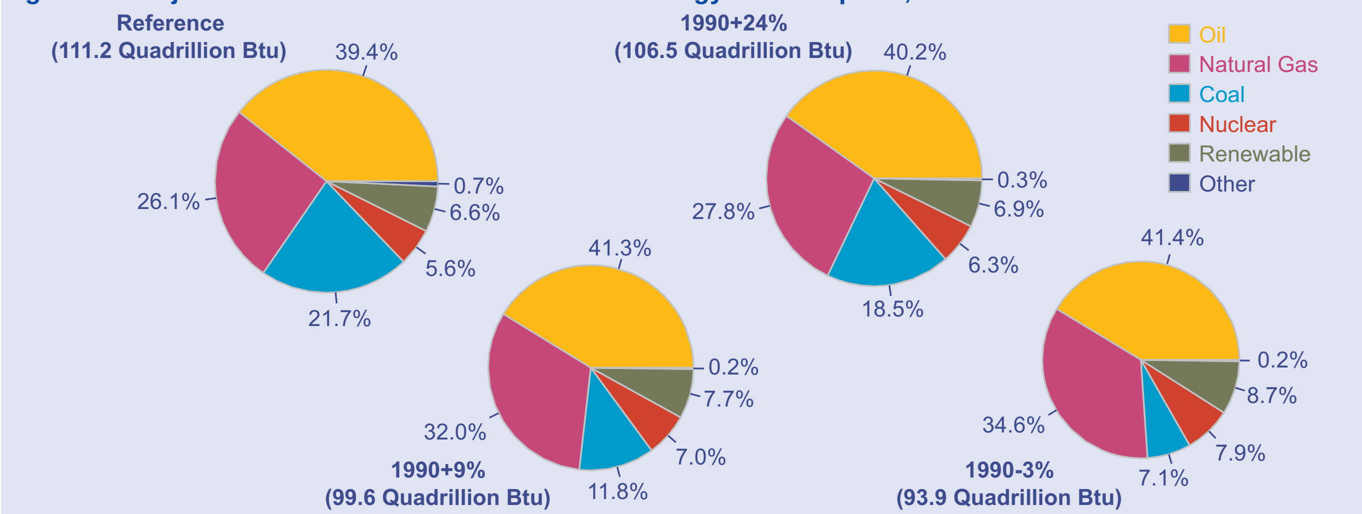


Source: Office of Integrated Analysis and Forecasting, National Energy Modeling System runs KYBASE.D080398A and FD09ABV.D080398B.

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

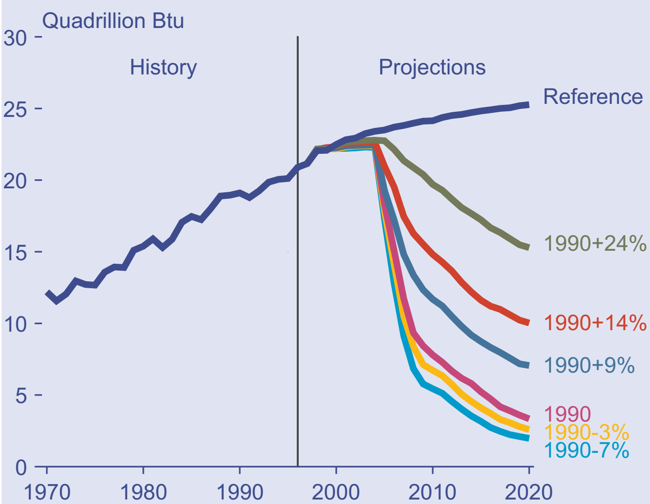
Figure 8. Projections of Fuel Shares of Total U.S. Energy Consumption, 2010



Note: "Other" includes net electricity imports, methanol, and liquid hydrogen.

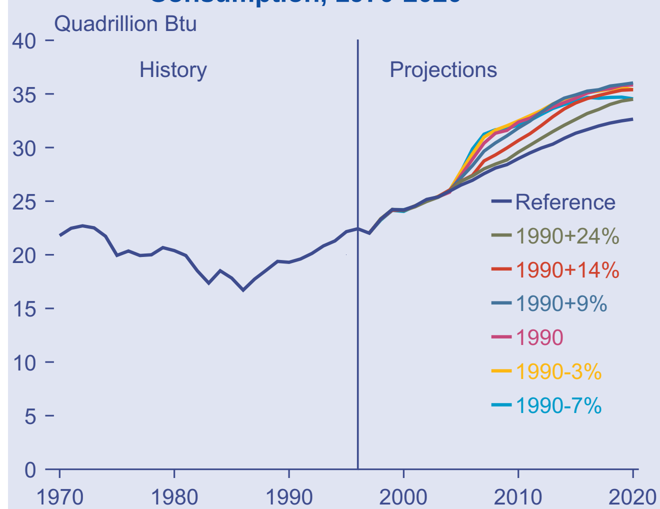
Source: Office of Integrated Analysis and Forecasting, National Energy Modeling System runs KYBASE.D080398A, FD24ABV.D080398B, FD09ABV.D080398B, and FD03BLW.D080398B.

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.

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



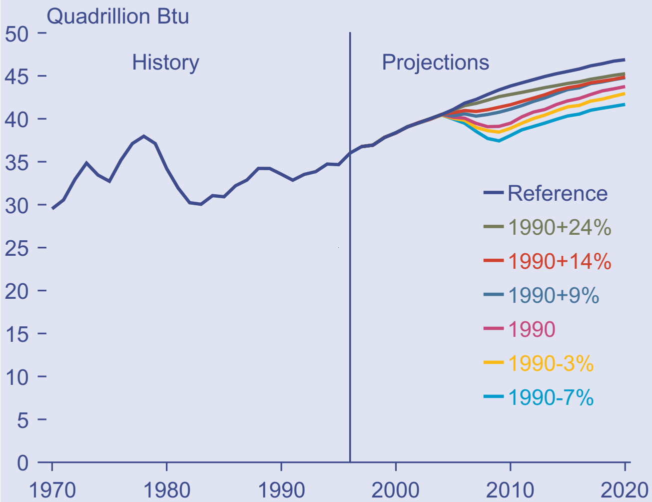
Sources: **History:** Energy Information Administration, *Annual Energy Review 1997*, DOE/EIA-0384(97) (Washington, DC, July 1998). **Projections:** Office of Integrated Analysis and Forecasting, National Energy Modeling System runs KYBASE.D080398A, FD24ABV.D080398B, FD1998.D080398B, FD09ABV. D080398B,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

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 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 gasoline demand, accounting for 43 percent of total

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



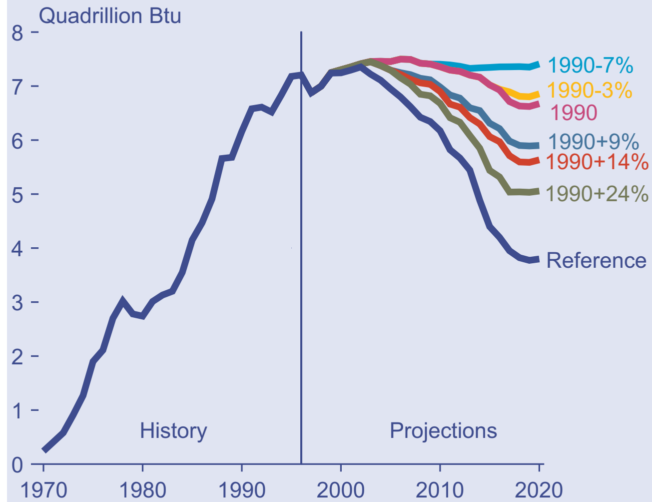
Sources: **History:** Energy Information Administration, *Annual Energy Review 1997*, DOE/EIA-0384(97) (Washington, DC, July 1998). **Projections:** Office of Integrated Analysis and Forecasting, National Energy Modeling System runs KYBASE.D080398A, FD24ABV.D080398B, FD1998.D080398B, FD09ABV.D080398B,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

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).

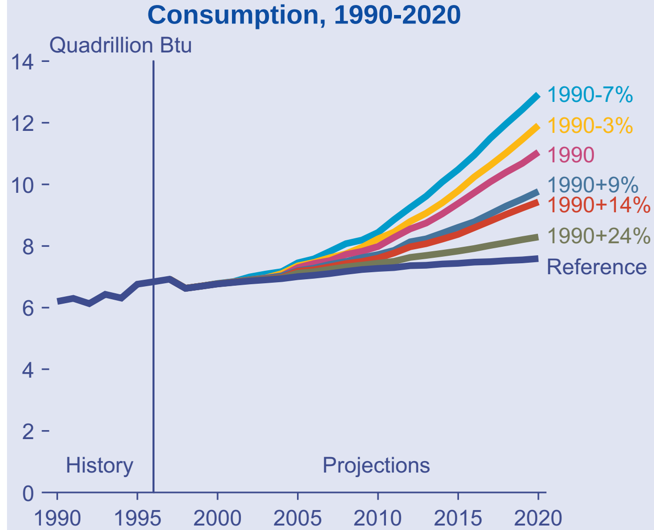
Consumption of renewable energy, which results in no net carbon emissions, is projected to be higher with carbon reduction targets (Figure 13). Most of the increase is in electricity generation, primarily with additions to wind energy systems and an increase in the use of biomass (wood, switchgrass, 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 compliance period, reflecting a relatively prolonged

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

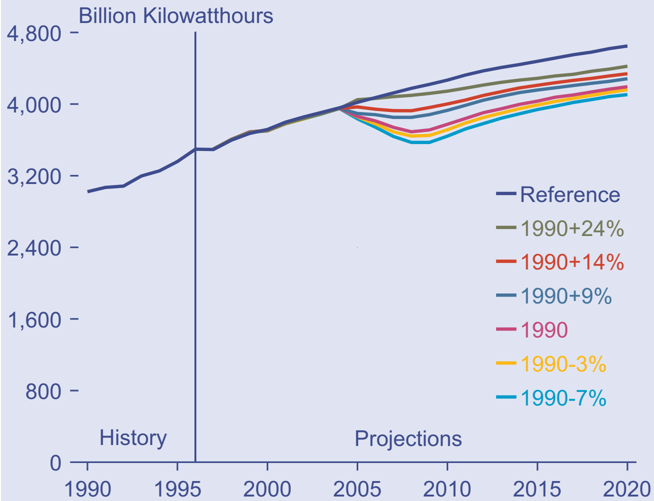


Sources: **History:** Energy Information Administration, *Annual Energy Review 1997*, DOE/EIA-0384(97) (Washington, DC, July 1998). **Projections:** Office of Integrated Analysis and Forecasting, National Energy Modeling System runs KYBASE.D080398A, FD24ABV.D080398B, FD1998.D080398B, FD09ABV.D080398B,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

period of market penetration as renewable technology costs and performance improve over time.

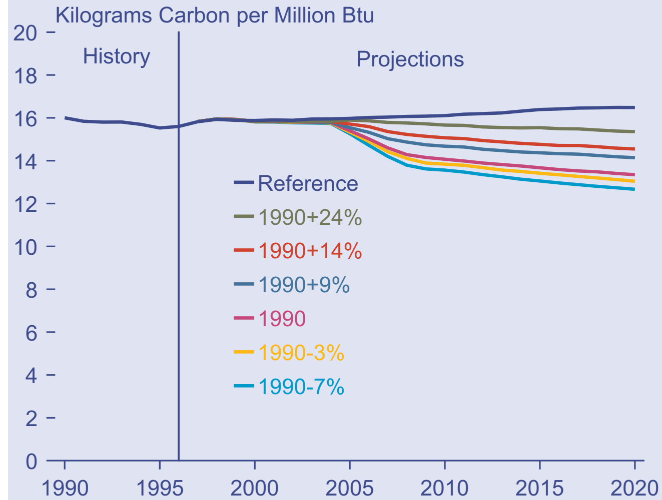
Electricity generation, which accounted for 35 percent of energy-related carbon emissions in 1996, is also significantly lower across all the cases (Figure 14). In the 1990-3% case, electricity sales in 2010 are 15 percent below the reference case projection, with percentage reductions of about 13 percent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

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.

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.

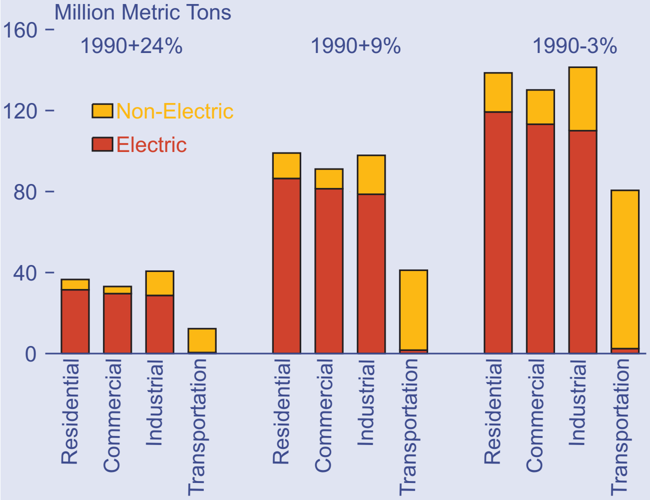
As the results have indicated, reductions in carbon emissions are also met through substitution away from carbon-intensive fuels, not just through energy efficiency improvements and reductions in energy services. The degree to which this occurs is indicated by the change in aggregate carbon intensity 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.

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



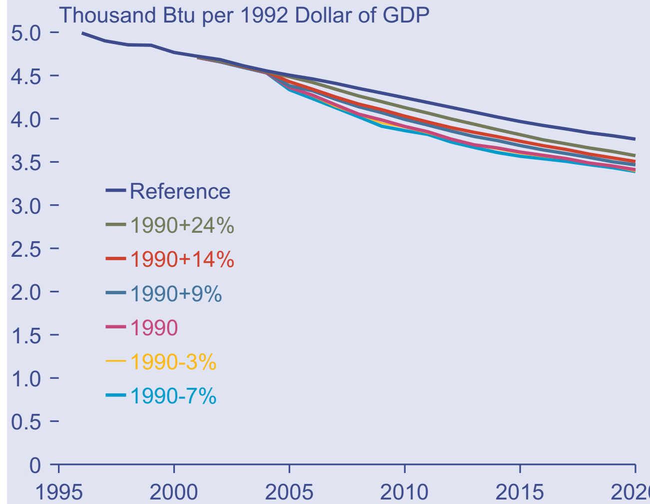
Note: Electricity emissions are from the fuels used to generate electricity and are attributed to the sectors relative to their shares of total electricity consumption.

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.

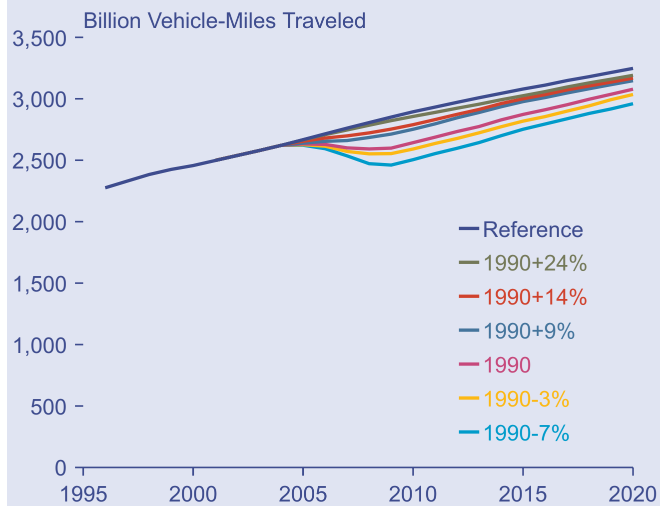
Carbon reductions in the transportation sector occur primarily as the result of reduced travel and the purchase of more efficient vehicles in response to higher energy prices. Compared with the reference case, light-duty vehicle travel (cars, vans, pickup trucks, and sport-utility vehicles) in 2010 is 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

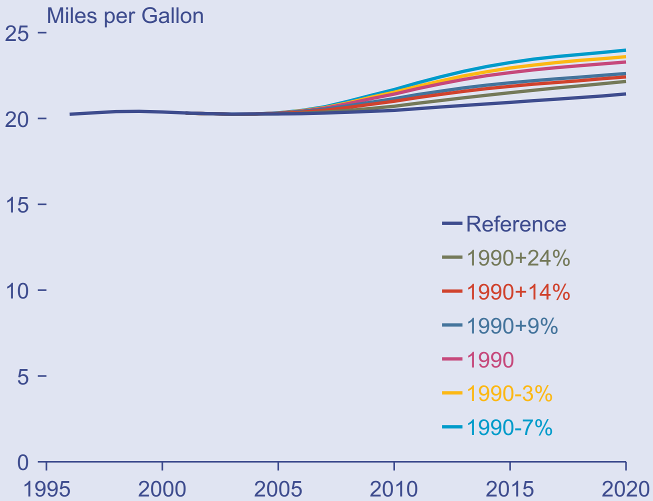


Source: Office of Integrated Analysis and Forecasting, National Energy Modeling System runs KYBASE.D080398A, FD24ABV.D080398B, FD1998.D080398B, FD09ABV.D080398B, FD1990.D080398B, FD03BLW.D080398B, and FD07BLW.D080398B..

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.

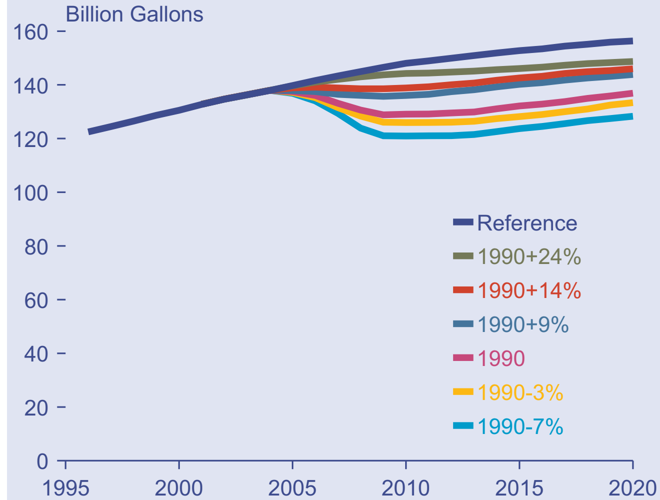
In the residential and commercial sectors, higher energy prices encourage investments in more efficient equipment and building shells and also reduce the demand

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.

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.

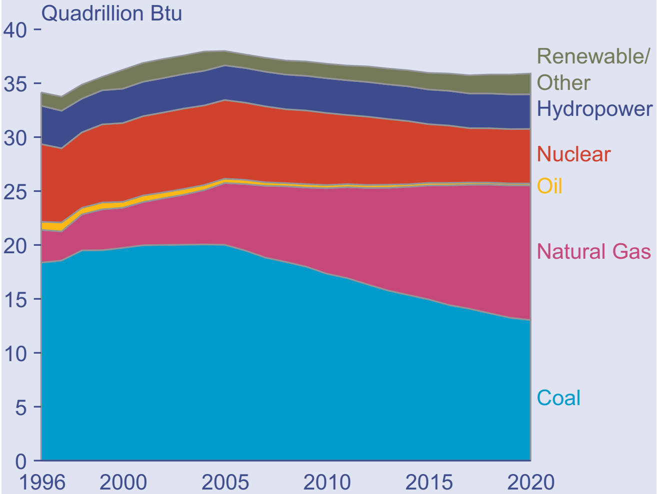
for energy services. In the residential sector, delivered energy use per household in 2010 drops by 4 percent in the 1990+24% case, 10 percent in the 1990+9% case, and 15 percent in the 1990-3% case compared with the reference case. Energy consumption for space conditioning accounts for 59 to 62 percent 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, 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.

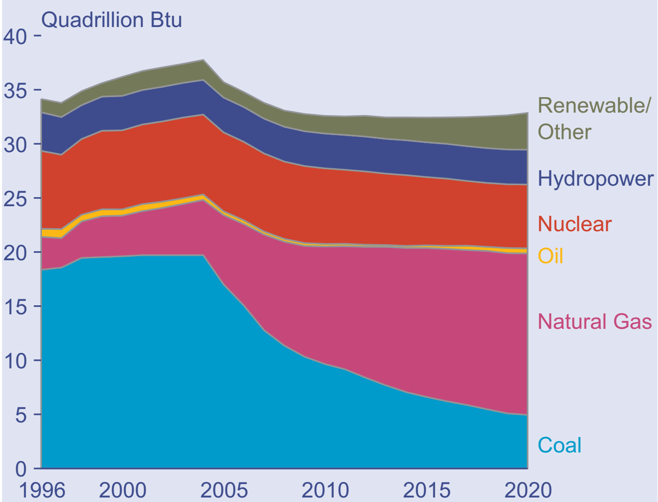
The mix of fuels used for electricity generation is projected to change rapidly as new plants come on line (Figures 21, 22, and 23). In the aggregate, cumulative investments by generators to reduce carbon emissions tend to bring down the carbon price over time. A slowdown in most new plant additions 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

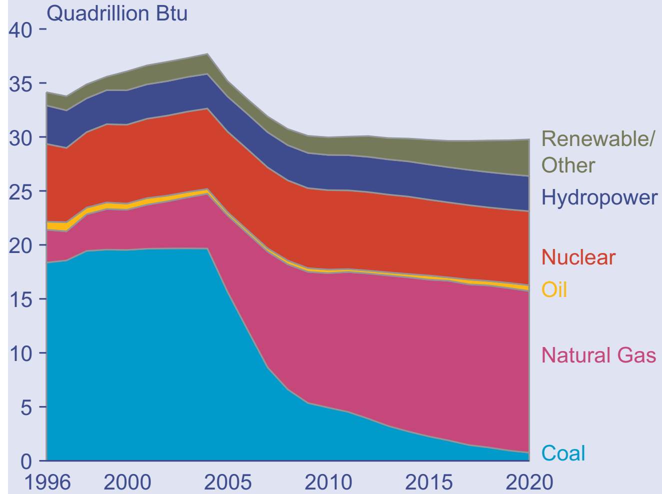


Source: Office of Integrated Analysis and Forecasting, National Energy Modeling System run FD09ABV.D080398B.

Sensitivity Cases

Among the sources of uncertainty in the effects of carbon mitigation polices 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.

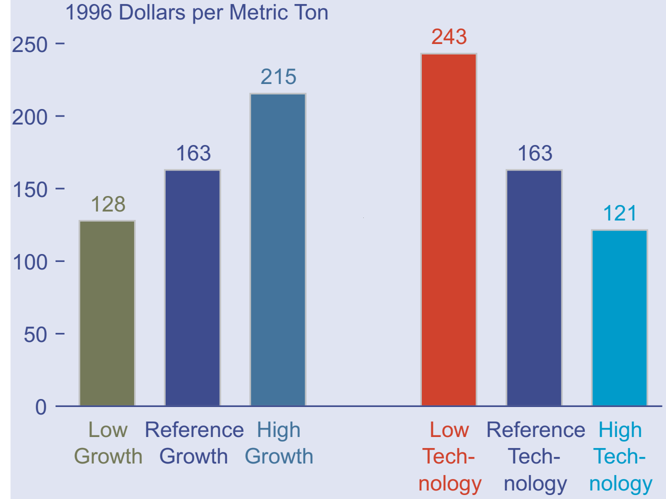
To reflect the uncertainty of potential economic growth, high and low economic growth sensitivity cases were analyzed against the 1990+9% case, using the same higher and lower economic growth assumptions as in *AEO98*. With higher economic growth, the industrial output and energy service demand are higher. 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 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.

Figure 24. 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.

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.