3. End-Use Energy Demand

Background

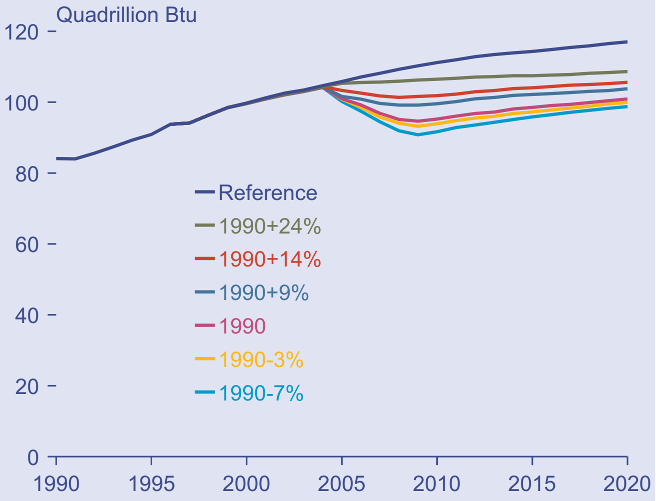
This chapter provides in-depth analyses of the carbon emissions reduction cases for the four end-use demand sectors—residential, commercial, industrial, and transportation. Additional analyses are included for a number of alternative cases, including low and high technology sensitivity cases, which have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

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.

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 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.

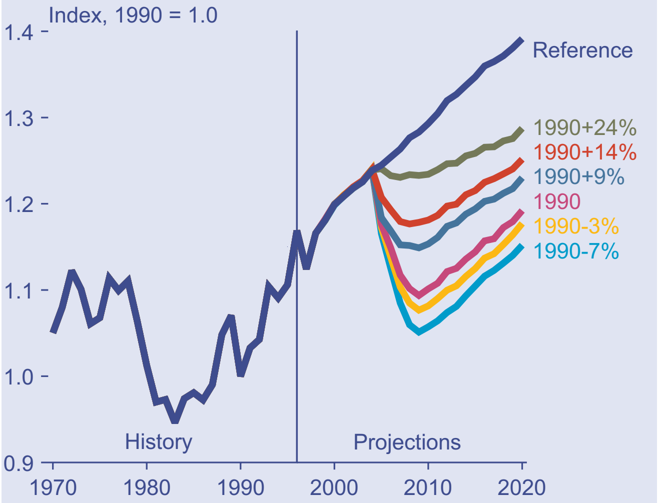
Technological advances and availability play a large role in determining future energy savings and carbon emission reductions. Even in today's marketplace, there exist many efficient technologies that could substantially reduce energy consumption and carbon emissions, however the relatively high initial 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, and FD07BLW.D080398B.

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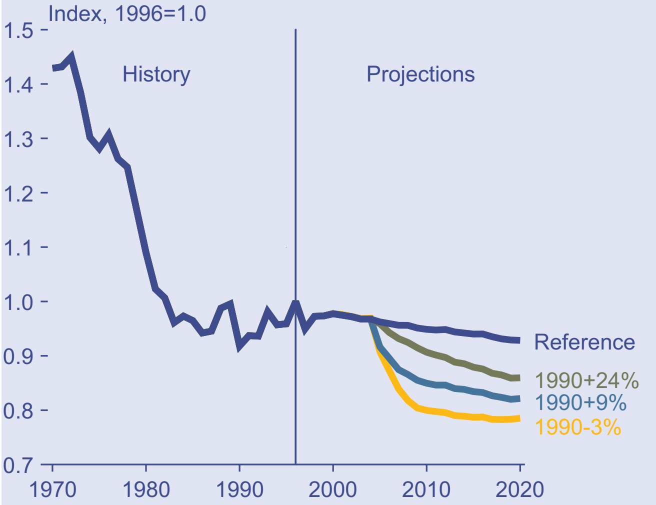
[24] The "hurdle rate" for evaluating energy efficiency investments has also been referred to as the "implicit discount rate" (i.e., the empirically based rate required to simulate actual purchases—the one implicitly used). These rates are often much higher than would be expected if financial considerations 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

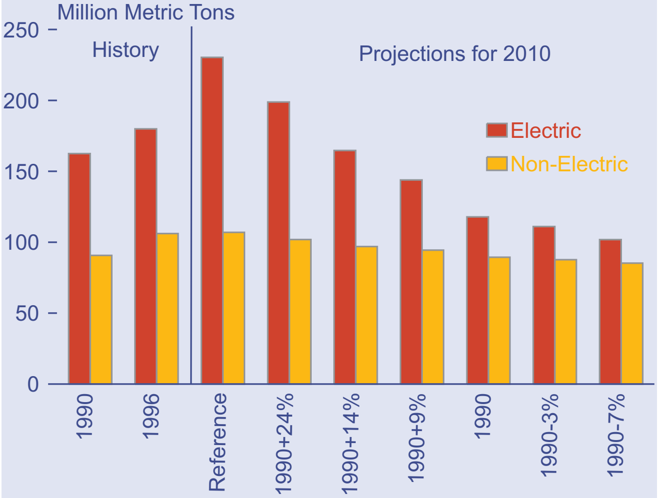


Sources: **History:** Energy Information Administration, *State Energy Data Report 1995*, DOE/EIA-0214(95) (Washington, DC, December 1997) and Data Resources Incorporated. **Projections:** Office of Integrated Analysis and Forecasting, National Energy Modeling System runs KYBASE.D080398A, FD24ABV.D080398B,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

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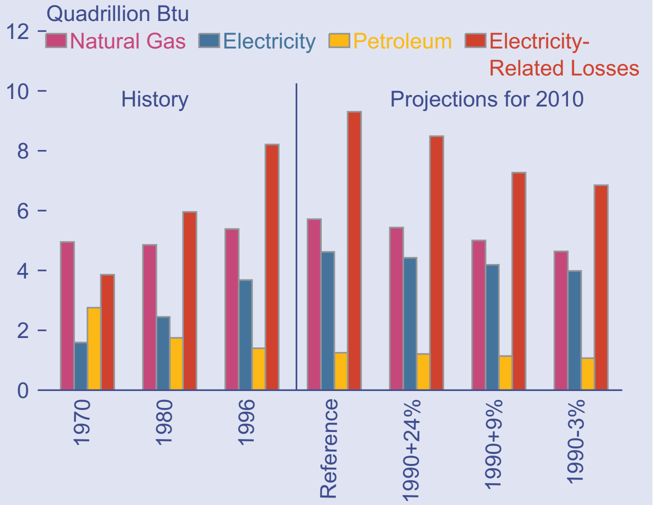
[25] The long-run elasticities reflect the effects of altered prices after 20 years for the last year of the forecast, 2020.

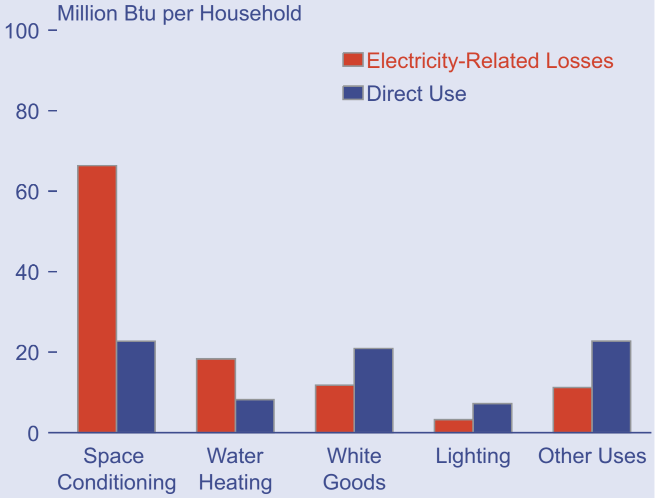
[26] U.S. Bureau of the Census, *Construction Reports*, series C20.

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



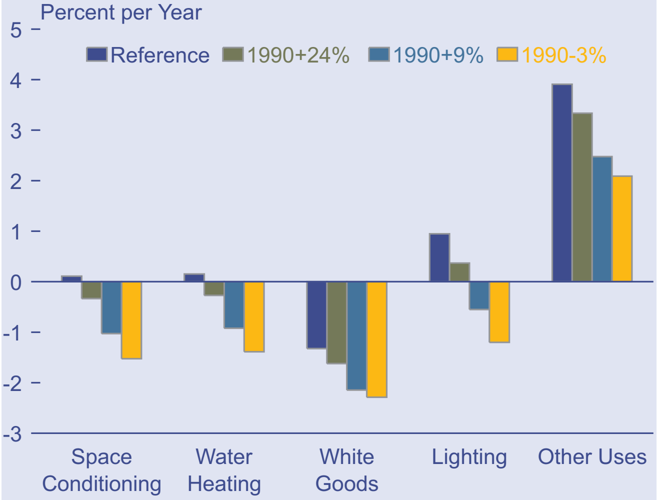
Sources: **History:** Energy Information Administration, *State Energy Data Report 1995*, DOE/EIA-0214(95) (Washington, DC, December 1997). **Projections:** Office of Integrated Analysis and Forecasting, National Energy Modeling System runs KYBASE.D080398A, FD24ABV.D080398B, FD09ABV.D080398B, and FD03BLW.D080398B.

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..

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 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 standards[28] 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)

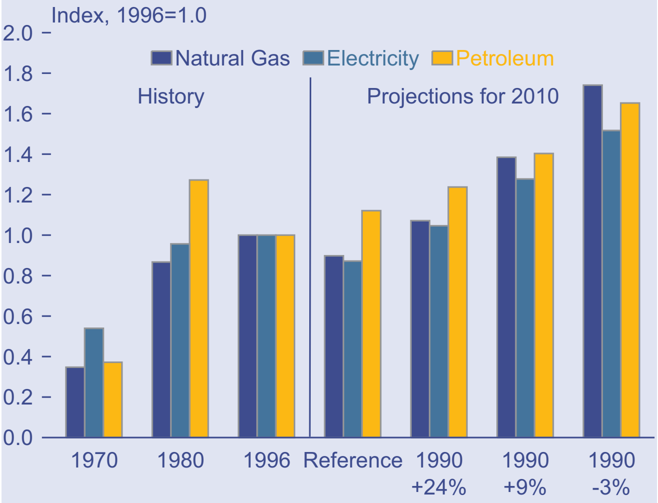
Technology	1990+24%	1990+9%	1990-3%
Air-Source Heat Pump	1.3	3.6	5.7
Electric Water Heater	0.3	2.4	13.6
Natural Gas Water Heater . .	1.1	3.7	4.8
Building Shell	1.0	3.3	5.5

Source: 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, and 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,

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

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

[30] Energy 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 inshipments 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.[f] 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.

[a] Dispersed 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.

[b] Energy 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.

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

[d] When 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.

[e] Fred Kemp, Manager of Government Programs, International Fuel Cells (South Windsor, CT), personal communication, August 1998.

[f] *New York Times* (June 17, 1998).

Table 5. Cost and Efficiency Indexes of Best Available Technologies for Selected Residential Appliances, 2015

(1998 Values = 1.00)

	Cost			Efficiency		
Technology	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).

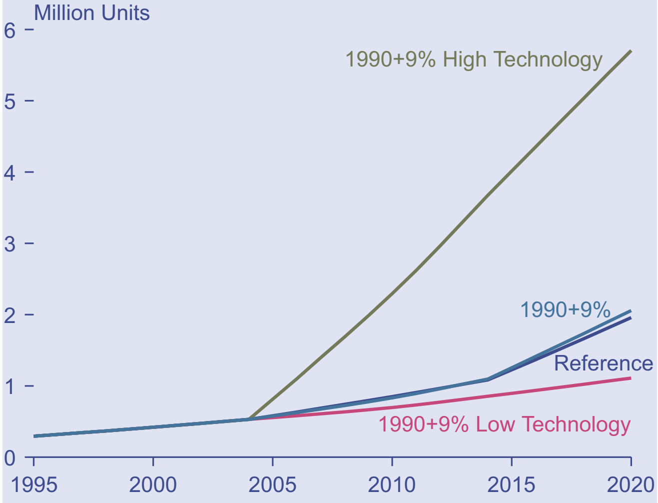
while ground-source heat pumps, which do not realize much gain in efficiency, are assumed to decline in cost by 44 percent in the high technology case by 2015.

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.

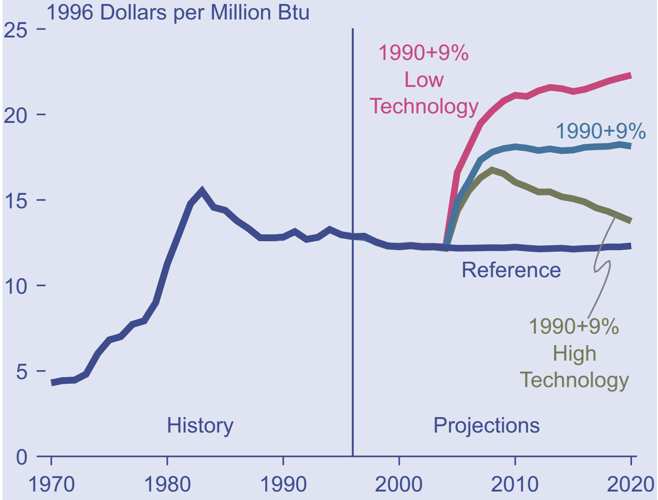
Energy fuel expenditures are a good indication of the success that technological advancement achieves in

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.

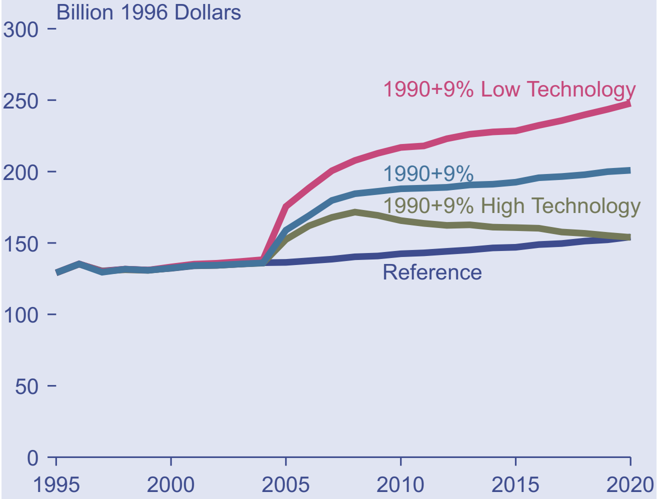
Figure 34. Average Residential Sector Energy Prices, 1995-2020



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, and 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

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[31] Energy Information Administration, *Housing Characteristics 1993*.

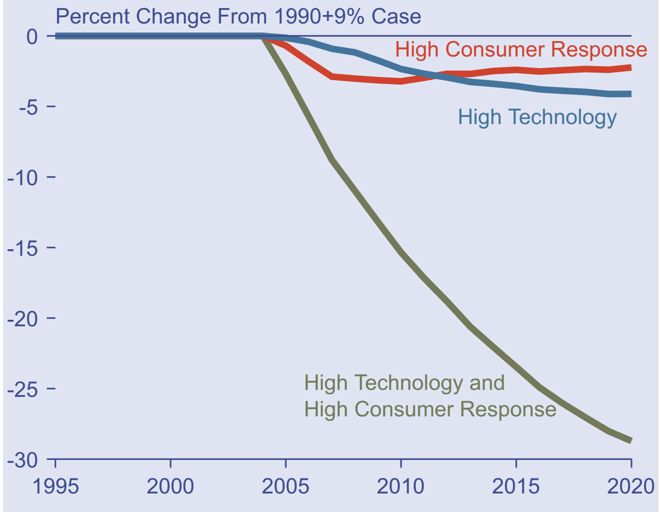
[32] Assumptions include lowering hurdle rates to 15 percent real, increasing the price sensitivity parameters to switch fuels, increasing short-run price elasticities from -0.25 to -0.40, and decreasing miscellaneous electricity penetration.

[33] Energy 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 being equal.

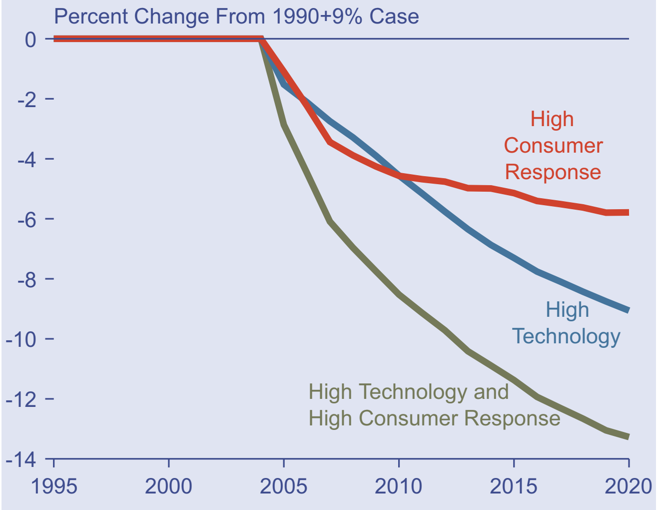
Figure 36. Changes From Reference Case Projections of Energy Intensity for Residential Water Heating in Three Sensitivity Cases, 1995-2020



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.

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[34] Intensity 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. Equipment 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

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[35] General 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

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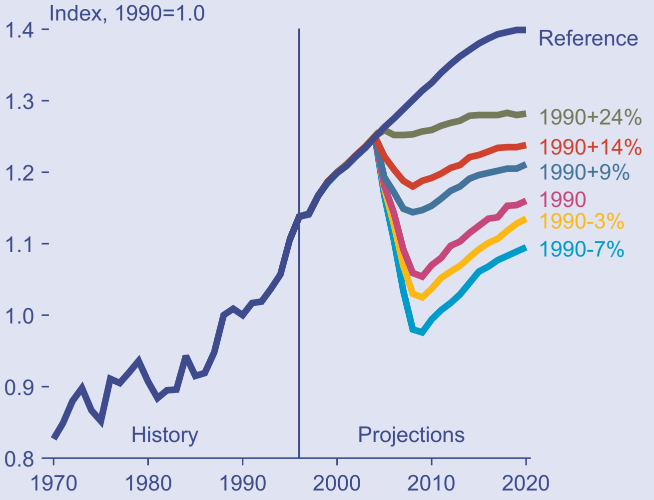
[36] The hurdle rates consist of both financial and nonfinancial components, as described for the residential sector.

[37] For the purposes of this study, the financial portion of the hurdle rates is considered to be 15 percent in real terms.

[38] Current 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).

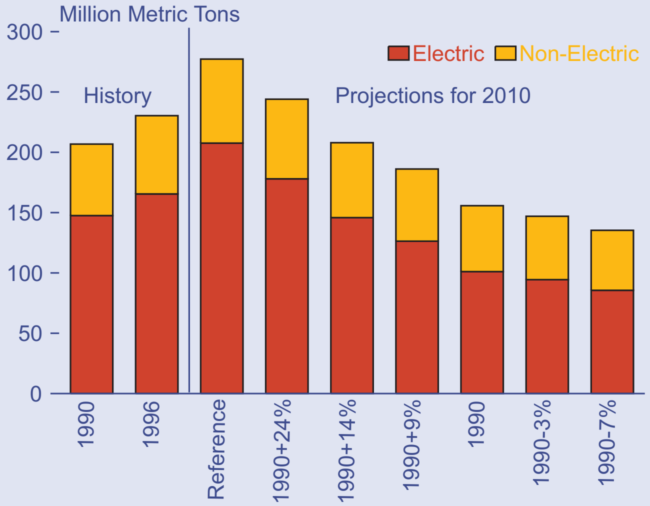
[39] As in the residential model, the long-run elasticities are for 2020 and represent the effects after 20 years of altered price regimes.

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, and FD07BLW.D080398B.

Figure 39. Commercial Sector Carbon Emissions, 1990, 1996, and 2010

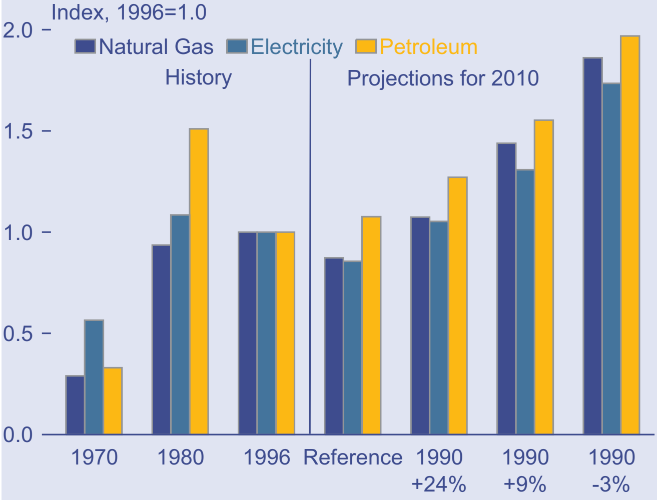


Note: Electricity emissions are from the fossil fuels used to generate the electricity used in this sector.

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

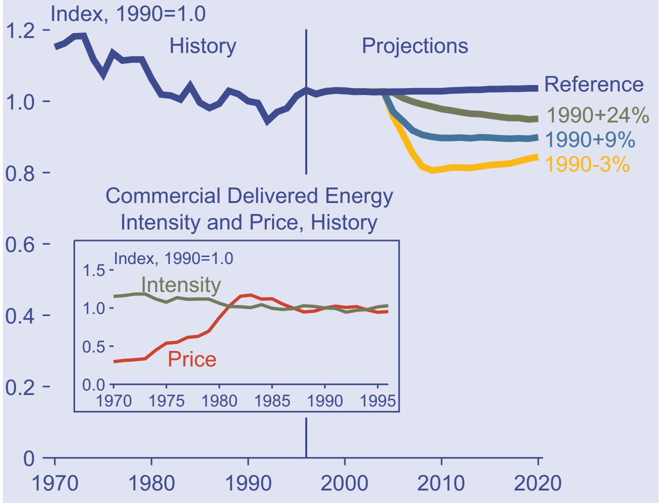


Sources: **History:** Energy Information Administration, *State Energy Price and Expenditure Report 1994*, DOE/EIA-0376(94) (Washington, DC, June 1997). **Projections:** Office of Integrated Analysis and Forecasting, National Energy Modeling System runs KYBASE.D080398A, FD24ABV.D080398B, FD09ABV.D080398B,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



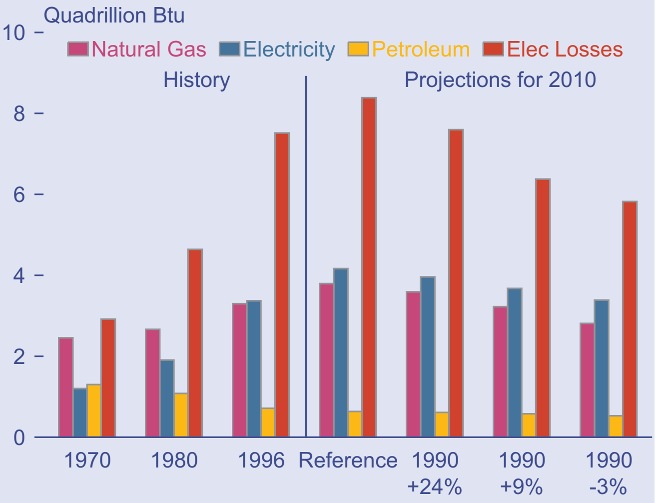
Sources: **History:** Energy Information Administration (EIA), *State Energy Data Report 1995*, DOE/EIA-0214(95) (Washington, DC, December 1997); EIA, *State Energy Price and Expenditure Report 1994*, DOE/EIA-0376(94) (Washington, DC, June 1997); and EIA, Commercial Buildings Energy Consumption Survey 1992 Public Use Data. **Projections:** Office of Integrated Analysis and Forecasting, National Energy Modeling System runs KYBASE. D080398A, FD24ABV.D080398B, FD09ABV.D080398B, and 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, and 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

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

Photovoltaics and Fuel Cells

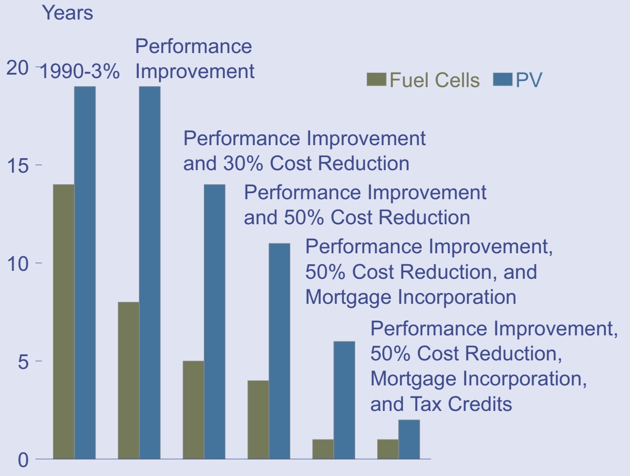
In every carbon reduction case considered in this report, neither photovoltaics nor fuel cells are projected to gain significant market penetration, because of their high costs. With payback periods of more than 20 years, the success of these technologies seems largely dependent on reducing production 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, 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 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.

Projected Payback Periods for Photovoltaic and Fuel Cell Purchases Under Different Assumptions, 2010



Source: Energy Information Administration, Office of Integrated Analysis and Forecasting.

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.

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[a] Energy 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).

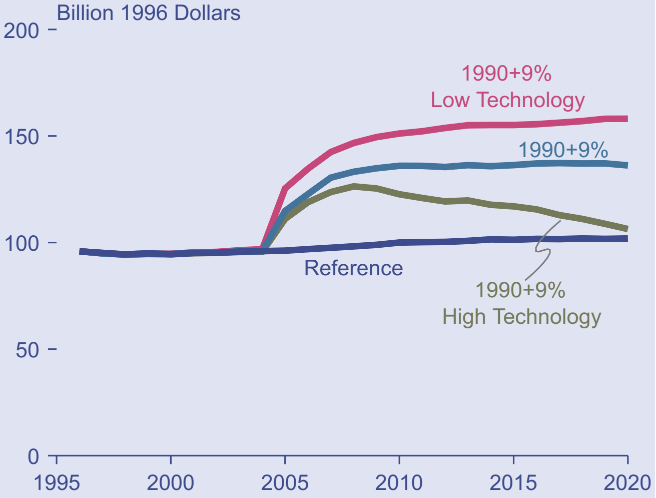
[b] Paul Maycock, PV Energy, personal communication, August 1998.

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.

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.

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).

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

[a] The 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.

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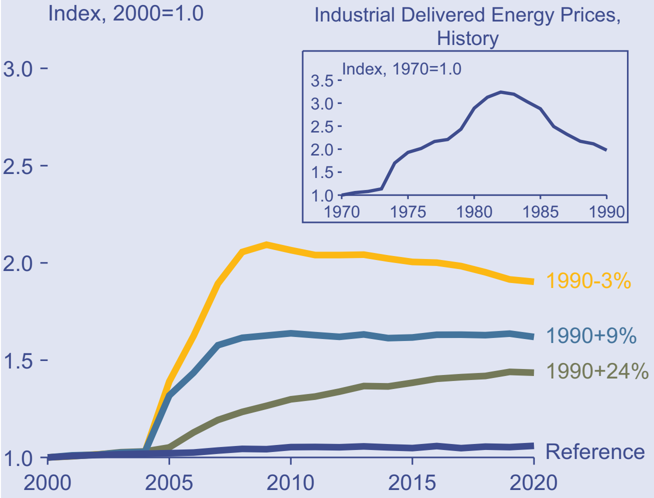
[41] Calculated form U.S. Department of Commerce, *1995 Annual Survey of Manufactures*, pp. 1-7 and 1-36.

[42] For 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.

[43] The 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

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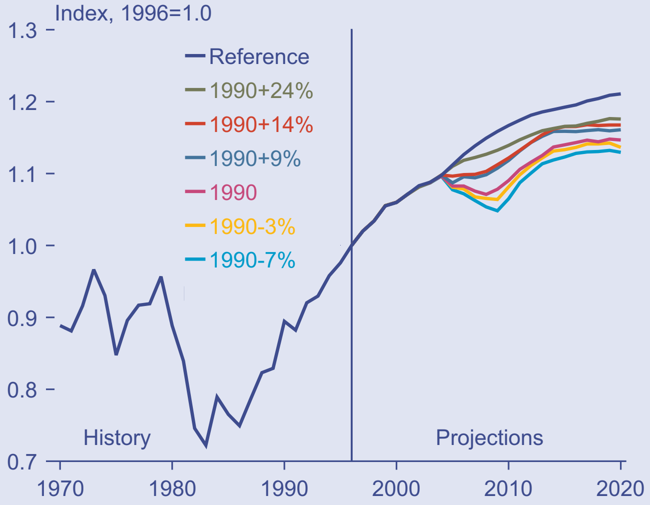
[44] Council of the Economic Advisers, *Economic Report of the President* (Washington, DC, February 1995), p. 381.

[45] For 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

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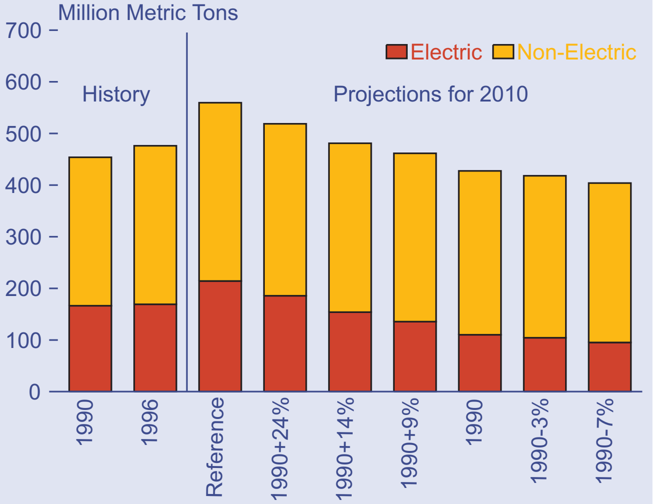
[46] Energy Information Administration, *Manufacturing Consumption of Energy 1994*, DOE/EIA-0512(94) (Washington, DC, December 1997), p. 168.

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.

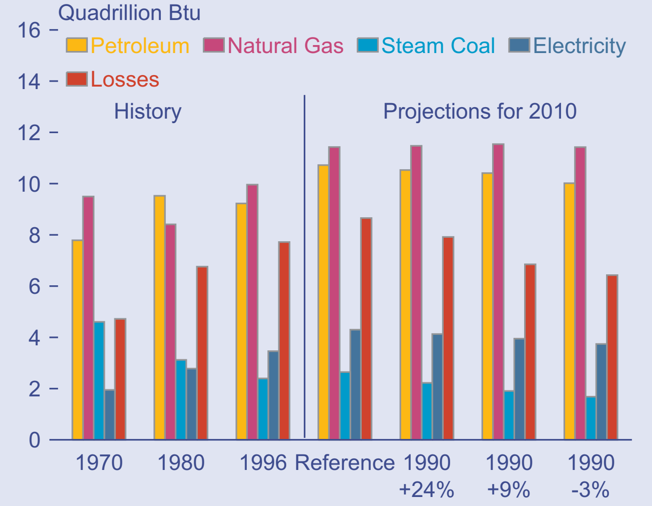
Sources: **History:** Energy Information Administration, *Emissions of Greenhouse Gases in the United States 1996*, DOE/EIA-0573(96) (Washington, DC, October 1997). **Projections:** Office of Integrated Analysis and Forecasting, National Energy Modeling System runs KYBASE.D080398A, FD24ABV.D080398B,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

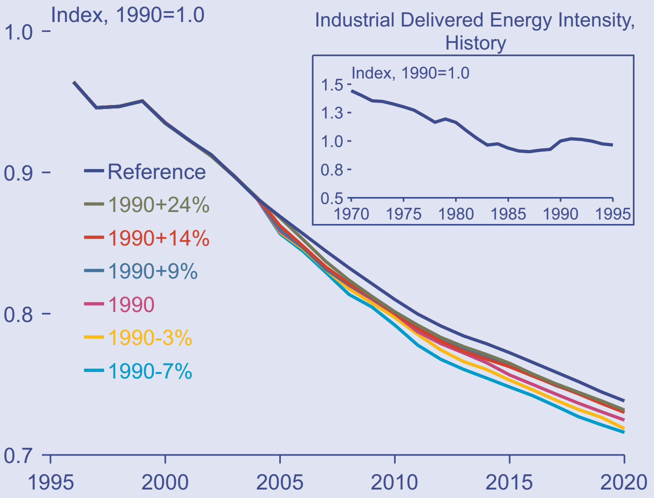
The projected rate of decline in industrial energy intensity is smaller in the more stringent carbon reduction cases (Figure 48). Some process steps in the energy-intensive industries approach the minimum level of energy intensity assumed to be practically achievable. In addition, in the more stringent carbon reduction cases, industrial output is more severely 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.

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.

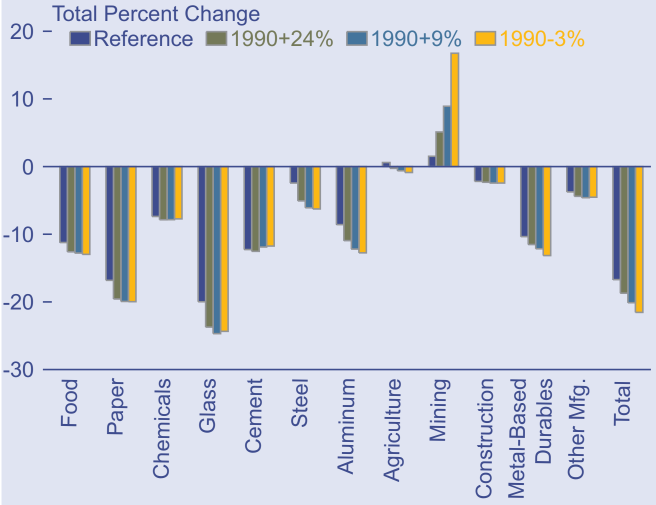
Figure 48. Projected Energy Intensity in the Industrial Sector, 1995-2020



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.

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

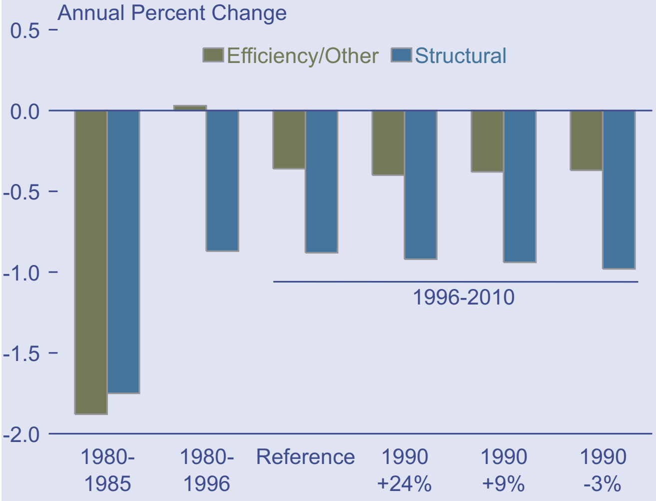
Figure 49. Projected Change in Industrial Sector Energy Intensity, 1996-2010



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

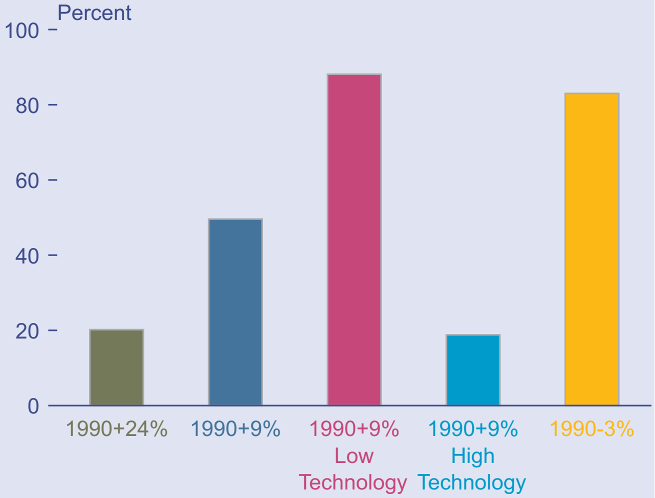
output of the most energy-intensive industries grows more slowly than other parts of the industrial sector, aggregate energy intensity will fall even though no individual industry's energy intensity has changed. This is the "structural" effect. The other is increased energy efficiency and shifts toward 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.

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.

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, 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).

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[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 indexed 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).

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[48] 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).

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.[b] 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 floorspace—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 kilowatthour when used as a simple-cycle turbine.[b] 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.[b] 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.

[a] Energy Information Administration, *Annual Energy Review 1996*, DOE / EIA-0384(96) (Washington, DC, July 1997).

[b] Interlaboratory Working Group on Energy-Efficient and Low-Carbon Technologies, "Scenarios of U.S. Carbon Reductions," LBNL-40533, ORNL / CON-444 (September 1997).

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

[d] See 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.)

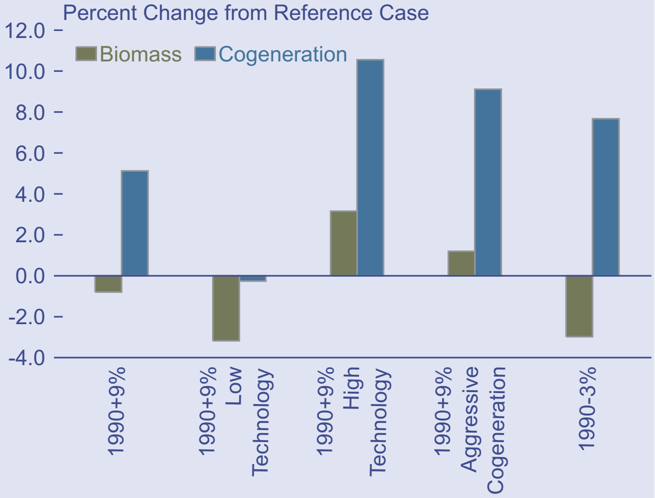
In the 1990+9% low technology case, industrial energy expenditures in 2010 are projected to be nearly double those in the 1990+9% carbon reduction case and $110 billion higher than those in the reference case. In the high technology sensitivity case, energy expenditures are projected to be only $23 billion 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.

[a] The 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.

[b] Charles 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.

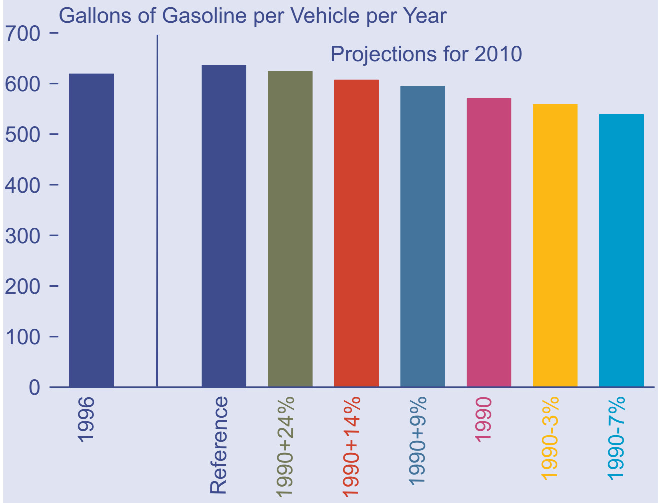
Depending on per capita income, fuel prices, and fuel economy, consumers may switch to either smaller size classes or smaller vehicles with lower horsepower requirements within a size class. The trend in vehicle sales toward or away from light trucks (vans, sport utility vehicles, and pickups) is determined 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

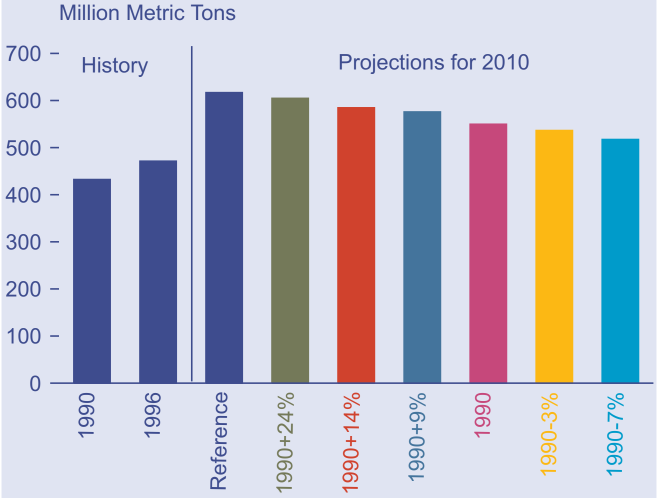
Source: Office of Integrated Analysis and Forecasting, National Energy Modeling System run KYBASE.D080398A.

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

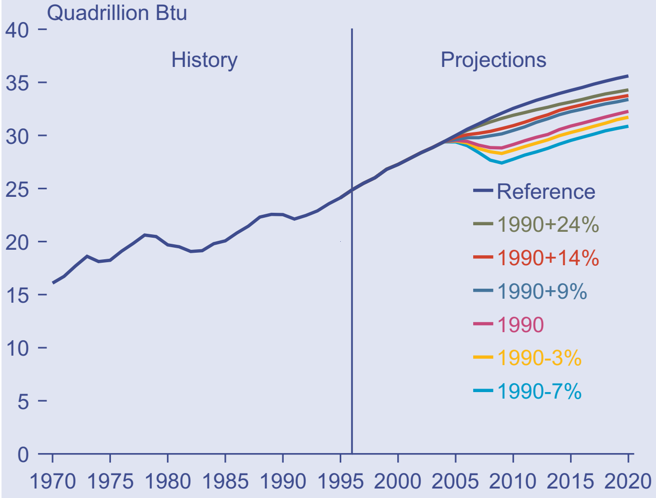
The transportation sector is the only sector that does not reach 1990 carbon emissions levels by 2010 in any of the carbon reduction cases (Figure 54). In the reference case, energy demand in the transportation sector is projected to exceed 1990 levels by approximately 10.7 quadrillion Btu in 2010, a 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



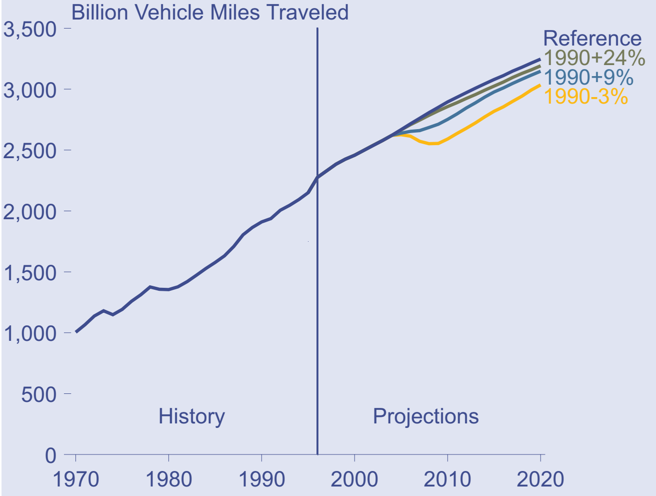
Sources: **History:** Energy Information Administration, *State Energy Data Report 1995*, DOE/EIA-0214(96) (Washington, DC, December 1997). **Projections:** Office of Integrated Analysis and Forecasting, National Energy Modeling System runs KYBASE.D080398A, FD24ABV.D080398B, FD1998.D080398B, FD09ABV.D080398B, 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, and 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

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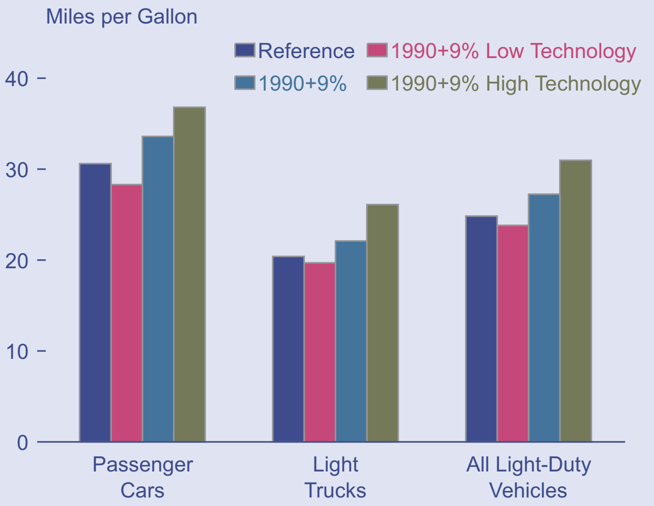
[49] Federal Highway Administration, *National Personal Travel Survey: 1990 NPTS Databook*, Vol. I (Washington, DC, November 1993), p. 3-18.

[50] U.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 economy 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 market for new light trucks in 1990, reached a low of

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

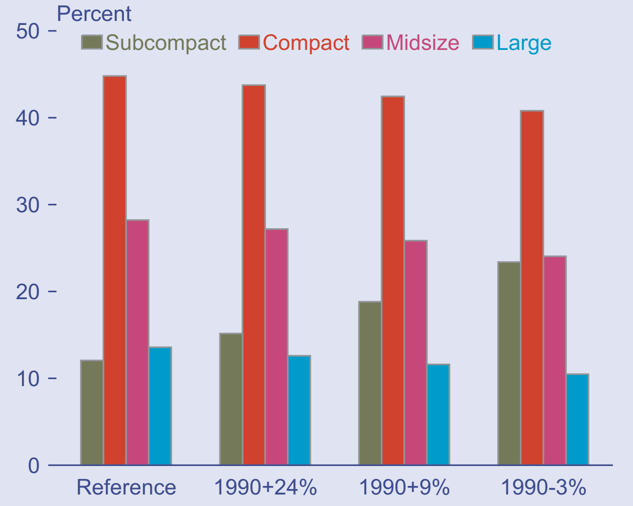
Source: Office of Integrated Analysis and Forecasting, National Energy Modeling System runs KYBASE.D080398A, FD09ABV.D080398B, and HITECH09.D080698A.

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.

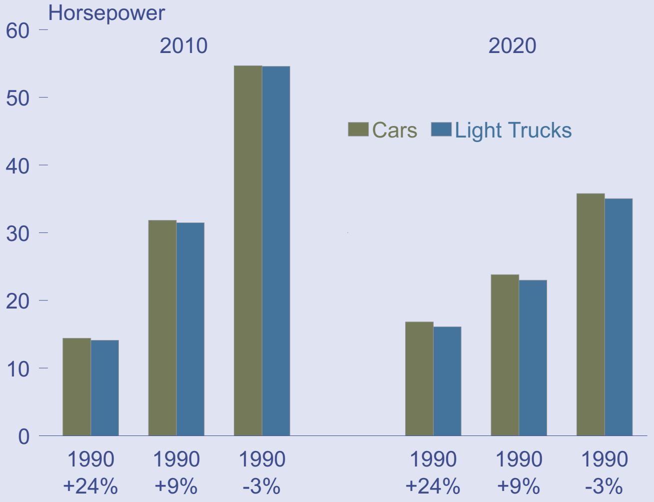
Figure 58. Projected Shares of Automobile Sales by Size Class, 2010



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).

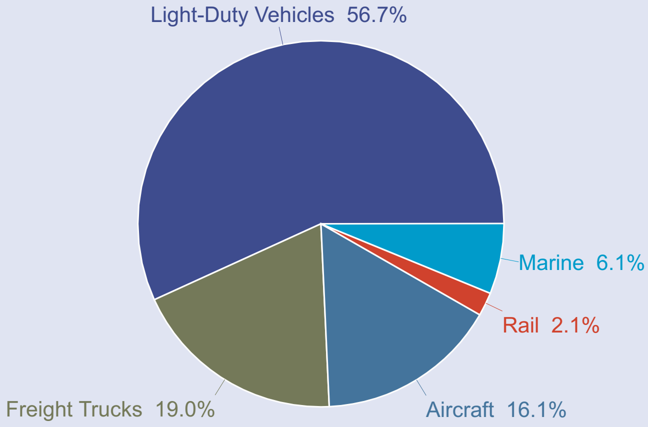
Figure 59. Projected Reductions From Reference Case Projections of Car and Light Truck Horsepower in the Carbon Reduction Cases, 2010 and 2020



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

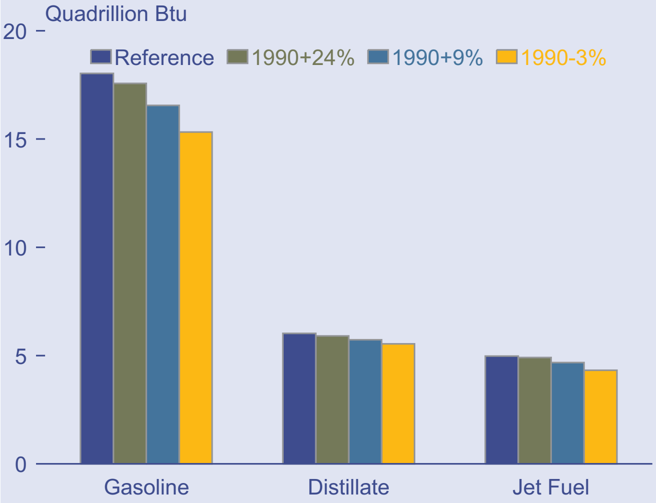
Fuel Consumption. Reductions in fuel use by light-duty vehicles (cars, pickup trucks, vans, and sport utility vehicles) are projected to account for more than two-thirds of the reduction in transportation energy consumption in 2010 in the carbon reduction cases relative to the reference case projections. 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.

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[51] This 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.

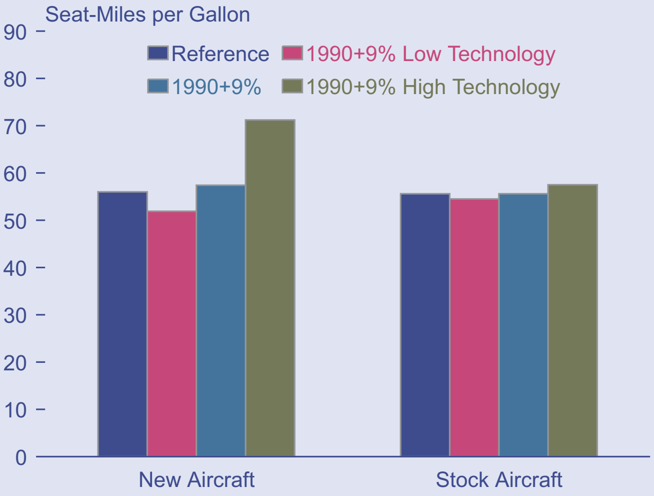
Between 2005 and 2008, air travel is projected to decline by 1.2 percent annually in the 1990-3% case as a result of a 19-percent average annual increase in jet fuel prices. In comparison, air travel declined by 2.2 percent from 1980 to 1981, when jet fuel prices increase by 49 percent. Similar to light-duty 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.D080398B, and HITECH09.D080698A.

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

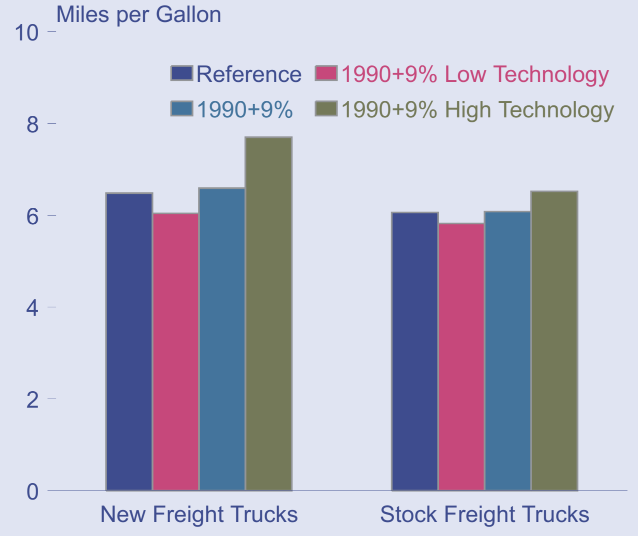
The projected demand for distillate fuel, used primarily for freight trucks and rail, is also lower in the carbon reduction cases than in the reference case in 2010—by 2 percent in the 1990+24% case, by 4.9 percent in the 1990+9% case, and by 8.3 percent in the 1990-3% case (see Figure 61). Distillate 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.

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

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 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%, 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.

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[a] U.S. Congress, Office of Technology Assessment, *Saving Energy in U.S. Transportation*, OTA-ETI-589 (Washington, DC, July 1994), pp. 5-6.

[b] S. 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.

[c] U.S. Congress, Office of Technology Assessment, *Saving Energy in U.S. Transportation*, OTA-ETI-589 (Washington, DC, July 1994), pp. 5-6.

[d] American Public Transit Association, *1994-1995 Transit Fact Book* (Washington, DC, February 1995), pp. 106-107.

[e] S. 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.

[f] Federal Highway Administration, *National Personal Travel Survey: 1990 NPTS Databook*, Vol. II, Chapter 7 (Washington, DC, November 1993).

[g] U.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]

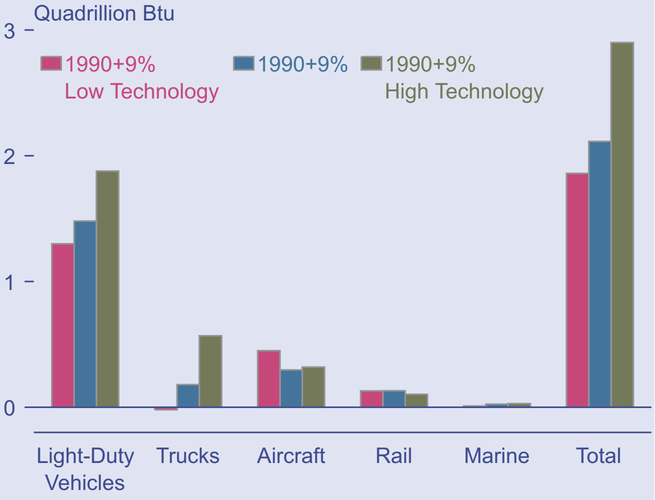
Higher projected carbon prices in the low technology sensitivity case lead to higher prices for all transportation fuels. In 2010, average fuel prices in the transportation sector are projected to be 14 percent higher in the 1990+9% low technology case than in the 1990+9% case. Gasoline prices are projected 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 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.

Figure 64. Projected Reductions From Reference Case Projections of Transportation Sector Fuel Consumption in High and Low Technology Sensitivity Cases, 2010



Source: Office of Integrated Analysis and Forecasting, National Energy Modeling System runs KYBASE.D080398A, FREEZE09.D080798A, FD09ABV.D080398B, and HITECH09.D080698A.

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

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[52] High 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.

engines is lower in the high technology case, because they are partially displaced by advanced thermodynamic engines. Substantial fuel efficiency improvements 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 goals[53] 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.

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.

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.

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.

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[53] U.S. Department of Energy, Office of Transportation Technologies, *Program Analysis Methodology: Final Report—Quality Metrics 98* (Washington, DC, April 16, 1997).