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Technology and Greenhouse Gas Emissions: An Integrated Scenario Analysis Using the LBNL-NEMS Model

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EXECUTIVE SUMMARY

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

Figure ES-1 on the following page illustrates the different points of view in a schematic way. The curves on this graph represent different "Production Possibility Frontiers" that characterize the relationship between carbon emissions mitigation and economic activity. The frontier defines the outer boundary of what is feasible given a set of technologies and economic activity levels.

Most modeling of the costs of reducing carbon emissions assumes that the reference case carbon intensity is on the frontier, and that any increase in carbon mitigation must also result in a decrease in Gross Domestic Product (this point of view corresponds to the curve labeled "Assumed Year 2010 Business-As-Usual Case Frontier"). Our analysis demonstrates that the "*Actual* Year 2010 Business-As-Usual Case Frontier" is further out than the assumed frontier, which means that both carbon mitigation and GDP can be increased at the same time, given the right set of policies and programs. In addition, since the frontier is a function of technology, and the cost of that technology is a function of policy choices made between now and 2010, taking aggressive actions now to reduce carbon emissions can actually move the frontier further out than it would be given the technologies that exist in the reference case. This possibility is represented by the curve labeled "Year 2010 Aggressive Implementation Case Frontier".

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

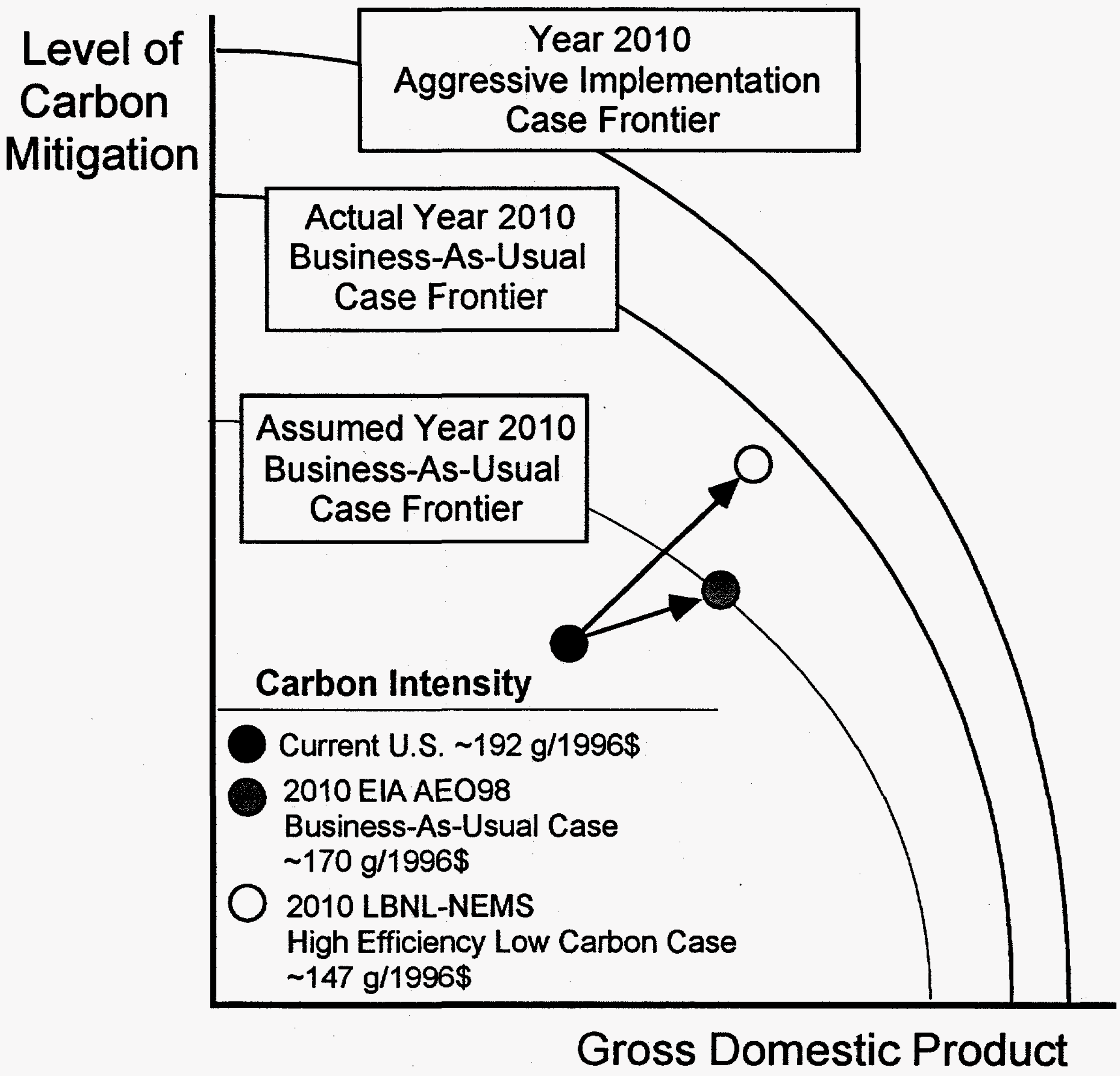
The U.S. economy now emits 192 grams of carbon for each dollar of value-added (measured as GDP in constant 1996 dollars) that it produces. With a "normal" rate of improvement in the Business-As-Usual case, it appears that by the year 2010, the nation would reduce this emissions rate to about 170 grams per dollar. Despite this improvement in the emissions rate, however, the anticipated growth in the economy will increase total carbon emissions to 1803 MtC in 2010, or to about 23 percent above 1996 levels.

The LBNL-NEMS analysis conducted in this study suggests that implementing a set of policies to encourage the development and deployment of energy-efficient and low-carbon technologies can close this gap — to the benefit of both the climate and the economy. In this study, we find a cost-effective path that can reduce the rate of carbon emissions to 147 grams per dollar of GDP. This will reduce carbon emissions to about 1530 MtC by 2010.

Other studies suggest that with the right mix of policies and technologies, the frontier might actually extend well beyond that described in this report (ASE et al. 1997, Brown et al. 1998, Interlaboratory Working Group 1997, Krause 1996, Laitner et al. 1998).

The HELC scenario analyzed in this study would result in significant annual net savings to the U.S. economy, even after accounting for all relevant investment costs and program implementation costs. This strategy would result in roughly half of the carbon reductions needed to meet the Kyoto target being achieved from domestic U.S. investments. *Not* pursuing this technology-led investment strategy would have an opportunity cost of more than $50B per year for the U.S. in 2010 and more than $100B per year by 2020.

Figure ES-1: Schematic production possibility frontiers



PREFACE

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

The work reviewed in this report was made possible through EPA funding of the E.O. Lawrence Berkeley National Laboratory (LBNL). In undertaking the assignment, LBNL was specifically asked to evaluate how different assumptions about technology diffusion might affect the opportunity for cost-effective reductions of energy-related carbon emissions. The analysis was primarily conducted by Jonathan G. Koomey and Cooper Richey (LBNL) under the overall guidance of EPA's Skip Laitner (who also supplied significant amounts of text). In addition, Robert Markel and Chris Marnay of LBNL contributed to the research leading up to the publication of this report.

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

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

Dr. Stephen Bernow, Tellus Institute
Boston, MA

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

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

Dr. Eban Goodstein, Lewis and Clark College
Portland, OR

Dr. Julie Fox Gorte, Northeast-Midwest Institute
Washington, DC

Dr. Lorna Greening, Economic Consultant
Boulder, CO

Dr. Bruce Hutton, University of Denver
Denver, CO

Dr. Florentin Krause, International Project for Sustainable Energy Paths
El Cerrito, CA

Dr. Andy Kydes, EIA Office of Integrated Analysis and Forecasting

Washington, DC

Dr. James E. McMahon, Lawrence Berkeley National Laboratory
Berkeley, CA

Dr. Alan H. Sanstad, Lawrence Berkeley National Laboratory
Berkeley, CA

Dr. Thomas Tietenberg, Colby College
Waterville, ME

Dr. Michael Toman, Resources for the Future
Washington, DC

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

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

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INTRODUCTION

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

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

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

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

(1) the large scale implementation of demand-side efficiency, comparable in scale to that presented in two recent policy studies on this topic;

(2) a variety of "alternative" electricity supply-side options, including biomass cofiring, extension of the renewables production tax credit for wind, increased industrial cogeneration, and hydropower refurbishment.

(3) the economic retirement of older and less efficient existing fossil-fired power plants; and

(4) a permit charge of \$23 per metric ton of carbon (1996\$/t),[1] assuming that carbon trading is implemented in the US, and that the carbon permit charge equilibrates at this level. This level of carbon permit charge, as discussed later in the report, is in the likely range for the Clinton Administration's position on this topic.

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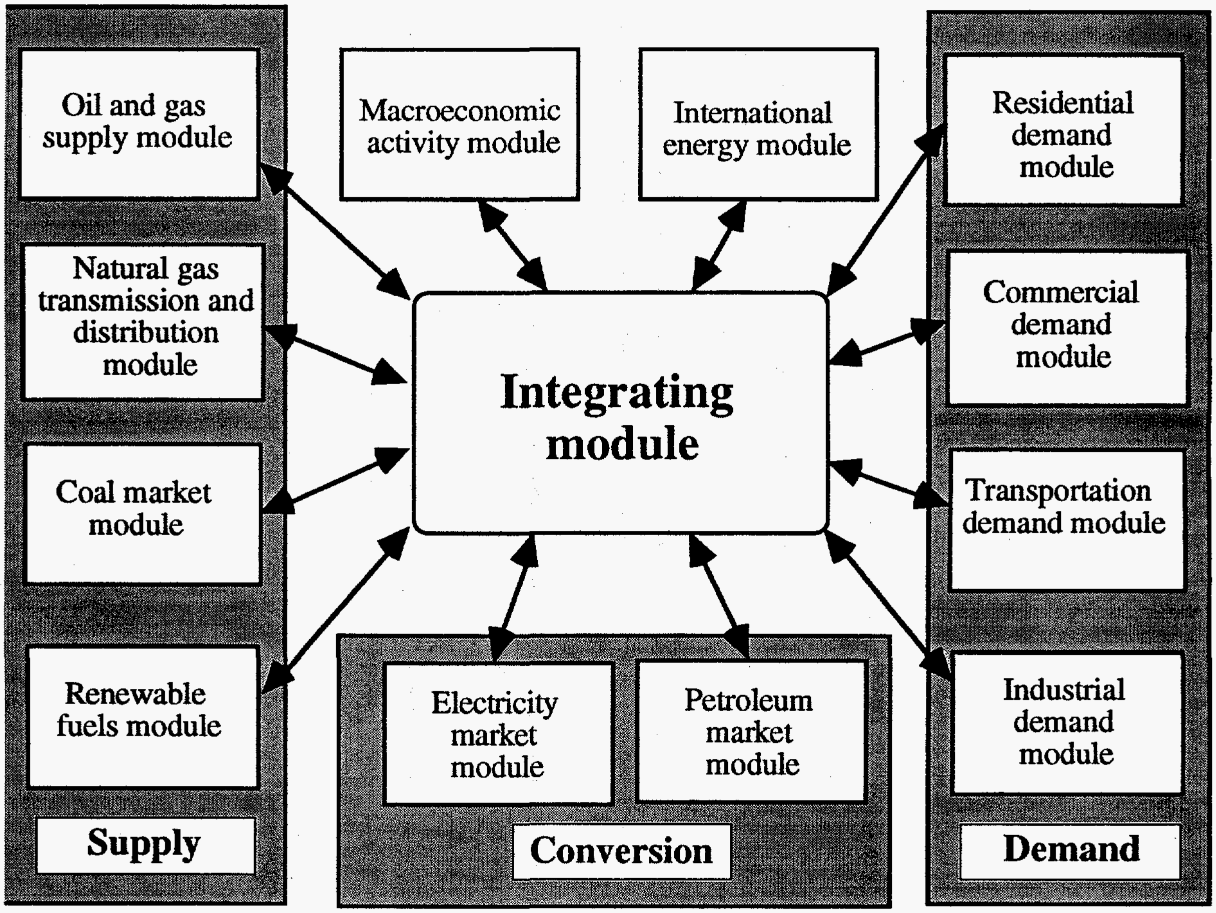
[1] In this paper, all monetary figures are in constant 1996 dollars, unless otherwise specified. All references to tons of carbon are to metric tons.

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

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

Figure 1: Schematic representation of the NEMS modeling system



Adapted from US DOE (1998b).

We rely on a modified version of the NEMS model[2] as an accounting tool, but also to capture the income, price, and intersectoral effects on both energy demand and fuel prices. Such interactions are treated exogenously in most bottom-up studies. We set out to determine whether an endogenous treatment within the LBNL-NEMS framework would alter the main conclusions of such studies.

Analytical objectives of this study

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

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

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

Incomplete technology portfolio

This analysis, because of time constraints, implemented an incomplete portfolio of carbon reduction options. For example, the Five-Lab study included (but we did not include) carbon savings from fuel cells, biomass and black liquor gasification, cement clinker replacement, industrial aluminum efficiency technologies, ethanol in light duty vehicles, repowering of coal plants with natural gas, life extension of nuclear power plants, and fossil power-plant efficiency improvements. Our analysis also includes less than one-third of the carbon savings from wind generation that is tapped in the Five-Lab study. It further omits carbon savings from the use of photovoltaics, landfill gas, combined heat and power in non-industrial space heating applications, and advanced efficiency options in the building sector. We include none of these carbon savings options, and for this reason, the total

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

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

METHODOLOGY

The scenario approach

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

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

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

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

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

We believe that such policies are capable of promoting the adoption of carbon saving technologies at the levels contained in our scenario, as shown in other analyses. For example, an analysis of programs either now in place or now under consideration — including such programs as the Climate Change Action Plan (CCAP), the President's

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

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

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

Demand side

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

On the demand side, NEMS interprets a series of "hurdle rates" (sometimes referred to as "implicit discount rates") as a proxy for all the various reasons why people don't purchase apparently cost-effective efficiency technologies. They include constraints for both the consumer (purchasing) and for the supplier (product manufacturing and distribution). Among the constraints are transaction costs, manufacturer aversion to innovation, information-gathering costs, hassle costs, misinformation, and information processing costs. The hurdle rates embody the consumers' time value of money, plus all of the other factors that prevent the purchase of the more efficient technologies. In this regard, the NEMS modeling framework follows a long and rich history in the economics of energy efficient technology adoption (DeCanio 1998, Howarth and Sanstad 1995, Koomey et al. 1996, Meier and Whittier 1983, Ruderman et al. 1987, Sanstad et al. 1993, Train 1985). See Ruderman et al. (1987) for a discussion of how implicit discount rates differ from the more standard use of the term "discount rate" with which most economists are familiar. In the residential and commercial sectors, for example, the financial component of the reference case hurdle rate is about 15 percent (in real terms) with the other institutional and market factors pushing such rates to well above 100 percent for some end-uses. Because our scenario embodies an emissions trading program that is coupled with a variety of non-price policies to eliminate many of the barriers to investing in cost-effective efficiency technologies, we reduce the hurdle rates for many end-uses in our High-efficiency/low-carbon Case.

Residential and commercial

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

Industrial

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

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

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

Transportation

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

Supply side

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

Carbon permit trading

We assume that the emissions trading system is implemented by giving away as many permits within the U.S. as the Kyoto cap would allow. Any transactions in the trading system to allow emissions up to the Kyoto cap will therefore constitute transfer payments between people and institutions within the U.S., while any such transactions to exceed the Kyoto cap are a real cost to the U.S. (these latter transactions are a transfer payment from the global perspective, however). We treat these two components of the carbon trading separately in the aggregate cost-benefit analysis below.

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

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

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

Economic retirement of fossil-fired plants

Existing fossil-fired generation is an important source of criteria air pollutants (particularly SO_2, NO_x, and particulates). These plants have largely been "grandfathered" by existing clean air regulations, so they are much dirtier than new fossil-fired plants being built today. The are also generally less efficient, so their carbon emissions per kWh are also greater than those of new fossil-fired plants. Because they are relatively expensive to operate, they are relegated to peaking and intermediate operation, so they generate fewer kWh than a new baseload plant would.

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

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

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

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

Hydroelectric refurbishments

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

Extension of the renewables production tax credit for wind

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

Biomass cofiring

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

Expansion of industrial cogeneration

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

Combined scenarios

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

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

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

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

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

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

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

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

When exploring the synergy between different policies in the HELC case, we focus on the 16 GW coal/100 GW oil-gas steam retirement case, because that is the level of retirements that is cost effective – based on our analysis of the present value of energy bills over the analysis period. When investigating the uncertainties surrounding retirements, we use all the different retirement levels plus the demand reductions, supply-side options, and carbon permit charge.

Investment costs

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

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

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

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

The programs-based perspective

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

For electricity supply side options, we also include program costs of 7% and 15% of investment costs for the optimistic and pessimistic cases, respectively (the Five lab study used program costs of 1% and 3% of total net costs for these investments). For purposes of estimating program costs for these investments, we made rough estimates of the investment costs related to these supply side changes (the LBNL-NEMS model correctly accounts for these investment costs, but does not report them separately in a convenient way, so a back-of-the-envelope calculation was required to compute program costs). For renewable electricity generation, we calculated program costs based on an assumed average capital cost of $1500/kW. For retirements, we assumed capital costs of $200/kW to shut the plants down. For all these options, we assumed a lifetime of 20 years, and real discount rates of 7% and 15% for the optimistic and pessimistic cases, respectively.

RESULTS

This section describes key analysis results, including savings in primary energy, carbon, and energy bills, as well as investment costs and program costs needed to implement the High Efficiency Low Carbon case. It also explicitly treats the transfer payments associated with the carbon permit trading system.

The High Efficiency case reduces demand in each of the end-use sectors, and in response, the electricity capacity expansion model in LBNL-NEMS builds 30 GW less coal capacity, 77 GW fewer gas-fired combined cycle plants, and 30 GW fewer combustion turbines by 2020. The high efficiency case also reduces natural gas demand, thus reducing gas prices and making gas more competitive with coal. The Carbon Charge promotes fuel switching towards less carbon intensive fuels, favoring natural gas and renewables over coal and oil. The Retirements Case forces old fossil-fired plants out of the fuel mix, and LBNL-NEMS chooses new plants to replace them. The supply-side options include adding additional capacity for hydroelectric refurbishments, biomass cofiring, cogeneration, and wind.

Primary energy use

Tables 1a and 1b, on the following page, show the energy use and carbon emissions results for 2010 and 2020 from a subset of our modeling runs. All options affect primary energy use, with the High Efficiency Case reducing primary energy demand the most, and the Carbon Charge, other electricity supply-side, and retirements options following far behind. Total primary energy demand, when all options are combined, is reduced by about 13 percent in 2010 and 22 percent in 2020.

Energy synergy is negative in 2010 and 2020 for the Carbon Charge + High Efficiency and HELC cases with varying retirement levels, while it is neutral in 2010 or slightly positive in 2020 for the Retirements + High Efficiency Case. The negative synergy in the Carbon Charge + High Efficiency Case results because the High Efficiency Case reduces the number of highly efficient natural gas power plants that would be built by 2020, but does not affect the number of gas/oil steam plants. When the Carbon Charge is put in place, the inefficient gas/oil steam plants are run in preference to coal plants. As a result, primary energy use goes up.

In the Retirements + High Efficiency Case, synergy is slightly positive in 2020. The High Efficiency Only Case prevents more coal plants from being built, but the existing coal plants are not retired, because the AEO98 version of NEMS does not have an endogenous retirement function. Instead, highly efficient advanced combined cycle plants and some combustion turbines, which are largely built after 2000, are displaced in the High Efficiency run. When coal plants are retired in the coal retirements only case, many of them are built back as coal plants. When the retirements are combined with High Efficiency, many of the retirements are not built back as coal plants. Instead, they are built back as high efficiency gas combined cycles, in large part because the High Efficiency technologies keep gas prices low and make gas-fired generation relatively more attractive than coal. These higher efficiency power plants increase the efficiency of electricity generation and reduce the primary energy used per kWh generated.

Figure 2 shows how our HELC scenario compares to the AEO98 baseline and historical trends in energy-GDP ratios. The AEO98 reference case projects a decline in energy/GDP ratio of about 0.9% per year, which is comparable to the historical rate of decline from 1960 to 1997 (1.1% per year). Our HELC scenario projects a decline in energy/GDP ratio of about 1.9% per year, which is somewhat faster than that experienced in the 1970 to

1995 period, but significantly slower than that experienced from 1976 to 1986. It is clear from history that the economy's energy intensity *can* improve at least as fast as postulated in our scenario, given the right incentives and policy changes.

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

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

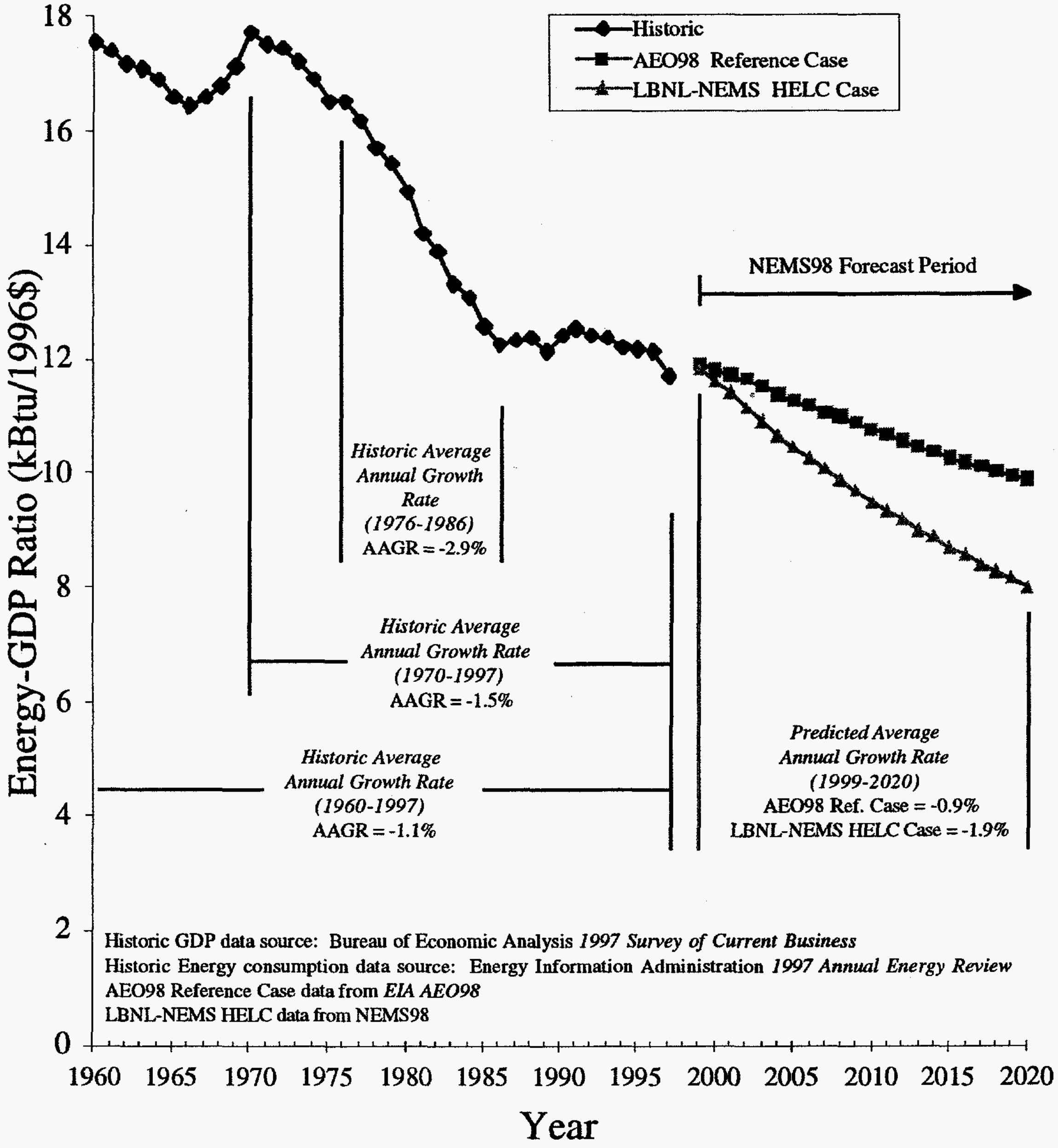
Note: Case numbers refer to cases listed in Appendix B.

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

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

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

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



Historic Average Annual Growth Rate (1976-1986) AAGR = -2.9%

Historic Average Annual Growth Rate (1970-1997) AAGR = -1.5%

Historic Average Annual Growth Rate (1960-1997) AAGR = -1.1%

Predicted Average Annual Growth Rate (1999-2020)
AEO98 Ref. Case = -0.9%
LBNL-NEMS HELC Case = -1.9%

Historic GDP data source: Bureau of Economic Analysis *1997 Survey of Current Business*
Historic Energy consumption data source: Energy Information Administration *1997 Annual Energy Review*
AEO98 Reference Case data from *EIA AEO98*
LBNL-NEMS HELC data from NEMS98

Carbon emissions

Total carbon emissions decline 15% in 2010 and 23% in 2020 when all options are combined, as shown in Tables 1a and 1b (above). The savings are larger in percentage terms than for primary energy because carbon emissions are also affected by fuel switching. The High Efficiency Case is the most efficacious in terms of absolute carbon savings, but savings from the Carbon Charge and other supply-side options are also significant. The sum of carbon savings from coal and oil and gas retirements is relatively small (about 5% of the savings in the High Efficiency Only Case). In 2010, carbon synergy is positive for the Carbon Charge/High Efficiency Case, while it can be either positive or negative for the various HELC cases with various combinations of retirements. Carbon synergy is negative for all cases in 2020.

In 2010, total carbon savings for the HELC case are about 274 MtC, which brings total emissions to 1530 MtC, about 14% above 1990 levels (1346 MtC). The Kyoto Protocol specifies that, in the years 2008-2012, the total U.S. greenhouse gas emissions should average 7% below 1990 levels. If this standard were applied only to carbon emissions for the year 2010, the U.S. would need to reduce total emissions by 554 MtC in that year. According to this scenario, then, about half of the savings needed to meet the Kyoto target are achieved domestically. The balance of the reductions — about 280 MtC — would have to come from the international trading of greenhouse gas permits. This result depends on the assumptions detailed above, including a $23/ton carbon permit price.

As noted elsewhere, a number of other studies suggest that an even larger potential exists for domestic reductions (ASE et al. 1997, Brown et al. 1998, Interlaboratory Working Group 1997, Krause 1996, Laitner et al. 1998). However, the resources needed to achieve these additional reductions are not incorporated into the scenarios described in this report.

Power plant retirements

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

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

Energy bill savings

As shown in Tables 2a and 2b, the impact of the “Climate Change Investment Strategy" appears to be highly positive in terms of the nation’s overall energy expenditures. Total energy costs for all sectors in 2010, for example, are decreased by $89 billion (in 1996 dollars). This result is made possible by the cost-effective technology investments outlined

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

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

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

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

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

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

in the scenario analysis. When the carbon permit charge transfer payments are removed, the total energy bill falls even further, by an additional $35 billion.

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

Investment and program implementation costs

The results of our simplified calculation of additional annualized investment costs for our HELC case are shown in Tables 3a and 3b. Supply-side investment costs (with the exception of cogeneration) are already captured in the bill savings calculations, while the energy efficiency investment costs are not tracked in the AEO98 version of the NEMS model.

We applied costs of conserved energy from the Five Lab study to the energy savings calculated from our scenarios in each of the demand sectors. We also estimated the cost of cogeneration investments. The optimistic and pessimistic assumptions for discount rates and program costs correspond to those used in the Five Lab study cost analysis. Total additional investment costs in 2010 are $40 to $60B/year, and program implementation costs range from $3 to $9B/year. In 2020, total additional investment costs are between $80 and $100B/year, while program implementation costs range from $5 to $17B/year.

Impact on the Nation's Economy

As summarized in Tables 3a and 3b, total net savings in 2010 (after accounting for investment costs and program implementation costs) are between $80 and $60 billion per year for the optimistic and pessimistic cases, respectively. While these investment cost estimates, at best, are of "one significant figure" accuracy, they convey a qualitative picture that is similar to the results of the Five Lab study. The energy bill savings from the incremental efficiency options more than offset the sum of incremental investment and program costs for those options. The results do not match exactly with the Five Lab results because of differences between the options included in our scenario and those in the Five Lab study, and because of feedbacks captured in the NEMS model that were not included in the Five Lab study. The results in 2020 contain larger net savings than in 2010.

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

	AEO98 Reference case 2010	*HELC case Optimistic costs 2010*	*HELC case Pessimistic costs 2010*
Energy bills without carbon permit trading transfer payments	639	515	515
Additional incremental investment beyond that captured in energy bills (energy efficiency and cogeneration)	0	37	56
Program implementation costs	0	3	9
Total cost of energy services	639	555	580
Net cost	*N/A*	*-84*	*-59*
Cost of additional permits to meet Kyoto goal (@ $23/t)	13	6.4	6.4
Net cost including cost of additional permits	*13*	*-77*	*-52*

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

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

	AEO98 Reference case 2020	*HELC case Optimistic costs 2020*	*HELC case Pessimistic costs 2020*
Energy bills without carbon permit trading transfer payments	684	456	456
Additional incremental investment beyond that captured in energy bills (energy efficiency and cogeneration)	0	77	104
Program implementation costs	0	5	17
Total cost of energy services	684	538	577
Net cost	*N/A*	*-146*	*-107*
Cost of additional permits to meet Kyoto goal (@ $23/t)	16	5.9	5.9
Net cost including cost of additional permits	*16*	*-140*	*-101*

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

We also estimate the additional cost of permits needed to meet the Kyoto goal. These permits are in excess of those assumed to be distributed in the U.S. when the emissions trading system is first created. They represent a cost to the U.S. (although from the global perspective, they are just a transfer payment). The costs are the difference in carbon emissions between the Kyoto goal for the U.S. and those in the scenario, multiplied by \$23/t. In the AEO98 reference case in 2010, the U.S. would have to purchase about \$13B/year worth of emissions allowances to meet the Kyoto goal.[3] The reduced emissions in the HELC case would result in international emissions credit purchases of about \$6B/year, a savings of more than \$6B/year in these permit costs compared to the reference case.

The HELC scenario would result in significant annual net savings to the U.S. economy, even after accounting for all relevant investment costs and program implementation costs. *Not* pursuing this technology-led investment strategy would have an opportunity cost of more than \$50B per year for the U.S. in 2010 and more than \$100B per year by 2020. In any case, this scenario identifies significant "no-regrets" options that make sense to implement even if climate change is not a concern.

If a scenario shows cost-effective investments — that is, investments which generate a net savings over a reasonable period of time, the nation's Gross Domestic Product (GDP) should also increase. However, we do not report the NEMS GDP estimates since the NEMS model does not adequately track changes in investment or capital to provide a reliable estimate of the economic impacts of our investment scenario. At the same time, we can report on a modeling exercise using the AMIGA model (a general equilibrium model with rich sectoral detail).[4]

The runs conducted with the AMIGA model were also based upon the technology assumptions of the Five-Lab study, but with a more complete accounting for investment costs than that of the LBNL-NEMS framework. Within the AMIGA system, the level of technology associated with the Five-Lab study, together with a \$50/tC permit price, generated a much higher level of domestic carbon reductions — 366 MtC in the year 2010. In that analysis, GDP increased by \$63 billion in 2010, or about 0.6 percent higher than in the reference case. Employment shows a small net gain of about 35,000 jobs by 2010 (Hanson 1998). Hence, the AMIGA evaluation of a Climate Change Investment Strategy, similar in scope to that analyzed here, provides a clear indication that the United States can achieve a significant level of domestic carbon reductions and still maintain a competitive momentum to the benefit of the nation's economy.

DISCUSSION

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

Our analysis explicitly treats carbon savings from end-uses and technologies that are currently "hard-wired" in the NEMS framework, including miscellaneous electricity and residential lighting. Any policy study using NEMS that merely uses carbon charges or

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[3] This simplified calculation ignores the effect the \$23/t permit trading fee would have on emissions.

[4] AMIGA is the *All Modular Industry Growth Assessment* system developed by the Argonne National Laboratory. It has been developed with the capability to represent and evaluate many of the specific policy options now under discussion for reducing energy-related carbon emissions.

other price instruments to achieve carbon reductions essentially assumes that no savings can be achieved in these building sector end-uses. Since miscellaneous electricity and residential lighting are responsible for a large fraction of growth in the buildings sector, it is inappropriate to ignore them.

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

Implementing technological change

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

Understanding power plant retirements

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

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

Effect of integrated analysis

There does appear to be an effect of using an integrated modeling approach, though it is smaller than we initially expected. When all the options in our HELC case (with the $23/tC charge) are implemented separately in the LBNL NEMS framework, we find total savings of 280 MtC in 2010. When implemented together in the LBNL-NEMS model, however, we found total savings of only 274 MtC, about a 2% reduction from the non-integrated assessment.

This relatively small effect indicates that sectoral studies that do not conduct integrated all-energy-sector analyses may not be missing much, though it is not possible to generalize this finding without significant future work. At least some of the important changes we implemented on the demand side are independent of prices (e.g., savings in miscellaneous electricity and residential lighting), but many other important changes (e.g., the reductions in discount rates) increase the model's sensitivity to price changes. This area is clearly one that warrants further investigation.

FUTURE WORK

Additional carbon saving options

Several carbon saving options have not been included in this analysis, including

1) combined heat and power in non-industrial space heating applications;
2) photovoltaics;
3) fuel cells;
4) landfill gas;
5) repowering of old coal plants with natural gas;
6) advanced efficiency options in the building sector; and
7) ethanol in the transportation sector.

These other options are potentially important, and in each case will increase the carbon savings from the high efficiency low carbon case. A comprehensive assessment for Europe that included these options uncovered significant cost effective carbon reduction potentials associated with these technologies (Krause et al. 1994, Krause et al. 1995a, Krause et al. 1995b), and we expect the same conclusions to hold for the U.S.

Better treatment of currently analyzed carbon saving options

Industrial cogeneration, biomass, hydroelectric refurbishments, and wind generation have been treated in a relatively cursory manner in this work. The resource potentials for these options are potentially large. A more careful assessment of the geographic variations in resource availability and costs could potentially pay dividends in terms of further carbon reductions. Wind, in particular, could contribute many times more power than in our HELC case, based on its rapidly declining costs and the large absolute size of the resource. Detailed analysis of these options for Europe has demonstrated large unrealized cost-effective potentials (Krause et al. 1994, Krause et al. 1995a).

Improvements in synergy index

In the current version of this analysis, the synergy index is calculated based on annual energy use or emissions. In future work, we expect to convert the synergy index to use *cumulative* energy use or emissions, thus giving a more accurate picture of the total response over time to our policy excursions. We also will explicitly attempt to assess synergies in costs and benefits for different scenarios.

Implementation roadmap for programs and policies

Our scenario analysis is predicated on the existence of successful programs and policies to promote cost-effective energy efficiency technologies. Further work is clearly needed to lay out an implementation path for such policies. This roadmap would be similar to that created by Brown (1993, 1994) for the residential sector, but would cover policies and programs in all sectors.

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

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

Ancillary benefits of power plant retirements

One variable that we have not explicitly treated in our retirements analysis is the interaction between criteria pollutants (e.g., SO_2, NO_x, and particulates), energy efficiency, and retirement levels. Efficiency improvements and retirements both reduce criteria pollutant emissions, and within many urban airsheds, these pollutants have a value to society that is known or can be approximated. An analysis using Geographic Information Systems that assesses the economic characteristics of specific power plants and the local value of reducing urban air pollution could determine which additional power plants it might be cost effective to retire given those ancillary benefits.

Other aspects of power plant retirements

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

Power plant efficiency

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

Macroeconomic effects in NEMS

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

In addition, it is clear that the macroeconomic forecast generated by the reduced form version of the DRI model is solely dependent on energy prices passed from the integrating module of the NEMS model. It is therefore impossible for the AEO98 version of the NEMS modeling framework using the reduced form macro model to reflect accurately the effect of a reduction in energy *bills*. This problem limits the usefulness of this tool in assessing macroeconomic impacts from programs and policies that are designed to reduce energy bills. We do not know if the EIA version of NEMS using the full DRI model suffers from this limitation, but if it does, it is a fundamental one.

Review of gas supply and demand interactions

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

Regional distribution of hydroelectric refurbishment capacity

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

CONCLUSIONS

The LBNL-NEMS analysis demonstrates some key policy conclusions:

(1) The domestic U.S. options analyzed here achieve about half of the carbon reductions needed to meet the Kyoto commitment. This is a significant fraction of the total commitment that actually reduces the nation's total cost of energy services. The rest of the savings will need to come from international emissions trading and other options we did not analyze. This result is dependent on our assumption of a $23/ton carbon permit price, as well as the other assumptions detailed above.

(2) Many carbon savings options are not included in our analysis. These include fuel cells, biomass and black liquor gasification, cement clinker replacement, industrial aluminum efficiency technologies, ethanol in light duty vehicles, repowering of coal plants with natural gas, life extension of nuclear power plants, fossil power-plant efficiency improvements, photovoltaics, landfill gas, combined heat and power in non-industrial space heating applications, and advanced efficiency options in the building sector. The potential of some other options (such as wind generation and industrial cogeneration) are probably underestimated in our study. For these reasons, we believe the total carbon savings calculated here are substantially less than the full potential.

(3) Power plant retirements are a key option for carbon reductions that have been inadequately explored heretofore. They combine ancillary benefits from criteria air pollutant reductions with positive carbon synergy when implemented in combination with energy efficiency.

(3) Demand and supply-side options can work together to create positive synergy. Switching power plants to natural gas will increase demand for that fuel, and drive up the price. If large amounts of energy efficiency options are implemented in concert with the switch to gas-fired power plants, the price of natural gas can be kept below reference case levels, which allows these power plants to compete more effectively with coal.

(5) NEMS is not a complete cost accounting framework (particularly for demand-side investments and cogeneration), so any estimates of the GDP effects of various energy policy options must be viewed with extreme caution. This problem is not unique to

NEMS, but it is an important issue for anyone attempting to interpret the results of any NEMS analysis.

(6) Our analysis explicitly incorporates carbon savings from miscellaneous electricity, residential lighting, and industrial cogeneration, which are currently "hard-wired" in the NEMS framework. Any NEMS analysis that implements large shifts in policy (such as carbon permit trading and non-price policies) but does not exogenously treat these hard-wired items is not correctly assessing the costs of reducing carbon emissions.

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

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

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

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

A.1 All sectors

Carbon charge

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

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

(1) Changing the epmcntl file

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

---

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

(2) *Changing the epmdata file:*

In the epmdata file, the carbon charge factors on lines 39 through 61 are replaced with carbon factors representing a 23 $/t or 50 $/t carbon charge. Specific values are listed below, by carbon charge level.

23 $/tC (1996$) carbon charge:

```
0.000000  1500  0.40    98
0.000000  1532  0.40    99
0.003000  1552  0.40    2000
0.007500  1570  0.40    1
0.010000  1584  0.40    2
0.015000  1606  0.40    3
0.017300  1625  0.40    4
0.017300  1530  0.40    2005
0.017300  1480  0.40    6
0.017300  1430  0.40    7
0.017300  1390  0.40    8
0.017300  1360  0.40    9
0.017300  1344  0.40    2010
0.017300  1344  0.40    11
0.017300  1344  0.40    12
0.017300  1344  0.40    13
0.017300  1344  0.40    14
0.017300  1344  0.40    2015
0.017300  1344  0.00    16
0.017300  1344  0.00    17
0.017300  1344  0.00    18
0.017300  1344  0.00    19
0.017300  1344  0.00    2020
```

50$/tC (1996$) carbon charge:

```
0.00000  1500  0.40    98
0.00000  1532  0.40    99
0.00750  1552  0.40    2000
0.01500  1570  0.40    1
0.02250  1584  0.40    2
0.03000  1606  0.40    3
0.03770  1625  0.40    4
0.03770  1530  0.40    2005
0.03770  1480  0.40    6
0.03770  1430  0.40    7
0.03770  1390  0.40    8
0.03770  1360  0.40    9
0.03770  1344  0.40    2010
0.03770  1344  0.40    11
0.03770  1344  0.40    12
0.03770  1344  0.40    13
0.03770  1344  0.40    14
0.03770  1344  0.40    2015
0.03770  1344  0.00    16
0.03770  1344  0.00    17
0.03770  1344  0.00    18
0.03770  1344  0.00    19
0.03770  1344  0.00    2020
```

A.2 Electric utility sector

Early retirement of coal plants

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

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

Table A.2.1 Coal plant retirement level criteria

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

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

Early retirement of gas/oil steam turbine plants

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

Biomass co-firing

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

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

Increasing hydropower capacity

Section 7.3.1.3 of the *Five Lab Study* estimates that given relicensing issues and environmental regulations, the net capacity addition due to efficiency improvements and added capacity will be between 10 GW and 16 GW. Taking 13 GW as a midpoint, new capacity in existing hydropower plants is phased in over the years 2000 to 2008 in the plant data file through additional units added to existing hydropower plants. This additional hydropower capacity is distributed evenly across all 13 NERC regions.

Extending wind credit

In the ecpdat file, the last year of eligibility for the generation subsidy (UPIGSYL) for wind is changed from 1999 to 2020 and the generation subsidy duration (in years) (UPIGSYR) is changed from 10 to 25.

A.3 Residential sector

Energy efficiency

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

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

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

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

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

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

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

the lastyear field of the original line is set to 1999

the firstyear field of the duplicate line is set to 2000

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

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

Line 10043 is changed from

```
EFF(3)=88.00     ! SHOULD BE 88.00
```

to:

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

Lines 10047 through 10055 are changed from the following values:

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

to the following values:

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

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

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

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

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

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

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

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

A.4 Commercial sector

Energy efficiency

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

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

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

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

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

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

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

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

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

Line 3295 is changed from

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

to

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

and after Line 3318, the following code is added

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

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

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

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

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

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

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

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

A.5 Industrial sector

Energy efficiency

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

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

(1) Changing the RETRATE coefficients

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

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

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

(2) Changing the HITECH modifiers to the ENPINT variable

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

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

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

(3) Changing the TPC coefficients

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

Table A.5.3 TPC parameters in the EIA AEO98 Hi-Tech case and LBNL-NEMS HELC case

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

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

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

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

(1) High Efficiency savings are reported (rather than HELC) to exclude feedback from supply-side options.

Increase natural gas cogeneration

Based on off-line analysis (US DOE 1997b), natural gas cogeneration is increased by 35 GW (@ 70% electric capacity factor), or 215 TWh by 2010. The following changes are made to the ind.f source code to implement this increase: natural gas cogeneration is increased 215 TWh by 2010 in the ELGEN calculation, the associated gas fuel consumption is removed from the GCTFUEL calculation, and the gas fuel consumption is accounted for in the FUELADD calculation using a net heat rate of 1.75.

(1) Increasing natural gas cogeneration in the ind.f source code

Lines 7834-7838 which contain the following code:

```
  IF(TEMP(11).GT.0.0.and.cinter(inddir,indreg,pm).ne.0.0)THEN
  ELGEN(pm)=(EXP(cINTER(inddir,indreg,pm)))*(STEMCUR**GSTEAM)
 ELSE
  ELGEN(pm)=0.0
 ENDIF
```

are replaced by the following code

```
C ***** LBNL --- INCREASING GAS COGEN BY 215 TWh -- 35GW @ 70%CF
     IF (PM.EQ.2) THEN
C       OPEN(1,FILE='cogendump',STATUS='old')
C       WRITE(1,*)'YR is ',IYR,'--BASELINE COGEN IS ',ELGEN(2)
        IF ((IYR.GE.2001) .AND. (IYR.LT.2010)) THEN
          ELGEN(pm) = ELGEN(pm) * (IYR-1999.0) / 10.0 * 6.0
       ELSE IF (IYR.GE.2010) THEN
         ELGEN(pm) = ELGEN(pm) * 6.0
       ENDIF
C       WRITE(1,*)'         --MODIFIED COGEN IS ',ELGEN(2)
C       CLOSE(1)
      ENDIF
C ***** LBNL END *****
```

(2) Removing incremental gas cogeneration from GCTFUEL calculation

After Line 8210, which contains the following code:

```
GCTFUEL=ELGEN(2)*GENEQPHTRT(2)/3412.0 ! Trillion Btu
```

the following code is inserted:

```
C ***** LBNL ***** REMOVING INCREMENTAL GAS COGENERATION FROM GCTFUEL
    IF ((IYR.GE.2001) .AND. (IYR.LT.2010)) THEN
      GCTFUEL=GCTFUEL / (6.0 * (IYR - 1999.0) / 10 )
     GCTFUEL=GCTFUEL +
    *       ELGEN(2) * 5.0/6.0 * (IYR - 1999.0) / 10 * 1.75
    ELSE IF (IYR.GE.2010) THEN
     GCTFUEL=GCTFUEL / 6.0
     GCTFUEL=GCTFUEL +
    *      ELGEN(2) * 5.0/6.0 * 1.75    ! 1.75 HEAT RATE 4 INC. GAS
    ENDIF
C ***** LBNL END *****
```

(3) Accounting for incremental gas cogeneration

Lines 8313 to 8321, which contain the following code:

```
    DO I = L,M  ! division aggregated to region
     DO IP = 1,3 ! prime mover
      DO IF = 1,6 ! fuel
       fueladd(INDREG,if) = fueladd(indreg,if) + 0.5 *
1        (SICGEN(I,YR,INDDIR,IF,IP,3)*3412.0/10**6)
      ENDDO
     ENDDO
    ENDDO
```

are replaced by the following code:

```
 DO I = L,M  ! division aggregated to region
        DO IP = 1,3 ! prime mover
         DO IF = 1,6 ! fuel
           fueladd(INDREG,if) = fueladd(indreg,if) + 0.5 *
    1        (SICGEN(I,YR,INDDIR,IF,IP,3)*3412.0/10**6)!
C ***** LBNL --- ACCOUNTING FOR GAS COGEN WITH HEATRATE OF 1.75
           IF ((IYR.GE.2001) .AND. (IYR.LT.2010)) THEN
            fueladd(INDREG,if) = fueladd(INDREG,if) -
    *            0.5 * 5.0/6.0 * (IYR - 1999.0) / 10 *
    *           (SICGEN(I,YR,INDDIR,IF,IP,3)*3412.0/10**6)
          ELSE IF (IYR.GE.2010) THEN
            fueladd(INDREG,if) = fueladd(INDREG,if) -
    *            0.5 * 5.0/6.0 *
    *         (SICGEN(I,YR,INDDIR,IF,IP,3)*3412.0/10**6)
          ENDIF
C ***** LBNL END *****
         ENDDO
        ENDDO
       ENDDO
```

A.6 Transportation sector

Energy efficiency

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

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

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

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

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

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

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

(2) Changing the truck technology characteristics in the cffuel.v1.3 input file:

There are no differences between the default AEO97 and default AEO98 versions of the cffuel.v1.3 file. Therefore, the original Five Lab Study HELC cffuel input file is used as the LBNL-NEMS HELC Case cffuel input file. Table A.6.1 lists the technology parameters that we modified in the cffuel input file. Table A.6.2 lists the technologies which we modified in the cffuel file, as well as which parameters (see Table A.6.1 for parameter number mapping) we modified for each technology in the medium and heavy truck categories.

Table A.6.1 Technology parameters we modified in the cffuel file

Parameter Number	Parameter Name	Parameter Description
1	CAVAILYR	year in which new technology becomes available
2	FUELAPPL	technology-fuel applicability matrix
3	TRIGPRC	technology trigger price
4	CYCLE	years until 99% penetration
5	PRCVAR	price variation coefficient
6	ESHRT	maximum share of technology at trigger price
7	PRCVAR	superseding matrix
8	MPGINCR	incremental technology fuel economy improvement

Table A.6.2 Technology parameters* we modified by technology in the cffuel file by truck category

	Modified Technology Parameter Number*	
Truck Model Technologies	medium trucks	heavy trucks
Aerodynamic Features	3	3
Radial Tires	3	3
Axle or Drive Ratio	3	3
Fuel Economy Engine	3	3
Variable Fan Drive	3	3
Improved Tires & Lubricants	3,4,8	3,4,6,8
Electronic Engine Controls	3,4,8	3,4,6,8
Electronic Transmission Controls	3,4,8	3,4,6,8
Advanced Drag Reduction	1,2,,4,5,6,8	1,3,4,5,6,8
Turbocompound Diesel Engine	1,2,3,4,5,6,8	1,3,4,6,8
Heat EngineÄLE-55	1,2,4,5,6,8	1,3,4,5,6,8
Blank 14	1,2,3,4,5,6,7,8	1,2,3,4,5,6,7,8
Blank 15	1,2,3,4,5,6,8	1,5,8

* See Table A.6.1 for parameter number mapping

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

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

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

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

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

Light Duty Vehicle Module (rows 1 to 1151)

Section 1 (rows 1 to 183)

In this section of the input data, there are seven technology parameters for the fifty seven default technologies. The technologies are separated by car and light truck categories. Table A.6.3 lists the seven fuel economy model technology parameters for each technology. Table A.6.4 lists the technologies which are modified, as well as which parameters (see Table A.6.3 for parameter number mapping) are modified for each technology in the car and light truck category. Twenty one of the fifty six default technologies are modified and five new technologies are added in this section of the input file.

Table A.6.3 Technology parameters we modified

Parameter Number	Parameter Name	Parameter Description
1	TFET	fractional change (%) in fuel economy
2	TCABST	change in cost ($)
3	TCWGTT	weight based change in cost ($/lb)
4	TWABST	change in weight (lbs)
5	TWWGTT	change in weight based on original weight (lb/lb)
6	IFRSTT	first year technology is available
7	THPT	fractional change (%) in horsepower

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

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

* See Table A.6.3 for parameter number mapping

** replaces lean burn technology in the AEO98 Reference Case

*** technology added (rather than modified)

Section 2 (rows 231-567)

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

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

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

* technology added (rather than modified)

Section 3 (rows 688 to 845)

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

Section 4(rows 857 to 1151)

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

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

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

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

Section 1 (rows 1237 to 1312)

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

Section 2 (rows 1313 to 1327)

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

Freight Transport Module (rows 1407 to 1432)

Section 1 (no longer in trninput file)

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

Section 2 (rows (1421 to 1425)

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

Section 3 (1426 to 1432)

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

Air Travel Module (rows 1433 to 1463)

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

Miscellaneous Transportation Energy Demand Module (rows 1464 to 1549)

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

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

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

APPENDIX C: SUMMARIES OF KEY REVIEW COMMENTS

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

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

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

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

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

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

> Response: Our focus was on creating scenarios that illustrate the economic and environmental opportunities associated with a high-efficiency/low-carbon technology path. Although the American Petroleum Institute and others have written commentaries that are critical of the Five-Lab findings, the resource potential for this path is well documented in a large number of other studies that we reference. Whether one believes these potentials or not, our goal was to learn what we could about such technology-based scenarios using the LBNL-NEMS integrating framework.
>
> The authors believe that a combination of an emissions trading program and a variety of different non-price policies can lead to changes in energy service markets of the magnitude required. These non-price policies include voluntary agreements with industry, cost-effective minimum efficiency standards, ENERGY STAR programs, utility incentive programs funded through "line charges," targeted tax credits, golden carrots, government and industry purchases of high efficiency technologies now on the market, and technology procurement by government and industry for technologies close to commercialization. The program experience over

the last two decades solidly demonstrates that these non-price programs work well and have been shown to be cost-effective.

Comment (4): If indeed the economy could costlessly achieve the energy savings posited it would be beneficial. But the savings are not costless. Aside from the fact that a $23/t carbon charge is needed, many would see large additional costs, explicit and hidden, in the regime being analyzed. These costs must be taken into account in assessing the overall economic impact.

Response: This is an important point. As a significant improvement in our final study, we have included a more detailed estimate of the investment, transaction and program costs necessary to drive the kind of scenarios illustrated in this analysis. Tables 3a and 3b summarize our findings that a high-efficiency/low-carbon path can lead to a net economic benefit for the U.S. economy. We recognize, however, that more work needs to be done in this area.

Comment (5): The criticism of price-driven studies here is overdone and unwarranted.

Response: We agree, and to that extent we have modified the discussion in that regard. We note, however, the significant evidence suggesting that a "smart" set of policies and programs can reduce the size of the price signal that might otherwise be needed to ease the economy onto a cost-effective technology path of reducing greenhouse gas emissions. Price matters, but it is not all that matters. Among the requirements are that the signal be clear and unambiguous, not necessarily large. Again, this assumes effective policies and programs such as those described in comment (3) above.

Comment (6): It is important to explicitly lay out the exact "non-price" policies that are needed to achieve the level of energy efficiency levels in the Five-Lab scenario.

Response: We agree that this is an important step, but it was not possible to do so within the strict time and resource constraints of this study. We have added text to describe "the programs-based approach" and listed some of the non-price policies that would be important in any large-scale effort to implement energy efficiency. We have also explicitly accounted for program costs in our summary cost-benefit analysis, just as the Five-Lab study did.

Comment (7): The report is too critical of the NEMS modeling framework

Response: The statements about the limitations of the NEMS modeling framework are important because NEMS is the official model of the US DOE, and it is important for the policy analysis community to understand its limitations. This should in no way be taken to imply that we disapprove of the NEMS framework. In fact, we believe it is the best of the integrated models, because of its comprehensive treatment of supply-side technologies (particularly in the electricity sector) and its detailed treatment of energy demand at the end-use level. As one of the few users of NEMS outside of EIA, we believe it is our responsibility to be explicit in whatever technical concerns we have about the model, because few other people are in a position to do so. EIA continually makes improvements in their modeling framework every year, in part as a response to improved data and analyses from researchers outside EIA. We believe that explicitly listing areas where the model can be improved is helpful for all who are concerned with improving the modeling of U.S. energy policies.

Comment (8): The AEO forecast embodies historical relationships with little change from past trends, but you are clearly moving away from that historical record in a positive way, and that needs to be brought out in your analysis.

Response: This is also an important issue, both within the modeling and the policy arenas. We think the evidence points in the direction of establishing a smart set of policies and programs that can break with historical relationships. This is especially true with respect to implementing a high-efficiency/low-carbon future. We also believe that the historical record has not been fully understood with respect to the ongoing opportunities to close that efficiency gap. The current generation of Energy Star programs and the various Research and Development initiatives supported by the U.S. Department of Energy all underscore this point.

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

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

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

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

Comment (11): Many carbon savings options, such as repowering of coal-fired power plants with natural gas, renewables, and advanced efficiency technologies, are not included in the scenarios.

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

Comment (12): It is interesting that your HELC case has declining prices and declining demand. This result seems counterintuitive from the perspective of Economics 101.

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

Comment (13): The HELC case involves diverting capital from other uses, so that there is an opportunity cost to these investments that is not included in your analysis

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

Comment (14): Strengthen the comments on macro effects found in the LBNL-NEMS. That's a weak point in the model so you should be clear on that yourselves.

> Response: We agree with this point. Since the AEO98 version of NEMS does not track either energy efficiency technology investments or energy bill savings with respect to their impact on GDP and personal consumption expenditures, the model may understate the positive impacts of a cost-effective technology path. It is for that reason that we expanded the discussion on the full investment and program transition costs to establish the net positive benefits of scenarios bolstered by the Five-Lab study and similar analysis.

APPENDIX D: KEY OUTPUTS FROM SELECTED MODELING RUNS

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

Table D-1: LBNL-NEMS High-Efficiency/Low Carbon Cases
All-Sector Forecast Summary 2010 Page 1 of 2

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

Table D-1: LBNL-NEMS High-Efficiency/Low Carbon Cases
All-Sector Forecast Summary 2010 Page 2 of 2

	AEO98 Ref Case	LBNL-NEMS CC-Hieff Case	LBNL-NEMS HE-Ret Case	LBNL-NEMS CC-Ret Case	LBNL-NEMS HELC Case	LBNL-NEMS HELC Case	LBNL-NEMS HELC Case	LBNL-NEMS HELC Case	LBNL-NEMS HELC Case
demand side efficiency measures	-	hieff	hieff	-	hieff	hieff	hieff	hieff	hieff
carbon charge ($/tC)	-	23	-	23	23	23	23	23	50
coal retirements (GW)	-	-	16	16	-	16	-	16	16
natural gas and oil retirements (GW)	-	-	100	100	-	0	100	100	100
supply-side improvements	-	-	-	-	cf/cg/hy/wd	cf/cg/hy/wd	cf/cg/hy/wd	cf/cg/hy/wd	cf/cg/hy/wd
	2010	2010	2010	2010	2010	2010	2010	2010	2010
Primary Energy (Quadrillion Btu)									
Residential	21.6	20.1	20.2	20.9	20.0	19.9	19.7	19.7	19.3
Commercial	16.9	15.2	15.1	16.4	15.1	15.0	14.9	14.8	14.6
Industrial	40.5	36.4	36.1	39.9	35.6	35.5	35.3	35.3	35.0
Transportation	33.1	29.4	29.6	32.8	29.4	29.3	29.3	29.3	29.0
Total	112.2	101.1	101.0	109.9	100.0	99.8	99.2	99.1	97.9
Electricity Sales (TWh)									
Residential	1350	1188	1199	1336	1187	1187	1187	1187	1175
Commercial	1200	1033	1041	1185	1034	1034	1034	1034	1025
Industrial	1282	1131	1096	1304	1015	1014	1014	1013	1035
Transportation	46	52	53	46	52	52	52	52	52
Total	3877	3404	3388	3871	3289	3287	3288	3286	3287
Carbon Emissions by Sector (Mt)									
Residential	338	305	305	321	294	292	287	286	273
Commercial	274	239	237	261	229	228	223	222	213
Industrial	563	496	494	545	472	471	466	466	455
Transportation	628	557	562	622	556	556	556	556	549
Total	1803	1596	1598	1749	1552	1548	1531	1529	1491
Utilities	663	566	551	628	515	511	495	492	470
Carbon Emissions by Source (Mt)									
Petroleum	762	676	684	747	674	675	673	673	665
Natural Gas	424	390	383	429	389	388	388	386	394
Coal	616	529	530	572	487	484	469	469	430
Other	2	1	1	1	1	1	1	1	1
Total	1803	1596	1598	1749	1552	1548	1531	1529	1491
Average Energy Prices to All Users (96$/MBtu)									
Petroleum Products	8.02	7.49	7.15	8.31	7.48	7.48	7.49	7.50	7.92
Natural Gas	3.70	3.49	2.93	4.25	3.37	3.36	3.37	3.35	3.95
Coal	1.11	1.66	1.06	1.66	1.66	1.66	1.63	1.64	2.33
Electricity	17.32	18.20	16.73	19.11	18.21	18.28	18.18	18.24	19.87
Average Energy Price to Elec Gen (96$/MBtu)									
Fossil Fuel Average	1.57	1.88	1.25	2.18	1.82	1.83	1.81	1.81	2.54
Petroelum Products	3.84	3.97	4.20	5.16	4.25	4.24	4.63	4.62	5.15
Distillate Fuel	5.33	5.11	4.67	5.70	5.11	5.10	5.11	5.10	5.59
Residual Fuel	3.46	3.59	3.84	4.68	3.85	3.84	4.25	4.26	4.79
Natural Gas	2.84	2.55	1.95	3.52	2.36	2.39	2.40	2.40	3.07
Steam Coal	1.09	1.64	1.03	1.63	1.63	1.63	1.61	1.61	2.30
Energy Consumption (Quadrillion Btu)									
Petroleum Subtotal	44.3	39.2	39.7	43.5	39.2	39.2	39.1	39.1	38.7
Natural Gas	29.6	27.2	26.7	29.9	27.2	27.1	27.1	27.0	27.5
Coal Subtotal	24.0	20.7	20.7	22.4	19.1	18.9	18.4	18.3	16.9
Nuclear Power	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4
Renewable Energy	7.4	7.2	7.2	7.3	7.8	7.8	7.9	8.0	8.0
Electricity Imports	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.4
Others	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Total	112.2	101.1	101.0	109.9	100.0	99.8	99.2	99.1	97.9
Macroeconomic Indicators									
GDP (billion 1996$)	10394	10417	10451	10362	10420	10421	10421	10423	10386
Real Consumption	6997	7013	7045	6969	7017	7017	7017	7018	6984
Real Investment	1917	1926	1935	1908	1926	1928	1926	1928	1919
Real Government Spending	1651	1652	1659	1647	1653	1653	1653	1653	1648
Real Exports	2570	2572	2588	2556	2573	2575	2575	2575	2558
Real Imports	2771	2775	2824	2727	2779	2781	2781	2782	2729
Unemployment Rate (%)	5.5	5.4	5.3	5.6	5.4	5.4	5.4	5.4	5.4
Energy Bill (billion 1996$)	639	559	517	683	550	551	549	550	594
Energy/GDP Ratio (kBtu/1996$)	10.8	9.7	9.7	10.6	9.6	9.6	9.5	9.5	9.4
Carbon/GDP Ratio (g/1996$)	173	153	153	169	149	149	147	147	144

Table D-2: LBNL-NEMS High-Efficiency/Low Carbon Cases
All-Sector Forecast Summary 2020 Page 1 of 2

	AEO98 Ref Case	LBNL-NEMS 23 $/t C-C Case	LBNL-NEMS High-Eff Case	LBNL-NEMS Coal Retire Case	LBNL-NEMS Gas-Oil Retire Case	LBNL-NEMS SupplySide Case
demand side efficiency measures	-	-	hieff	-	-	-
carbon charge ($/tC)	-	23	-	-	-	-
coal retirements (GW)	-	-	-	16	-	-
natural gas and oil retirements (GW)	-	-	-	-	100	-
supply-side improvements	-	-	-	-	-	cf/cg/hy/wd
	2020	2020	2020	2020	2020	2020
Primary Energy (Quadrillion Btu)						
Residential	23.2	22.8	21.7	23.0	23.1	23.1
Commercial	17.4	17.1	15.5	17.3	17.3	17.4
Industrial	41.6	41.2	34.6	41.4	41.4	40.7
Transportation	36.5	36.1	27.7	36.4	36.4	36.4
Total	118.6	117.2	99.5	118.2	118.3	117.6
Electricity Sales (TWh)						
Residential	1548	1533	1337	1546	1542	1546
Commercial	1304	1286	1090	1303	1301	1308
Industrial	1392	1411	1059	1389	1384	1256
Transportation	64	63	79	64	64	64
Total	4308	4293	3566	4301	4291	4173
Carbon Emissions by Sector (Mt)						
Residential	379	363	344	374	378	370
Commercial	296	283	255	292	295	289
Industrial	589	571	476	585	588	565
Transportation	692	684	526	692	692	691
Total	1956	1901	1601	1942	1952	1915
Utilities	745	712	609	731	741	698
Carbon Emissions by Source (Mt)						
Petroleum	822	810	637	822	818	822
Natural Gas	474	481	417	475	472	467
Coal	658	608	545	642	659	624
Other	3	3	2	3	3	3
Total	1956	1901	1601	1942	1952	1915
Average Energy Prices to All Users (96$/MBtu)						
Petroleum Products	8.12	8.42	6.26	8.11	8.12	8.12
Natural Gas	3.86	4.36	2.87	3.90	3.92	3.87
Coal	1.00	1.59	0.98	1.00	1.00	1.01
Electricity	16.01	17.56	15.02	16.08	16.61	16.04
Average Energy Price to Elec Gen (96$/MBtu)						
Fossil Fuel Average	1.66	2.30	1.31	1.69	1.68	1.67
Petroelum Products	4.21	4.52	3.63	4.13	4.98	4.40
Distillate Fuel	5.64	5.99	4.42	5.63	5.61	5.64
Residual Fuel	3.77	4.15	3.27	3.73	4.47	3.87
Natural Gas	3.15	3.73	2.13	3.21	3.28	3.23
Steam Coal	0.97	1.56	0.95	0.97	0.97	0.98
Energy Consumption (Quadrillion Btu)						
Petroleum Subtotal	47.6	47.0	37.2	47.6	47.5	47.6
Natural Gas	33.1	33.6	29.1	33.2	33.0	32.6
Coal Subtotal	25.6	23.7	21.3	25.0	25.7	24.3
Nuclear Power	4.1	4.1	4.1	4.1	4.1	4.1
Renewable Energy	7.7	8.4	7.4	7.9	7.7	8.6
Electricity Imports	0.3	0.3	0.3	0.3	0.3	0.3
Others	0.2	0.2	0.1	0.2	0.2	0.2
Total	118.6	117.2	99.5	118.2	118.3	117.6
Macroeconomic Indicators						
GDP (billion 1996$)	12013	11989	12088	12012	12005	12008
Real Consumption	8405	8380	8475	8405	8400	8402
Real Investment	2320	2316	2341	2320	2317	2318
Real Government Spending	1807	1802	1818	1806	1806	1807
Real Exports	3694	3673	3736	3693	3693	3695
Real Imports	4577	4506	4727	4575	4577	4583
Unemployment Rate (%)	5.7	5.6	5.6	5.7	5.7	5.7
Energy Bill (billion 1996$)	684	727	459	685	691	678
Energy/GDP Ratio (kBtu/1996$)	9.9	9.8	8.2	9.8	9.9	9.8
Carbon/GDP Ratio (g/1996$)	163	159	132	162	163	159

Table D-2: LBNL-NEMS High-Efficiency/Low Carbon Cases
All-Sector Forecast Summary 2020

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	AEO98 Ref Case	LBNL-NEMS CC-Hieff Case	LBNL-NEMS HE-Ret Case	LBNL-NEMS CC-Ret Case	LBNL-NEMS HELC Case	LBNL-NEMS HELC Case	LBNL-NEMS HELC Case	LBNL-NEMS HELC Case	LBNL-NEMS HELC Case
demand side efficiency measures	-	hieff	hieff	-	hieff	hieff	hieff	hieff	hieff
carbon charge ($/tC)	-	23	-	23	23	23	23	23	50
coal retirements (GW)	-	-	16	16	-	16	-	16	16
natural gas and oil retirements (GW)	-	-	100	100	-	0	100	100	100
supply-side improvements	-	-	-	-	cf/cg/hy/wd	cf/cg/hy/wd	cf/cg/hy/wd	cf/cg/hy/wd	cf/cg/hy/wd
	2020	2020	2020	2020	2020	2020	2020	2020	2020
Primary Energy (Quadrillion Btu)									
Residential	23.2	21.2	21.4	22.6	21.2	21.1	21.0	20.9	20.4
Commercial	17.4	15.2	15.2	16.9	15.1	15.0	15.0	14.9	14.7
Industrial	41.6	34.4	34.4	41.0	33.7	33.6	33.6	33.5	33.2
Transportation	36.5	27.4	27.7	36.1	27.3	27.3	27.3	27.3	27.0
Total	118.6	98.2	98.7	116.6	97.3	97.1	96.9	96.6	95.2
Electricity Sales (TWh)									
Residential	1548	1322	1334	1527	1323	1323	1322	1322	1306
Commercial	1304	1080	1089	1281	1082	1082	1083	1082	1072
Industrial	1392	1089	1058	1411	975	978	979	978	998
Transportation	64	78	79	63	78	78	78	78	78
Total	4308	3570	3560	4282	3459	3461	3462	3461	3454
Carbon Emissions by Sector (Mt)									
Residential	379	331	338	361	323	320	319	315	299
Commercial	296	247	250	281	240	237	237	233	223
Industrial	589	467	472	570	447	446	444	442	430
Transportation	692	519	525	684	518	518	517	517	510
Total	1956	1564	1585	1897	1527	1520	1517	1508	1461
Utilities	745	590	594	708	549	541	539	529	501
Carbon Emissions by Source (Mt)									
Petroleum	822	626	635	806	624	624	622	622	614
Natural Gas	474	428	415	485	419	422	422	423	431
Coal	658	509	534	604	484	473	471	461	415
Other	3	2	2	3	2	2	2	2	2
Total	1956	1564	1585	1897	1527	1520	1517	1508	1461
Average Energy Prices to All Users (96$/MBtu)									
Petroleum Products	8.12	6.64	6.27	8.41	6.65	6.64	6.64	6.64	7.02
Natural Gas	3.86	3.35	2.86	4.50	3.25	3.27	3.33	3.28	3.85
Coal	1.00	1.56	0.96	1.57	1.56	1.55	1.54	1.53	2.22
Electricity	16.01	16.50	15.16	18.33	16.42	16.44	16.38	16.41	18.13
Average Energy Price to Elec Gen (96$/MBtu)									
Fossil Fuel Average	1.66	1.92	1.29	2.37	1.85	1.87	1.87	1.86	2.58
Petroelum Products	4.21	4.03	4.15	5.37	4.16	4.16	4.62	4.62	5.18
Distillate Fuel	5.64	4.88	4.43	5.97	4.88	4.86	4.88	4.89	5.42
Residual Fuel	3.77	3.71	3.95	4.84	3.85	3.86	4.42	4.42	5.00
Natural Gas	3.15	2.68	2.11	3.95	2.53	2.56	2.62	2.56	3.19
Steam Coal	0.97	1.53	0.93	1.54	1.53	1.52	1.50	1.50	2.19
Energy Consumption (Quadrillion Btu)									
Petroleum Subtotal	47.6	36.6	37.2	46.8	36.5	36.5	36.4	36.5	36.0
Natural Gas	33.1	29.9	29.0	33.9	29.2	29.4	29.5	29.5	30.1
Coal Subtotal	25.6	19.9	20.8	23.6	18.9	18.5	18.4	18.0	16.3
Nuclear Power	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1
Renewable Energy	7.7	7.4	7.3	7.8	8.2	8.1	8.1	8.2	8.4
Electricity Imports	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Others	0.2	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.1
Total	118.6	98.2	98.7	116.6	97.3	97.1	96.9	96.6	95.2
Macroeconomic Indicators									
GDP (billion 1996$)	12013	12057	12085	11980	12060	12059	12058	12059	12023
Real Consumption	8405	8445	8474	8374	8448	8448	8446	8448	8412
Real Investment	2320	2334	2340	2313	2335	2334	2334	2334	2327
Real Government Spending	1807	1813	1818	1801	1813	1813	1813	1813	1806
Real Exports	3694	3715	3736	3671	3717	3717	3716	3717	3692
Real Imports	4577	4653	4729	4498	4659	4660	4659	4660	4569
Unemployment Rate (%)	5.7	5.6	5.6	5.7	5.6	5.6	5.6	5.6	5.6
Energy Bill (billion 1996$)	684	499	460	739	491	491	491	491	532
Energy/GDP Ratio (kBtu/1996$)	9.9	8.1	8.2	9.7	8.1	8.0	8.0	8.0	7.9
Carbon/GDP Ratio (g/1996$)	163	130	131	158	127	126	126	125	122

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

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

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

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

	AEO98 Reference Case	23 $/t Carbon Charge Case	50 $/t Carbon Charge Case	High Efficiency Case	HELC Case (23 $/tC)	HELC Case (50 $/tC)
conversion factor (kWhprimary/kWhsite)	3.04	3.01	2.98	3.11	2.96	2.93