2. Analysis of Strategies with *AEO2001* Technology Assumptions

In the request from Senators Jeffords and Lieberman, the Energy Information Administration (EIA) was asked to analyze the impacts of emissions limits on nitrogen oxides (NO_x), sulfur dioxide (SO_2), carbon dioxide (CO_2), and mercury (Hg) from electricity generators against four cases with different assumptions concerning technology development and policies to reduce energy consumption and promote the use of cleaner technologies. The first case uses the reference case technology characteristics in the *Annual Energy Outlook 2001* (*AEO2001*).[18] The second case assumes the high technology assumptions for energy demand, electricity generation, and fossil fuel supply in *AEO2001*. The other two cases are based on the moderate and advanced cases from *Scenarios for a Clean Energy Future* and are discussed in Chapter 3.[19] In all four cases, the same emissions limits are imposed on all electricity generators, excluding cogenerators.[20] The start date for the reductions is 2002. By 2007, NO_x emissions are reduced to 75 percent below 1997 levels, SO_2 emissions to 75 percent below the full implementation of the Phase II requirements under Title IV of the Clean Air Act Amendments of 1990, Hg emissions to 90 percent below 1999 levels, and CO_2 emissions to 1990 levels.

Although the analysis in *AEO2001* focuses on the reference case, a number of sensitivity cases are presented in the report to explore various uncertainties in energy markets, including world oil prices, U.S. economic growth, technology development and adoption, nuclear costs and construction times, and oil and natural gas resources. Many of these sensitivities are analyzed by changing the reference case assumptions in one energy sector at a time. One case in *AEO2001* combines slower technology improvements relative to the reference case for the residential, commercial, industrial, and transportation demand sectors and for advanced fossil generating technologies. Another case in *AEO2001* combines more rapid technology improvements for the same sectors and for new renewable generating technologies.

The advanced technology case in this analysis combines the high technology case in *AEO2001* with lower aging-related costs for nuclear power plants and the high technology assumptions for fossil fuel supply, including lower costs and higher finding rates (reserve additions per well) and success rates (successful wells drilled) for oil and gas supply, and higher productivity and lower costs for coal production, relative to the reference case. This analysis does not address either the likelihood that all the assumptions in this case would occur or the costs that would be required to achieve these technology improvements. However, under current levels of research and development, the reference case is considered to be the most likely case for technology development. This chapter presents the impact of the advanced technology assumptions relative to the reference case and the analysis of the emissions limits for both the reference and the advanced technology cases.

Impact of Emissions Limits on the Reference Case

With the imposition of emissions limits on the reference case, the average delivered price of electricity in 2020 is projected to be 33 percent higher than in the reference case due to the cost to electricity generators of meeting the limits. Projected wellhead natural gas prices are also higher by 20 percent as a result of higher natural gas consumption by electricity generators. Due to the higher energy prices that result from the assumed emissions limits, total energy consumption is projected to be reduced by 7 quadrillion British thermal units (Btu) in 2020, or 5 percent (Figure 2), and projected energy expenditures are higher. The primary energy intensity of the economy—defined as total energy consumption per dollar of gross domestic product (GDP)—is projected to decline at an average annual rate of 1.9 percent between 1999 and 2020, compared to 1.6 percent in the reference case (Figure 3).

Projected consumption of coal and electricity is lower with the emissions limits than in the reference case without the limits; however, as electricity generators reduce the use of coal, the projected use of existing

[18] Energy Information Administration, *Annual Energy Outlook 2001*, DOE/EIA-0383(2001) (Washington, DC, December 2000), web site www.eia.doe.gov/oiaf/aeo/index.html.

[19] Interlaboratory Working Group, *Scenarios for a Clean Energy Future*, ORNL/CON-476 and LBNL-44029 (Oak Ridge National Laboratory, Oak Ridge, TN, and Lawrence Berkeley National Laboratory, Berkeley, CA, November 2000), web site www.ornl.gov/ORNL/Energy_Eff/CEFOnep.pdf.

[20] At this time, emissions limits on cogenerators are not represented.

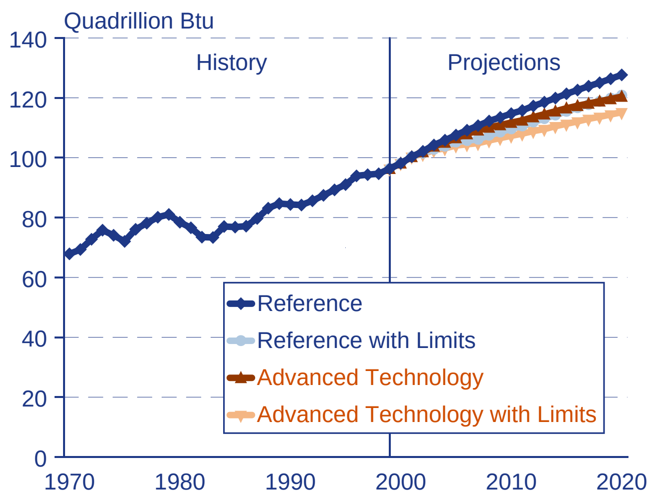
nuclear power plants and natural gas and renewable generating technologies is higher, raising the consumption of these energy sources, relative to the reference case. Because of reduced energy consumption and the shift in the fuel mix to more natural gas, renewables, and nuclear power, projected CO_2 emissions in 2020 are reduced by 287 million metric tons carbon equivalent, or 14 percent, relative to the reference case, and other emissions are also reduced (Figures 4 through 7).

Electricity and Renewables

The introduction of emissions limits in the reference case results in substantially higher projected average delivered electricity prices relative to the reference case. Projected prices are 31 percent higher in 2010 and 33 percent higher in 2020 even as consumers reduce their consumption of electricity by 6 and 9 percent in 2010 and 2020, respectively (Figure 8 and Table 4). Annual expenditures are expected to be $158 more per household in 2010 and $154 more in 2020 as revenue to electricity providers is $58 billion and $59 billion higher in 2010 and 2020, respectively.

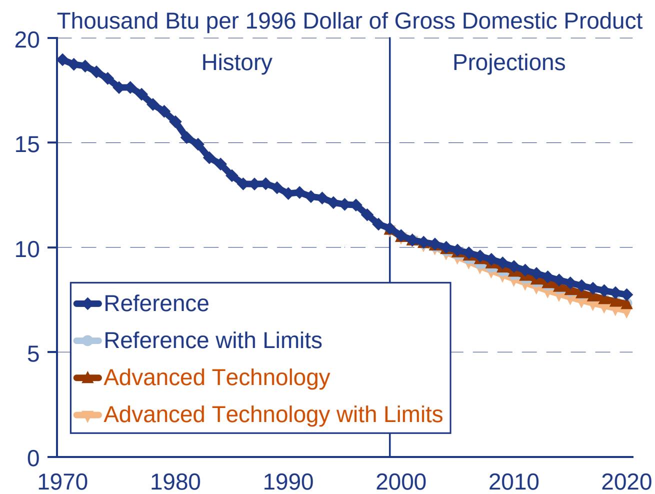
Prices are expected to increase because the cost of producing power with emission limits is more expensive than without limits. There are additional costs associated with the installation of emission control equipment, the purchase of emissions permits, and costs for fuels

Figure 2. Energy Consumption in Four Cases, 1970-2020



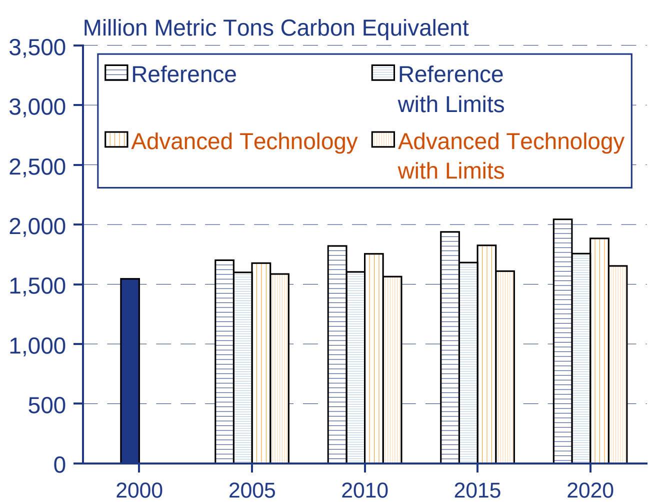
Source: National Energy Modeling System, runs SCENABS.D080301A, SCENAEM.D081601A, SCENBBS.D080301A, and SCENBEM.D081701A.

Figure 3. Primary Energy Intensity in Four Cases, 1970-2020



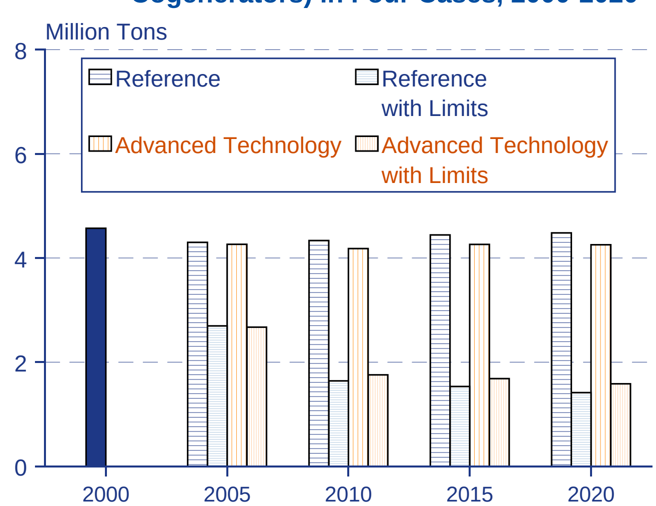
Source: National Energy Modeling System, runs SCENABS.D080301A, SCENAEM.D081601A, SCENBBS.D080301A, and SCENBEM.D081701A.

Figure 4. Carbon Dioxide Emissions in Four Cases, 2000-2020



Source: National Energy Modeling System, runs SCENABS.D080301A, SCENAEM.D081601A, SCENBBS.D080301A, and SCENBEM.D081701A.

Figure 5. Nitrogen Oxides Emissions from Generating Units (Excluding Cogenerators) in Four Cases, 2000-2020

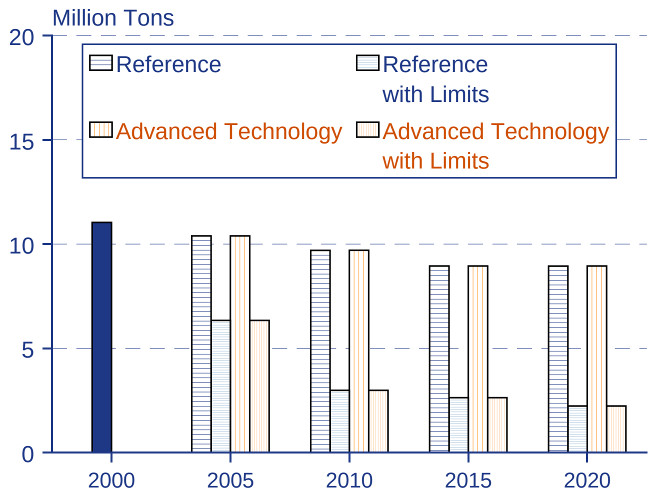


Source: National Energy Modeling System, runs SCENABS.D080301A, SCENAEM.D081601A, SCENBBS.D080301A, and SCENBEM.D081701A.

used to generate electricity. For example, in the case with emissions limits, 37 gigawatts of flue gas desulfurization equipment are expected to be constructed in 2020 compared with 17 gigawatts in the reference case. There are also additional investments for fabric filters and spray coolers to reduce emissions of Hg. Prices for fossil fuels are also expected to be higher. Natural gas prices to electricity generators are projected to be $4.52 per thousand cubic feet in 2020 in the reference case with limits compared with $3.68 in the reference case without limits. The effective price of natural gas to electricity generators, which includes the cost of a CO_2 allowance, reaches $6.31 per thousand cubic feet when the emissions limits are imposed. The higher projected price for natural gas also results from the higher costs associated with producing additional quantities of natural gas in the case with limits, which raises the average wellhead price of natural gas. Although the price of coal delivered to electricity generators is lower in 2020 when emissions limits are imposed, $17.28 per short ton compared to $19.34 per short ton in the case without limits, the effective price is projected to reach $81.28 per short ton, after including the CO_2 allowance cost.

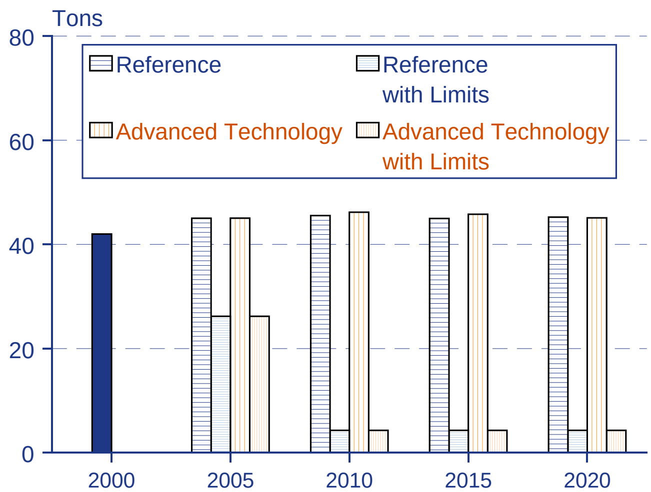
The projected higher electricity prices cause consumers to reduce their use of electricity, although higher projected natural gas prices dampen the impact of the higher electricity prices. Sales of electricity are expected to be lower by 261 billion kilowatthours in 2010 and by 443 billion kilowatthours in 2020 (Figure 9). These lower levels of consumption, combined with fuel switching by electricity generators, are reflected in the levels and types of generation. Projected coal-fired generation is reduced by 962 billion kilowatthours in 2010 and by 1,261 billion kilowatthours in 2020, 43 percent and 55 percent, respectively (Figure 10). The lower levels of coal-fired generation are expected to occur because emissions limits on controlled gases and Hg discourage the use of coal more than other fuels. Compared with coal, natural gas has lower emissions per unit, resulting in higher projected consumption levels for natural gas compared with the reference case without limits. The use of renewable sources and nuclear power is also expected to be higher in the case with limits because the costs of coal- and petroleum-fired generation are relatively more expensive. By 2010, nonhydropower renewable technologies, including geothermal, wind, biomass, municipal solid waste and landfill gas, and solar, are expected to produce 94 billion kilowatthours more than

Figure 6. Sulfur Dioxide Emissions from Generating Units (Excluding Cogenerators) in Four Cases, 2000-2020



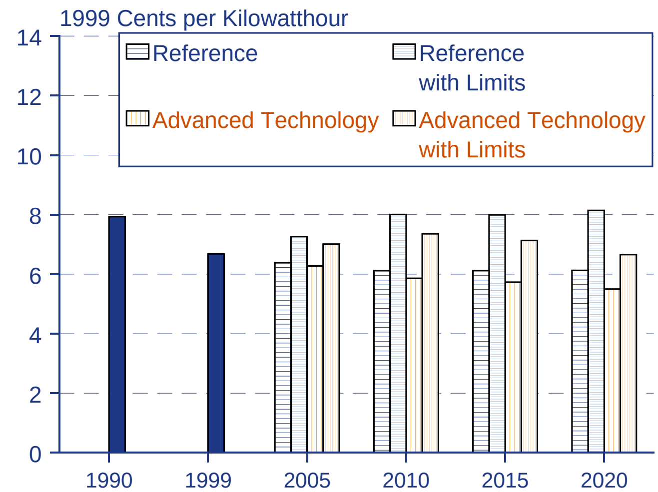
Source: National Energy Modeling System, runs SCENABS.D080301A, SCENAEM.D081601A, SCENBBS.D080301A, and SCENBEM.D081701A.

Figure 7. Mercury Emissions from Generating Units (Excluding Cogenerators) in Four Cases, 2000-2020



Source: National Energy Modeling System, runs SCENABS.D080301A, SCENAEM.D081601A, SCENBBS.D080301A, and SCENBEM.D081701A.

Figure 8. Electricity Prices in Four Cases, 1990-2020



Source: National Energy Modeling System, runs SCENABS.D080301A, SCENAEM.D081601A, SCENBBS.D080301A, and SCENBEM.D081701A.

Table 4. Electricity Projections in the Reference and Advanced Technology Cases, 2010 and 2020

Projections	1999	Reference: Without Emissions Limits	Reference: With Emissions Limits	Advanced Technology: Without Emissions Limits	Advanced Technology: With Emissions Limits
		2010			
Average Delivered Electricity Prices (1999 Cents per Kilowatthour)	**6.7**	**6.1**	**8.0**	**5.9**	**7.4**
Electricity Sales (Billion Kilowatthours)	**3,294**	**4,133**	**3,872**	**4,049**	**3,835**
Generation, Excluding Cogenerators (Billion Kilowatthours)	**3,369**	**4,204**	**3,914**	**4,125**	**3,885**
Coal	1,830	2,238	1,276	2,240	1,324
Natural Gas	370	826	1,395	719	1,292
Nuclear Power	730	720	741	744	744
Renewables, Excluding Hydropower	46	95	189	101	213
Hydropower	310	301	303	301	302
Emissions, Excluding Cogenerators					
SO_2 (Million Tons)	13.5	9.7	3.0	9.7	3.0
NO_x (Million Tons)	5.4	4.3	1.6	4.2	1.8
Hg (Tons)	43.4	45.5	4.3	46.2	4.3
CO_2 (Million Metric Tons Carbon Equivalent)	556	691	476	667	475
Allowance Prices					
SO_2 (1999 Dollars per Ton)	0	180	46	168	152
NO_x (1999 Dollars per Ton)[a]	0	0	0	0	0
Hg (Million 1999 Dollars per Ton)	0	0	482	0	510
CO_2 (1999 Dollars per Metric Ton Carbon Equivalent)	0	0	93	0	69
Annual Household Electricity Bill (1999 Dollars)	**892**	**936**	**1,094**	**901**	**1,013**
Total Electricity Revenue (Billion 1999 Dollars)	**222**	**252**	**310**	**239**	**284**
		2020			
Average Delivered Electricity Prices (1999 Cents per Kilowatthour)	**6.7**	**6.1**	**8.1**	**5.5**	**6.7**
Electricity Sales (Billion Kilowatthours)	**3,294**	**4,763**	**4,320**	**4,610**	**4,294**
Generation, Excluding Cogenerators (Billion Kilowatthours)	**3,369**	**4,821**	**4,311**	**4,674**	**4,309**
Coal	1,830	2,302	1,041	2,246	1,146
Natural Gas	370	1,488	2,072	1,331	1,911
Nuclear Power	730	610	669	672	720
Renewables, Excluding Hydropower	46	99	217	109	223
Hydropower	301	300	302	300	301
Emissions, Excluding Cogenerators					
SO_2 (Million Tons)	13.5	9.0	2.2	9.0	2.2
NO_x (Million Tons)	5.4	4.5	1.4	4.3	1.6
Hg (Tons)	43.4	45.2	4.3	45.1	4.3
CO_2 (Million Metric Tons Carbon Equivalent)	556	773	475	716	474
Allowance Prices					
SO_2 (1999 Dollars per Ton)	0	200	221	145	703
NO_x (1999 Dollars per Ton)[a]	0	0	0	0	0
Hg (Million 1999 Dollars per Ton)	0	0	306	0	374
CO_2 (1999 Dollars per Metric Ton Carbon Equivalent)	0	0	122	0	58
Annual Household Electricity Bill (1999 Dollars)	**892**	**980**	**1,134**	**886**	**974**
Total Electricity Revenue (Billion 1999 Dollars)	**222**	**291**	**350**	**254**	**288**
Cumulative Additions of Emissions Control Equipment, 1999-2020 (Gigawatts)					
SO_2 Scrubbers	—	17.5	37.0	9.8	40.5
Selective Catalytic Reduction (SCRs)	—	91.1	101.9	91.0	98.2
Selective Noncatalytic Reduction (SNCRs)	—	46.0	37.1	27.2	39.1
Hg Fabric Filters	—	0.0	88.3	0.0	95.7
Hg Spray Coolers	—	0.0	49.2	0.0	63.5
Cumulative Resource Cost, 2001-2020 (Billion 1999 Dollars)	**—**	**2,031**	**2,208**	**1,837**	**1,979**

[a]Regional NO_x limits are included in the reference case, but the corresponding allowance costs are not included in the table because they are not comparable to a national NO_x limit.

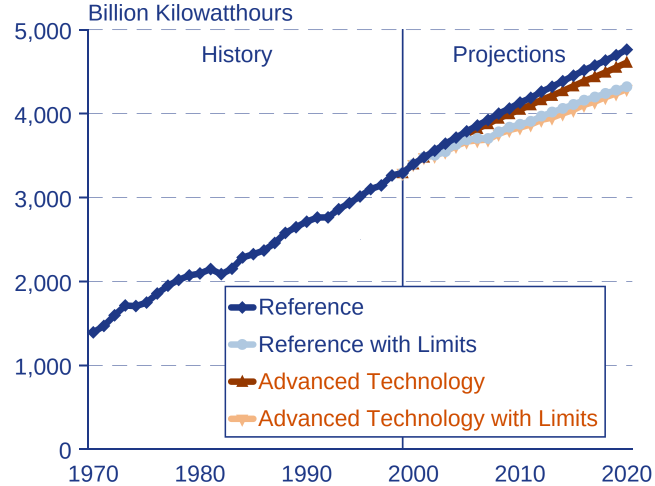
Source: National Energy Modeling System, runs SCENABS.D080301A, SCENAEM.D081601A, SCENBBS.D080301A, and SCENBEM.D081701A.

the 95 billion kilowatthours generated in the reference case without limits. In 2020, these renewable technologies are expected to generate 217 billion kilowatthours in the reference case with emissions limits, compared to 99 billion kilowatthours in the case without limits. Projected nuclear generation is higher by 21 billion kilowatthours in 2010 and by 59 billion kilowatthours in 2020, 3 percent and 10 percent, respectively, compared to the case without limits.

The higher projected price for electricity is due, in part, to the costs of obtaining emission permits. CO_2 emissions permit costs are included in the price of the fossil fuel to electricity generators. For the other three emissions, the permit costs are effectively included in the electricity price based on the cost incurred by the marginal generator.

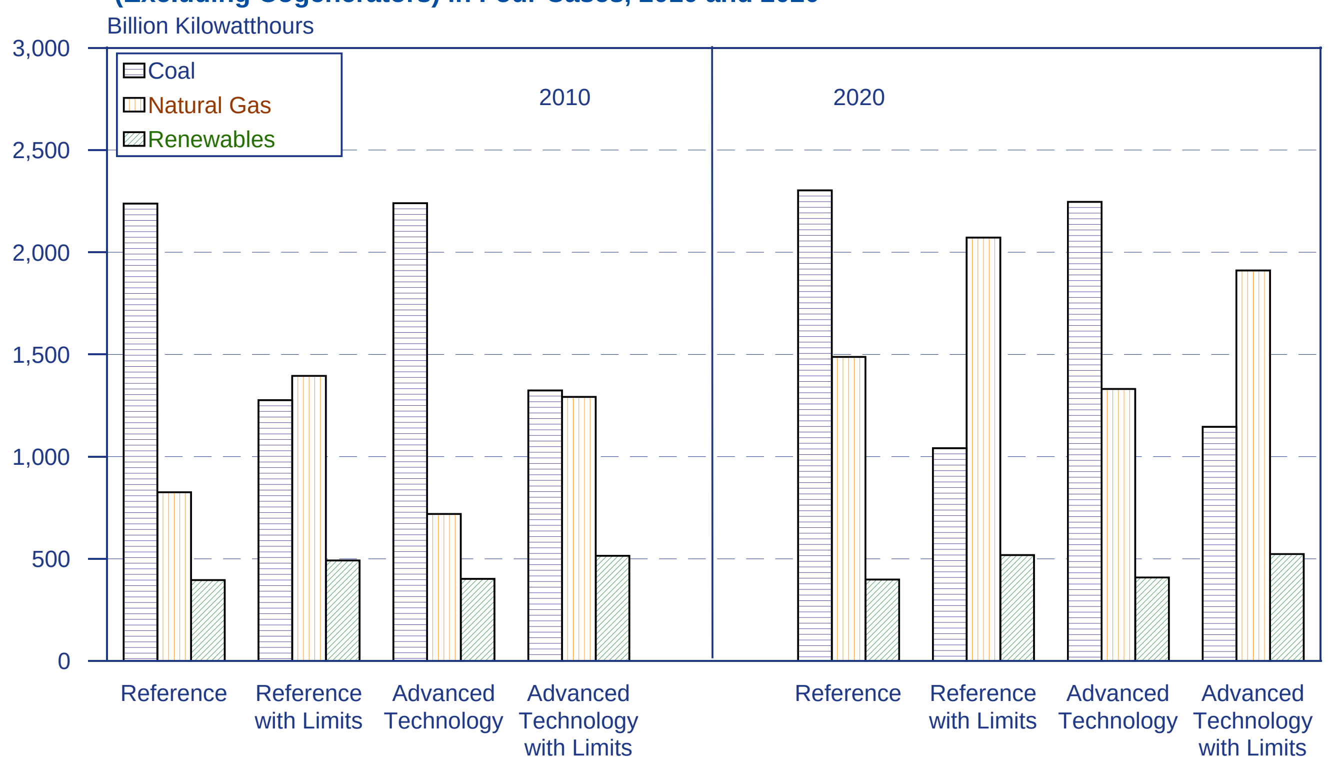
The costs for SO_2 permits are projected to be \$46 per ton in 2010 and \$221 per ton in 2020 in the reference case with emissions limits (Figure 11). The current price level for SO_2 permits is approximately \$175 per ton.[21] In 2020, the cost of SO_2 permits is projected to be \$21 per ton higher than in the reference case without emissions limits, reflecting lower emissions limits and required investments in emissions control equipment. The price for CO_2 permits is expected to be \$93 per metric ton carbon equivalent in 2010, increasing to \$122 per metric ton carbon equivalent in 2020 (Figure 12). This cost for CO_2 permits reflects the need to retire existing coal-fired capacity and switch to less carbon-intensive fuels, primarily natural gas. Currently, there are no economical technologies to sequester CO_2 emissions from coal plants. The cost for NO_x emission allowances is expected

Figure 9. Electricity Sales in Four Cases, 1970-2020



Source: National Energy Modeling System, runs SCENABS.D080301A, SCENAEM.D081601A, SCENBBS.D080301A, and SCENBEM.D081701A.

Figure 10. Projected Electricity Generation from Coal, Natural Gas, and Renewable Fuels (Excluding Cogenerators) in Four Cases, 2010 and 2020



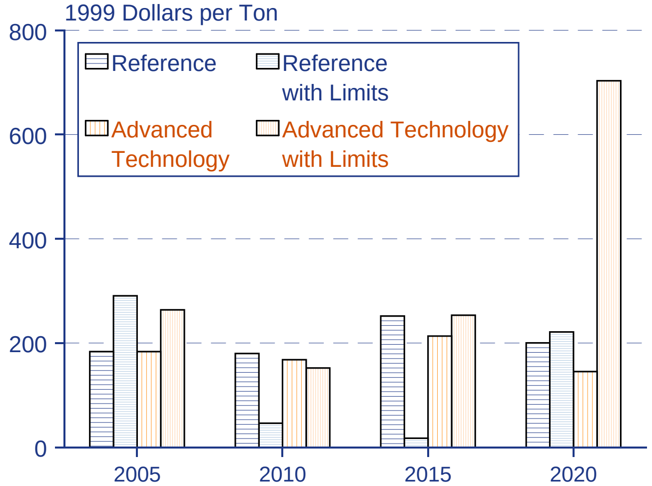
Source: National Energy Modeling System, runs SCENABS.D080301A, SCENAEM.D081601A, SCENBBS.D080301A, and SCENBEM.D081701A.

[21] See web site www.epa.gov/airmarkets/arp/.

to decline to zero by 2010 because the actions taken to meet the CO_2 limits result in NO_x emissions being within the specified limit (Figure 13). The Hg control costs are expected to be $482 million per ton in 2010 and $306 million per ton in 2020 (Figure 14). Although the unit cost of Hg removal is high, the total cost for reducing Hg emissions is small when compared with costs to reduce CO_2 emissions.

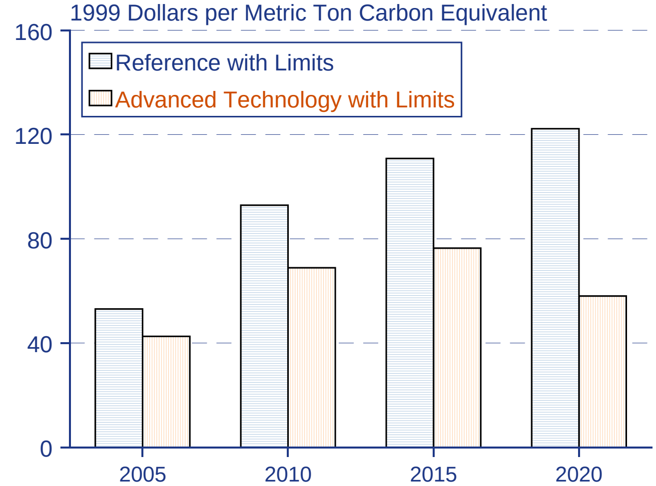
There are costs to power producers associated with electricity generation resulting from the emissions limits. The total cost of producing electric power includes the cost of fuels to generate electricity, operations and maintenance costs, investments in plants and equipment, and costs to purchase power from other generators. The sum of all these costs is called the resource cost. This resource cost is different from the marginal cost of generating electricity because it includes fixed costs, such as investments and portions of operations and maintenance costs, that do not vary based on production levels. Producers may not recover these fixed costs in competitive markets when the market price of electricity is at the same level as their marginal production costs, which only include fuel and certain other costs that vary with output levels. However, over time, producers need to recover their resource costs in order to remain in business. In the competitive marketplace which is assumed in these projections, a power producer would recover these costs during periods when the market price of power is higher than its production cost, for example,

Figure 11. Sulfur Dioxide Allowance Price in Four Cases, 2005-2020



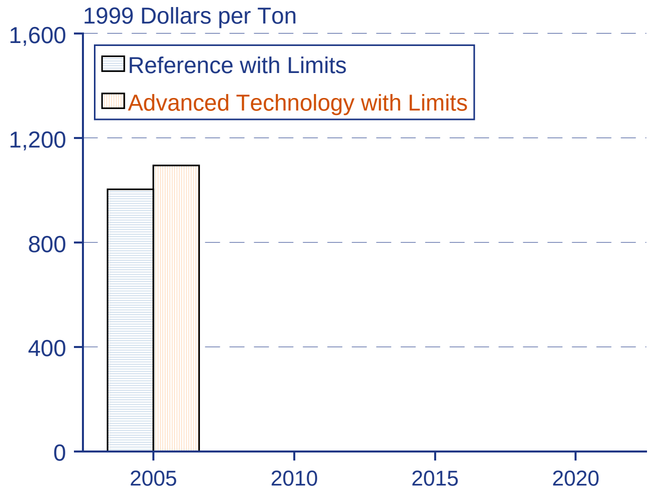
Source: National Energy Modeling System, runs SCENABS.D080301A, SCENAEM.D081601A, SCENBBS.D080301A, and SCENBEM.D081701A.

Figure 12. Carbon Dioxide Allowance Price in Two Cases, 2005-2020



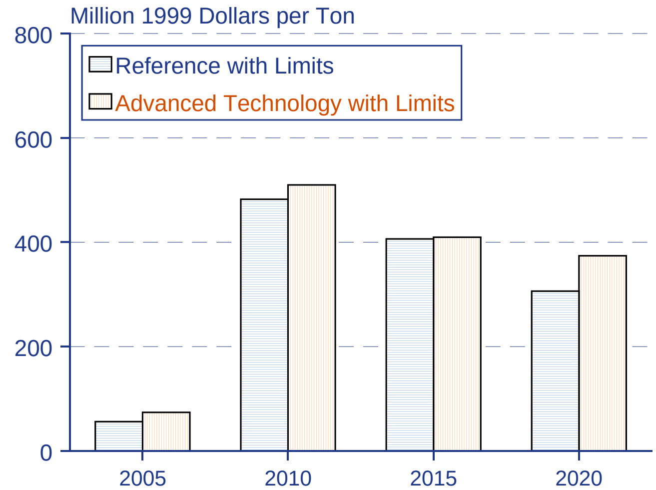
Source: National Energy Modeling System, runs SCENAEM.D081601A and SCENBEM.D081701A.

Figure 13. Nitrogen Oxides Allowance Price in Two Cases, 2005-2020



Source: National Energy Modeling System, runs SCENAEM.D081601A and SCENBEM.D081701A.

Figure 14. Mercury Allowance Price in Two Cases, 2005-2020



Source: National Energy Modeling System, runs SCENAEM.D081601A and SCENBEM.D081701A.

when a high-production-cost combustion turbine sets the market price while a low-production-cost pulverized coal unit is producing electricity.

For all the cases with emissions limits analyzed in this study, the resource costs are projected to be higher relative to the resource costs in the comparable cases without emissions limits. The largest increase is for fuels used to generate electricity. There are also costs associated with purchases of power from other generators and investment costs for new generation facilities or for retrofitting plants with emission control equipment.

From 2001 through 2020, the cumulative resource costs to generate electricity are expected to be $2,208 billion (undiscounted 1999 dollars) in the reference case with emissions limits, compared to $2,031 billion in the same case without the limits. Thus, the projected incremental cumulative expenditures attributable to emission limits that would be incurred by electricity generators is $177 billion, a 9-percent increase (Figure 15). These costs exclude the costs of emission permits that must be purchased by electricity generators because they are funds that are transferred among industry participants and do not represent actual resource consumption. The costs of the emissions permits are included in the delivered price of electricity, to the extent that they can be passed through to consumers.

In the reference case with emissions limits, the annualized resource costs in 2007 (the year the limits are fully imposed), which include financing and capital recovery costs, are $19.9 billion higher than projected in the reference case without limits. These incremental costs due to emissions limits are expected to be reduced to $19.1 billion and $18.1 billion in 2010 and 2020, respectively.

Natural Gas

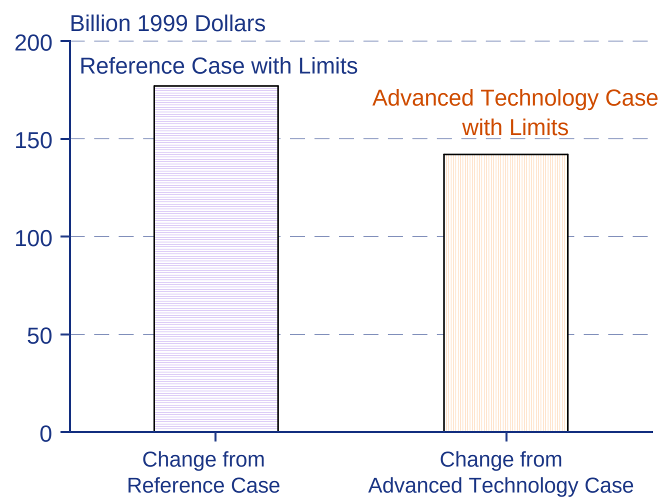
In the reference case, natural gas consumption is expected to increase at an average annual rate of 2.3 percent over the forecast horizon. By 2020, total natural gas consumption is expected to reach 35.0 trillion cubic feet, an increase of 61 percent from 1999 levels (Table 5). One of the fastest growing sectors for natural gas consumption is electricity generation. By 2020, the amount of natural gas consumed by electricity generators, excluding cogenerators, is expected to reach 11.2 trillion cubic feet, three times the volume used in 1999. In the next few years, natural gas prices are expected to decline from their record-high levels reached over the winter of 2001, dropping to $2.84 per thousand cubic feet at the wellhead by 2006. Although increased domestic production and imports keep pace with consumption, prices in the longer term rise as total demand grows, and wellhead prices are projected to reach $3.10 per thousand cubic feet by 2020 in the reference case.

Imposing emissions limits on electricity generators is expected to increase the demand for natural gas, during a period when the demand is already expected to be growing quickly. Because CO_2 emissions from natural gas are relatively low compared with other fossil fuels and natural gas is virtually free of SO_2 and Hg, electricity generators can help meet their emissions requirements by switching to natural gas. Imposing the limits on the reference case leads to higher natural gas demand by electricity generators. By 2020, the demand for natural gas by electricity generators is expected to reach 13.9 trillion cubic feet, 24 percent higher than the level of 11.2 trillion cubic feet projected in the case without emissions limits. Also, projected natural gas consumption in the commercial and industrial sectors is higher, primarily for cogeneration. As a result, total natural gas consumption in 2020 is projected to increase to 38.4 trillion cubic feet, compared to 35.0 trillion cubic feet in the reference case without emissions limits.

Higher natural gas demand results in higher prices. By 2020, the projected wellhead price reaches $3.72 per thousand cubic feet in the case with the emissions limits, compared to $3.10 per thousand cubic feet in the case without the limits (Figure 16). This results in higher natural gas prices for end users. Industrial prices, which are more closely tied to the wellhead price, are higher by 16 percent in 2020 compared to the reference case, while residential prices, which include more distribution costs, are higher by 8 percent.

The required increases in natural gas supply are met through higher imports and higher domestic production (Figure 17). Total net imports of natural gas are projected

Figure 15. Impacts of Emission Limits on Cumulative Resource Costs for Electricity Generation, 2001-2020



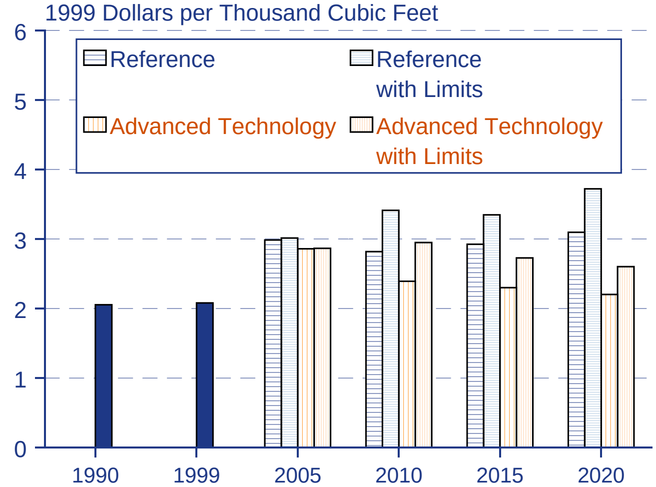
Source: National Energy Modeling System, runs SCENABS.D080301A, SCENAEM.D081601A, SCENBBS.D080301A, and SCENBEM.D081701A.

to be 2.1 trillion cubic feet higher in 2020 in the reference case with emissions limits than they are in the case without the limits, with most of the additional imports coming from Mexico or as liquefied natural gas from countries such as Algeria, Australia, and Qatar. About 0.3 trillion cubic feet of additional net imports are projected from Canada. Total domestic production in 2020 is projected to be 1.3 trillion cubic feet higher in the reference case with emissions limits than it is in the reference case without the limits. Increased unconventional natural gas production, which becomes more economic at the higher prices in the case with emissions limits, accounts for 0.9 trillion cubic feet of the additional domestic production.[22]

Coal

Primarily due to the CO_2 limits, projected coal consumption is sharply reduced from the level in the reference case when emissions limits are imposed. When the costs associated with acquiring CO_2 allowances are added to the delivered price of coal, the effective delivered price to generators is projected to triple relative to that in the reference case by 2010 and reaches \$3.97 per million Btu in 2020, approximately four times the reference case price (Table 6). Due to CO_2 emissions reductions and measures taken to meet the Hg limit, coal-fired electricity generation is projected to lose a substantial share of the market to natural-gas-fired generation, compared with the share of coal-fired generation in the reference case. In addition, higher projected electricity prices cause total electricity sales to decline, reducing overall generation requirements.

Figure 16. Natural Gas Wellhead Price in Four Cases, 1990-2020



Source: National Energy Modeling System, runs SCENABS.D080301A, SCENAEM.D081601A, SCENBBS.D080301A, and SCENBEM.D081701A.

Table 5. Natural Gas Market Projections in the Reference and Advanced Technology Cases, 2010 and 2020

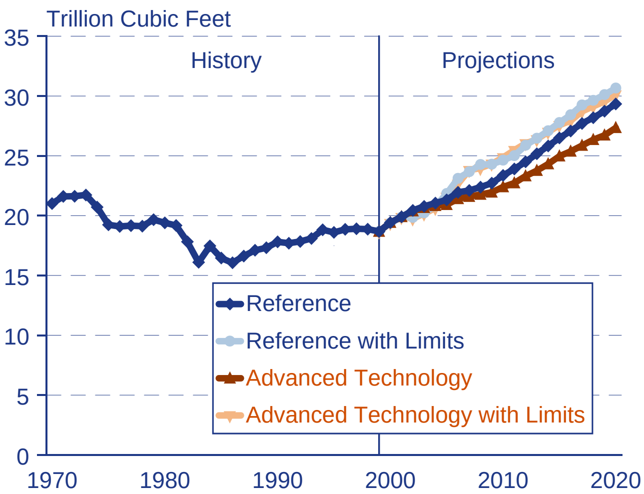
Projections	1999	Reference: Without Emissions Limits	Reference: With Emissions Limits	Advanced Technology: Without Emissions Limits	Advanced Technology: With Emissions Limits
2010					
Average Wellhead Price (1999 Dollars per Thousand Cubic Feet)	2.08	2.82	3.41	2.39	2.95
Delivered Price to Electricity Generators (1999 Dollars per Thousand Cubic Feet)	2.62	3.30	4.18	2.87	3.70
Effective Delivered Price to Electricity Generators[a] (1999 Dollars per Thousand Cubic Feet)	2.62	3.30	5.55	2.87	4.71
Consumption by Electricity Generators, Excluding Cogenerators (Trillion Cubic Feet)	3.8	6.8	9.7	5.9	8.8
Total Consumption (Trillion Cubic Feet)	21.8	28.2	31.1	27.0	29.9
Domestic Production (Trillion Cubic Feet)	18.7	23.4	24.6	22.4	24.9
2020					
Average Wellhead Price (1999 Dollars per Thousand Cubic Feet)	2.08	3.10	3.72	2.20	2.60
Delivered Price to Electricity Generators (1999 Dollars per Thousand Cubic Feet)	2.62	3.68	4.52	2.75	3.44
Effective Delivered Price to Electricity Generators[a] (1999 Dollars per Thousand Cubic Feet)	2.62	3.68	6.31	2.75	4.29
Consumption by Electricity Generators, Excluding Cogenerators (Trillion Cubic Feet)	3.8	11.2	13.9	9.1	11.9
Total Consumption (Trillion Cubic Feet)	21.8	35.0	38.4	32.4	35.6
Domestic Production (Trillion Cubic Feet)	18.7	29.3	30.7	27.3	30.1

[a]Effective delivered price reflects the cost impact of CO_2 emission allowances in cases that include a CO_2 limit.
Source: National Energy Modeling System, runs SCENABS.D080301A, SCENAEM.D081601A, SCENBBS.D080301A, and SCENBEM.D081701A.

[22]Unconventional natural gas includes low-permeability or tight sandstones, natural gas shales, and coalbed methane.

Because of lower installed coal-fired generation capacity and lower utilization of the remaining coal-fired capacity, projected coal consumption for electricity generation in 2020 is reduced to a level that is 43 percent of that in the reference case. Total coal production is projected to decline at a slower rate than the demand for coal in the electricity generation sector because, as a result of lower coal prices, consumption is projected to increase in other sectors not subject to the CO_2 limits, including industrial and coking coal and coal exports, assuming other countries do not impose new limits on coal consumption (Figure 18).

Figure 17. Natural Gas Production in Four Cases, 1970-2020



Source: National Energy Modeling System, runs SCENABS.D080301A, SCENAEM.D081601A, SCENBBS.D080301A, and SCENBEM.D081701A.

Although CO_2 limits have the greatest impact on coal consumption, both SO_2 and Hg emissions limits are projected to add to the cost of using coal and contribute to further reductions in coal-fired generation. In 2020, an additional 20 gigawatts of scrubber retrofits are projected to be added to meet the more stringent emissions limits on SO_2 and Hg. The assumed technology costs for emissions removal are based on current estimates. Coal production is projected to be reduced in all regions and shift to sources with lower Hg content, such as mines located in the Rocky Mountains, and away from lignite and waste coal, which have relatively high Hg content.

End-Use Demand

Residential

Of all the cases analyzed in this report, emissions limits have the largest impact on residential energy prices in the reference case because it is the case with the highest

Table 6. Coal Market Projections in the Reference and Advanced Technology Cases, 2010 and 2020

Projections	1999	Reference: Without Emissions Limits	Reference: With Emissions Limits	Advanced Technology: Without Emissions Limits	Advanced Technology: With Emissions Limits
2010					
Consumption by Electricity Generators, Excluding Cogenerators (Million Short Tons)	920	1,139	623	1,125	644
Production (Million Short Tons)	1,102	1,289	783	1,271	800
Minemouth Price (1999 Dollars per Short Ton)	17.13	14.19	14.63	12.73	13.40
Delivered Price to Electricity Generators (1999 Dollars per Million Btu)	1.21	1.06	0.98	0.98	0.93
Effective Delivered Price to Electricity Generators[a] (1999 Dollars per Million Btu)	1.21	1.06	3.35	0.98	2.69
Average SO_2 Content (Pounds per Million Btu)	2.0	1.8	1.8	1.8	1.8
Average Hg Content (Pounds per Trillion Btu)	7.7	7.3	6.1	7.2	6.1
CO_2 Allowance Cost (1999 Dollars per Million Btu)	0.00	0.00	2.37	0.00	1.76
2020					
Consumption by Electricity Generators, Excluding Cogenerators (Million Short Tons)	920	1,190	515	1,133	563
Production (Million Short Tons)	1,102	1,336	679	1,271	716
Minemouth Price (1999 Dollars per Short Ton)	17.13	12.93	12.61	10.76	10.97
Delivered Price to Electricity Generators (1999 Dollars per Million Btu)	1.21	0.98	0.84	0.85	0.78
Effective Delivered Price to Electricity Generators[a] (1999 Dollars per Million Btu)	1.21	0.98	3.97	0.85	2.26
Average SO_2 Content (Pounds per Million Btu)	2.0	1.7	1.8	1.7	1.8
Average Hg Content (Pounds per Trillion Btu)	7.7	7.1	6.2	7.1	6.0
CO_2 Allowance Cost (1999 Dollars per Million Btu)	0.00	0.00	3.12	0.00	1.48

[a]Effective delivered price reflects the cost impact of CO_2 emission allowances in cases that include a CO_2 limit.

Source: National Energy Modeling System, runs SCENABS.D080301A, SCENAEM.D081601A, SCENBBS.D080301A, and SCENBEM.D081701A.

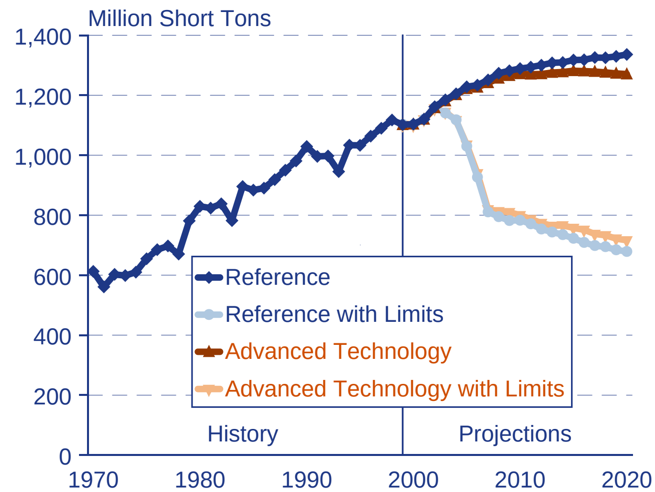
level of demand. The higher demand for energy, particularly electricity, in the reference case relative to all other cases causes projected generation costs to be higher with emissions limits, translating into higher end-use prices. Relative to the reference case, average residential energy prices are projected to be 17 percent higher in both 2010 and 2020 (Table 7). However, projected residential electricity prices are 25 and 26 percent higher in 2010 and 2020, respectively. The higher prices in the case with emissions limits are projected to reduce residential energy demand, as consumers react to the higher prices by purchasing more efficient appliances and reducing their demand for energy services (Figure 19).

Since residential electricity prices are projected to increase more than the other fuels as a result of the emissions limits, the projected demand for electricity shows the largest decrease, as consumers switch to other fuels for their heating needs and overall appliance efficiency increases for electric equipment, such as air conditioners. The projected reduction in electricity demand is reflected in reduced CO_2 emissions attributed to energy use in the residential sector. Of the projected CO_2 reduction of 76 million metric tons carbon equivalent in the residential sector in the case with emissions limits in 2010, virtually all is attributed to the projected decrease in electricity demand. In 2020, the projected residential CO_2 emissions are reduced by 102 million metric tons carbon equivalent, or 27 percent, relative to the reference case.

Commercial

The imposition of emissions limits in the reference case results in a 4-percent reduction in projected commercial delivered energy use in 2010, with electricity accounting for 74 percent of the projected decrease (Table 8). In 2020, commercial energy demand is projected to be reduced by 2 percent, relative to the reference case. The cost of

Figure 18. Coal Production in Four Cases, 1970-2020



Source: National Energy Modeling System, runs SCENABS. D080301A, SCENAEM.D081601A, SCENBBS.D080301A, and SCENBEM.D081701A.

Table 7. Residential Sector Projections in the Reference and Advanced Technology Cases, 2010 and 2020

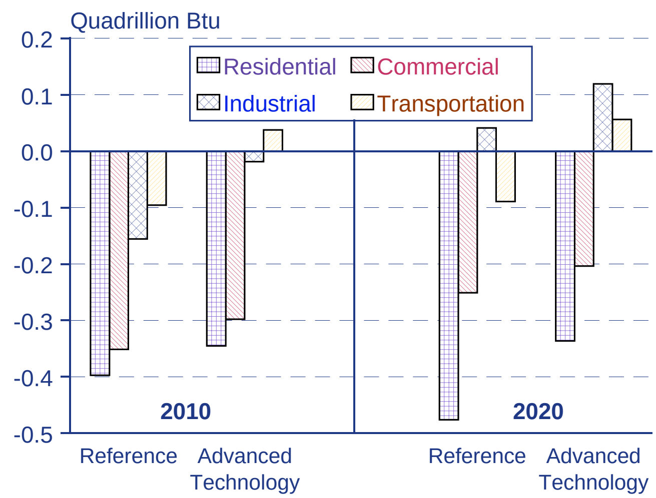
Projections	1999	Reference: Without Emissions Limits	Reference: With Emissions Limits	Advanced Technology: Without Emissions Limits	Advanced Technology: With Emissions Limits
		2010			
Delivered Energy Consumption (Quadrillion Btu)	10.7	12.2	11.8	11.8	11.4
Electricity	3.9	4.9	4.6	4.8	4.6
Natural Gas	4.9	5.5	5.5	5.3	5.2
Petroleum	1.4	1.3	1.3	1.2	1.2
Average Delivered Prices (1999 Dollars per Million Btu)	13.18	13.41	15.70	13.12	14.99
Electricity	23.69	22.19	27.74	21.55	25.86
Natural Gas	6.52	6.70	7.22	6.38	6.88
Petroleum	7.55	9.37	9.45	9.28	9.26
CO_2 Emissions (Million Metric Tons Carbon Equivalent)	290	346	270	334	265
		2020			
Delivered Energy Consumption (Quadrillion Btu)	10.7	13.5	13.0	12.8	12.4
Electricity	3.9	5.7	5.3	5.6	5.3
Natural Gas	4.9	6.1	6.0	5.7	5.6
Petroleum	1.4	1.2	1.3	1.1	1.1
Average Delivered Prices (1999 Dollars per Million Btu)	13.18	13.62	16.00	12.67	14.15
Electricity	23.69	22.16	27.83	20.41	23.66
Natural Gas	6.52	6.56	7.11	5.79	6.21
Petroleum	7.55	9.47	9.48	9.23	9.22
CO_2 Emissions (Million Metric Tons Carbon Equivalent)	290	383	281	357	274

Source: National Energy Modeling System, runs SCENABS.D080301A, SCENAEM.D081601A, SCENBBS.D080301A, and SCENBEM. D081701A.

complying with emissions limits causes projected commercial electricity prices to be 33 percent higher in 2010 and 34 percent higher in 2020, compared to the reference case, while average natural gas prices to the sector are projected to be higher by 9 percent and 10 percent in 2010 and 2020, respectively, as electricity generators turn to natural gas to minimize their compliance costs. Commercial consumers are expected to minimize their own energy costs in the case with emissions limits through measures such as shutting off lights and equipment while not in use and by purchasing more efficient equipment.

In this analysis, commercial sector distributed generation resources are assumed to be exempt from the emissions limits imposed on the electricity generation sector because they are typically small systems. Because electricity prices increase much more dramatically than natural gas prices, commercial consumers are expected to generate more electricity to meet their own requirements, producing more than twice as much electricity using natural-gas-fired distributed generation technologies in 2010 and about six times as much in 2020 in the case with emissions limits. Although water and space heating needs are met using some of the heat produced when generating electricity, additional natural gas is required to fuel distributed generation resources. CO_2 emissions reductions attributed to purchased electricity are projected to be 74 million metric tons carbon equivalent in 2010 and 102 million metric tons carbon equivalent in 2020. Total projected commercial sector CO_2 emissions are reduced by 75 million metric tons carbon equivalent, or 24 percent, in 2010 and by 99 million metric tons carbon equivalent, or 29 percent, in 2020.

Figure 19. Impacts of Emission Limits on Delivered Energy Consumption in Two Cases, 2010 and 2020



Source: National Energy Modeling System, runs SCENABS.D080301A, SCENAEM.D081601A, SCENBBS.D080301A, and SCENBEM.D081701A.

Industrial

Imposing emissions limits on the electric generation sector has essentially no impact on total delivered industrial energy consumption in the reference case because

Table 8. Commercial Sector Projections in the Reference and Advanced Technology Cases, 2010 and 2020

Projections	1999	Reference: Without Emissions Limits	Reference: With Emissions Limits	Advanced Technology: Without Emissions Limits	Advanced Technology: With Emissions Limits
		2010			
Delivered Energy Consumption (Quadrillion Btu)	**7.5**	**9.9**	**9.5**	**9.8**	**9.5**
Electricity	3.7	4.9	4.6	4.8	4.6
Natural Gas	3.1	4.2	4.1	4.2	4.1
Petroleum	0.6	0.6	0.6	0.6	0.6
Average Delivered Prices (1999 Dollars per Million Btu)	**13.28**	**12.23**	**15.33**	**11.50**	**14.02**
Electricity	21.64	18.76	24.94	17.76	22.67
Natural Gas	5.34	5.63	6.15	5.26	5.77
Petroleum	4.99	6.27	6.27	6.14	6.11
CO_2 Emissions (Million Metric Tons Carbon Equivalent)	**242**	**315**	**240**	**309**	**241**
		2020			
Delivered Energy Consumption (Quadrillion Btu)	**7.5**	**10.9**	**10.6**	**10.9**	**10.7**
Electricity	3.7	5.6	5.2	5.5	5.2
Natural Gas	3.1	4.5	4.7	4.6	4.7
Petroleum	0.6	0.6	0.6	0.6	0.6
Average Delivered Prices (1999 Dollars per Million Btu)	**13.28**	**12.55**	**15.54**	**10.89**	**12.61**
Electricity	21.64	18.83	25.32	16.56	20.14
Natural Gas	5.34	5.67	6.21	4.84	5.26
Petroleum	4.99	6.37	6.32	6.17	6.14
CO_2 Emissions (Million Metric Tons Carbon Equivalent)	**242**	**347**	**248**	**331**	**250**

Source: National Energy Modeling System, runs SCENABS.D080301A, SCENAEM.D081601A, SCENBBS.D080301A, and SCENBEM.D081701A.

the industrial sector chooses to generate more of its own electricity (which is assumed to be exempt from the emissions limits), primarily from natural gas, accounting for a slight increase in total industrial energy consumption. While total delivered energy consumption is not significantly affected by the emissions limits, the fuel mix is altered. The projected industrial electricity price in 2010 is 40 percent higher than in the reference case due to the emissions limits and 43 percent higher in 2020 (Table 9). As a result, purchased electricity consumption is projected to be lower by 7 percent, or 0.3 quadrillion Btu, relative to the reference case in 2010 and by 13 percent, or 0.6 quadrillion Btu in 2020. At the same time, consumption of both petroleum products and natural gas is projected to be higher. Projected cogeneration from natural gas is higher by 61 percent in 2010 and 128 percent in 2020 compared to the reference case without emissions limits.[23]

CO_2 emissions attributable to the industrial sector are reduced by 62 million metric tons carbon equivalent, or 12 percent, in 2010 and by 83 million metric tons carbon equivalent, or 14 percent, in 2020. The CO_2 reductions result from the reduction in purchased electricity.

Transportation

In the reference case, transportation energy use increases at an average annual rate of 1.8 percent through 2020, with light-duty vehicles accounting for 57 percent of total transportation energy use in 2020 (Table 10). Growth in travel by all modes combined with modest fuel efficiency improvements causes the transportation sector to have the fastest projected growth of all the end-use sectors.

Petroleum-based fuels account for 96 percent of total transportation demand in 2020. Because the transportation sector is almost entirely dependent on petroleum, the emissions limits on electricity generators and the subsequent impact on natural gas and coal markets have little impact on the sector. Applying the emissions limits to the reference case causes no significant changes in efficiency or travel demand with the exception of rail and natural gas pipeline shipments, which are correlated with coal and natural gas consumption. As a result of projected changes in fuel utilization by electricity generators, reduced coal shipments are projected to lower rail travel by 18 percent and subsequent energy use by 16 percent in 2020 (Table 11). The higher demand for natural gas is projected to raise pipeline energy use by 5 percent in 2020, relative to the reference case. Overall, there is a slight reduction in transportation energy use, about 0.1 quadrillion Btu in both 2010 and 2020. Projected CO_2 emissions from the transportation sector are reduced by 3 and 5 million metric tons carbon equivalent in 2010 and 2020, respectively, less than 1 percent.

AEO2001 High Technology Assumptions

The *AEO2001* reference case assumes continued improvements in technology for both energy consumption and production. As noted in Chapter 1, the residential, commercial, transportation, electricity generation, and refining sectors of NEMS explicitly represent individual energy-consuming technologies and their characteristics. Equipment choices are made for individual technologies as new equipment is needed to meet growing demand for energy services or to replace retired equipment. Technologies are chosen based on the overall costs relative to competing technologies, subject to assumptions about consumer choice and implied hurdle rates as derived from existing data. In the industrial demand sector, technology improvements for the major processing steps or end uses for the energy-intensive industries are represented by technology possibility curves of efficiency improvements over time. Due to data limitations and the heterogenous nature of the industrial sector, it is impractical to represent individual technologies in the same manner as in the other end-use demand sectors. However, industrial cogeneration capacity additions are based on an explicit representation of technology cost and performance.

Similar to the industrial sector, technology improvements for fossil fuel supply are also represented, but in a less detailed manner. In the oil and gas supply sector, technology progress for exploration and production activities is represented by annual improvements in finding rates, success rates, and drilling, lease equipment and operating costs, in accordance with historical trends. Significant improvements in exploration and production, such as three-dimensional seismology and horizontal drilling and completion, have served to reduce the cost of oil and gas supply activities. Technological advances in the coal industry, such as improvements in coal haulage systems at underground mines, contribute to increases in productivity, as measured in average short tons of coal per miner per hour. Productivity improvements are assumed to continue but to moderate in magnitude over the forecast horizon.

AEO2001 presents a range of alternative cases that vary key assumptions about technology improvement and penetration.[24] For the end-use demand and electricity

[23]Total industrial output includes oil and gas production, coal mining, and refining. Consequently, the value of total industrial output may increase in the cases with emissions limits.

[24]Energy Information Administration, *Assumptions to the Annual Energy Outlook 2001*, DOE/EIA-0554(2001)(Washington, DC, December 2001), web site www.eia.doe.gov/oiaf/fore_pub.html.

generation sectors, a more rapid pace of technology improvements in energy-consuming equipment is projected to reduce energy consumption and encourage more advanced fossil-fired and renewable technologies than in the reference case. In the end-use demand sectors, experts in technology engineering were consulted to derive high technology assumptions, considering the potential impacts of increased research and development for more advanced technologies.[25] It is possible that even further technology improvements

Table 9. Industrial Sector Projections in the Reference and Advanced Technology Cases, 2010 and 2020

Projections	1999	Reference: Without Emissions Limits	Reference: With Emissions Limits	Advanced Technology: Without Emissions Limits	Advanced Technology: With Emissions Limits
		2010			
Industrial Output (Billion 1992 Dollars)	4,722	6,223	6,212	6,217	6,217
Industrial Output Growth (Annual Percent, 1999-2010)	—	2.54	2.52	2.53	2.53
Delivered Energy Consumption (Quadrillion Btu)	27.6	31.1	31.0	30.7	30.7
Petroleum	9.5	10.5	10.6	10.2	10.4
Natural Gas	9.8	11.3	11.3	11.2	11.2
Coal	2.5	2.6	2.5	2.5	2.4
Renewables	2.2	2.6	2.6	2.8	2.8
Purchased Electricity	3.6	4.2	3.9	4.0	3.8
Delivered Energy Intensity (Thousand Btu per 1992 Dollar of Output)	5.84	5.00	4.99	4.94	4.93
Change in Delivered Energy Intensity (Annual Percent, 1999-2010)	—	-1.39	-1.42	-1.51	-1.51
Average Delivered Prices (1999 Dollars per Million Btu)	5.29	5.62	6.50	5.27	5.98
Electricity	13.12	12.04	16.84	11.29	15.13
Natural Gas	2.79	3.46	4.02	3.07	3.60
Petroleum	5.54	6.07	6.16	5.91	5.92
CO_2 Emissions (Million Metric Tons Carbon Equivalent)	480	533	471	515	462
		2020			
Industrial Output (Billion 1992 Dollars)	4,722	8,083	8,098	8,069	8,068
Industrial Output Growth (Annual Percent, 1999-2020)	—	2.59	2.60	2.58	2.58
Delivered Energy Consumption (Quadrillion Btu)	27.6	34.7	34.8	33.8	33.9
Petroleum	9.5	11.6	11.7	11.0	11.2
Natural Gas	9.8	12.7	13.2	12.4	12.8
Coal	2.5	2.6	2.6	2.3	2.3
Renewables	2.2	3.1	3.1	3.6	3.6
Purchased Electricity	3.6	4.8	4.1	4.5	4.0
Delivered Energy Intensity (Thousand Btu per 1992 Dollar of Output)	5.84	4.30	4.29	4.18	4.20
Change in Delivered Energy Intensity (Annual Percent, 1999-2020)	—	-1.45	-1.45	-1.57	-1.56
Average Delivered Prices (1999 Dollars per Million Btu)	5.29	5.82	6.60	5.08	5.55
Electricity	13.12	12.07	17.30	10.36	13.39
Natural Gas	2.79	3.73	4.32	2.88	3.30
Petroleum	5.54	6.12	6.13	5.85	5.80
CO_2 Emissions (Million Metric Tons Carbon Equivalent)	480	585	502	543	478

Source: National Energy Modeling System, runs SCENABS.D080301A, SCENAEM.D081601A, SCENBBS.D080301A, and SCENBEM.D081701A.

[25]Buildings: Energy Information Administration (EIA), *Technology Forecast Updates—Residential and Commercial Building Technologies* (Arthur D. Little, Inc., September 1998) and EIA, *Technology Forecast Updates—Residential and Commercial Building Technologies—Advanced Adoption Case* (Arthur D. Little, Inc., September 1998). Industrial: EIA, *Aggressive Technology Strategy for the NEMS Model* (Arthur D. Little, Inc., September 1998). Transportation: U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, *Scenarios of U.S. Carbon Reductions: Potential Impacts of Energy Technologies by 2010 and Beyond*, ORNL / CON-444 (Washington, DC, September 1997); Office of Energy Efficiency and Renewable Energy, Office of Transportation Technologies, *OTT Program Analysis Methodology: Quality Metrics 2000* (November 1998); J. DeCicco and M. Ross, *An Updated Assessment of the Near-Term Potential for Improving Automotive Fuel Economy* (Washington, DC: American Council for an Energy-Efficient Economy, November 1993); and F. Stodolsky, A. Vyas, and R. Cuenca, *Heavy and Medium Duty Truck Fuel Economy and Market Penetration Analysis, Draft Report* (Chicago, IL: Argonne National Laboratory, August 1999).

Table 10. Transportation Energy Consumption in the Reference and Advanced Technology Cases, 2010 and 2020

Projections	1999	Reference		Advanced Technology	
		Without Emissions Limits	With Emissions Limits	Without Emissions Limits	With Emissions Limits
		2010			
Energy Use by Mode (Quadrillion Btu)					
Light-Duty Vehicle	15.5	19.2	19.1	18.0	18.0
Heavy-Duty Vehicle	4.5	5.8	5.8	5.6	5.6
Air	3.5	4.6	4.5	4.5	4.6
Rail	0.6	0.7	0.6	0.6	0.6
Marine	1.3	1.5	1.5	1.5	1.5
Pipeline Fuel	0.7	0.9	1.0	0.9	1.0
Lubricants	0.2	0.3	0.3	0.3	0.3
Total	**26.3**	**32.8**	**32.7**	**31.3**	**31.3**
Energy Use by Fuel Type (Quadrillion Btu)					
Motor Gasoline	15.9	18.9	18.9	17.9	17.9
Distillate	5.1	7.0	6.9	6.6	6.5
Jet Fuel	3.5	4.5	4.5	4.5	4.5
Residual Fuel	0.7	0.9	0.9	0.9	0.9
Other Petroleum	0.3	0.4	0.4	0.4	0.4
Petroleum Subtotal	*25.5*	*31.6*	*31.5*	*30.2*	*30.1*
Methanol (M85)	0.00	0.00	0.01	0.00	0.01
Ethanol (E85)	0.01	0.03	0.03	0.05	0.05
Electricity	0.06	0.12	0.12	0.09	0.09
Compressed Natural Gas	0.02	0.09	0.09	0.13	0.13
Liquid Hydrogen	0.00	0.00	0.00	0.00	0.00
Pipeline Fuel	0.7	0.9	1.0	0.9	1.0
Total	**26.3**	**32.8**	**32.7**	**31.3**	**31.3**
CO_2 Emissions (Million Metric Tons Carbon Equivalent)	**498**	**626**	**623**	**597**	**596**
		2020			
Energy Use by Mode (Quadrillion Btu)					
Light-Duty Vehicle	15.5	21.7	21.7	18.8	18.8
Heavy-Duty Vehicle	4.5	6.7	6.7	6.2	6.2
Air	3.5	6.0	6.0	5.9	5.9
Rail	0.6	0.7	0.6	0.6	0.6
Marine	1.3	1.5	1.5	1.5	1.5
Pipeline Fuel	0.7	1.1	1.2	1.0	1.1
Lubricants	0.2	0.3	0.3	0.3	0.3
Total	**26.3**	**38.2**	**38.1**	**34.3**	**34.4**
Energy Use by Fuel Type (Quadrillion Btu)					
Motor Gasoline	15.9	21.3	21.2	18.4	18.4
Distillate	5.1	8.2	8.1	7.3	7.3
Jet Fuel	3.5	6.0	6.0	5.8	5.8
Residual Fuel	0.7	0.9	0.9	0.9	0.9
Other Petroleum	0.3	0.4	0.4	0.5	0.5
Petroleum Subtotal	*25.5*	*36.7*	*36.6*	*32.9*	*32.9*
Methanol (M85)	0.00	0.00	0.00	0.01	0.00
Ethanol (E85)	0.01	0.04	0.04	0.07	0.07
Electricity	0.06	0.17	0.17	0.12	0.12
Compressed Natural Gas	0.02	0.16	0.15	0.22	0.21
Liquid Hydrogen	0.00	0.00	0.00	0.00	0.00
Pipeline Fuel	0.7	1.1	1.2	1.0	1.1
Total	**26.3**	**38.2**	**38.1**	**34.3**	**34.4**
CO_2 Emissions (Million Metric Tons Carbon Equivalent)	**498**	**730**	**725**	**653**	**652**

Source: National Energy Modeling System, runs SCENABS.D080301A, SCENAEM.D081601A, SCENBBS.D080301A, and SCENBEM.D081701A.

beyond those assumed in the high technology case could occur if there were a very aggressive research and development effort.

The revised assumptions include earlier years of introduction, lower costs, higher maximum market potential, or higher efficiencies than assumed in the reference case or a combination of these assumptions. In addition, in the residential sector, existing building shell efficiencies are assumed to improve by 15 percent over 1997 levels by 2010, and commercial building shell efficiencies are assumed to increase 50 percent faster than in the reference case. In the industrial sector, more rapid technology is implemented by increasing the rate of energy intensity decline for the processes and end uses in the process and assembly component of the industrial model, as presented in Appendix B. In addition, recovery of by-product biomass is assumed to grow more rapidly in the high technology case, 1 percent per year compared with 0.2 percent per year in the reference case. Since the impact of improved technology is amplified if existing equipment is retired more quickly, the industrial high technology case also assumes more rapid retirement rates.

Although more advanced technologies may reduce energy consumption, in general they are more expensive when initially introduced. In order to penetrate into the market, advanced technologies must be purchased by consumers; however, many potential purchasers may not be willing to buy more expensive equipment that has a long period for recovering the additional cost through energy savings, and many consumers may value other attributes more than energy efficiency. Penetration can also be slowed by the turnover of the capital stock.

Table 11. Transportation Efficiency and Travel in the Reference and Advanced Technology Cases, 2010 and 2020

Projections	1999	Reference: Without Emissions Limits	Reference: With Emissions Limits	Advanced Technology: Without Emissions Limits	Advanced Technology: With Emissions Limits
		2010			
Energy Efficiency Indicators					
New Light-Duty Vehicle (Miles per Gallon)	24.2	27.2	27.3	31.9	31.8
New Car (Miles per Gallon)	27.9	32.5	32.5	36.3	36.2
New Light Truck (Miles per Gallon)	20.8	23.3	23.4	28.3	28.3
Light-Duty Fleet (Miles per Gallon)	20.5	21.0	21.0	22.3	22.3
Aircraft Efficiency (Seat Miles per Gallon)	51.7	56.1	56.1	56.1	56.1
Freight Truck Efficiency (Miles per Gallon)	6.0	6.4	6.4	6.7	6.7
Rail Efficiency (Ton Miles per Thousand Btu)	2.8	3.1	3.1	3.3	3.3
Domestic Shipping (Ton Miles per Thousand Btu)	2.3	2.7	2.7	2.7	2.7
Travel					
Light-Duty Vehicle (Billion Miles)	2,394	3,059	3,053	3,072	3,073
Heavy-Duty Vehicle (Billion Miles)	204	279	278	278	278
Air (Billion Seat Miles)	1,099	1,586	1,582	1,586	1,587
Rail (Billion Ton Miles)	1,353	1,708	1,450	1,701	1,462
Domestic Shipping (Billion Ton Miles)	661	778	756	771	765
		2020			
Energy Efficiency Indicators					
New Light-Duty Vehicle (Miles per Gallon)	24.2	28.1	28.1	34.9	34.8
New Car (Miles per Gallon)	27.9	32.5	32.5	39.1	39.0
New Light Truck (Miles per Gallon)	20.8	24.7	24.7	31.4	31.4
Light-Duty Fleet (Miles per Gallon)	20.5	21.5	21.6	25.1	25.1
Aircraft Efficiency (Seat Miles per Gallon)	51.7	60.3	60.3	61.8	61.8
Freight Truck Efficiency (Miles per Gallon)	6.0	6.9	6.9	7.5	7.5
Rail Efficiency (Ton Miles per Thousand Btu)	2.8	3.4	3.4	3.8	3.8
Domestic Shipping (Ton Miles per Thousand Btu)	2.3	3.0	3.0	3.2	3.2
Travel					
Light-Duty Vehicle (Billion Miles)	2,394	3,575	3,573	3,597	3,599
Heavy-Duty Vehicle (Billion Miles)	204	352	352	352	351
Air (Billion Seat Miles)	1,099	2,316	2,316	2,318	2,318
Rail (Billion Ton Miles)	1,353	1,967	1,611	1,932	1,633
Domestic Shipping (Billion Ton Miles)	661	890	861	873	869

Source: National Energy Modeling System, runs SCENABS.D080301A, SCENAEM.D081601A, SCENBBS.D080301A, and SCENBEM.D081701A.

To represent more rapid technology development in the electricity generation sector, the costs and efficiencies of advanced fossil-fired and new renewable generating technologies are assumed to improve from reference case values, based on assessments from the U.S. Department of Energy (DOE) Office of Energy Efficiency and Renewable Energy, DOE Office of Fossil Energy, and the Electric Power Research Institute.[26] For nuclear power plants, the reference case assumes that operating costs will increase after the plant reaches 30 years of age, at which point they increase by $0.25 per kilowatt per year for the next ten years, then by $13.50 per kilowatt per year for the next ten years. After 50 years of age, costs increase by about $25 per kilowatt per year. After 30 years of operation, the operating costs are evaluated every ten years, and the plant continues in operation if the operating costs are lower than the cost of building new capacity. For the high technology case in *AEO2001*, these aging-related cost increases are assumed to be 25 percent of those in the reference case.

For central station renewable generating technologies, capital costs in the high technology case are reduced so that, by 2020, they are the lower of either 15 percent below the reference case or approximately the costs specified by the DOE Office of Energy Efficiency and Renewable Energy and the Electric Power Research Institute in their joint 1997 report *Renewable Energy Technology Characterizations*.[27] Fixed operations and maintenance costs for renewable energy technologies are assumed to be lower than in the reference case and are designed to approximate costs in the same report. Lower capital costs are also assumed for residential and commercial photovoltaic systems. Higher capacity factors are assumed for wind and solar thermal central station generating capacity, reaching an average of 47 percent for wind power by 2020 compared with 38 percent in the reference case and 77 percent for solar thermal compared with 42 percent in the reference case. Finally, biomass energy supplies are assumed to be 10 percent higher than in the reference case, lowering the cost of biomass technologies through lower fuel costs.

For fossil fuel supply, assumptions of more rapid technology and productivity improvements increase the supplies and reduce the production costs. For conventional oil and natural gas supply, reference case parameters for the effects of technological progress on finding rates, drilling, lease equipment and operating costs, and success rates are increased by 25 percent. For unconventional natural gas, key exploration and production technologies are also increased by 25 percent. For enhanced oil recovery, cost reductions for drilling, completing, and equipping production wells and the penetration of horizontal well technology are also assumed to increase over reference case levels. The undiscovered recoverable resource base for natural gas miscible recovery is assumed to increase over the forecast period with advances in technology. Canadian supply parameters are adjusted to simulate the assumed impacts of rapid oil and natural gas technology development on Canadian supply. Although more rapid technology development increases the domestic supply potential of crude oil, oil prices are assumed to be set on world markets and are not affected by the technology improvements.[28] Natural gas production is higher and prices are reduced with more rapid technology improvements.

More rapid technology development in coal production is represented by increasing labor productivity and reducing labor and equipment costs, relative to the reference case. In 2020, national labor productivity, measured as short tons per miner per hour, increases from 10.22 in the reference case to 14.12 in the more rapid technology development case, reflecting a 4.0-percent increase in the annual labor productivity growth rate at underground coal mines and a 3.6-percent increase at surface coal mines. Labor wage rates for coal mine production workers and equipment costs are assumed to decline by 0.5 percent per year in real terms in the high technology case but remain constant in real terms in the reference case.

In general, more rapid development for advanced energy-consuming technologies will tend to encourage the adoption and penetration of these technologies, reducing energy consumption, improving energy efficiency, and increasing the use of more advanced technologies, relative to the reference case. However, consumers continue to make decisions concerning the adoption of these technologies in the same fashion, so these technologies must still be cost effective to penetrate the market.

All of these assumptions for more rapid improvements in technology are based on higher levels of research and development funding than assumed in the reference case and result in the successful development of the technologies. More rapid technology development could be possible with higher funding or breakthrough developments. The levels of funding necessary for the successful achievement of the technology characteristics

[26]Fossil-fired generating technologies: U.S. Department of Energy, Office of Fossil Energy. Renewable Generating Technologies: U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, and Electric Power Research Institute, *Renewable Energy Technology Characterizations*, EPRI-TR-109496 (Washington, DC, December 1997).

[27]U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, and Electric Power Research Institute, *Renewable Energy Technology Characterizations*, EPRI-TR-109496 (Washington, DC, December 1997).

[28]For this study, the potential for worldwide technology improvements in oil production was not addressed.

assumed in the advanced technology case are not known, nor are the environmental benefits quantified. The simultaneous success of all technology research would seem unlikely. History has shown that research and development funding levels cannot be directly tied to the successful development of new technologies. Since the reference case of *AEO2001* is based on historical levels of funding and technology development, the technology trends assumed in the reference case are considered to be the most likely trends.

AEO2001 presents a high technology case that combines the high technology assumptions in the energy-consuming sectors, both end-use demand and electricity generation by fossil fuels and renewables. However, the request by Senators Jeffords and Lieberman specified an advanced technology case that includes all demand and supply sectors. The introduction of more rapid technology improvements for oil and natural gas supply and higher productivity improvements and cost reductions for coal supply tend to reduce the prices of these fossil fuels. Lower prices for coal and natural gas, combined with technology improvements in electricity generation by fossil fuels and renewable sources and lower nuclear costs, will tend to lower the price of electricity. Reduced prices for coal, natural gas, and electricity are likely to discourage the adoption of the more efficient and advanced technologies to some degree by making them less cost effective than they otherwise would be.

In this advanced technology case, the projected average wellhead price of natural gas reaches $2.20 per thousand cubic feet in 2020, compared with $2.71 per thousand cubic feet in the advanced technology case without the improved technology for fuel supply (Table 12). The projected average minemouth price of coal is reduced from $12.83 per short ton in 2020 in the advanced technology case without fuel supply improvements to $10.76 per short ton, and projected average delivered electricity prices are reduced from 5.8 cents per kilowatthour to 5.5 cents per kilowatthour. In the advanced technology case, these lower prices have the effect of raising total energy consumption in 2020 by 1 percent to 120.4 quadrillion Btu, compared with 119.3 quadrillion Btu in the case without the fuel supply technology improvements. Electricity demand in 2020 is raised from 4,581 to 4,610 billion kilowatthours, or 1 percent. This rebound effect of lower fuel prices on energy consumption, while noticeable, is small and does not significantly impact the costs of the emissions reductions in this analysis.

Impact of Advanced Technology Assumptions on Energy Markets

As a result of the more rapid assumed technology development, total energy consumption in 2020 is projected to be reduced by 7 quadrillion Btu, or 6 percent, compared to the reference case, due to the earlier adoption of more efficient technologies in the end-use demand sectors. The primary energy intensity of the economy is projected to decline at an average annual rate of 1.9 percent between 1999 and 2020, compared to 1.6 percent in the reference case. Projected consumption of all fossil fuels and electricity is lower compared to the reference case; however, the use of existing nuclear power and renewable technologies is higher due to the assumed cost and performance improvements. Because of reduced energy consumption and the shift in the fuel mix to more renewables and nuclear power, projected CO_2 emissions in 2020 are reduced by 160 million metric tons carbon equivalent, or 8 percent, compared to the reference case.

Partly due to lower projected consumption but primarily due to the more rapid technology development assumed for the production of fossil fuels, the prices of both natural gas and coal are expected to be lower in the advanced technology case compared to the reference case. In 2020, the wellhead price of natural gas is expected to be $2.20 per thousand cubic feet in the advanced technology case, compared to $3.10 per thousand cubic feet in the reference case. The projected minemouth price of coal in 2020 is projected to be $10.76 per short ton and $12.93 per short ton in the advanced technology and reference cases, respectively. Since the price of crude oil is assumed to be set on world markets, the projected price of oil does not change. Lower projected prices for natural gas and coal, combined with lower electricity demand that reduces the need for new capacity, contribute to lower electricity prices. The average delivered price of electricity in 2020 is projected to be 5.5 cents per kilowatthour in the advanced technology case compared to 6.1 cents per kilowatthour in the reference case. As a result of lower projected prices and demand, energy expenditures are also lower.

End-Use Demand

Residential

Incorporating the advanced technology assumptions allows consumers to choose more efficient appliances at lower costs, relative to the reference case. Although average energy prices are projected to be lower by more than 2 percent relative to the reference case in 2010 and by 7 percent in 2020, projected residential energy demand is nearly 4 percent and 5 percent lower in 2010 and 2020, respectively, due to the advanced technology assumptions. Natural gas accounts for more than half of the reduction, as average building shell efficiency is projected to be nearly 10 percent higher than in the reference case in 2010 and 16 percent higher in 2020, reducing the amount of energy needed for space heating. Increases in building shell efficiency are driven by the adoption of more energy-efficient construction materials as well as an increase in awareness and familiarity of energy-efficient construction practices on the part of builders.

Table 12. Summary of Energy Market Projections in the Reference and Advanced Technology Cases, 2010 and 2020

Projections	1999	Reference	Advanced Technology Without Fuel Supply Technology Improvements	Advanced Technology With Fuel Supply Technology Improvements
			2010	
Production (Quadrillion Btu)	**73.3**	**80.9**	**79.8**	**80.7**
Petroleum	15.1	14.6	14.4	15.0
Natural Gas	19.2	24.0	22.9	23.0
Coal	23.1	26.5	26.0	26.1
Nuclear Power	7.8	7.7	7.7	8.0
Renewable Energy	6.5	7.9	8.3	8.2
Primary Energy Consumption (Quadrillion Btu)	**96.3**	**114.7**	**111.5**	**111.7**
Petroleum	37.9	44.3	42.4	42.4
Natural Gas	22.3	28.9	27.7	27.7
Coal	21.4	25.6	25.1	25.1
Nuclear Power	7.8	7.7	7.7	8.0
Renewable Energy	6.5	7.9	8.3	8.2
Change in Primary Energy Intensity (Annual Percent Change, 1999-2010)	**—**	**-1.6**	**-1.9**	**-1.8**
Electricity Sales (Billion Kilowatthours)	**3,294**	**4,133**	**4,041**	**4,049**
Prices				
World Oil Price (1999 Dollars per Barrel)	17.22	21.37	21.37	21.37
Natural Gas Wellhead Price (1999 Dollars per Thousand Cubic Feet)	2.08	2.82	2.52	2.39
Coal Minemouth Price (1999 Dollars per Short Ton)	17.13	14.19	13.92	12.73
Average Delivered Electricity Price (1999 Cents per Kilowatthour)	6.7	6.1	5.9	5.9
CO_2 Emissions[a] (Million Metric Tons Carbon Equivalent)	**1,511**	**1,821**	**1,754**	**1,755**
			2020	
Production (Quadrillion Btu)	**73.3**	**87.6**	**84.0**	**86.3**
Petroleum	15.1	15.2	14.6	15.5
Natural Gas	19.2	30.1	27.7	28.1
Coal	23.1	27.1	26.2	25.9
Nuclear Power	7.8	6.5	5.8	7.2
Renewable Energy	6.5	8.4	9.1	9.1
Primary Energy Consumption (Quadrillion Btu)	**96.3**	**127.7**	**119.3**	**120.4**
Petroleum	37.9	50.4	45.8	45.7
Natural Gas	22.3	35.9	33.1	33.2
Coal	21.4	26.3	25.3	25.1
Nuclear Power	7.8	6.5	5.8	7.2
Renewable Energy	6.5	8.4	9.1	9.1
Change in Primary Energy Intensity (Annual Percent Change, 1999-2020)	**—**	**-1.6**	**-1.9**	**-1.9**
Electricity Sales (Billion Kilowatthours)	**3,294**	**4,763**	**4,581**	**4,610**
Prices				
World Oil Price (1999 Dollars per Barrel)	17.22	22.41	22.41	22.41
Natural Gas Wellhead Price (1999 Dollars per Thousand Cubic Feet)	2.08	3.10	2.71	2.20
Coal Minemouth Price (1999 Dollars per Short Ton)	17.13	12.93	12.83	10.76
Average Delivered Electricity Price (1999 Cents per Kilowatthour)	6.7	6.1	5.8	5.5
CO_2 Emissions[a] (Million Metric Tons Carbon Equivalent)	**1,511**	**2,044**	**1,891**	**1,884**

[a] CO_2 emissions are from energy combustion only and do not include emissions from energy production or industrial processes.
Source: National Energy Modeling System, runs SCENABS.D080301A, SCENBBS.D080301A, and SCENB1BS.D080301A.

Residential electricity demand, which is projected to grow faster than any other fuel over the projection period, is reduced by 1 percent relative to the reference case in 2010 and by 2 percent in 2020. Most electric appliances available to the residential sector are considered "mature," and thus gains in efficiency due to the adoption of advanced technologies are relatively modest in this case. In addition, the growth in miscellaneous electronic appliances, which is the fastest growing component of electricity demand, is assumed to grow at the same rate projected in the reference case. Because there are no data to characterize their efficiency levels, growth rates are based on the potential for more households to use these appliances. Consumer hurdle rates, which are important determinants of the projected penetration of more efficient appliances, are also assumed to remain at the same levels as in the reference case.

The advanced technology assumptions are based on increased research and development funding that could lead to improvements in available technologies but would not impact the way in which consumers make decisions to purchase new equipment. Average delivered electricity prices are projected to be lower by 8 percent in 2020 relative to the reference case, reducing the financial incentive to invest in energy efficiency. These factors all contribute to the modest savings in residential energy demand projected in this case.

As a result of the lower projected energy consumption, residential sector CO_2 emissions are projected to be reduced by 12 and 26 million metric tons carbon equivalent, or 3 and 7 percent, in 2010 and 2020, respectively. More than half of the CO_2 reduction in 2010 results from lower projected electricity demand, while 65 percent of the CO_2 reduction in 2020 is attributable to lower electricity demand.

Commercial

In the advanced technology case, projected commercial electricity demand is 1 percent lower in 2010 and 2 percent lower in 2020, relative to the reference case, as consumers adopt more advanced lighting technologies and information technology-related equipment. Lower natural gas prices lead to higher projected natural gas consumption, offsetting part of the reduction in delivered electricity use. The availability of advanced technologies does not necessarily lead to their adoption. Factors other than energy costs, such as limited investment funds and different incentives for renters and owners still enter into purchase decisions. For this reason, consumer behavior in the advanced technology case is assumed to be the same as in the reference case. Therefore, with lower fuel prices, consumers are expected to have less incentive to invest in more efficient end-use equipment and distributed generation technologies, limiting the projected effect of more optimistic technology assumptions. The reference case represents the pace of technological progress expected with historical levels of research and development funding. Technological progress in the advanced technology case represents the potential impacts of increased research and development. However, the amount of funding required to achieve these advances is unknown.

Due to the reduced electricity demand, projected commercial sector CO_2 emissions are 6 million metric tons carbon equivalent, or 2 percent, lower than reference case projections in 2010 and 16 million metric tons carbon equivalent, or 5 percent, lower in 2020, including CO_2 emissions from the fuels used to generate electricity for the commercial sector.

Industrial

In the advanced technology case, 0.9 quadrillion Btu less energy is projected to be consumed by the industrial sector in 2020 than in the reference case. Industrial delivered energy intensity is projected to decline by 1.6 percent per year though 2020 in this case, compared with a 1.5-percent annual decline in the reference case. While some individual industry intensities are projected to decline almost twice as rapidly in the advanced technology case as in the reference case, the aggregate intensity is not as strongly affected because the composition of industrial output is similar in the two cases.

In the advanced technology case, projected consumption of all industrial energy sources is lower compared to the reference case, except for renewables. Consumption of renewable energy sources is projected to be higher by 7 percent, or 0.2 quadrillion Btu, in 2010 and by 16 percent, or 0.5 quadrillion Btu, in 2020. Most of the increase in renewables occurs in the paper industry. In the advanced technology case, more renewables are assumed to be available due to more efficient recovery of pulping liquor and wood byproducts. Due to the lower energy consumption, projected industrial CO_2 emissions are reduced by 18 and 42 million metric tons carbon equivalent, or 3 and 7 percent, in 2010 and 2020, respectively.

Transportation

For the transportation sector, the advanced technology case includes assumptions of lower costs and improved efficiencies for advanced technologies, comparable to those provided by the DOE Office of Transportation Technologies, the American Council for an Energy-Efficient Economy, and Argonne National Laboratory for light and heavy vehicles and to those assumed in a DOE interlaboratory study for air, rail, and marine travel.[29] The efficiency gains rely heavily on the success of government research and development programs as well as a shift in consumer demand for more efficient technologies.

In the advanced technology case, new light-duty vehicle fuel efficiency is projected to improve to 31.9 miles per gallon by 2010 and to 34.9 miles per gallon by 2020, compared to 27.2 and 28.1 miles per gallon in 2010 and 2020, respectively, in the reference case. Heavy truck, aircraft, rail, and marine efficiencies are all projected to improve. Compared to the reference case, there is no significant change in travel demand projected for any travel mode with the exception of rail and natural gas pipelines which are reduced due to projected reductions in coal and natural gas consumption relative to the reference case. As a result of the projected efficiency improvements, transportation energy use is projected to be reduced by 4 percent in 2010 and by 10 percent in 2020, compared to the reference case, and projected CO_2 emissions are reduced by 29 and 77 million metric tons carbon equivalent, or 5 and 11 percent, in 2010 and 2020, respectively.

Electricity and Renewables

In the advanced technology case, improvements in the projected efficiency of end-use equipment and building shells as well as in the cost and performance of electricity generating technologies are assumed to be available earlier than in the reference case. These technological improvements reduce the projected growth in electricity sales as consumers benefit from more efficient end-use equipment than in the reference case. Electricity sales are expected to grow at an average annual rate of 1.6 percent compared with 1.8 percent in the reference case. As a result, the need for new investment in generation capacity and other equipment is reduced. The lower level of investment, combined with lower projected costs of fuels used to generate electricity, results in lower projected electricity prices. For example, prices to residential customers in 2020 are projected to be 8 percent lower than in the reference case.

Average delivered electricity prices to all consumers in the advanced technology case are projected to be 10 percent lower than in the reference case in 2020. In addition, CO_2 emissions are reduced due to reductions in the use of fossil fuels to generate electricity. In 2020, projected CO_2 emissions from electricity generators are 57 million metric tons carbon equivalent lower than the 773 million metric tons carbon equivalent in the reference case. There are also modest reductions in projected emissions of NO_x and Hg.

In the advanced technology case, emissions are reduced primarily because the lower projected demand for electricity reduces the use of coal and natural gas for electricity generation relative to the reference case. Coal consumption by electricity generators is expected to be lower by 57 million short tons in 2020 while projected natural gas use is lower by 2 trillion cubic feet, even though the projected delivered prices of these fuels to generators are considerably lower than in the reference case. Lower projected consumption of fossil fuels reflects the lower requirements for generation.

By 2020, the need for new capacity is expected to be 33 gigawatts lower, compared to the cumulative capacity additions in the reference case, which are mostly natural-gas-fired combined-cycle plants. However, more coal and renewable capacity additions are expected because of the assumed cost and performance improvements in the advanced technology case. Almost 7 gigawatts more coal capacity is expected to be constructed by 2020 compared with the reference case. The projected increase in renewable capacity is more modest, an additional 2 gigawatts of cumulative capacity additions by 2020 in the advanced technology case, compared to the reference case. Although no new nuclear plants are expected to be constructed, there are fewer retirements of existing plants because the advanced technology case assumes lower aging-related costs. By 2020, 10 gigawatts of nuclear capacity is projected to be retired, compared to 21 gigawatts in the reference case. As a result, projected nuclear generation in 2020 is 10 percent higher than in the reference case.

Natural Gas

In the advanced technology case, more rapid technological change in the end-use and generating sectors results in increased efficiency, which reduces the demand for natural gas compared to the reference case. Total natural gas consumption in the advanced technology case is projected to reach 32.4 trillion cubic feet in 2020, 7 percent lower than the 35.0 trillion cubic feet in the reference case. The largest decrease in consumption is in the electricity generation sector. By 2020, natural gas consumption by electricity generators, excluding cogenerators, is projected to reach 9.1 trillion cubic feet, 2.0 trillion cubic feet lower than it is in the reference case. Residential and industrial demand is also projected to be lower in the advanced technology case in 2020 by a total of 0.6 trillion cubic from the reference case.

[29]U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, *Scenarios of U.S. Carbon Reductions: Potential Impacts of Energy Technologies by 2010 and Beyond,* ORNL / CON-444 (Washington, DC, September 1997); Office of Energy Efficiency and Renewable Energy, Office of Transportation Technologies, *OTT Program Analysis Methodology: Quality Metrics 2000* (November 1998); J. DeCicco and M. Ross, *An Updated Assessment of the Near-Term Potential for Improving Automotive Fuel Economy* (Washington, DC: American Council for an Energy-Efficient Economy, November 1993); and F. Stodolsky, A. Vyas, and R. Cuenca, *Heavy and Medium Duty Truck Fuel Economy and Market Penetration Analysis, Draft Report* (Chicago, IL: Argonne National Laboratory, August 1999).

The *AEO2001* reference case assumes that technological improvements will lower drilling costs, increase success rates, and increase reserves added per well at the average rates of change measured over the last two decades. In the advanced technology case, the improvement in the projected rate of technological development for natural gas exploration and development is assumed to be faster, and it influences domestic natural gas supplies in three ways. First, faster technological development lowers the costs of future drilling. Second, the ratio of successful wells to total wells drilled is higher, as technological improvement reduces the number of dry holes. Finally, the volume of reserves added with each well drilled is higher, allowing fewer wells to be drilled to meet required production volumes.

As in the high oil and natural gas technology case in *AEO2001*, the rates of technological change for onshore, conventional gas sources, the largest component of domestic production, are assumed to be 25 percent faster in the advanced technology case than in the reference case. With these assumptions, onshore, conventional natural gas reserves per well drilled are larger and drilling is more accurate and less expensive, allowing more production with lower cost than in the reference case. The technology growth rates assumed in the advanced technology case have been seen over short periods in the last two decades but are higher than the average achieved over the same time period. For unconventional and offshore production, faster technology improvements lead to earlier development of these resources than assumed in the reference case, allowing for earlier production.

While the more rapid technological improvement allows natural gas supplies to grow more quickly, the advanced technology case also reduces the total demand for natural gas even though prices are lower. In the advanced technology case, lower demand and more easily accessible supplies result in lower wellhead prices which are projected to be $2.20 per thousand cubic feet in 2020, compared to $3.10 per thousand cubic feet in the reference case, relative to an estimated level of $3.53 per thousand cubic feet in 2000, converted to 1999 dollars.

The assumptions used in the high oil and natural gas technology case in *AEO2001* are designed to analyze the effects of rapid technological growth. The advanced technology case in this study shows that these rapid technological change assumptions can have a strong impact on natural gas prices and potential supply. However, the actual mechanism of reaching these higher levels of technological growth, such as additional expenditures for research and development, is not explicitly represented in this case. In order to increase the rate of technological development to the level projected in the advanced technology case, research and development expenditures would likely need to be higher than they have been in recent years. Given the lower prices in the advanced technology case, the effort required to increase the rate of technological improvement to the levels achieved in the *AEO2001* rapid technology case may be difficult to sustain. The advanced technology case evaluates what the effects of faster technological growth could be on natural gas markets but does not determine how these advances might be achieved nor does it assess the likelihood that faster technological progress will actually occur. Maintaining the high rate of technological development assumed in this case could prove challenging for the industry.

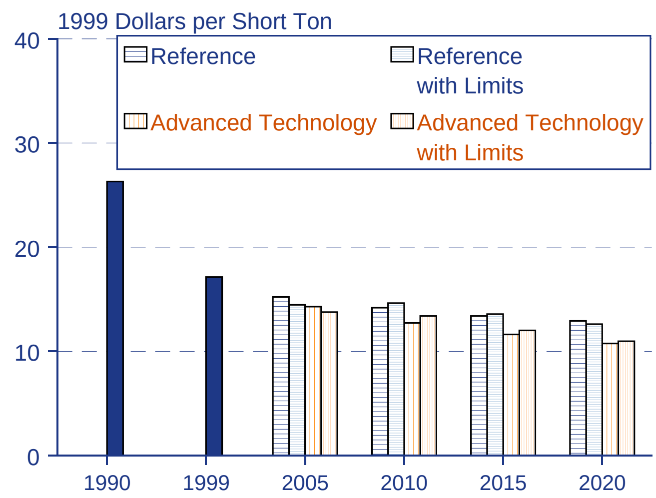
Coal

In the advanced technology case, projected coal prices to all sectors decline relative to the reference case, as a result of assumed higher labor productivity gains in the coal industry of 3.8 percent per year and decreasing factor input costs of 0.5 percent per year (Figure 20). Technology improvements also occur for natural gas supply and electricity generation technologies, and a variety of efficiency gains are achieved in the end-use demand sectors, offsetting the positive impact that lower fuel prices would otherwise have on projected coal consumption. Because electricity sales are projected to increase at a lower rate between 1999 and 2020 compared to the reference case, projected coal shipments to electricity generators, excluding cogenerators, are 5 percent lower in 2020 than in the reference case. In 2020, coal is projected to have a 48-percent market share of generation, excluding cogenerators, reduced from 54 percent in 1999, but approximately the same share as in the reference case.

Impact of Emissions Limits on the Advanced Technology Case

In 2020, the average delivered price of electricity is projected to be 22 percent higher in the advanced technology case with emissions limits than in the same case without the limits. Projected wellhead natural gas prices are also higher by 18 percent as a result of higher natural gas consumption by electricity generators. Due to

Figure 20. Coal Minemouth Prices in Four Cases, 1990-2020



Source: National Energy Modeling System, runs SCENABS.D080301A, SCENAEM.D081601A, SCENBBS.D080301A, and SCENBEM.D081701A.

the higher energy prices, total energy consumption is projected to be reduced by 5 quadrillion Btu in 2020, or 4 percent, relative to the advanced technology case without emissions limits, and energy expenditures are higher.

The primary energy intensity of the economy is projected to decline at an average annual rate of 2.1 percent between 1999 and 2020 in the advanced technology case with emissions limits, compared to 1.9 percent in the advanced technology case without limits. Total projected consumption of coal and electricity is lower compared to the advanced technology case without limits; however, the projected consumption of natural gas, nuclear power, and renewable sources is higher as electricity generators shift from using coal to using more existing nuclear power and more natural gas and renewable generating technologies. Because of reduced energy consumption and the shift in the fuel mix to more natural gas, renewables, and nuclear power, projected CO_2 emissions in 2020 are reduced by 231 million metric tons carbon equivalent, or 12 percent, relative to the advanced technology case without limits.

Electricity and Renewables

When emissions limits are included in the advanced technology case, there are additional costs of producing electricity that are reflected in the prices that consumers pay. Reducing emissions of SO_2, NO_x, Hg, and CO_2 results in 22-percent higher projected average delivered electricity prices in 2020, compared to the case without emissions limits. Consumers respond to the higher projected electricity prices by reducing projected consumption by 7 percent in 2020, compared to the advanced technology case without limits. The increase in projected electricity prices results in part from increased projected costs of fossil fuels used to generate electricity and the costs of holding or buying emissions permits. Effective delivered natural gas prices to generators in 2020 are projected to be 56 percent higher than in the case without emissions limits, while effective coal prices are 166 percent higher, due to the costs of obtaining CO_2 emissions permits and, for natural gas, the higher costs of production.

SO_2, NO_x, CO_2, and Hg emissions reductions are partly achieved by changes in the projected mix of capacity used to generate electricity. In the advanced technology case with emissions limits, additional construction of 35 gigawatts of natural-gas-fired combined-cycle and combustion turbine capacity and almost 18 gigawatts of renewables capacity is projected compared to the case without emissions limits. Natural gas use by electricity generators (excluding cogenerators) is expected to be 2.8 trillion cubic feet higher in 2020, or 30 percent, compared to the case without emissions limits. The additional projected renewable capacity is mostly wind and geothermal, plus increased output from biomass co-fired with coal in coal-fired plants, along with small increases in municipal solid waste and dedicated biomass. In addition, fewer existing nuclear plants are expected to be retired, 3 gigawatts compared to 10 gigawatts in the case without emissions limits, raising projected nuclear power generation by 7 percent in 2020.

In addition to purchasing allowance permits, electricity generators are also expected to make investments in emission control equipment to reduce emissions of SO_2, NO_x, and Hg. In the advanced technology case with emissions limits, there are 31 gigawatts more SO_2 scrubber retrofits added when emission limits are imposed, compared to 10 gigawatts in the advanced technology case without emissions limits. In both the advanced technology cases with and without emission limits, there are investments in selective catalytic reduction and selective noncatalytic reduction to reduce NO_x emissions. However, the level is somewhat higher in the case with emission limits reflecting the more stringent reductions required for NO_x emissions. Control equipment, including fabric filters and spray coolers, is also projected to be built to reduce Hg emissions in the case with emissions limits. The level of investment in Hg controls is greater in the advanced technology case with emissions limits than in the reference case with emissions limits because the higher levels of coal-fired generation require more controls to achieve the emission limits.

The projected allowance price for SO_2 increases from $145 per ton in the advanced technology case to $703 per ton in the same case with emissions limits. After the Hg limits are reached, the cost of additional scrubbers is reflected in the SO_2 allowance price. Similar to the reference case with the emissions limits, the cost for NO_x emission allowances is expected to decline to zero because the actions taken to meet the CO_2 limits result in NO_x emissions being within the specified limit. In 2020, the cost of the CO_2 emission allowances is expected to be $58 per metric ton carbon equivalent which is less than one-half the cost of those allowance costs in the reference case with emissions limits. The CO_2 allowance price declines from 2015 to 2020 because of the increasing share of natural gas. The cost of Hg allowances in the advanced technology case with emissions limits is expected to reach $374 million per ton compared to $306 million per ton in the reference case without emissions limits. Because there are fewer changes to meet the CO_2 emissions levels in the advanced technology case, which also help to reduce Hg emissions, more effort is needed to meet the Hg limits.

The lower projected electricity demand and the improved generator efficiency in the advanced technology case reduce the cost to electricity generators of achieving compliance with the CO_2 emissions limits. In the advanced technology case with emissions limits, the cumulative resource costs are expected to be $1,979 billion, compared to $1,837 billion in the advanced technology case without the limits, an 8-percent increase. This additional $142 billion cost of complying with the emissions limits in the advanced technology case is $35 billion less than the cost of complying with the same limits under reference case assumptions.

When the emissions limits are imposed on the advanced technology case, the incremental annualized resource costs for electricity generators in 2007 are projected to be $19.4 billion, declining to $16.8 billion and $11.9 billion in 2010 and 2020, respectively—smaller incremental costs due to the emissions limits than are projected in the reference case with emissions limits.

Natural Gas

Similar to the reference case, imposing emissions limits in the advanced technology case results in higher demand and higher prices for natural gas, compared to the same case without the limits. However, the more rapid growth in natural gas exploration and production technology in the advanced technology case restrains projected natural gas prices from rising as high as in the reference case with emissions limits. In 2020, the average wellhead price of natural gas is projected to be $2.60 per thousand cubic feet in the advanced technology case with emissions limits. This is 18 percent higher than the $2.20 per thousand cubic feet in the same case without emissions limits, but 30 percent lower than the $3.72 per thousand cubic feet reached by imposing the emissions limits on the reference case.

Natural gas consumption by electricity generators, excluding cogenerators, is projected to reach 11.9 trillion cubic feet in 2020 in the advanced technology case with emissions limits, an increase of 2.8 trillion cubic feet, or 30 percent, from the same case without emissions limits. Natural gas consumption is also projected to be higher in the commercial and industrial sectors, primarily for cogeneration. Total natural gas consumption is projected to reach 35.6 trillion cubic feet by 2020 in the advanced technology case with emissions limits, 3.3 trillion cubic feet higher than in the case without emissions limits.

Higher natural gas demand caused by the imposition of the emissions limits results in more domestic production and higher prices. Higher domestic natural gas production accounts for nearly all of the difference in the natural gas supplies. In 2020, projected domestic natural gas production in the advanced technology case with emissions limits is 30.1 trillion cubic feet, 2.8 trillion cubic feet higher than projected in the case without emissions limits. Unlike in the reference case, the additional demand for natural gas does not lead to a strong increase in natural gas imports. Although total natural gas demand increases through 2020, the average wellhead price is projected to decline slowly after peaking at $3.03 per thousand cubic feet in 2007 due to the impact of the advanced technology assumptions. These lower projected prices do not make the additional imports which are projected to occur in the reference case with emissions limits feasible. Therefore, most of the supply response to the higher levels of natural gas consumption in the advanced technology case with emissions limits is projected to come from increased natural gas production both onshore and offshore in the lower 48 States.

Coal

The addition of emissions limits to the advanced technology case is projected to result in significant shifts in coal consumption levels and supply patterns. In 2020, projected consumption by electricity generators is reduced to 563 million short tons, compared to 1,133 million short tons in the advanced technology case without emissions limits, a 50-percent difference. Projected coal production patterns shift rapidly in response to the stringent limits. Lignite production in 2010 is projected to decline from 92 million short tons to 12 million short tons with the addition of the limits because of its high Hg content. Projected coal production from the Powder River Basin also declines by 288 million short tons by 2020 because the CO_2 limits and the resulting CO_2 allowance costs result in displacement of coal by natural gas in many electricity generation markets.

Rocky Mountain coal, which has low Hg and SO_2 content, initially gains in output, primarily replacing lignite, and generally maintains production levels similar to the advanced technology case without limits. In 2020, projected bituminous coal production is 175 million short tons lower in the advanced technology case with limits, compared to the same case without limits, but increases market share relative to subbituminous coal, serving the electricity generation market at sharply reduced levels. Although low-sulfur coal is projected to decline at the slowest rate, gradual withdrawals from the SO_2 allowance bank and the installation of scrubbers in existing coal plants help to maintain a reduced level of production from mid- and high sulfur coal sources. The industrial and export markets are assumed to be largely unaffected by the emission limits.

End-Use Demand

Residential

The impact of emissions limits on the advanced technology case is very similar to the impact on the reference case. Given the lower projected demand in the advanced technology case, relative to the reference case, emissions limits are easier to attain, causing energy prices to increase less than in the reference case with emissions limits. As a result of the emissions limits applied to the advanced technology case, residential electricity prices are 20 percent higher in 2010, compared to 25 percent in the reference case with emissions limits, causing a 6-percent reduction in projected electricity demand in the advanced technology case with emissions limits compared to the same case without limits. In 2020, the residential electricity prices are 16 percent higher in the advanced technology case when the emissions limits are imposed, reducing the projected electricity demand by 5 percent. The impact of the emissions limits on residential natural gas prices and consumption is very similar to the reference case. CO_2 emissions are reduced by 69 and 83 million metric tons carbon equivalent, or 21 and 23 percent, in 2010 and 2020, respectively, compared to the advanced technology case without emissions limits, primarily due to the lower demand for electricity.

Commercial

Imposing emissions limits on the advanced technology case reduces projected commercial delivered energy consumption by 3 percent in 2010 and by 2 percent in 2020, relative to the case without emissions limits, while projected electricity demand is reduced by 5 and 6 percent in 2010 and 2020, respectively. Projected electricity and natural gas prices in 2010 are 28 percent and 10 percent higher, respectively, with emissions limits compared to the case without limits. In 2020, the electricity and natural gas prices are projected to be 22 and 9 percent higher.

As in the reference case with emissions limits, the higher projected electricity prices in the advanced case with emissions limits encourage commercial establishments to turn to cogeneration, using natural gas to produce 79 percent and 339 percent more electricity in 2010 and 2020 than projected in the advanced case without emissions limits. Projected CO_2 emissions in the commercial sector are lower by 68 and 81 million metric tons carbon equivalent, or 22 and 24 percent, in 2010 and 2020, respectively, due to the emissions limits.

Industrial

When the emissions limits are applied to the advanced technology case, total delivered energy consumption in the industrial sector is projected to be essentially unchanged from the advanced technology case without the emissions limits. Applying emissions limits in the advanced technology case is projected to raise the industrial electricity price by 34 and 29 percent in 2010 and 2020, respectively, while the projected natural gas price is 17 and 15 percent higher. As a result, the consumption of purchased electricity is projected to be 6 percent lower in 2010 and 11 percent lower in 2020 relative to the advanced technology case without emissions limits.

In the advanced technology case with emissions limits, projected industrial natural gas consumption is 0.4 quadrillion Btu higher in 2020 than in the advanced technology case without emissions limits, accounting for the slight increase in total industrial energy consumption. Cogeneration using natural gas is projected to be 57 percent higher in 2010 than in the case without the emissions limits and 100 percent higher in 2020. Projected CO_2 emissions are reduced by 53 and 65 million metric tons carbon equivalent, or 10 and 12 percent, in 2010 and 2020, primarily due to the lower purchased electricity demand.

Transportation

Emissions limits have a similar impact on the transportation sector in the advanced technology case as in the reference case. The only significant change with the emissions limits is a projected shift of travel from rail to pipeline due to a shift in fuel utilization from coal to natural gas by electricity generators. Total projected energy consumption in the transportation sector is slightly higher due to higher pipeline use of natural gas, and CO_2 emissions are projected to be essentially unchanged.

Macroeconomic Impacts

Methodology

The imposition of emission limits on electricity generators is expected to affect the U.S. economy primarily through higher delivered energy prices. Higher energy costs would reduce the use of energy by shifting production toward less energy-intensive sectors, by replacing energy with labor and capital in specific production processes, and by encouraging energy conservation. Although reflecting a more efficient use of higher cost energy, the change would also tend to lower the productivity of other factors in the production process because of a shift in the prices of capital and labor relative to energy. Moreover, an increase in energy prices would raise non-energy intermediate and final product prices and introduce cyclical behavior in the economy, resulting in output and employment losses in the short term. In the long term, however, the economy can be expected to recover and move back to a more stable growth path.

Relative to a reference case projection for energy markets, a case with emissions limits has impacts on the aggregate economy. However, with alternative projections for energy markets, the same emissions limits will have different impacts on energy markets and subsequently different impacts on the economy. The macroeconomic assessment in this section evaluates the impacts of emissions limits on the reference case and the advanced technology case.

The macroeconomic analysis assumes a marketable emissions permit system, with a no-cost allocation of permits. In meeting the targets, power suppliers are free to buy and sell allowances at a market-determined price for the permits, which represents the marginal cost of abatement of any given emission.

Macroeconomic Impacts of Emissions Limits on the Reference Case

The introduction of emissions limits in the reference case results in a substantial increase in energy prices and subsequently in aggregate prices for the economy. The wholesale price index for fuel and power (WPI-Fuel and Power) gives an indication of the overall change in energy prices across all fuels. The WPI-Fuel and Power is projected to rise rapidly above the reference case without emissions limits by 14.6 percent in 2007, the target year for emissions reduction (Table 13). Thereafter, this index remains approximately 15 percent above the reference case without limits through 2020.

Higher projected electricity and natural gas prices initially affect only the energy portion of the consumer price index (CPI). The higher projected energy prices are expected to be accompanied by general price effects as they are incorporated in the prices of other goods and services. In this case, the level of the CPI is projected to be about 0.7 percent above the reference case without limits by 2007 and to moderate only slightly to approximately 0.6 percent above the reference case level through 2020.

How would the projected changes in energy prices affect the general economy? Capital, labor, and production processes in the economy would need to adjust to accommodate the new, higher set of energy and non-energy prices. Higher energy prices would affect both consumers and businesses. Households would face higher prices for energy and the need to adjust spending patterns. Rising expenditures for energy would take a larger share of the family budget for consumption of goods and services, leaving less for savings. Energy services also represent a key input in the production of goods and services. As energy prices increase, the costs of production rise, placing upward pressure on the prices of all intermediate goods and final goods and services in the economy. These transition effects tend to dominate in the short run, but dissipate over time.

The unemployment rate is projected to rise by 0.4 percentage points above the reference case with no limits in 2007. Along with the projected increase in inflation and unemployment, real output of the economy is projected to be lower. Real GDP is projected to be 0.8 percent lower relative to the reference case with no limits in 2007, and employment in non-agricultural establishments is projected to be lower by one million jobs. Similarly, real disposable income is expected to be reduced by 1.0 percent.

As the economy adjusts to higher energy prices, projected inflation begins to subside after 2007. At the same time, the economy begins to return to its long-run growth path. By 2020, the projected unemployment rate is 0.1 percentage points above the reference case, and real GDP is projected to be 0.3 percent below the reference case projection. The impact on non-agricultural employment is projected to moderate to just over 400,000 jobs relative to the reference case in 2020.

Table 13. Macroeconomic Impacts of Emissions Limits in the Reference and Advanced Technology Cases, 2007, 2010, and 2020

Projections	2007	2010	2020
Wholesale Price for Fuel and Power (Percent Change From Case Without Limits)			
Reference Case	14.6	15.0	14.7
Advanced Technology	13.6	13.4	10.5
Real Gross Domestic Product (Percent Change From Case Without Limits)			
Reference Case	-0.8	-0.3	-0.3
Advanced Technology	-0.7	-0.2	-0.1
Consumer Price Index (Percent Change From Case Without Limits)			
Reference Case	0.7	0.7	0.6
Advanced Technology	0.6	0.4	0.1
Unemployment Rate (Change From Case Without Limits)			
Reference Case	0.4	0.1	0.1
Advanced Technology	0.3	0.1	0.0
Disposable Income (Percent Change From Case Without Limits)			
Reference Case	-1.0	-0.7	-0.5
Advanced Technology	-0.9	-0.4	-0.2
Nonagricultural Employment (Million Jobs, Change From Case Without Limits)			
Reference Case	-1.0	-0.4	-0.4
Advanced Technology	-0.8	-0.3	-0.2

Note: All percent changes have been rounded to one decimal point.
Source: Simulations of the DRI Macroeconomic Model of the U.S. Economy based on National Energy Modeling System, runs SCENABS.D080301A, SCENAEM.D081601A, SCENBBS.D080301A, and SCENBEM.D081701A.

Macroeconomic Impacts of Emissions Limits on the Advanced Technology Case

The advanced technology case incorporates more rapid improvements for end-use demand, electricity generation, and fossil fuel supply technologies, relative to the reference case. As a result, the impact of emissions limits on energy prices is moderated in the advanced technology case, compared to the reference case. Imposing emissions limits raises the WPI-Fuel and Power by 13.6 percent, relative to the advanced technology case without the limits, compared to the 14.6-percent increase in the reference case. By 2020, the WPI-Fuel and Power is projected to be 10.5 percent higher in the advanced technology case when emissions limits are imposed, compared to 14.7 percent higher in the reference case when the limits are imposed.

Because the impact on energy prices is less in the advanced technology case than in the reference case, the impacts on price, employment, and real output in the aggregate economy are also less. The peak impact on the CPI in 2007 is projected to be 0.6 percent as compared to 0.7 percent in the reference case. By 2020, in the advanced technology case with emissions limits, the projected CPI is only 0.1 percent above the same case without the limits, and the impact on real GDP is projected to be only 0.1 percent below the advanced technology case without the limits. Compared to the reference case, imposing emissions limits under the advanced

Macroeconomic Effects of Alternative Implementation Instruments

All the cases considered assume a marketable emission permit system, with a no-cost allocation of the permits based on historical emissions. In meeting the targets, power suppliers are free to buy and sell allowances at a market-determined price for the permits, which represents the marginal cost of abatement of any given emission. An alternative form of permit system would auction the permits to power suppliers. The price paid for the auctioned permits would equal the price paid for traded permits under the no-cost allocation system used for this study. However, the two systems imply a different distribution of income.

In the no-cost allocation system, there would be a redistribution of income flows between power suppliers in the form of purchases of emission permits. There would be no net burden on the power suppliers as a whole, only a transfer of funds among firms. While all firms are expected to benefit from trading, the burden would vary among firms. With a Federal auction system, in contrast, there would be a net transfer of income from power suppliers to the Federal government. The key question at this juncture turns on the use of the funds by the Federal government. If the funds were returned to the power suppliers, the effect would be the same as in the no-cost allocation scheme, but with the Federal government establishing the permit market mechanism. Another use of the funds might be to return them to consumers either in the form of a lump-sum transfer or in the form of a personal income tax cut, compensating consumers for the higher prices paid for energy and non-energy goods and services.[a]

Relative to the no-cost allocation of permits, an auction that transfers funds to consumers in a lump sum would help to maintain their level of overall consumption. With the transfer, however, total investment would decline relative to the allocation system. The two effects would tend to counterbalance each other, but not completely. Returning collected auction funds to the consumer would tend to have a slightly more positive effect than the negative effect on investment for the first few years, but investment would tend to rebound faster and contribute increasingly to the recovery. As a result, real GDP would be expected to recover to reference case levels faster under the no-cost allocation system. Over the entire period, however, the net impacts on real GDP are expected to be similar in both magnitude and pattern under the two potential allocation schemes.

Another approach is to recycle the auctioned revenues to either consumers or businesses through a reduction in marginal tax rates on capital or labor. Unlike the no-cost allocation or the lump-sum payment to consumers, this approach may lower the aggregate cost to the economy by shifting the tax burden away from distortionary taxes on labor and capital toward the taxation of an environmental pollutant. Most often research on this topic is based on a general equilibrium approach, where all factors are assumed to be utilized fully, as in the work by Goulder, Parry, and Burtraw.[b] Revenue recycling benefits may also apply in a setting where transition effects on the economy, such as considered in the current EIA study, are the focus.[c]

[a]For a discussion of the relative merits of alternative instruments, see Perman, Ma, and McGilvray, “Pollution Control Policy,” in *Natural Resource and Environmental Economics* (Addison Wesley Longman, 1996).

[b]L.H. Goulder, I.W.H Parry, and D. Burtraw, “Revenue-Raising Versus Other Approaches to Environmental Protection: The Critical Significance of Pre-existing Tax Distortions,” *RAND Journal of Economics*, Vol. 28. (Winter 1997), pp. 708-731.

[c]See also Energy Information Administration (EIA), *Impacts of the Kyoto Protocol on U.S. Energy Markets and Economic Activity*, SR/OIAF/98-03 (Washington, DC, October 1998), Chapter 6, “Assessment of Economic Impacts” and EIA, *Analysis of Strategies for Reducing Multiple Emissions from Electric Power Plants: Sulfur Dioxide, Nitrogen Oxides, Carbon Dioxide, and Mercury and a Renewable Portfolio Standard*, SR/OIAF/2001-03 (Washington, DC, July 2001), Chapter 4, “Fuel Market and Macroeconomic Impacts.”

technology assumptions is less costly to the aggregate economy as it transitions to a new equilibrium position toward the end of the forecast period. In the advanced technology case, there is a lower projected demand for energy and lower emissions, due to the introduction of more advanced and more efficient technologies at a lower cost. Thus, the structure of the baseline energy market has a significant effect on the magnitude and profile of the economic impacts of emissions limits.