Economic Analysis of a Multi-Emissions Strategy

Prepared for:

Senators James M. Jeffords and Joseph I. Lieberman

U.S. Environmental Protection Agency
Office of Air and Radiation
Office of Atmospheric Programs

October 31, 2001

Table of Contents

Executive Summary ii
1. Introduction 1
1.1. Background 1
1.2. Technology Scenarios 1
1.3. Multi-Emission Targets 2
1.4. Other Analytical Assumptions 3
2. Multi-Emissions Analysis 4
2.1. Modeling Technology Assumptions 5
2.1.1. Reference Case Scenario 5
2.1.2. Advanced Technology Scenario 5
2.1.3. CEF Moderate Case Scenario 6
2.1.4. CEF Advanced Technology Scenario 7
2.1.5. Implementation of the Technology Assumptions 7
2.1.6. Reasonableness of the Scenario Assumptions 9
2.2. Results of the Scenario Analysis 11
2.2.1. Emissions Projections 11
2.2.2. Changes in Electric Generating Expenditures 12
2.2.3. Marginal Costs 14
2.2.4. Fuel Use Impacts 16
2.2.5. Energy Price Impacts 16
2.2.6. Economy-wide Impacts 17
2.3. The Results in Context 18
3. Conclusions 18
4. References 20
5. Appendices 22
5.1. Description of the AMIGA Model 22
5.2. Summary Tables for Study Scenarios 24
5.2.1. Reference Case Projections 24
5.2.2. Scenario A: Emission Constraints Using Reference Case Technologies 25
5.2.3. Scenario B: Emission Constraints Using Advanced Case Technologies 26
5.2.4. Scenario C: Emission Constraints Using the Moderate CEF Scenario Assumptions 27
5.2.5. Scenario D: Emission Constraints Using the Advanced CEF Scenario Assumptions 28

Executive Summary

In response to a May 17, 2001 request from Senators James M. Jeffords (VT) and Joseph I. Lieberman (CT), this report describes the results of a modeling study done to evaluate the potential impacts of reducing nitrogen oxides (NO_x), sulfur dioxide (SO_2), mercury (Hg), and carbon dioxide (CO_2) emissions from the US electric power sector. In their request, Senators Jeffords and Lieberman asked the Environmental Protection Agency to undertake an economic assessment of four technology-based scenarios designed to achieve the following emissions caps in the US electric power sector by the year 2007:

- Reduce nitrogen oxides (NO_x) emissions to 75 percent below 1997 levels;
- Reduce sulfur dioxide (SO_2) emissions to 75 percent below full implementation of the Phase II requirements under title IV;
- Reduce mercury (Hg) emissions to 90 percent below 1999 levels; and
- Reduce carbon dioxide (CO_2) emissions to 1990 levels.

The request also specified that EPA should evaluate the cost of achieving these reductions using four alternative technology scenarios:

- The Energy Information Agency's Standard Technology Scenario.
- The Energy Information Agency's High Technology Scenario, including technology assumptions with earlier introduction, lower costs, higher maximum market potential, or higher efficiencies than the Standard Scenario.
- Two scenarios from *Scenarios for a Clean Energy Future* published by Oak Ridge National Laboratory, National Renewable Energy Laboratory, and Lawrence Berkeley National Laboratory, which include assumptions about changes in consumer behavior, additional research and development, and voluntary and information programs.

Under each scenario, the costs of meeting the emission constraints are included in the price of electricity. Such costs include the purchase and installation of emissions control equipment and the purchase of emissions permits. Factors that mitigate projected cost increases include the availability of more cost-effective, energy efficient technologies for both consumers and electricity suppliers. EPA's analysis indicates that, under the conditions described above:

- Electricity prices in 2015 would increase by about 32% to 50%, depending on the technology scenario.
- Coal-fired electric generation would decline by 25% to 35% by the year 2015.
- Overall costs, measured by the decline in household consumption of goods and services, would be between $13 and $30 billion annually or 0.1% to 0.3% of total consumption. Under all four of the policy scenarios evaluated in this assessment, gross domestic product (GDP) would remain relatively unchanged as sacrificed consumption permits higher investment and government spending to reduce emissions.
- Oil and gas-fired generation would be expected increase by about 8% under more restrictive technology assumptions, but decrease by as much as 20% under scenarios that

embody more optimistic assumptions about energy-efficiency demand and supply technologies.

The combination of increased prices and the availability of more energy-efficient equipment and appliances are projected to reduce electricity demand by about 10%. With the combination of higher prices and improved efficiency, total expenditures for electricity consumption in 2015 are projected to increase by about 17% to 39%, depending on the scenario.

The increase in electricity prices and cost of the program, as well as the impact on the fuel mix, varies considerably based the technology future that is assumed. For example, the 30% electricity price increase, the $13 billion reduction in personal consumption, and the 25% decline in coal use are all associated with the Clean Energy Future Advanced Scenario, which includes the most optimistic technology assumptions. Likewise, the 50% electricity price increase, the $30 billion reduction in personal consumption, and the 35% decline in coal usage are all associated with EIA's Standard Technology Scenario.

EPA was not asked to evaluate the merits of the alternative technology scenarios. We note, however, that they are the subject of considerable controversy. The Clean Energy Future scenarios have been criticized on several grounds: assumed changes in consumer behavior that are not consistent with historic behavior patterns, results from research and development funding increases that have not occurred, and voluntary and information programs for which there is no analytic basis for evaluating the impacts. On the other hand, supporters of those scenarios point to economic analyses showing that the assumed investments can pay for themselves over time. The range of estimates associated with the different technology scenarios highlights the importance of the technology assumptions.

In conducting the modeling requested by Senators Jeffords and Lieberman, EPA has assumed that the reductions would be achieved through a nationwide "cap-and-trade" system similar to the Acid Rain program established under the 1990 Amendments to the Clean Air Act, together with increasing penetration and performance of energy technologies. In accordance with the Senators' request, the analysis also assumes the use of banked allowances made possible by early emissions reductions achieved in the years 2002 through 2006. (In practice, significant reductions beginning in 2002 would be difficult to achieve.) Because of the contribution of those banked allowances to overall emissions reductions, the analysis shows emissions in 2007 above the caps. Regardless, 2007 emissions are substantially reduced from current levels. At the end of 2015 a small pool of banked allowances continues to be available for use in later years. The analysis contained in the report covers the years 2002 through 2015.

The results provided in this analysis should not be construed as forecasts of actual scenario outcomes. Rather, they are assessments of how the future might unfold compared to a previously defined reference case — given the mix of technology and policy assumptions embodied in each of the scenarios. The results also imply a national commitment that is successful in achieving the level of emission reductions described within the report.

The economic impacts of the emissions reduction scenarios are evaluated using Argonne National Laboratory's AMIGA model, a 200-sector computer general equilibrium model of the

U.S. economy. The modular design and economy-wide coverage of the AMIGA model makes it a logical choice to analyze alternative technology scenarios. Although it does employ the same plant-level coverage of the electricity sector as the IPM and NEMS models used in other analyses, the pollution control technology assumptions are not included at the same level of detail as the IPM model. This may be particularly relevant for mercury controls, where the effectiveness varies by coal type, and may be difficult to model correctly without additional detail. In addition, we note that the AMIGA model is relatively new and has not been subject to the same degree of peer-review and scrutiny as the older IPM and NEMS models. It would be desirable in future work to establish the comparability of results across these models.

1. Introduction

1.1. Background

Responding to an earlier Congressional request, the Energy Information Administration (EIA) released a detailed study reviewing the effects of a so-called "three pollutant" strategy in December 2000 (Energy Information Administration, 2000). The three emissions in the EIA assessment included nitrogen oxides (NO_x), sulfur dioxide (SO_2), and carbon dioxide (CO_2). Although a coordinated climate and air quality policy appeared to lower costs compared to a series of separate policy initiatives, the EIA assessment indicated significant costs associated with capping emissions.

At about the same time, five of the nation's national energy laboratories released an extensive review of some 50 different policy options that might achieve cost-effective reductions of both air pollutants and carbon dioxide (CO_2) emissions. The study, *Scenarios for a Clean Energy Future* (Interlaboratory Working Group, 2000), indicated that domestic investments in energy-efficient and clean energy supply technologies could achieve substantial reductions in both sets of emissions at a small but net positive benefit for the economy.

On May 17, 2001, Senators James M. Jeffords (VT) and Joseph I. Lieberman (CT) sent a letter to EIA and EPA seeking further clarity in the scenarios examined by the December EIA analysis, stating that "the analysis appears to unnecessarily limit the market and technology opportunities that might significantly affect the costs and benefits of emission reductions. In particular, the potential contributions of demand-side efficiency, gas-fired cogeneration and of renewable energy sources appear to be inadequately represented."

In responding to this request, EPA modeled the combined impacts of both the emissions caps and the advanced technology scenarios specified by the Senators. We are aware that EIA has modeled the combined impacts but has also modeled the effects of the emission caps and the advanced technology scenarios separately. This approach provides perhaps a better technique for isolating the actual costs of the emissions caps. We have reviewed the EIA analysis of these separate effects and we believe that they offer interesting and important insights and that if we had performed the same kind of analysis we would have seen similar results.

This report responds to the Senators' request. The results provided in this analysis should not be construed as forecasts of actual scenario outcomes. Rather they are assessments of how the future might unfold compared to a previously defined reference case — given a national commitment to achieve the emission reductions, and given the mix of technology and policy assumptions embodied in each of the scenarios.

1.2. Technology Scenarios

In the letter to Administrator Whitman, Senators Jeffords and Lieberman asked for an analysis of four different scenarios, requesting that EPA "analyze the cost and benefits, including all sectors of the economy and impacts on both the supply and demand side of the equation, of the following multi-pollutant emission control scenarios for the nation's electricity generators. Where feasible, this should include power plants both within the conventionally defined electric utility sector as well as electricity generated by industrial cogenerators and other independent power producers."

The four scenarios are identified as follows:

- ***Scenario A: Standard Technology Scenario.*** Assume standard technology characteristics as defined in AEO2001. Further assume a start date of 2002. By 2007 reduce NO_x emissions 75 percent below 1997 levels, reduce SO_2 emissions to 75 percent below full implementation of the Phase II requirements under title IV, reduce mercury emissions 90 percent below 1999 levels, and reduce CO_2 emissions to 1990 levels.

- ***Scenario B: High Technology Scenario.*** Continue the 2002 start date, but assume the advanced technology assumptions of both the supply and demand-side perspectives that are referenced in AEO2001. By 2007 reduce NO_x emissions 75 percent below 1997 levels, reduce SO_2 emissions to 75 percent below full implementation of the Phase II requirements under title IV, reduce mercury emissions 90 percent below 1999 levels, and reduce CO_2 emissions to 1990 levels.

- ***Scenario C: Moderate Clean Energy Future Scenario.*** Continue the 2002 start date, but assume the moderate supply and demand-side policy scenario of the Clean Energy Future (CEF) study. By 2007 reduce NO_x emissions 75 percent below 1997 levels, reduce SO_2 emissions to 75 percent below full implementation of the Phase II requirements under title IV, reduce mercury emissions 90 percent below 1999 levels, and reduce CO_2 emissions to 1990 levels.

- ***Scenario D: Advanced Clean Energy Future Scenario.*** Continue the 2002 start date, but assume the advanced supply and demand-side policy scenario of the Clean Energy Future study. By 2007 reduce NO_x emissions 75 percent below 1997 levels, reduce SO_2 emissions to 75 percent below full implementation of the Phase II requirements under title IV, reduce mercury emissions 90 percent below 1999 levels, and reduce CO_2 emissions to 1990 levels.

In requesting an analysis of these four scenarios, the Senate request asked for "…results through 2020, in periods of five years or less, using the Annual Energy Outlook 2001 (AEO2001) as the baseline."

1.3. Multi-Emission Targets

Table 1 identifies the 2007 emission caps used for each of the four scenarios. The emission cap is defined by a benchmark emission level that is modified by the desired level (percentage) of reduction. For example, the benchmark for the SO_2 emissions cap is the Phase II requirements of the Clean Air Act Amendments. That total, 8.95 million short tons, is reduced by a specific percentage (75 percent) to reach the emissions cap of 2.24 million tons. Following a similar pattern, the remaining emission caps are set as 1.51 million tons for NO_x emissions, 4.8 tons for mercury emissions, and 475 million metric tons (MtC) of carbon emissions.

Table 1. Benchmark Emission Levels and Assumed Emission Caps

Pollutant (Benchmark)	Benchmark Emissions	Fraction Reduced	2007 Emission Cap
SO_2 (tons in Title IV)	8.95 million tons	75%	2.24 million tons
NO_x (tons in 1997)	6.04 million tons	75%	1.51 million tons
Hg (tons in 1999)	48 tons	90%	4.8 tons
C (metric tons in 1990)	475 million metric tons	-	475 million metric tons

1.4. Other Analytical Assumptions

As previously noted, the letter from Senators Lieberman and Jeffords requested that EPA use four different sets of technology and policy assumptions to meet the specified emission caps shown in Table 1. The full set of technology and policy assumptions are described more fully in section two of this report. All scenarios are implemented in 2002. At the same time, there are other key assumptions that EPA adopted to facilitate the evaluation of the four scenarios.

In addition to the different technology scenarios, EPA was asked to include the assumption that utilities would begin to make cost-effective emission reductions in the five years that precede the 2007 compliance date. These early reductions would be “banked” for use in the post-2007 period of analysis. For purposes of this simulation, the amount of allowances banked from 2002 through 2006 was calculated as the simple difference between the reference case projections and the actual emission trajectory of each scenario. The decision to earn and hold early allowances is based on the assumption that allowances are viewed as an asset that must earn at least an 8% real return.[1]

Following the assumption used in the CEF study, all four of the policy scenarios assume nationwide restructuring of the electric utility industry. This implies that prices are based on the marginal rather than the regulated, cost-of-service pricing now used throughout much of the country.

EPA employed the Argonne National Laboratory’s AMIGA modeling system to evaluate the impact of capping emissions under the four different technology scenarios. AMIGA is a 200 plus sector model of the U.S. economy that captures a wide variety of technology characteristics and their resulting impact on key indicators such as emissions, employment and income.[2] EPA

[1] In practice, it is more likely that significant reductions that contribute to any kind of allowance bank would be difficult to achieve before 2004. Assuming a delay in implementation to 2004 would raise the economic impact of any of the scenarios.

[2] AMIGA is especially suited to the task identifying and evaluating a different mix of technologies in the production of goods and services within the United States. It is not only a 200 plus sector model of the U.S. economy, but it also includes the Argonne Unit Planning and Compliance model and database that captures a wide variety of technology characteristics within the electric generating sector, including industrial combined heat and power systems and the typically available emission control technologies. When the electricity module is integrated with

asked Argonne to benchmark AMIGA to the reference case projections of AEO2001. AMIGA was then modified to approximate the assumptions behind each of the four scenarios.

An economic analysis of a policy compares the world with the policy (the policy scenario) to the world absent the policy (the reference case or baseline scenario). The impacts of policies or regulations are measured by the resulting differences between these two scenarios. In effect, any meaningful analysis should compare the full set of benefits and costs to the extent possible.

For purposes of this exercise, there are at least seven categories of costs and four benefits that might be reviewed. The costs include: (1) direct investment costs, (2) operating and maintenance costs, (3) research and development and other government program costs, (4) transaction, search, and compliance costs, (5) adjustment costs associated with large changes in specific capital stocks, (6) lost economic flexibility created by additional emission requirements, and (7) potential interactions with the existing tax system. At the same time, there are at least four categories of benefits. These include: (1) direct savings from lower compliance costs, (2) process efficiency and other productivity gains, (3) environmental and health benefits not captured within normal market transactions, and (4) spillovers and/or learning induced by either the technology investment, or the R&D efforts.

The costs associated with the emission limits in each scenario are computed as the increased expenditures on pollution control, investment in more efficient equipment and appliances, research and development, tax incentives, and additional government programs — all relative to the reference case. The increased costs are coupled with credits for reductions in fuel use and productivity gains from technology. The economic impact of each scenario is reported in two ways. The first is as a change in household personal consumption, measuring the goods and services available for consumers to enjoy after subtracting these net expenditures. The second is as a change in economic output measured as Gross Domestic Product (GDP).

The AMIGA model reasonably captures those costs and benefits noted above that arise in market transactions. Some, such as loss of flexibility and adjustment costs on the cost side, and health benefits and spillovers on the benefit side, remain beyond the scope of this analysis.

2. Multi-Emissions Analysis

This section provides additional details about the technology assumptions that underpin the four emission scenarios. It also describes the results of the scenario analysis, both in terms of the various marginal costs associated with emission control strategies and the economy-wide impact of each scenario. Although EPA made every effort to calibrate AMIGA to the AEO2001 reference case, AMIGA is a different modeling system than EIA's National Energy Modeling System (NEMS). Hence, it was not possible to reproduce the exact AEO2001 reference case

---

the larger macroeconomic system, the model can then generate key outputs including projected electricity sales and net generation, resulting emissions for each of the four pollutants under consideration, and the set of energy and permit prices associated with the resulting production levels. Finally, AMIGA can provide an estimate of the consequent impact on the economy including key indicators as consumption, investment, government spending, GDP, and employment (Hanson, 1999). For more background on the AMIGA model, see Appendix 5.1.

projections. Moreover, Argonne researchers recently upgraded AMIGA to incorporate SO_2, NO_x, and mercury emissions. For this and other reasons, AMIGA currently reports results only through the year 2015. Nonetheless, the differences in the resulting baseline projections are minor for the purposes of this analysis.

2.1. Modeling Technology Assumptions

Scenarios A and B are based on the AEO2001 standard and advanced technology characteristics, respectively. The standard technology assumptions of scenario A were used by EIA in the development of the AEO2001 “reference case” projections. The advanced technology assumptions of scenario B were used as a sensitivity analysis in the AEO2001. They demonstrated the effects of earlier availability, lower costs, and/or higher efficiencies for more advanced equipment than the reference case.[3]

Scenarios C and D are based on the recently published DOE-sponsored report, *Scenarios for a Clean Energy Future* (Interlaboratory Working Group, 2000; see also, Brown, et al, 2001). Both of the CEF scenarios assumed nationwide restructuring of the electric utility industry. From an analytical perspective, this means that prices are based on the marginal costs of generation, transmission and distribution of electricity rather than the regulated, cost-of-service pricing now used throughout much of the country. Moreover, both scenarios reflected increased spending for research and development and other programs designed to accelerate the development and deployment of low-carbon, energy efficient technologies. Each of the scenario assumptions are described more fully in the sections that follow.

2.1.1. Reference Case Scenario

The scenario A reference case assumes a “business-as-usual” characterization of technology development and deployment. As projected in the AEO2001 assessment, the nation’s economy is projected to grow at 2.9% per year in the period 2000 through 2020. Given anticipated energy prices and the availability of standard technologies, the nation’s primary energy use is expected to grow 1.3% annually while electricity consumption is projected to increase by 1.8% annually. Further details are provided in Appendix 5.2.1.

2.1.2. Advanced Technology Scenario

Under the AEO 2001 advanced technology characterization, scenario B assumes that a large number of technologies have earlier availability, lower costs, and/or higher efficiencies. For example, the high efficiency air conditioners in the commercial sector are assumed to cost less than in scenario A. This encourages a greater rate of market penetration as electricity prices rise in response to the emissions caps. Building shell efficiencies in scenario B are assumed to improve by about 50 percent faster than in scenario A.

[3] The AEO2001 was published in December 2000 (Energy Information Administration, 2000).

On the utility's side of the meter, the heat rates for new combined cycle power plants are assumed to be less compared to the standard case assumptions. This means that more kilowatt-hours of electricity are generated for every unit of energy consumed by the power plants. Moreover, wood supply increases by about 10% and the capacity factor of wind energy systems increases by about 15-20% compared to the reference case assumptions. In the AEO2001 report, the combination of higher efficiencies and earlier availability of the technologies lowers the growth in electricity use from 1.8% in the reference case to 1.6%.

2.1.3. CEF Moderate Case Scenario

The authors of the *Clean Energy Future* (CEF) report describe their analysis as an attempt to "assess how energy-efficient and clean energy technologies can address key energy and environmental challenges facing the US" (Brown, et al, 2001). In that regard, they evaluated a set of about 50 policies to improve the technology performance and characterization of the residential, commercial, industrial, transportation, and electricity generation sectors. The policies include increased research and development funding, equipment standards, financial incentives, voluntary programs, and other regulatory initiatives. These policies were assumed to change business and consumer behavior, result in new technological improvements, and expand the success of voluntary and information programs.

The selection of policies in the CEF study began with a sector-by-sector assessment of market failures and institutional barriers to the market penetration of clean energy technologies in the US. For buildings, the policies and programs include additional appliance efficiency standards; expansion of technical assistance and technology deployment programs; and an increased number of building codes and efficiency standards for equipment and appliances. They also include tax incentives to accelerate the market penetration of new technologies and the strengthening of market transformation programs such as Rebuild America and Energy Star labeling. They further include so-called public benefits programs enhanced by electricity line charges.

For industry, the policies include voluntary agreements with industry groups to achieve defined energy efficiency and emissions goals, combined with a variety of government programs that strongly support such agreements. These programs include expansion and strengthening of existing information programs, financial incentives, and energy efficiency standards on motors systems. Policies in the CEF analysis were assumed to encourage the diffusion and improve the implementation of combined heat and power (CHP) in the industrial sector. For electricity, the policies include extending the production tax credit of 1.5 cents/kWh over more years and extending it to additional renewable technologies.

Broadly speaking, the CEF Moderate scenario can be thought of as a 50% increase in funding for programs that promote a variety of both demand-side and supply-side technologies. For example, the moderate scenario assumes a 50% or $1.4 billion increase in cost-shared research, development, and demonstration of efficient and clean-energy technologies (in 1999 dollars with half as federal appropriations and half as private-sector cost share). It further assumes a careful targeting of funds to critical research areas and a gradual, 5-year ramp-up of funds to allow for careful planning, assembly of research teams, and expansion of existing teams and facilities. In addition, the CEF moderate scenario anticipates increased program spending of $3.0 and $6.6 billion for the years 2010 and 2020, respectively. These expenditures include production incentives and investment tax credits for renewable energy, energy efficiency and transportation technologies. They further include increased spending for programs such as DOE's Industrial Assessment Centers and EPA's Energy Star programs.

The combined effect of the R&D and program expenditures, together with other policies described in the CEF report, implies a steady reduction in total energy requirements over the period 2000 through 2020. By the year 2020, for example, primary energy consumption and electricity sales were projected to decrease by 8% and 10%, respectively, compared to the CEF reference case.

2.1.4. CEF Advanced Technology Scenario

Building on the policies of the moderate scenario, the CEF advanced scenario assumes a doubling of cost-shared R&D investments, resulting in an increased spending of $2.9 billion per year (again, in 1999 dollars with half as federal appropriations and half as private-sector cost share). In addition, the advanced scenario anticipates increased program spending of $9.0 and $13.2 billion for the years 2010 and 2020, respectively. The added spending covers all sectors including buildings, industry, transportation, and electric generation.

The combined effect of the program and R&D expenditures, together with other policies described in the CEF report (including a $50 carbon charge applied in the CEF Advanced Scenario), drove a steady reduction in the need for energy compared to the CEF reference case. By 2020 total energy use fell by 19% compared to the reference case. At the same time, electricity sales in 2020 were projected to decrease by 24% compared to the CEF reference case.

2.1.5. Implementation of the Technology Assumptions

The assumptions embedded in each of these scenarios have the effect of progressively increasing market penetration of higher performance energy efficiency and energy supply technologies. As shown in Table 2, the net effect of these assumptions is to lower the expected level of electricity consumption while continuing to meet the same level of service demanded by utility customers. The technology assumptions also have the effect of increasing the availability of cleaner energy supply technologies that reduce the level of emissions per kilowatt-hour of generation. The critical assumption used in the EPA analysis is that program spending affects both supply and demand technologies in a way that interacts with the emission caps that are to be imposed in 2007.

Benchmarked to the year 2010, Table 2 shows the percentage change of key indicators for each scenario with respect to its respective reference case. These changes provide EPA with approximate targets so that each of the scenarios can be mapped into the AMIGA model. As such, the figures in Table 2 should be seen as inputs into the AMIGA model, not outputs of the model.

Table 2. Influence of Technology Assumptions on Key Scenario Indicators - 2010

Indicator	Scenario A Standard Technology Case	Scenario B Advanced Technology Case	Scenario C CEF Moderate Case	Scenario D CEF Advanced Case
Primary Energy	0%	-2.5%	-3.4%	-6.3%
Electricity Sales	0%	-2.4%	-5.9%	-6.8%
Carbon Emissions	0%	-5.0%	-7.4%	-10.7%
NOx Emissions	0%	-2.6%	-5.4%	-8.1%

By definition, scenario A assumes the standard technology assumptions of the AEO2001 reference case. Hence, there are no additional programs or policies that generate changes in the reference case technologies when the emission caps are imposed by the year 2007. The level of technology responsiveness grows for scenarios B, C, and D as a result of greater program spending.

The CEF advanced scenario, for example, assumes a significant increase in program funds to promote a variety of both demand-side and supply-side technologies. As a result of this greater level of program activity, there is an accelerated penetration of energy-efficient technologies that drives electricity sales down by 6.8 percent in 2010 (compared to the CEF reference case for that same year). At the same time, the combination of a lower demand for electricity and an increased investment in cleaner energy supply technologies reduces both carbon and NO_x emissions by 10.7 and 8.1 percent, respectively (again, compared to the CEF 2010 reference case). As EPA modeled this scenario, the bundle of policies in the CEF advanced scenario became, in effect, a complement to the emission caps imposed by 2007.

To avoid overestimating the impact of the policy scenarios in this analysis, EPA made a number of adjustments before implementing the CEF assumptions in the four scenarios reported here. First, the CEF analysis was benchmarked to a 1999 reference case. In the AEO2001 reference case, however, the demand for electricity in 2020 is about 10% higher compared to the CEF reference case. Second, the Senate request asked EPA to assume a 2002 start date in running the technology and policy scenarios. In effect, there are fewer years in which programs can achieve the desired level of technology improvement compared to the CEF scenarios. In addition, the CEF analysis includes a significant review of transportation technologies and policies. EPA chose to exclude all assumptions related to transportation, focusing only on the supply and demand-side technologies associated with electricity and natural gas consumption.

With the adjustments described above now reflected in the current analytical framework, and using the program cost information documented in the CEF study, Table 3 summarizes the incremental program costs that were assumed as necessary to drive the kind of changes in electricity consumption and emissions described in Table 2. Since transportation programs drove a significant part of the CEF expenditures, and since there are fewer years to implement policies, the estimated program expenditures are also smaller compared to the CEF assumptions.

Table 3. Incremental Policy Costs of the Technology Scenarios (billion 1999 dollars)

Scenario	2002	2005	2010	2015
Scenario A	0.0	0.0	0.0	0.0
Scenario B	0.8	1.6	2.7	2.9
Scenario C	1.2	2.3	4.3	4.8
Scenario D	2.1	3.9	5.2	5.5

Because scenario A characterizes existing program and technology performance, no additional funds are required to drive that scenario. Scenario B, on the other hand, anticipates some changes in the technology characterization that will affect the electricity sector as shown in Table 2. While the AEO2001 analysis anticipated no program spending to drive these changes, EPA assumed that additional spending would be required for scenario B. Calibrating to the CEF policy scenarios, EPA estimated that program and policy spending would increase by $0.8 billion in 2002, rising steadily to $2.9 billion by 2015. For scenario C, program spending increased by $1.2 billion starting in 2002, rising to $4.8 billion by 2015. Finally, program spending in scenario D started at $2.1 billion in 2002 and increased to $5.5 billion by the last year of this analysis.[4]

The net effect of mapping increased program spending together with adjustments needed to update the assumptions of the CEF policy scenarios can be highlighted by reviewing the change in electricity generation for scenario D. In the CEF Advanced Scenario (based on a 1999 reference case), for example, the level of electricity generation in 2010 was lowered by 10% from the reference case requirements of 3,920 billion kilowatt-hours (kWh). As the CEF technology assumptions were applied in scenario D within this analysis (updated to the AEO2001 reference case), electricity generation was reduced by 9% from 4,253 billion (kWh). The trend was more pronounced in 2015. Rather than a roughly 16% reduction from a generation level of 4,200 billion kWh in the 1999 CEF Advanced Case, the scenario D equivalent in this analysis achieved only a 12% reduction from a generation of 4,580 billion kWh.

2.1.6. Reasonableness of the Scenario Assumptions

The results of the technology–driven scenarios should not be interpreted as an EPA endorsement of any of the policies or technology assumptions behind each of scenarios described in this report. On the one hand, EPA has not conducted any significant review of the EIA assumptions that underpin the AEO2001 projections. On the other hand, some analysts do not necessarily agree with the assumptions and projected level of impacts in the CEF assessment despite the fact that it was peer-reviewed and its findings published this fall in an academic journal. The EIA (2001), for example, notes that the CEF policies assume changes in consumer behavior that are not consistent with historically observed behavior patterns. Moreover, the EIA suggests that there is little documentation to support the assumed technological improvements generated by the research and development (R&D) initiatives described in the report. Finally, EIA notes that

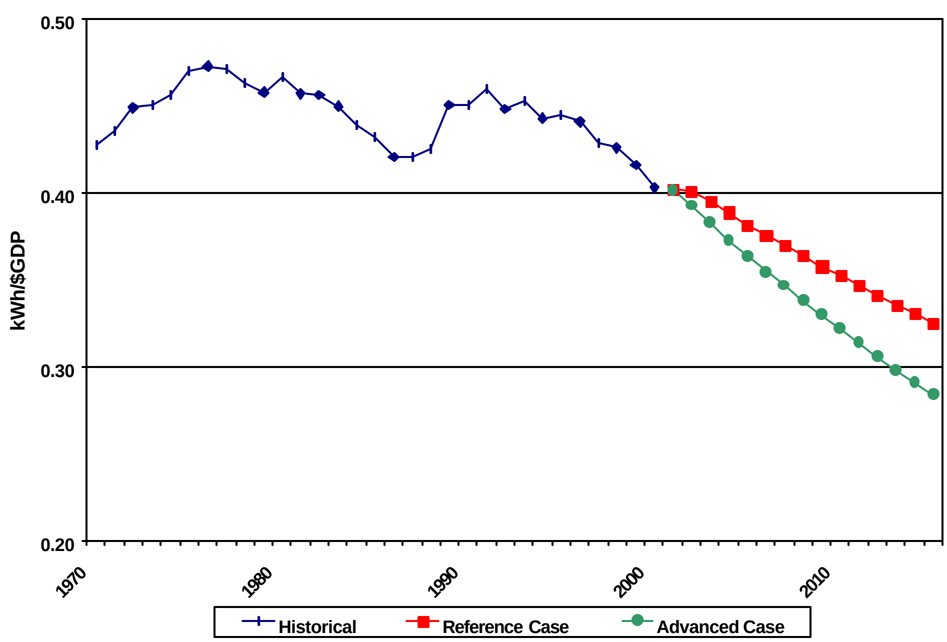
[4] The program spending assumptions developed in this analysis are used only to approximate the impact of the CEF scenarios. They do not reflect EPA endorsement of these spending levels.

the effectiveness of voluntary or information programs may be less than assumed in the CEF scenarios. At the same time, the lead CEF analysts have responded to the EIA assertions by citing relevant economic literature and noting that the CEF study is one of "the most carefully documented and complete analysis of U.S. energy futures that has ever been funded by the U.S. government" (Koomey, et al, 2001).

Notwithstanding these concerns, EPA attempted to respond to the Senators' request by mapping in the critical assumptions of the CEF as a range of policies that provide a set of alternative assumptions about the future. In this regard, the scenarios are more like descriptions of alternative future outcomes rather than predictions or recommendations about how the future should unfold.

To provide a more complete context for understanding the magnitude of the changes in electricity generation that are suggested by the different scenarios, the figure below illustrates both the historical and projected trends in the nation's electricity generation. The information is shown as the number of kWh per dollar of GDP (measured in constant 1999 dollars). The historical data covers the period 1970 through 2000 while the projected trends are through the year 2015. The historical period shows a moderate level of volatility. The reference case projections suggest an annual rate of declining intensity of 1.6% per year through 2015 with a final value 0.33 kWh/$.

Historical and Projected US Electricity Trends (kWh per 1999 $ GDP)



In comparison to the reference case, Scenario D (adapting the CEF Advanced Case assumptions) reflects a national commitment to improve both electricity supply and the efficiency of demand-side technologies. The presumption is that such a commitment would be supported by a significant increase in R&D and program spending as described above. Under these assumptions, the nation's electricity intensity is projected to decline at an annual rate of 2.5%, dropping to a final intensity of 0.28 kWh/$. This level of decline is greater than previously seen in the recent past. In the period 1980 through 1986, for example, and again 1993 through 2000, the annual rate of decline was only 1.7 percent. Hence, it appears that the assumptions driving the advanced scenario are aggressive. At the same time, however, the research undertaken by the CEF analysts indicates that the technology is available to achieve such a reduction should a national commitment be successful in driving similar policies.

2.2. Results of the Scenario Analysis

With the model benchmarked to AEO2001, and given the different mix of scenario assumptions previously described, AMIGA reports the results in the figures and tables that follow. More complete data, including reference case assumptions, are available in Appendix 5.2.

2.2.1. Emission Projections

All program and policy assumptions have a start date of 2002. Moreover, the analysis anticipates the use of banked allowances made possible by early emissions reductions achieved in the years 2002 through 2006 (as requested in the Senate letter). Figures 1 through 4 on the following page illustrate both the emissions projections and the impact of banking the early reductions on all four emissions caps implemented in 2007.

Although all four categories of emissions are down substantially, they only achieve 50-75% of the proposed cap by 2007 (shown as the dotted horizontal line in each of the above figures). This is because of the availability of the banked allowances that can be used by sources to meet emissions caps in 2007 and beyond. Note that costs would be noticeably higher if power plants were required to actually hit the target in 2007. In 2015, carbon and mercury emissions continue to be 15% or more above the target.

The reductions that generate the banked allowances are shown as the area to the left of each vertical dotted line as the differences between the reference case and scenario emission trajectories. The emissions above the cap are shown to the right of each vertical dotted line and between the scenario emissions and the dotted horizontal line. Subtracting these two areas on each graph reveals the level of the bank in 2015. Using Scenario D as an example, the remaining allowances in 2015 are 100 million metric tons for carbon, 1.3 million tons for SO_2, 0.2 million tons for NO_x and 25 tons for mercury. In the case of carbon, the bank would last another two years at the rate of drawdown in 2015, or longer if the drawdown declined.

Figure 1. Carbon Emissions (million metric tons)

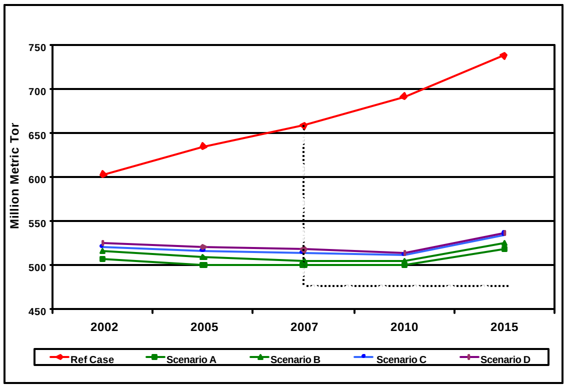


Figure 2. SO_2 Emissions (million tons)

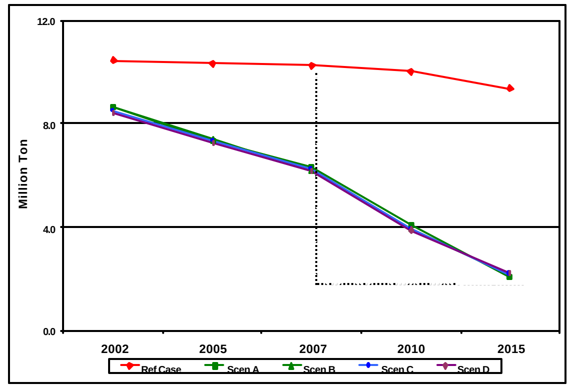


Figure 3. NO_x Emissions (million tons)

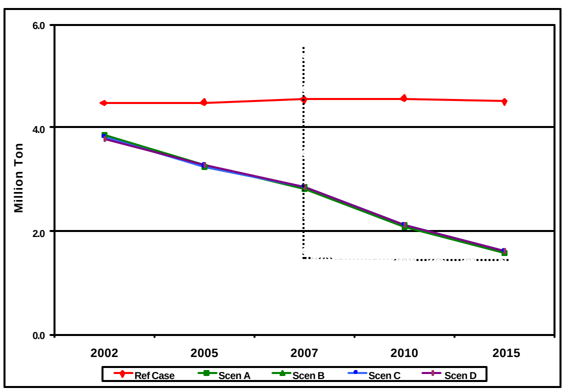
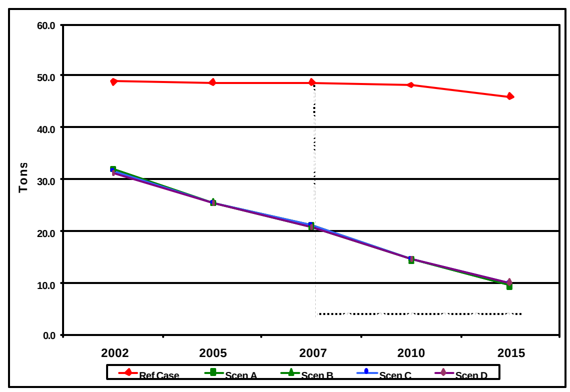


Figure 4. Mercury Emissions (tons)



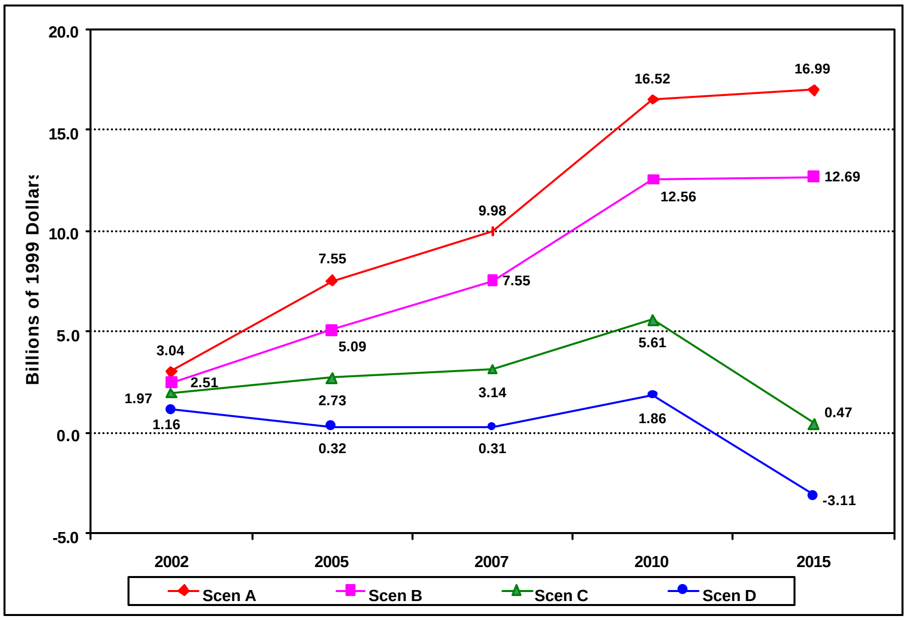
2.2.2. Changes in Electric Generation Expenditures

Given the assumptions and economic drivers in each of the scenarios, the AMIGA model calculates the capital investment, operation and maintenance, and fuel costs necessary to meet consumer demand for electricity. The incremental expenditures required to generate electricity under each of the four scenarios as compared to the reference case are summarized in Figure 5 (in billions of 1999 dollars). In effect, the incremental expenditures reflect the range of decisions made by the electricity sector to comply with each of the four scenario constraints—but do not reflect efforts made *outside* the electricity sector. Because these expenditures ignore spending on energy efficiency, research and development outside the electricity sector—spending that can be substantial—they are not measures of program costs. Note that incremental expenditures are incurred as early as 2002 in all four scenarios to generate early reductions that can be banked for use in 2007 and beyond.

The generation expenditures vary in each of the scenarios change for at least three reasons: (1) the size of the allowance bank made possible by early reductions driven, in part, by program spending prior to the introduction of the caps; (2) the varying levels of demand for electricity over time, resulting in changes in the overall mix of generation resources; and, (3) the gradual reduction in the banked allowances available for withdrawal necessitating additional actions to reduce emissions.

As expected, scenario A has the largest increase with expenditures rising by nearly $17 billion in 2015 compared to the reference case. The higher level of expenditures is driven by a 21% increase in unit generation costs caused primarily by the emissions caps and offset only slightly by a small decrease in electricity demand. With less energy efficiency technology penetrating the market, a greater level of control equipment must be installed and operated which, in turn, drives up the cost of generation. Scenario B follows a similar pattern with expenditure increases being offset by further reductions in electricity demand as more efficient technology penetrates the market. The expenditures for scenario C decline even further as reduced demand continues to lower both the level generation and the unit cost of that generation compared to scenario A. Scenario D, on the other hand, actually shows a decline in total expenditures by 2015. The combination of a 12.5% reduction on generation load together with only an 11.9% increase in the unit cost of generation (both with respect to the reference case) results in a $3.11 billion reduction in total electric generation expenditures.

Figure 5. Incremental Expenditures on Electric Generation (Billions of 1999$)



2.2.3. Marginal Costs

The marginal costs of emission reductions over the period 2005 through 2015 are shown in Figures 6 through 9 for all four scenarios.

Figure 6. Projected Marginal Cost of Carbon Reductions ($/Metric Ton)

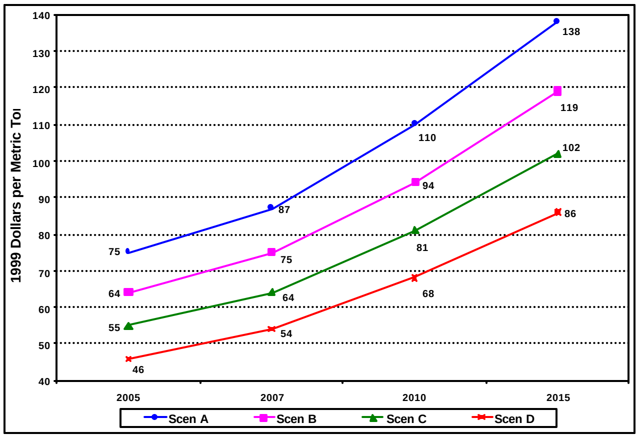


Figure 7. Projected Marginal Cost of SO_2 Reductions ($/Ton)

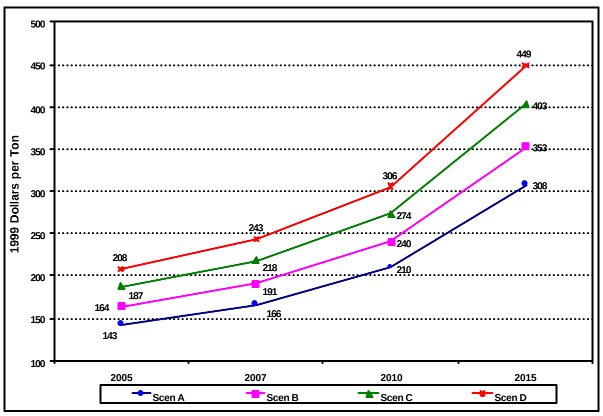


Figure 8. Projected Marginal Cost of NO_x Reductions ($/Ton)

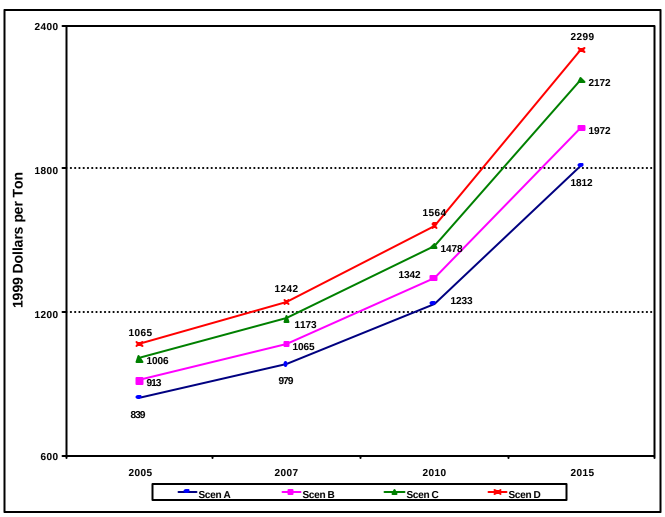
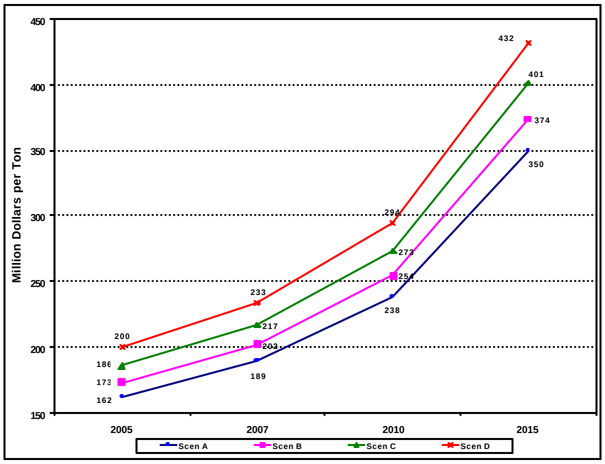


Figure 9. Projected Marginal Cost of Hg Reductions ($Million/Ton)



The marginal cost of carbon reductions range from $46 to $138/metric ton through 2015 with each scenario showing successively smaller costs as technology characteristics improve and more energy-efficient and/or low carbon technologies penetrate the market. The marginal cost of SO_2 and NO_x reductions through 2015 are less than $450/ and $2,300/ton, respectively, in all four multi-emissions reduction scenarios. The marginal cost of mercury reductions by 2015 ranges from $350 million/ton to $432 million/ton, again depending on the scenario.

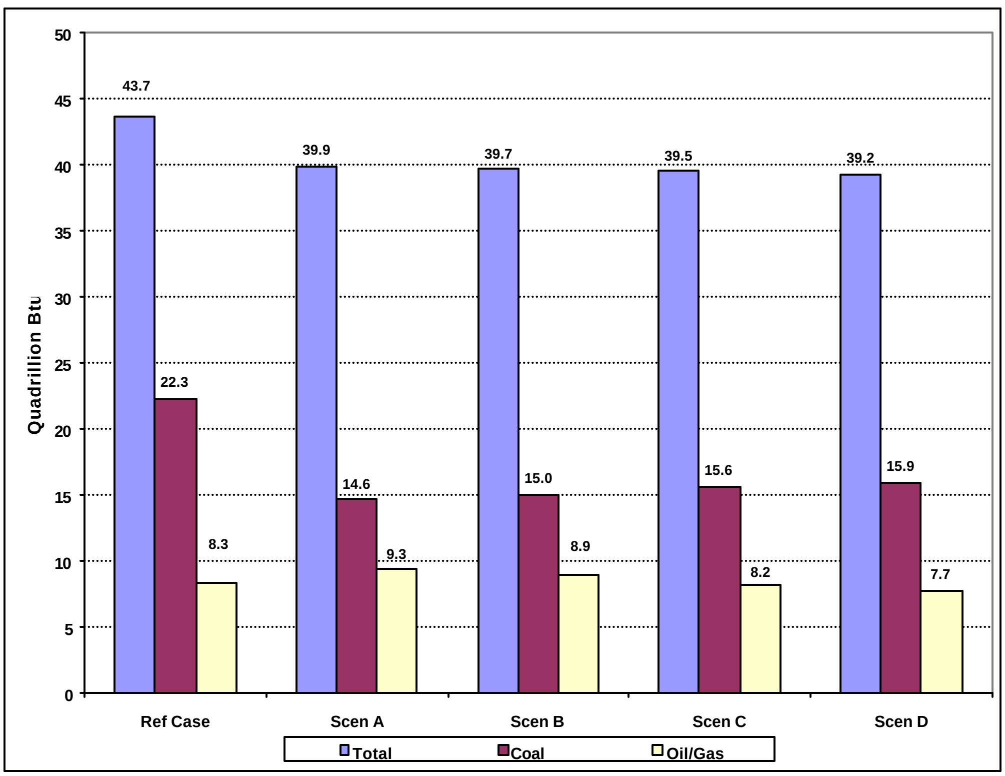
It is important to note that marginal cost reflects the additional cost of one more ton of reductions, and not the total cost associated with each pollutant. One can make a very rough estimation of this overall cost for each pollutant, on top of the costs associated with the other three, by multiplying half the marginal cost (to approximate average cost) by the volume of reductions. By 2015, as an example, scenario A returns cost estimates of $15.2 billion for carbon, $1.1 billion for SO_2, $2.7 billion for NO_x, and $6.4 billion for mercury. In Scenario D, the cost estimates are $8.6 billion for carbon, $1.6 billion for SO_2, $3.3 billion for NO_x, and $7.8 billion for mercury. Note that these figures cannot be added together for an overall estimate because they (a) double count the benefits of controlling multiple pollutants simultaneously, and (b) ignore the consequences of the underlying technology policy. We discuss overall costs below.

Surprisingly, the marginal cost of SO_2, NO_x, and Hg reductions increases as the marginal cost of carbon decreases. The reason appears to be that as efficiency technology penetrates the market and reduces carbon prices, more of a price signal is required to generate further reductions in the three conventional pollutants. In the advanced scenarios, for example, both demand reductions and the increased use of gas tends to reduce carbon emissions. But gas prices begin to rise which allows coal to make a modest comeback with respect to scenario A. This is especially true as cleaner and more efficient coal technologies begin to penetrate the market as assumed in scenarios B through D. In order to offset the tendency for coal-generated emissions to increase, permit prices need to adjust upward.

2.2.4. Fuel Use Impacts

Figure 10 shows both total electricity consumption and the fossil fuel consumption used in the generation of electricity for the year 2010. The results are in quadrillion Btu in both the reference case and each of the four policy scenarios. As each successive scenario generates a greater reduction in electricity demand, coal use is reduced significantly (by about 30 percent). Gas consumption increases slightly in scenarios A and B, and decreases by a small amount in scenarios C and D as lower electricity consumption reduces the need for new capacity.

Figure 10. Total Electricity Consumption and Fossil Fuel Generation in 2010 (Quadrillion Btu)



2.2.5. Energy Price Impacts

The model suggests that under the conditions described above, electricity prices are expected to increase by about 30% (under scenario D) to 50% (under scenario A) by the year 2015. This is the logical result of increased control costs and permit prices. The combination of increased prices and the availability of more energy-efficient equipment and appliances reduce electricity demand by about 10%. Total electricity expenditures increase by about 15% to 30% depending on the year and the scenario (see Table 3, below, and the tables in Appendix 5.2 for more detail on the changing pattern of expenditures).

2.2.6. Economy-wide Impacts

Table 3 provides a summary of key macroeconomic data for the year 2010 to compare the impact of emissions reductions on both personal consumption and other components of gross domestic product (GDP). The effects on personal consumption show a decline of between $13 billion and $31, or 0.1% to 0.3%, depending on the scenario. This reflects the cost of the program in terms of the decreased well being of households who must forego a fraction of their consumption of goods and services in order to pay for both research and development programs, energy efficiency improvements, and more expensive electricity production. Table 3 shows little change in GDP under any of the policy scenarios, reflecting the fact that this foregone consumption turns up as expenditures in other categories of GDP, namely, investment and government spending.[5]

Table 3. Summary of Economic Impacts by Scenario – 2010

Analytical Scenario	Electricity End Use Demand (Billion Kilowatt-hours)	Natural Gas Use in Electricity Generation (Quads)	Coal Use in Electricity Generation (Quads)	Electricity Expenditures (Billion 1999 Dollars)	Personal Consumption (Billion 1999 Dollars)	Investment (Billion 1999 Dollars)	Gross Domestic Product (Billion 1999 Dollars)
Reference	4,346	8.3	22.3	269.4	8,902.0	3,042.4	13,211.7
A. Standard Tech	4,156	9.3	14.6	353.9	8,870.9	3,067.3	13,204.3
B. High Tech	4,112	8.9	15.0	337.4	8,873.7	3,067.0	13,209.5
C. Mod CEF	4,070	8.2	15.6	323.0	8,881.7	3,066.8	13,218.9
D. Adv CEF	4,025	7.7	15.9	308.9	8,889.2	3,066.7	13,227.2

The AMIGA modeling system reports the costs and benefits of each scenario with several major exceptions. The first omitted benefit is spillover and productivity gains beyond energy bill savings. A number of studies suggest that energy efficiency technology investments also tend to increase overall productivity of the economy, especially in the industrial sector. (Sullivan, et al., 1997; Finman and Laitner, 2001; and Laitner, et al, 2001). To date, however, no systematic effort has been undertaken to incorporate such benefits into the current generation of policy models. Hence, this potential benefit is not reported at this time. The second missing benefit includes gains in environmental quality, especially improved health benefits.

On the cost side, the model ignores costs associated with rapid changes in capital stocks, as well as potential loss of flexibility and interactions with the existing tax system. For example, the model forecasts significant changes in the level and composition of electricity generation in 2002, ignoring the difficulty of rapidly changing the capital stock by then end of 2001. Losses in flexibility occur when pollution control activities potentially interfere with efficiency and other operational programs at a regulated facility. Finally, there are interactions with the tax system when, in response to a rise in the relative cost of purchased goods, people decide to enjoy more

[5] A more complete assessment of each policy scenario can be made by reviewing the more detailed data contained in the Appendix.

leisure (which is now relatively less expensive), work less, and lower taxable income (Parry and Oates, 2000).

2.3. The Results in Context

Recent studies suggest significant economic consequences as a result of substantial emission reduction strategies (EPRI, 2000; and EIA, 2000). On the other hand, the presumption of a trade-off between environmental and economic benefits may not provide an entirely appropriate framework for analysis of such policies (DeCanio, 1997). Indeed, there are a number of studies that show net economic benefits may be possible when a full accounting of both benefits and costs are included within an appropriate analysis (Krause, et al, 2001; and Bailie, et al, 2001).

At the same time, understanding the proper characterization and role of technology improvements (Edmonds, et al, 2000), and then capturing that characterization within an appropriate model structure (Peters, et al, 2001), is a critical aspect of all such economic assessments.

Finally, it is important to recognize that the mere existence of technologies and the potential for positive net benefits does not assure that these technologies will be commercialized and adopted, nor that the net benefits will be realized (Jaffe, et al, 2001). An unanswered question is whether and how policies might encourage these activities.

This current study, while drawing on credible data sources and applying a state-of-the-art modeling system, cannot adequately capture all such nuances associated with emission reduction scenarios. The results of this analysis should be viewed within this larger context.

3. Conclusions

The analysis suggests that under the conditions described above, emissions through 2015 will be significantly reduced although they won't meet the 2007 target. This is largely because of assumptions about the banking of allowances earned prior to 2007. At the same time, coal-fired electric generation is expected to decline by 25% to 35% by the year 2015. On the other hand, oil and gas-fired generation is projected to increase by about 8% under more restrictive technology assumptions, but decrease by as much as 20% under scenarios that embody more optimistic assumptions about energy-efficiency demand and supply technologies. Electricity prices are expected to increase by 32% to 50% in 2015, depending on the scenario.

The combination of increased prices and the availability of more energy-efficient equipment and appliances are projected to reduce electricity demand by about 10% compared to the reference case. With the combination of higher prices and improved efficiency, total expenditures for electricity consumption in 2015 are projected to increase by about 17% to 39% depending on the scenario. Interacting with other changes in consumer and business spending that is driven by each of the scenario assumptions, the personal consumption reduced by about 0.1% to 0.3%. This again depends on the year and the scenario.

The results provided in this analysis should not be construed as forecasts of actual scenario outcomes. Rather they are assessments of how the future might unfold compared to a previously defined reference case — given the mix of technology and policy assumptions embodied in each of the scenarios. The results from these scenarios imply a strong national commitment, one that is successful in developing the programs and policies necessary to achieve the level of emission reductions described within the report.

4. References

Alison, Bailie, Stephen Bernow, William Dougherty, Michael Lazarus, and Sivan Kartha, 2001. *The American Way to the Kyoto Protocol: An Economic Analysis to Reduce Carbon Pollution*, Tellus Institute and Stockholm Environment Institute, Boston, MA, July, 2001.

Brown, Marilyn A., Mark D. Levine, Walter Short, and Jonathan G. Koomey, 2001. "Scenarios for a clean energy future," *Energy Policy* Vol. 29 (November): 1179–1196, 2001.

DeCanio, Stephen J., 1997. "Economic Modeling and the False Tradeoff Between Environmental Protection and Economic Growth," *Contemporary Economic Policy*, Vol. 15 (October): 10-27, 1997.

Edmonds, Jae, Joseph M. Roop, and Michael J. Scott, 2000. *Technology and the economics of climate change policy*, Pew Center on Global Climate Change, Washington, DC, September 2000.

E-GRID, 2000. *Emissions & Generation Resource Integrated Database*, US Environmental Protection Agency, Washington, DC, http://www.epa.gov/airmarkets/egrid/factsheet.html.

Electric Power Research Institute, 2000. *Energy-Environment Policy Integration and Coordination Stud*y, TR-1000097, Palo Alto, CA, 2000.

Energy Information Administration, 1998. *Impacts of the Kyoto Protocol on U.S. Energy Markets and Economic Activit*y, SR/OIAF/98-03, Washington, DC, October 1998.

Energy Information Administration, 2000. *Analysis of Strategies for Reducing Multiple Emissions from Power Plants: Sulfur Dioxide, Nitrogen Oxides, and Carbon Dioxide*, SR/OIAF/2000-05 (Washington, DC, December 2000).

Energy Information Administration, 2001. *Analysis of Strategies for Reducing Multiple Emissions from Electric Power Plants with Advanced Technology Scenarios*, SR/OIAF/2001-05 (Washington, DC, October 2001).

Finman, Hodayah, and John A. "Skip" Laitner, 2001. "Industry, Energy Efficiency and Productivity Improvements," *Proceedings of the ACEEE Industrial Summer Study*, American Council for an Energy-Efficient Economy, Washington, DC, August 2001.

Hanson, Donald A, 1999. *A Framework for Economic Impact Analysis and Industry Growth Assessment: Description of the AMIGA System*, Decision and Information Sciences Division, Argonne National Laboratory, Argonne, IL, April, 1999.

Interlaboratory Working Group, 2000. *Scenarios for a Clean Energy Futur*e, ORNL/CON-476 and LBNL-44029 Oak Ridge, TN: Oak Ridge National Laboratory; Berkeley, CA: Lawrence Berkeley National Laboratory, November 2000.

Jaffe, AB, RN Newell, and RN Stavins, 2001. "Energy-efficient technologies and climate change policies: Issues and evidence." In *Climate Change Economics and Policy: An RFF Anthology*, edited by MA Toman. Washington: Resources for the Future.

Jeffords, James, and Joseph Lieberman, 2001. "Letter to EPA Administrator Christine Todd Whitman," May 17, 2001.

Koomey, Jonathan, Alan Sanstad, Marilyn Brown, Ernst Worrell, and Lynn Price, 2001. "Assessment of EIA's statements in their multi-pollutant analysis about the Clean Energy Futures Report's scenario assumptions," Memo to EPA's Skip Laitner, Lawrence Berkeley National Laboratory, Berkeley, CA, October 18, 2001.

Krause, Florentin , Paul Baer, and Stephen DeCanio, 2001. *Cutting Carbon Emissions at a Profit: Opportunities for the U.S.*, International Project For Sustainable Energy Paths, El Cerrito, CA, May 2001.

Laitner, John A. "Skip", Ernst Worrell, and Michael Ruth, 2001. "Incorporating the Productivity Benefits into the Assessment of Cost-effective Energy Savings Potential Using Conservation Supply Curves," *Proceedings of the ACEEE Industrial Summer Study*, American Council for an Energy-Efficient Economy, Washington, DC, August, 2001.

Parry, I.W.H. and W.E. Oates. "Policy Analysis in the Presence of Distorting Taxes" *Journal of Policy Analysis and Management* 19(4), pp 603-613.

Peters, Irene, Stephen Bernow, Rachel Cleetus, John A. ("Skip") Laitner, Aleksandr Rudkevich, and Michael Ruth, 2001. "A Pragmatic CGE Model for Assessing the Influence of Model Structure and Assumptions in Climate Change Policy Analysis ," Presented at the 2nd Annual Global Conference on Environmental Taxation Issues, Tellus Institute, Boston, MA, June 2001.

Sullivan, Gregory P., Joseph M. Roop, and Robert W. Schultz, 1997. "Quantifying the Benefits: Energy, Cost, and Employment Impacts of Advanced Industrial Technologies," *1997 ACEEE Summer Study Proceedings on Energy Efficiency in Industry*, American Council for an Energy-Efficient Economy, Washington, DC, 1997.

US Environmental Protection Agency, 2000b. *Guidelines for Preparing Economic Analysis*, EPA-240-R-00-003, Office of the Administrator, Washington, DC, September 2000.

5. Appendices

5.1. Description of the AMIGA Model

The *All Modular Industry Growth Assessment* (AMIGA) model is a general equilibrium modeling system of the U.S. economy that covers the period from 1992 through 2030.[6] It integrates features from the following five types of economic models:

1). *Multisector* – AMIGA starts by benchmarking to the 1992 Bureau of Economic Analysis (BEA) interindustry data, which a preprocessor aggregates to approximately 300 sectors;

2). *Explicit technology representation* – AMIGA reads in files with detailed lists of technologies (currently with a focus on energy-efficient and low-carbon energy supply technologies, including electric generating units) containing performance characteristics, availability status, costs, anticipated learning effects, and emission rates where appropriate;

3). *Computable General Equilibrium* – AMIGA computes a full-employment solution for demands, prices, costs, and outputs of interrelated products, including induced activities such as transportation and wholesale/retail trade;

4). *Macroeconomic* – AMIGA calculates national income, Gross Domestic Product (GDP), employment, a comprehensive list of consumption goods and services, the trade balance, and net foreign assets and examines inflationary pressures;

5). *Economic Growth* – AMIGA projects economic growth paths and long-term, dynamic effects of alternative investments including accumulation of residential, vehicle, and producer capital stocks.

In addition, the AMIGA system includes the Argonne Unit Planning and Compliance model that captures a wide variety of technology characteristics within the electric generating sector. This includes a system dispatch routine that allows the retirement and the dispatch of units on the basis of traditional cost criteria as well as the impact of various permit prices on operating costs. It also includes non-utility generation sources such as industrial combined heat and power applications and renewable energy systems.

Climate change mitigation policy has been the main application of the AMIGA system to date. But the AMIGA modeling system recently has been enhanced to include policies involving the reduction of sulfur dioxide, nitrogen oxide, and mercury emissions. Moreover, a new intertemporal optimization module has been added to AMIGA that allows an evaluation of early reductions and the banking of allowances to be incorporated into policy scenarios. Hence, the system is well suited to evaluate a variety of multi-emission strategies that are driven by price incentives as well as R&D programs, voluntary initiatives, and cap and trade policies.

[6] Because of recent upgrades and enhancements made in the model, the current reporting period is extended only through the year 2015. We expect the full reporting period to extend back to the year 2030 in the very near future.

The model includes a complete database of all electric utility generating units within the United States. The cost and performance characteristics of the electricity supply technologies generally follow those modeled within the Energy Information Administration's National Energy Modeling System. The characteristics associated with the various emission control technologies generally follow those modeled within the Integrated Planning Model used by the Environmental Protection Agency.

The AMIGA modeling system is a highly organized, flexible structure that is programmed in the C language. It includes modules for household demand, production of goods, motor vehicles, electricity supply, and residential and commercial buildings and appliances.

The production modules contain representations of labor, capital, and energy substitutions using a hierarchy of production functions. The adoption rates for cost-effective technologies depend on energy prices as well as policies and programs that lower the implicit discount rates (sometimes referred to as hurdle rates) that are used by households and businesses to evaluate energy-efficiency and energy supply measures.[7]

[7] For a more complete documentation of the AMIGA model, see Hanson, Donald A, 1999. *A Framework for Economic Impact Analysis and Industry Growth Assessment: Description of the AMIGA System,* Decision and Information Sciences Division, Argonne National Laboratory, Argonne, IL, April, 1999. For an example of other policy excursions using the AMIGA model, see, Hanson, Donald A. and John A. "Skip" Laitner, 2000, "An Economic Growth Model with Investment, Energy Savings, and CO_2 Reductions," *Proceedings of the Air & Waste Management Association*, Salt Lake City, June 18-22, 2000. Also see, Laitner, John A. "Skip", Kathleen Hogan, and Donald Hanson, "Technology and Greenhouse Gas Emissions: An Integrated Analysis of Policies that Increase Investments in Cost Effective Energy-Efficient Technologies," *Proceedings of the Electric Utilities Environment Conference*, Tucson, AZ, January 1999.

5.2. Summary Tables for Study Scenarios

5.2.1. Reference Case Projections

Table 1. Summary Data Energy Consumption and Emissions	1998	2002	2005	2007	2010	2015
Total Primary Energy (Quadrillion Btus)	96.47	102.91	107.81	110.78	115.23	122.07
Total Electricity Use (Billion Kilowatt-hours)	3,411	3,714	3,942	4,104	4,346	4,697
Total Electricity Expenditures (Billions of 1999$)	223.8	236.7	245.9	255.3	269.4	291.3
Electric Sector Carbon (Million Metric Tons)	559	603	635	658	691	738
SO_2 (Million Short Tons)	13.24	10.46	10.31	10.23	10.02	9.35
NO_X (Million Short Tons)	6.01	4.47	4.49	4.54	4.56	4.51
Mercury (Tons)	47.36	48.86	48.81	48.70	48.25	46.01

Table 2. Summary Data Electric Generation (Billion Kilowatt-hours)	1998	2002	2005	2007	2010	2015
Coal	1,829	1,961	2,055	2,100	2,157	2,189
Gas and Oil	462	584	672	788	967	1,329
Nuclear	674	712	740	732	720	639
Hydropower	325	322	323	323	323	324
Renewables	57	69	76	79	86	99
Total Generator Load	3,347	3,648	3,866	4,021	4,253	4,580

Table 3. Summary Data Cogeneration – Independent Power Production (Billion Kilowatt-hours)	1998	2002	2005	2007	2010	2015
Coal Cogeneration	52	52	52	52	52	52
Gas and Oil Cogeneration	220	240	255	262	274	293
Biomass Cogeneration	27	29	30	32	35	40
Municipal Solid Waste and Other Cogeneration	12	10	9	9	9	9
Other Renewables Generation	6	5	5	5	5	5
Total Independent Power Production	317	336	351	361	375	399
Amount for Own Use	158	171	181	188	199	212
Sales to grid	158	165	170	173	176	186

Table 4. Summary Data Selected Energy Prices (1999 dollars)	1998	2002	2005	2007	2010	2015
Wellhead Gas Price ($/MCF)	2.02	2.28	2.49	2.57	2.69	2.83
Average Electricity Price ($/MWh)	68.82	66.82	65.39	65.19	64.96	64.95
Carbon Permit Price ($/metric ton)	0	0	0	0	0	0
Sulfur Dioxide Permit Price ($/ton)	0	0	0	0	0	0
Nitrogen Oxide Permit Price ($/ton)	0	0	0	0	0	0
Mercury Permit Price (million $/ton)	0	0	0	0	0	0

Table 5. Summary Data Macroeconomic Data (Billions of 1999$)	1998	2002	2005	2007	2010	2015
Real Gross Domestic Product (GDP)	8,882.2	9,770.2	11,431.3	12,116.7	13,211.7	15,264.3
Real Investment	1,577.0	2,018.4	2,474.0	2,697.5	3,042.4	3,768.4
Real Consumption	5,933.6	6,763.9	7,681.7	8,180.2	8,902.0	10,361.2

5.2.2. Scenario A: Emission Constraints Using Reference Case Technologies

Table 1. Summary Data Energy Consumption and Emissions	1998	2002	2005	2007	2010	2015
Total Primary Energy (Quadrillion Btus)	96.47	100.94	104.97	107.54	111.37	117.14
Total Electricity Use (Billion Kilowatt-hours)	3,411	3,685	3,831	3,958	4,156	4,417
Total Electricity Expenditures (Billions of 1999$)	223.8	279.7	298.2	318.1	353.9	404.5
Electric Sector Carbon (Million Metric Tons)	559	507	500	499	499	518
SO_2 (Million Short Tons)	13.24	8.66	7.35	6.34	4.04	2.07
NO_X (Million Short Tons)	6.01	3.85	3.24	2.86	2.11	1.58
Mercury (Tons)	47.36	31.82	25.39	21.11	14.43	9.34

Table 2. Summary Data Electric Generation (Billion Kilowatt-hours)	1998	2002	2005	2007	2010	2015
Coal	1,829	1,668	1,609	1,566	1,467	1,406
Gas and Oil	462	644	746	855	1,095	1,429
Nuclear	674	712	740	732	720	639
Hydropower	325	322	323	323	323	323
Renewables	57	190	248	308	365	405
Total Generator Load	3,347	3,536	3,667	3,784	3,970	4,202

Table 3. Summary Data Cogeneration – Independent Power Production (Billion Kilowatt-hours)	1998	2002	2005	2007	2010	2015
Coal Cogeneration	52	52	52	52	52	52
Gas and Oil Cogeneration	220	303	318	325	337	356
Biomass Cogeneration	27	29	30	32	35	40
Municipal Solid Waste and Other Cogeneration	12	10	9	9	9	9
Other Renewables Generation	6	19	19	19	19	19
Total Independent Power Production	317	413	428	437	452	475
Amount for Own Use	158	210	221	228	239	253
Sales to grid	158	203	207	209	212	222

Table 4. Summary Data Energy and Permit Prices (1999 dollars)	1998	2002	2005	2007	2010	2015
Wellhead Gas Price ($/MCF)	2.02	2.77	3.33	3.45	3.63	3.53
Average Electricity Price ($/MWh)	68.82	80.52	82.59	85.29	90.36	97.15
Carbon Permit Price ($/metric ton)	0	59	75	87	110	138
Sulfur Dioxide Permit Price ($/ton)	0	113	143	166	210	308
Nitrogen Oxide Permit Price ($/ton)	0	666	839	979	1233	1812
Mercury Permit Price (million $/ton)	0	129	162	189	238	350

Table 5. Summary Data Macroeconomic Data (Billions of 1999$)	1998	2002	2005	2007	2010	2015
Real Gross Domestic Product (GDP)	8,882.2	9,764.6	11,426.0	12,109.9	13,204.3	15,260.1
Real Investment	1,577.0	2,023.0	2,488.0	2,714.6	3,067.3	3,790.2
Real Consumption	5,933.6	6,755.1	7,663.6	8,158.3	8,870.9	10,336.3

5.2.3. Scenario B: Emission Constraints Using Advanced Case Technologies

Table 1. Summary Data Energy Consumption and Emissions	1998	2002	2005	2007	2010	2015
Total Primary Energy (Quadrillion Btus)	96.47	101.03	104.87	107.32	111.00	116.54
Total Electricity Use (Billion Kilowatt-hours)	3,411	3,681	3,814	3,929	4,112	4,346
Total Electricity Expenditures (Billions of 1999$)	223.8	273.9	289.1	306.7	337.4	381.2
Electric Sector Carbon (Million Metric Tons)	559	516	509	504	504	524
SO_2 (Million Short Tons)	13.24	8.65	7.37	6.20	3.91	2.14
NO_X (Million Short Tons)	6.01	3.86	3.26	2.82	2.09	1.58
Mercury (Tons)	47.36	31.9	25.59	20.84	14.37	9.70

Table 2. Summary Data Electric Generation (Billion Kilowatt-hours)	1998	2002	2005	2007	2010	2015
Coal	1,829	1,692	1,649	1,586	1,501	1,476
Gas and Oil	462	652	723	841	1,048	1,318
Nuclear	674	712	740	732	720	639
Hydropower	325	322	323	323	323	323
Renewables	57	170	228	288	345	385
Total Generator Load	3,347	3,548	3,663	3,769	3,937	4,141

Table 3. Summary Data Cogeneration – Independent Power Production (Billion Kilowatt-hours)	1998	2002	2005	2007	2010	2015
Coal Cogeneration	52	52	52	52	52	52
Gas and Oil Cogeneration	220	290	305	313	324	343
Biomass Cogeneration	27	29	30	32	35	40
Municipal Solid Waste and Other Cogeneration	12	10	9	9	9	9
Other Renewables Generation	6	16	16	16	16	16
Total Independent Power Production	317	398	412	422	436	460
Amount for Own Use	158	203	213	220	231	245
Sales to grid	158	195	200	202	205	215

Table 4. Summary Data Energy and Permit Prices (1999 dollars)	1998	2002	2005	2007	2010	2015
Wellhead Gas Price ($/MCF)	2.02	2.65	3.12	3.25	3.45	3.53
Average Electricity Price ($/MWh)	68.82	78.72	80.29	82.69	86.96	92.95
Carbon Permit Price ($/metric ton)	0	51	64	75	94	119
Sulfur Dioxide Permit Price ($/ton)	0	130	164	191	240	353
Nitrogen Oxide Permit Price ($/ton)	0	725	913	1065	1342	1972
Mercury Permit Price (million $/ton)	0	137	173	202	254	374

Table 5. Summary Data Macroeconomic Data (Billions of 1999$)	1998	2002	2005	2007	2010	2015
Real Gross Domestic Product (GDP)	8,882.2	9,767.2	11,429.0	12,114.0	13,209.5	15,264.0
Real Investment	1,577.0	2,022.8	2,487.8	2,714.3	3,067.0	3,790.5
Real Consumption	5,933.6	6,757.1	7,665.2	8,160.3	8,873.7	10,337.1

5.2.4. Scenario C: Emission Constraints Using the Moderate CEF Scenario Assumptions

Table 1. Summary Data Energy Consumption and Emissions	1998	2002	2005	2007	2010	2015
Total Primary Energy (Quadrillion Btus)	96.47	101.08	104.81	107.25	110.76	116.21
Total Electricity Use (Billion Kilowatt-hours)	3,411	3,678	3,797	3,903	4,070	4,279
Total Electricity Expenditures (Billions of 1999$)	223.8	268.3	280.9	296.3	323.0	360.4
Electric Sector Carbon (Million Metric Tons)	559	520	515	513	512	535
SO_2 (Million Short Tons)	13.24	8.50	7.33	6.24	3.93	2.17
NO_X (Million Short Tons)	6.01	3.80	3.26	2.86	2.11	1.63
Mercury (Tons)	47.36	31.51	25.5	21.07	14.56	10.01

Table 2. Summary Data Electric Generation (Billion Kilowatt-hours)	1998	2002	2005	2007	2010	2015
Coal	1,829	1,701	1,680	1,641	1,559	1,558
Gas and Oil	462	657	693	775	964	1,182
Nuclear	674	712	740	732	720	639
Hydropower	325	322	323	323	323	323
Renewables	57	159	217	277	334	374
Total Generator Load	3,347	3,552	3,653	3,749	3,900	4,077

Table 3. Summary Data Cogeneration – Independent Power Production (Billion Kilowatt-hours)	1998	2002	2005	2007	2010	2015
Coal Cogeneration	52	52	52	52	52	52
Gas and Oil Cogeneration	220	284	299	306	318	337
Biomass Cogeneration	27	29	30	32	35	40
Municipal Solid Waste and Other Cogeneration	12	10	9	9	9	9
Other Renewables Generation	6	15	15	15	15	15
Total Independent Power Production	317	390	405	415	429	453
Amount for Own Use	158	199	209	216	227	241
Sales to grid	158	192	196	198	202	211

Table 4. Summary Data Energy and Permit Prices (1999 dollars)	1998	2002	2005	2007	2010	2015
Wellhead Gas Price ($/MCF)	2.02	2.54	2.93	2.99	3.09	2.98
Average Electricity Price ($/MWh)	68.82	77.12	78.29	80.36	84.06	89.25
Carbon Permit Price ($/metric ton)	0	44	55	64	81	102
Sulfur Dioxide Permit Price ($/ton)	0	148	187	218	274	403
Nitrogen Oxide Permit Price ($/ton)	0	799	1006	1173	1478	2172
Mercury Permit Price (million $/ton)	0	148	186	217	273	401

Table 5. Summary Data Macroeconomic Data (Billions of 1999$)	1998	2002	2005	2007	2010	2015
Real Gross Domestic Product (GDP)	8,882.2	9,767.6	11,431.7	12,120.2	13,218.9	15,275.7
Real Investment	1,577.0	2,022.7	2.487.7	2,714.1	3,066.8	3,790.8
Real Consumption	5,933.6	6,757.1	7,667.3	8,165.3	8,881.7	10,346.6

5.2.5. Scenario D: Emission Constraints Using the Advanced CEF Scenario Assumptions

Table 1. Summary Data Energy Consumption and Emissions	1998	2002	2005	2007	2010	2015
Total Primary Energy (Quadrillion Btus)	96.47	101.12	104.76	107.08	110.44	115.66
Total Electricity Use (Billion Kilowatt-hours)	3,411	3,675	3,779	3,875	4,025	4,208
Total Electricity Expenditures (Billions of 1999$)	223.8	263.2	273.0	286.2	308.9	340.9
Electric Sector Carbon (Million Metric Tons)	559	525	521	517	514	537
SO_2 (Million Short Tons)	13.24	8.41	7.24	6.13	3.88	2.24
NO_X (Million Short Tons)	6.01	3.79	3.27	2.85	2.11	1.62
Mercury (Tons)	47.36	31.09	25.3	20.87	14.41	10.12

Table 2. Summary Data Electric Generation (Billion Kilowatt-hours)	1998	2002	2005	2007	2010	2015
Coal	1,829	1,713	1,707	1,665	1,587	1,614
Gas and Oil	462	660	664	739	904	1,069
Nuclear	674	712	740	732	720	639
Hydropower	325	322	323	323	323	323
Renewables	57	149	207	267	324	364
Total Generator Load	3,347	3,556	3,642	3,726	3,859	4,009

Table 3. Summary Data Cogeneration – Independent Power Production (Billion Kilowatt-hours)	1998	2002	2005	2007	2010	2015
Coal Cogeneration	52	52	52	52	52	52
Gas and Oil Cogeneration	220	278	293	300	312	331
Biomass Cogeneration	27	29	30	32	35	40
Municipal Solid Waste and Other Cogeneration	12	10	9	9	9	9
Other Renewables Generation	6	14	13	13	13	13
Total Independent Power Production	317	383	398	407	422	445
Amount for Own Use	158	195	205	212	223	237
Sales to grid	158	188	192	195	198	208

Table 4. Summary Data Energy and Permit Prices (1999 dollars)	1998	2002	2005	2007	2010	2015
Wellhead Gas Price ($/MCF)	2.02	2.41	2.70	2.79	2.92	2.98
Average Electricity Price ($/MWh)	68.82	75.62	76.39	78.16	81.26	85.85
Carbon Permit Price ($/metric ton)	0	37	46	54	68	86
Sulfur Dioxide Permit Price ($/ton)	0	165	208	243	306	449
Nitrogen Oxide Permit Price ($/ton)	0	845	1065	1242	1564	2299
Mercury Permit Price (million $/ton)	0	159	200	233	294	432

Table 5. Summary Data Macroeconomic Data (Billions of 1999$)	1998	2002	2005	2007	2010	2015
Real Gross Domestic Product (GDP)	8,882.2	9,768.4	11,434.3	12,125.7	13,227.2	15,285.9
Real Investment	1,577.0	2,022.6	2,487.6	2,713.9	3,066.7	3,791.0
Real Consumption	5,933.6	6,757.1	7,668.4	8,170.0	8,889.2	10,355.9