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Scenarios for a clean energy future[☆]

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Abstract

This paper summarizes the results of a study—Scenarios for a Clean Energy Future—that assess how energy-efficient and clean energy technologies can address key energy and environmental challenges facing the US. A particular focus of this study is the energy, environmental, and economic impacts of different public policies and programs. Hundreds of technologies and approximately 50 policies are analyzed. The study concludes that policies exist that can significantly reduce oil dependence, air pollution, carbon emissions, and inefficiencies in energy production and end-use systems at essentially no net cost to the US economy. The most advanced scenario finds that by the year 2010, the US could bring its carbon dioxide emissions three-quarters of the way back to 1990 levels. The study also concludes that over time energy bill savings in these scenarios can pay for the investments needed to achieve these reductions in energy use and associated greenhouse gas emissions. © 2001 Elsevier Science Ltd. All rights reserved.

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1. Background

A number of major energy-related challenges face the US as it moves into the 21st century. US dependence on imported oil is growing, increasing the nation's vulnerability to supply and price disruptions. Electricity outages, power disturbances, and price spikes threaten US productivity, especially in the rapidly growing information-based service industries. Despite ongoing improvements in air quality, air pollution from burning hydrocarbons continues to cause high levels of respiratory illnesses, acid rain, and photochemical smog. Global climate change threatens to impose significant long-term costs from increasing temperatures, rising sea levels, and more extreme weather. The prosperity and well-being of future generations will be strongly affected by the manner in which the nation responds to these challenges.

Building upon a 1997 study, *Scenarios of US Carbon Reductions,* the US Department of Energy (DOE) commissioned an analysis of the potential for public policies and programs to foster efficient and clean energy technology solutions to these energy-related challenges. The earlier report, also known as the Five-Lab study (Interlaboratory Working Group, 1997), identified a portfolio of technologies that could reduce carbon emissions in the US to their 1990 levels by the year 2010. The follow-on study, the *Scenarios for a Clean Energy Future* (CEF) study identifies specific policies and programs that could motivate consumers and

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businesses to purchase such technologies (Interlaboratory Working Group, 2000). Thus, the CEF study responds to a recommendation by the President's Committee of Advisers on Science and Technology (PCAST), Panel on Energy Research and Development (1997), that the nation identify and adopt a commercialization strategy to complement its national energy R&D portfolio.

The Five-Lab study did not conduct a cross-sector, integrating analysis and was therefore unable to assess the full range of effects of its technology scenarios on the US economy. This limitation was addressed in a subsequent peer-reviewed report sponsored by the US Environmental Protection Agency (Koomey et al., 1998). A similar integrating analytical framework is used in the CEF study, which allows the effects of changes in energy use in each sector to be taken into account in the energy use patterns of the other sectors.

Other studies have used similar engineering-economic (i.e., "bottoms up") methodologies to assess carbon mitigation opportunities in the US. Many of these are described and compared with one another in Brown et al. (1998).

2. The policy scenarios

A scenario-based approach is used in the CEF study. The structured development of energy scenarios allows a range of public policies to be examined within the context of alternative assumptions about the future. Scenarios are stories—not predictions or recommendations—about how the future might unfold. They are useful for organizing scientific insight, gauging emerging trends, and considering alternatives.

The CEF study develops three primary scenarios: a business-as-usual (BAU) forecast and two alternative policy cases called the Moderate and Advanced scenarios. The BAU scenario assumes a continuation of current energy policies and a steady, but modest pace of technological progress. In contrast, the Moderate and Advanced scenarios are defined by policies that are consistent with increasing levels of public commitment and political resolve to solve the nation's energy-related challenges. Some of the public policies and programs that define the scenarios are cross-cutting; others are designed individually for each sector (buildings, industry, transportation, and electric generation). All of the scenarios are assessed for impacts through the year 2020.

The selection of policies began with a sector-by-sector assessment of market failures and institutional barriers to the market penetration of clean energy technologies in the US. These barriers are described in a separate article by Brown (2001) that is published in this same issue of *Energy Policy*. Numerous policies were chosen for examination. The final selection of policies was determined through discussions with representatives of business, universities, non-profit organizations and government to provide a broad range of opinions. This range gives decision-makers and the public an opportunity to study the advantages and disadvantages of different policy choices.

The policies that define the CEF scenarios include fiscal incentives, voluntary programs, regulations, and research and development. Many of the policies were selected on the basis of their potential to reduce carbon dioxide emissions. Others were designed specifically for air quality (e.g., reducing SO_2 emissions in the electric sector), oil security (e.g., alternative fuels research), and economic efficiency (e.g., restructuring of the electric sector). Regardless of the driving force behind them, almost all reduce carbon dioxide emissions and improve air quality. Policies are generally stronger in the Advanced than in the Moderate scenario, with larger expenditures on public-private RD&D partnerships, stricter standards, higher tax incentives, and greater government investment in programs promoting efficient and clean energy technologies. Some policies are assumed to begin in 2000; others are assumed to begin in subsequent years. Their impacts tend to be gradual, as stock turnover and other factors dampen initial responses.

The policies identified as most important in the Advanced scenario are summarized in Table 1. The sector-specific policies are described in greater detail in other papers in this special volume of Energy Policy: for the buildings sector see Koomey et al. (2001a), for industry see Worrell and Price (2001), for transportation see Greene and Plotkin (2001), and for the electricity sector see Hadley and Short (2001).

For buildings, the policies and programs include additional appliance efficiency standards; expansion of technical assistance and technology deployment programs; and an increased number of building codes and efficiency standards for equipment and appliances. They also include tax credits consistent with the Clinton Administration's 1999 Climate Change Technology Initiative (CCTI); strengthening of market transformation programs such as Rebuild America and Energy Star labeling; and related public benefits programs financed by electricity line charges.

For industry, the policies include voluntary agreements with industry groups to achieve defined energy efficiency and emissions goals, combined with a variety of government programs that strongly support such agreements. These programs include expansion and strengthening of existing information programs, financial incentives, and energy efficiency standards on motors systems. Policies are defined to encourage the

Table 1
Key policies in the advanced scenario[a]

Buildings	*Industry*
Efficiency standards for equipment	Voluntary programs
Voluntary labeling and deployment programs	Voluntary agreements with individual industries and trade associations
Transportation	*Electric generators*
Voluntary fuel economy agreements with auto manufacturers[b]	Renewable energy portfolio standards and production tax credits
"Pay-at-the-pump" auto insurance	Electric industry restructuring
Cross-sector policies	
Doubled federal research and development	Domestic carbon trading system

[a] Each policy is specified in terms of magnitude and timing. For instance, "Efficiency standards for equipment" comprise 16 new equipment standards introduced in various years with specific levels of minimum efficiencies.

[b] These voluntary agreements, because they are met in the Advanced scenario, would have the same effect as a corporate average fuel economy (CAFE) standard of the same level.

diffusion and improve the implementation of combined heat and power (CHP) in the industrial sector.

For transportation, the policies include a combination of financial incentives for efficient automobiles ("golden carrots"), several government programs, and voluntary energy efficiency targets for light-duty vehicles. The pay-at-the-pump automobile insurance program involves paying for a portion of automobile insurance by means of an added fee to gasoline, thereby "variabilizing" the cost of insurance to reflect miles traveled and the fuel economy of one's vehicle. Thus, the increase in the price of gasoline is somewhat offset by lower insurance premiums (depending on how much one travels).

For electricity, the policies include extending the production tax credit of 1.5¢/kWh over more years and extending it to additional renewable technologies, setting stricter standards, and facilitating the deployment of wind energy. The scenarios also include net metering capped at 1% in the Moderate scenario and 5% in the Advanced scenario. This policy allows on-site generation that exceeds site loads to be sold back to the grid at retail electricity prices. Net metering creates incentives for distributed generation that can have environmental and reliability benefits through higher efficiencies and reduced transmission and distribution requirements.

Two key policies in the Advanced scenario for all of the sectors are the domestic carbon trading system and increased R&D resources.

- *Domestic carbon trading system.* Emissions trading programs work by allocating allowances that permit the release of limited quantities of emissions during a specified period (e.g., annually). They allow sources to comply with the cap by reducing emissions or purchasing permits from other sources that can reduce emissions at lower cost. A firm's response will depend on its costs of control compared with the market price of carbon permits. We assume that the domestic carbon trading program is announced in 2002 and is implemented in 2005.[1] Each year, beginning in 2005, permits are sold in a competitive auction run by the federal government. The carbon emissions limit is set so that the permit price equilibrates at $50/tC (in 1997$) throughout the study period.[2] (A $25/tC case is also analyzed.) The federal government collects the carbon permit revenues and transfers them back to the public. The goal of the carbon permit rebate is to leave people's "incomes" intact while changing the relative price of carbon-based fuels.
- *Increased R&D resources.* The Moderate scenario assumes a 50% increase in federal government appropriations for cost-shared research, development, and demonstration (RD&D) in efficient and clean-energy technologies. The increase is based on an assumed baseline of $1.4 billion in current federal energy R&D. This baseline, and the assumed increase includes research on energy efficient end-use technologies as well as power generation technologies using renewable resources, natural gas, coal, and nuclear energy.[3] Since these resources are spent in public/private RD&D partnerships, they are matched by private-sector funds. The increase is assumed to be implemented gradually between 2000 and 2005, and to continue through 2020. The Advanced scenario assumes that the federal government doubles its appropriations for cost-shared RD&D, resulting in

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[1] To model the effect of announcing a carbon trading system in 2002, we assume that the market operates as though there were a gradually increasing increment to the cost of carbon-based fuels. The increase is based on the addition of $12/tC beginning in 2002, rising to $25/tC in 2003, $37/tC in 2004, and $50/tC in 2005. This modeling approach is equivalent to assuming that a domestic carbon trading program is implemented in 2002 with a carbon emissions limit that is increasingly constraining over the four-year period, causing carbon permit values to rise to $50/tC in 2005.

[2] $50 per tonne of carbon corresponds to 12.5 cents per gallon of gasoline or 0.5 cents per kWh for electricity produced from natural gas at 53% efficiency (or 1.3 cents per kWh for coal at 34% efficiency). $25/tC corresponds to half these incremental costs.

[3] The estimate of current federal energy R&D is based on a 1997 report by the President's Committee of Advisors on Science and Technology (PCAST, 1997), entitled "Federal Energy Research and Development for the Challenges of the Twenty-First Century". This PCAST report recommended that the United States double its federal energy R&D expenditures by the year 2003. EPRI (1999) recommends a 150% increase (i.e., more than doubling) of US electricity-related R&D in order to resolve the energy–carbon conflict and achieve other energy-related goals.

an increase of $2.8 billion per year (half as federal appropriations and half as private-sector cost share). Both scenarios assume a careful targeting of funds to critical research areas and a gradual, 5-year ramp-up of funds to allow for careful planning, assembly of research teams, and expansion of existing teams and facilities.

Several of the policies in the CEF scenarios are coupled to produce significant positive synergies. For instance, research prepares clean energy technologies to respond to opportunities created by incentives and to meet subsequent codes and standards. Efficiency gains from policies directed at the buildings and industrial sectors prevent or temper price increases from rising natural gas demand in the power sector, which results from policies such as the domestic carbon trading system. At the same time, some policies compete with one another. For example, policies that strengthen the performance of energy-efficient technologies foreclose the rapid penetration of many clean energy supply options in the 2020 timeframe, despite the inclusion of policies intended to promote them, since less energy supply is needed.

The policy set examined here is not exhaustive. Some potentially complementary policies are not included because of modeling difficulties (e.g., in the case of policies that target the improved performance of roofs, walls, windows, and foundations in existing buildings). In other cases, policies included in the CEF study are less stringent than the policies modeled in other studies. Examples include the higher levels of efficiency for appliances and the larger annual reductions in energy intensity for industrial plants specified by Geller et al. (1999). Policies aimed at reducing vehicle miles of travel (vmt) were not included, because the BAU forecast already includes a vmt growth rate that our reviews indicated are unrealistically low (see Southworth, 2001, for a review of this literature and policies to reduce vmt). Finally, numerous policies examined in other studies are omitted, because they were considered to exceed the levels of action or cost that were used as guidelines to define the Moderate and Advanced scenarios. Examples of policies not included are:

- *Buildings:* mandate the demand-side management programs run by electric utility companies in the 1980s and first half of the 1990s, which were responsible for a substantial fraction of the energy efficiency improvements already realized in the buildings sector.
- *Industry:* establish tax incentives for new capital investments in energy equipment to accelerate the rate at which technological innovation diffuses into industries, thereby more quickly retiring outmoded and inefficient production equipment and facilities.
- *Transportation:* enact greenhouse gas standards for motor fuels that would be specified as a limit on the average greenhouse gas emissions factor of all motor fuels.
- *Electricity:* require all coal-fired power plants to meet the same emissions standards as new plants under the Clean Air Act, thereby removing the "grandfathering" clause that has allowed higher polluting, older coal-fired plants to continue to operate unabated.

Clearly, inclusion of such policies would result in accelerated progress toward meeting US energy and environmental goals.

3. Methodology

This study uses various assessment methods, analytic tools, and expert judgments to analyze the impacts of individual policies. The CEF-NEMS model—based on the Energy Information Administration's (EIA) National Energy Modeling System (NEMS)—is then employed to quantitatively integrate the impacts of each scenario's policies. The integration step of CEF-NEMS allows the estimated effects of changes in energy use in each sector to be considered in the resultant energy use patterns of the other sectors. The CEF-NEMS also assesses additional changes in energy demand where new policies or technologies affect energy prices. The report uses a framework for analyzing direct costs and benefits that was developed for the Five-Lab study and for Koomey et al., 1998. Macroeconomic impacts and feedback are separately assessed through an analysis of previously published modeling results (see Sanstad et al., 2001).

The EIA's Reference case from the *Annual Energy Outlook 1999* (the most recent available from the EIA at the time of this analysis) is used as the starting point for the BAU forecast. Thus the EIA's Reference case assumptions on fossil fuel supplies, world oil prices, energy transport, end-use service demands, and macroeconomic growth underlie the three CEF scenarios.[4]

The BAU forecast and the EIA Reference case differ only slightly. The BAU forecast uses different base year values and stock turnover rates for several industries, which result in a lower rate of growth of energy use. This is the principal cause of the CEF BAU forecast having ~0.5% lower total energy use in 2010 and 2020 than the

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[4] While these reference case assumptions differ slightly from those used in the *Annual Energy Outlook 2000*, the overall conclusions of the CEF study would be similar if these more recent assumptions were used.

EIA Reference case. Carbon emissions in the BAU forecast are almost 1% less in 2010 and are 3% less in 2020 than in the EIA Reference case, primarily because the BAU assumes lower nuclear power relicensing costs.

To capture the policies of the Moderate and Advanced scenarios, CEF-NEMS inputs (such as technology and process characterizations, stock turnover rates, consumer discount rates, and fuel prices) are changed from the BAU forecast. Translation of these policies into the inputs required by CEF-NEMS was conducted through off-line analysis, reference to past studies, expert judgment, and outside review. This process enabled quantitative estimates of the impacts of key voluntary policies such as appliance labeling and energy audit programs.

As an engineering economic study, the CEF analysis is unable to incorporate the full impact of market-wide behavioral responses to policies. Therefore, the final estimates of costs and benefits should be considered the costs and benefits of the technology and policy implementation, not of the comprehensive impacts of these policies. For example, although the technical analysis was based on comparing products with similar characteristics (e.g., automobiles of the same expected size), technology improvements can change the mix of products and features demanded by consumers. These potential changes are not reflected in this study. Likewise, potential feedbacks from any technology or policy-induced shifts in sector output on energy use are not reflected in this analysis.

4. Results

Key findings of this study are presented in Table 2 for the BAU forecast and for the Moderate and Advanced scenarios. Results are also shown for one of the numerous alternative policy sets that are examined—in this case, the Advanced scenario with a domestic carbon trading system that equilibrates at an allowance price of $25/tC. Dozens of alternative policies were analyzed to reflect the unpredictable nature of political and consumer views and to highlight the diversity of policy options (see Koomey et al., 2001a). The presentation of results with three or more significant figures here and throughout this report is not intended to imply high precision, but rather is designed to facilitate comparison among the scenarios and to allow the reader to better track the results. An uncertainty range for each value would be preferred to our single-point estimates, but the analysis required to prepare such ranges was not possible given the available resources and the process described above.

4.1. Energy use

The Moderate and Advanced scenarios produce reductions in energy use as a result of the many CEF policies that are directed at the adoption of energy-efficient technologies. Efficiency standards play a major role in reducing energy demand in the buildings sector. Voluntary agreements with industries and voluntary labeling and deployment programs are also key to the substantial demand reductions of these scenarios. Such

Table 2
Selected results for 2010 and 2020[a]

			2010 Scenarios			
	1990	1997	BAU forecast	Moderate	Advanced ($25/tC)	Advanced ($50/tC)
US primary energy use in quadrillion Btu	84.2	94.0	110.4	106.5	101.0	99.3
(Percent change from BAU)	—	—	—	(−4%)	(−9%)	(−10%)
US energy Bill						
in billion 1997$	516	552	651	595	598	634[b]
(Percent change from BAU)	—	—	—	(−9%)	(−8%)	(−3%)
US carbon emissions in million metric tons	1346	1480	1769	1684	1539	1463
(Percent change from BAU)	—	—	—	(−5%)	(−13%)	(−17%)
			2020 Scenarios			
US primary energy use in quadrillion Btu	84.2	94.0	119.8	110.1	98.8	96.8
(Percent change from BAU)	—	—	—	(−8%)	(−18%)	(−19%)
US energy bill in billion 1997$	516	552	694	594	541	572a
(Percent change from BAU)	—	—	—	(−14%)	(−22%)	(−18%)
US carbon emissions in million metric tons	1346	1480	1922	1740	1472	1347
(Percent change from BAU)	—	—	—	(−9%)	(−23%)	(−30%)

[a] A number of key technologies were not modeled within the CEF-NEMS framework, including combined heat and power (CHP), solar domestic

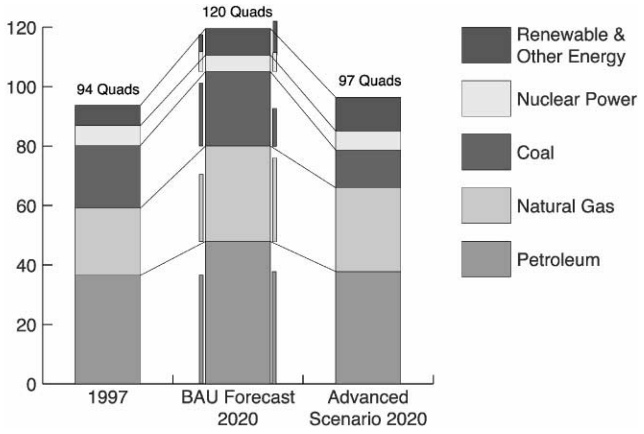

Fig. 1. Energy consumption by source.

efficiency improvements are generally most economic when it is time to replace existing equipment; they therefore take time to materialize.

In the Advanced scenario, the nation consumes 20% less energy in 2020 than it is predicted to require in the BAU forecast (Fig. 1). These savings of 23 quadrillion Btu (quads) are equal to almost one-quarter of the nation's current energy use. They are enough to meet the current energy needs of all the citizens, businesses, and industries located in the top three energy consuming states (Texas, California, and Ohio) or the combined current energy needs of the 30 lowest consuming states.

Accelerated technology improvements from expanded RD&D contribute significantly to energy savings in every sector of the economy. For example, in buildings, by 2005 research produces a 20-W mini-HID with an electronic ballast that has the same brightness as a 100-W incandescent lamp and an incremental cost of $7.50. In the steel industry, the development of near net shape casting technologies saves up to 4 MBtu/ton steel and reduces production costs between $20 and $40/ton. In the transportation sector, research is estimated to drive down the cost of a hydrogen fuel cell system to an increment of $1540 more than a comparable gasoline vehicle in 2020.

Energy use reductions in the Advanced scenario are more than twice those of the Moderate scenario because of two types of policy changes. First, the policies of the Moderate scenario have been strengthened in the Advanced scenario. For example, RD&D has been further expanded, voluntary programs are broadened, and performance standards in the buildings sector have been applied to more end uses. Secondly, additional policies are applied in the Advanced scenario, including domestic carbon trading, voluntary agreements to improve the fuel economy of light-duty vehicles, and pay-at-the-pump automobile insurance.

Table 3 shows the energy consumption by fuel type for the BAU, Moderate, and Advanced scenarios. Several observations are notable.

First, fossil fuel consumption is reduced in both the Moderate and Advanced scenarios, compared with the BAU scenario, while a higher proportion of nuclear power is retained and renewable energy grows more rapidly. However, the magnitude and composition of these trends differ across the two policy scenarios. For example, coal consumption is impacted much less in the Moderate than in the Advanced scenario. In the Moderate scenario, coal consumption continues to increase through 2020. Relative to the BAU forecast, coal consumption declines by about the same magnitude as natural gas and petroleum in both 2010 and 2020—on the order of 5–8% from 1997 levels. In contrast, in the Advanced scenario with a $50/tonne carbon permit price, coal use declines to 77% of 1997 consumption in 2010 and 60% of 1997 consumption by 2020. Even with the significant decline in coal consumption in the Advanced scenario, the growth in demand for natural gas is lower than in the BAU forecast. This is because of the increased energy savings from efficiency investments, the increased use of renewable energy, and the maintenance of nuclear power.

The use of renewable energy sources increases above BAU by 10% in the Moderate scenario and by 31% and 27% in the Advanced scenario for 2010 and 2020, respectively. In 2020, non-hydro renewables double from 2.3 quads in the BAU scenario to 4.6 quads in the Advanced scenario. Such contributions, consistent with cost projections for renewables in this time period, are especially notable for their long-term role. This analysis suggests that the 20-year CEF scenario horizon could see the beginning of a significant growth in renewables.

Another implication of the fuel use results is that growth in petroleum consumption slows in both the Moderate and Advanced scenarios (by 9–21% in 2020 compared with BAU). Nuclear power retirements continue in all cases, but at much lower rates in the Advanced scenario than in BAU (6.4 quads of nuclear power consumed in 2020, compared with 5.6 quads in BAU).

The off-line analysis of combined heat and power (CHP) policies suggests that increased CHP in industry would result in the following adjustments to the scenario results. It would increase natural gas consumption, decrease petroleum-based industrial boiler fuels, decrease coal in both the electricity and industrial sectors, and slow the growth of wind and biopower, especially in the Advanced scenario in 2020.

Table 3

(a) Energy consumption by sector (quadrillion Btu)[a,b]

			2010			2020		
	1990	1997	BAU	Mod.	Adv.	BAU	Mod.	Adv.
Residential	16.3	19.0	21.2	20.4 (−4%)	19.3 (−9%)	23.2	21.1 (−9%)	18.3 (−20%)
Commercial	13.1	15.2	17.3	16.7 (−3%)	15.9 (−9%)	18.5	17.0 (−9%)	15.4 (−18%)
Industrial	32.2	34.8	38.8	37.2 (−4%)	34.7 (−11%)	41.2	38.0 (−8%)	34.3 (−17%)
Transportation	22.6	25.0	33.1	32.2 (−3%)	29.8 (−10%)	36.8	34.1 (−7%)	28.9 (−21%)
Total	84.2	94.0	110.3	106.5 (−4%)	99.5 (−10%)	119.8	110.3 (−8%)	97.0 (−19%)
Electric generators[c]	30.1	34.2	39.3	37.5 (−5%)	34.6 (−12%)	42.9	38.4 (−10%)	32.6 (−24%)

(b) Energy consumption by source (quadrillion Btu)[d]

			2010			2020		
Petroleum	33.6	36.5	44.1	42.5 (−4%)	39.7 (−10%)	47.9	43.7 (−9%)	37.8 (−21%)
Natural gas	19.3	22.6	28.3	26.1 (−8%)	26.2 (−7%)	32.1	28.1 (−12%)	28.2 (−12%)
Coal	19.1	21.1	23.7	22.6 (−5%)	16.3 (−31%)	25.0	23.0 (-8%)	12.7 (−49%)
Nuclear power	6.2	6.7	6.2	6.2 (0%)	6.7 (8%)	5.6	4.9 (−13%)	6.4 (14%)
Renewable energy	6.2	6.8	7.8	8.6 (10%)	10.2 (31%)	8.9	9.9 (11%)	11.3 (27%)
Other[e]	0.3	0.3	0.4	0.5 (25%)	0.4 (0%)	0.4	0.6 (50%)	0.6 (50%)
Total	84.1	94.0	110.5	106.5 (−4%)	99.5 (−10%)	119.8	110.3 (−8%)	97.0 (−19%)

[a] Notes: BAU = Business-As-Usual; Mod. = Moderate; Adv. = Advanced. Numbers in parentheses represent the percentage change compared with BAU. Source for 1990 electric generators data: Energy Information Administration (1990), Table 3a, p. 44. Source for other 1990 data and 1997 data: Energy Information Administration (1998a), Table 3b, p. 141.

[b] An off-line analysis suggests that policies tackling barriers to CHP in industry could reduce energy consumption by an additional 0.3 quads in the Moderate scenario in 2010 and by an additional 0.5 quads in 2020. The energy saved by new CHP systems in the Advanced case are estimated to be considerably larger: 1.1 quads in 2010 and 2.4 quads in 2020.

[c] The primary energy consumed by electric generators is distributed across consumption sectors and therefore is fully included in the row labeled "Total".

[d] Note: BAU = business-as-usual; Mod. = Moderate; Adv. = Advanced. Numbers in parentheses represent the percentage change compared with BAU.

[e] Other sources include methanol and liquid hydrogen.

4.2. Carbon emissions[5]

By 2020, carbon emissions in the Advanced scenario are 30–32% lower than in the BAU forecast. These emission reductions are nearly three times those of the Moderate scenario (Figs. 2 and 3). This much stronger performance of the Advanced scenario results from the focus of many of its policies on the use of low-carbon energy resources.

The electric sector in particular experiences a strong shift to low-carbon fuels. The policies that drive this conversion include domestic carbon trading, expansion of the production tax credit for renewables, restrictions on emissions of particulate matter, and restructuring of the electricity industry that allows cost-effective options to be introduced more quickly. These Advanced scenario policies produce a 47% reduction in carbon emissions in the electric sector by 2020. The largest portion of these electric sector reductions comes from the repowering or replacement of coal-fired power plants by natural gas-fired

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[5] Greenhouse gases include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and a host of engineered chemicals such as sulfur hexafluoride (SF_6), hydro-fluorocarbons (HFCs), and perflorocarbons (PFCs). It is convenient to refer to greenhouse gas emissions in terms of their carbon equivalent and the reduction of greenhouse gases as a reduction in carbon emissions. We follow this convention here.

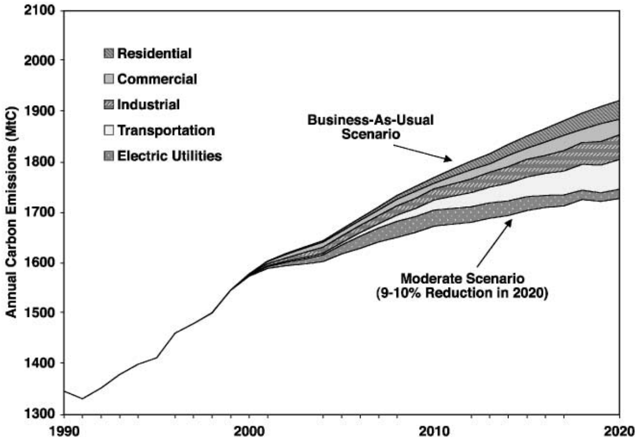

Fig. 2. Carbon emission reductions, by sector, in the Moderate scenario.

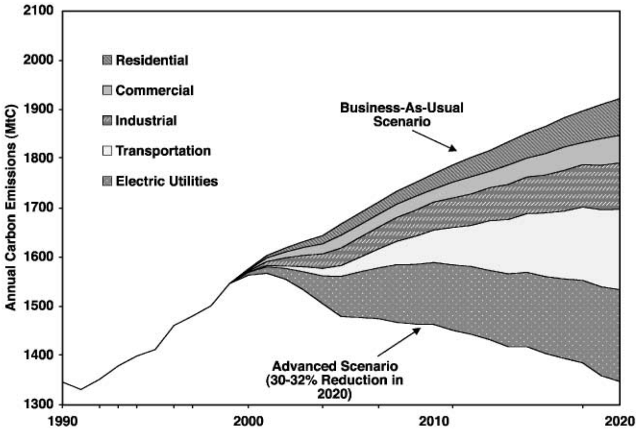

Fig. 3. Carbon emission reductions, by sector, in the Advanced scenario.

power generation as well as wind, biomass, and geothermal power. The off-line analysis of combined heat and power in industry suggests the potential to reduce carbon dioxide emissions by an additional 40 MtC in 2020.

Overall, the Moderate scenario brings CO_2 emissions 20% of the way back to 1990 levels by 2010; the Advanced scenario with a carbon permit value of \$25/tC brings them 54% of the way down; and the Advanced scenario at \$50/tC closes 72% of the gap. (This is increased to 78% when the results of the off-line analysis of combined heat and power policies are included.) In the context of the US Kyoto Protocol goal of reducing greenhouse gas emissions to 7% below 1990 levels by 2010, the CEF policies would need to be supplemented by other means such as international carbon trading, reductions in other greenhouse gases, and stronger domestic policies. In the Advanced scenario, carbon emissions drop fully to 1990 levels by the year 2020.

4.3. Key policies and technologies

The value of different types of policies and programs depends upon the sector-specific market and organizational barriers that inhibit the full implementation of cost-effective technologies.

4.3.1. Buildings

The largest energy and carbon savings in residential buildings are due to improvements in "miscellaneous" electric uses including cooking, clothes dryers, clothes washers, dishwashers, color TVs, and personal computers. A large fraction of these savings comes from movement toward a "1-W" standby loss goal by 2010, based on the switch-mode power supplies that are now widely used in the best new equipment. Next in rank order are space cooling, space heating, water heating, and lighting.

In commercial buildings, lighting and "miscellaneous" end-uses dominate the energy and carbon savings. "Miscellaneous uses" include a collection of small end-uses such as ventilation, cooking, and refrigeration. Space cooling and heating and office equipment are next in importance.

Minimum equipment efficiency standards and voluntary programs are the two most important contributors to energy savings; building codes, tax credits, other incentive programs, and R&D generally play a supporting role. In residential heating and cooling end-uses, building codes take on a larger role. For electronics end-uses, where rapid technological innovation and the proven success of voluntary efforts hold sway, the voluntary programs capture most of the savings.

4.3.2. Industry

Energy is saved in all industrial subsectors under both the Moderate and Advanced scenarios. Continuing intra- and inter-sectoral shifts, as well as ongoing efforts to reduce environmental impacts and improve energy efficiency, contribute to the savings within the industrial sector. Decarbonization of the power sector contributes to carbon savings, especially in electricity-intensive industrial subsectors.

Voluntary agreements between government and industry are the key policy mechanism for achieving these savings. These voluntary agreements are supported by information programs, technology demonstrations, energy efficiency audit programs, financial incentives, and funding for R&D.

The energy-efficiency improvements across scenarios are attributed to increased awareness among plant and company management of opportunities to cut energy costs, as well as strengthened programs to assist in implementing technologies and measures to reduce carbon emissions.

A number of cross-cutting technologies—such as combined heat and power, waste recycling, process control and management, steam distribution system upgrades, improved energy recovery, motor and drive system improvements, and preventive maintenance—contribute significantly to the savings in the policy scenarios. Much of the efficiency improvement results from replacing old process equipment with state-of-the-art equipment instead of new equipment of average efficiency as components and plants are retired. Energy savings in the steel, cement, and aluminum industry are also influenced by the increased use of waste materials. Large improvements in the generation, distribution, and use of steam contribute to savings in the food, paper, and chemical industries.

The CEF policy scenarios accelerate the development and implementation of these practices and technologies, increasing energy efficiency beyond that assumed in the BAU scenario. In the steel industry, new technologies such as scrap preheating for electric arc furnaces are more efficient than the technologies used in existing plants, and new casting technologies reduce material and energy losses further. New advanced smelting reduction technologies lead to significant savings after 2010 in the Advanced scenario. In the pulp and paper industry, improved paper machines as well as reduced bleaching and increased wastepaper recycling impact energy use, and black liquor gasification substantially changes the energy profile of pulping in the long term. In cement making, the key technologies and measures are the introduction of blended cements and the gradual retirement of old wet-process clinker plants, which are replaced by modern pre-heater pre-calciner kilns. While some of these technologies are currently available or being developed, there is still a large potential for further development or deployment.

4.3.3. Transportation

The rate at which carbon emissions from transport can be reduced is limited by the lack of opportunities for retrofitting technologies, together with constraints on the quantities of low-carbon fuels, such as cellulosic ethanol, that can be supplied over the next 10 to 20 years. As a result, the impacts of policies and technologies in 2010 are far less than their impacts in 2020. Indeed, the maximum impacts of advanced technologies are yet to be realized even in 2020.

In the Moderate scenario, a combination of several conventional technologies and the turbo-charged direct injection (TDI) diesel have the greatest impact on passenger car and light-truck fuel economy. Even with incentives of up to $4000 per vehicle, advanced alternative technologies appear to be unable to overcome the market barriers of higher initial cost (especially at low production volumes) and, in the case of alternative-fuel vehicles, limited fuel availability. Encouraged by continuing, though decreasing, tax subsidies, cellulosic ethanol is a key technology for reducing carbon emissions, because it can be readily integrated into existing fuel systems via blending with gasoline. Similarly, modest gains are achieved in the Moderate scenario in non-highway modes of transport.

The key distinguishing features of the Advanced scenario are

- the greater degree of technological success, attributed to a doubling of R&D investment;
- a voluntary commitment to improved efficiency by vehicle manufacturers that accelerates the introduction of technology and, for cars and light trucks, deemphasizes vehicle weight and horsepower; and
- significant fuel price signals for highway vehicles in the form of pay-at-the-pump insurance fees and a modest carbon permit price.

The combined effect of these measures is an array of impressive new technologies in large numbers. TDI diesels play a major role in the light-duty vehicle market, with sales exceeding 1 million after 2005 and standing at 2.6 million per year in 2020. In the same year, 2.2 million fuel cell vehicles are sold, representing 10% of the new light-duty vehicle market. Hydrogen fuel cell vehicles are the most successful, accounting for 1.0 million of the 2.2 million total sales in 2020. In 2020, 3.9 million hydrogen fuel cell vehicles are on the road consuming 0.1 quads of hydrogen annually. Advanced technologies also improve fuel economy significantly in non-highway transport.

Energy efficiency is also improved by restraining the large forecasted growth in vehicle horsepower (hp). In 1998, the average hp of new passenger cars sold in the US was 155. In the BAU forecast, passenger car hp increases to 251 by 2020. Light truck horsepower increases even more, from 189 in 1998 to 293 in 2020. The Advanced scenario foresees much more modest increases, to 174 hp for cars and 199 hp for light trucks. Since vehicle weight decreases in the Advanced scenario by about 12 per cent for passenger cars, vehicle acceleration performance would still be about 25 per cent faster than today's cars.

4.3.4. Electric generators

The demand reductions due to policies described in the end-use sectors greatly limit the growth in electric generation, especially in the Advanced scenario. Within the electric sector, the key policy driving the changes is the domestic carbon trading system in the Advanced scenario. The resulting carbon permit price

- makes the building of new coal plants cost-ineffective and increases the retirement of coal and other fossil steam plants between 1997 and 2020—from 66 GW

in the BAU scenario to 187 GW in the Advanced scenario,
- impacts the variable cost of production, causing the remaining carbon-intensive technologies to lower their capacity, and
- encourages extension of the life of existing nuclear plants and development of non-hydro renewables, especially wind and biomass.

Restructuring also plays a significant role. By removing incentives for regulated utilities to retain capital investments that are no longer cost-effective, deregulation encourages the retirement of inefficient plants when new plants represent a more cost-effective option. A somewhat contrary impact is that restructuring promotes real-time pricing and customer shifts in peak load requirements. This lowers the need for additional capacity as existing plants operate more fully, which in turn reduces the need to build new, cleaner plants that displace older plants. In the Advanced scenario, while electricity generation drops 2% between 2010 and 2020, generation capacity declines by 4%.

The third major policy driving the changes in the electric sector is the production tax credit (PTC) for non-hydro renewable energy, especially wind. The renewable portfolio standard (RPS) also creates strong incentives for renewable energy development. By creating growth in wind energy through 2004 in the Moderate scenario) or 2008 (in the Advanced scenario), these policies encourage the development of a strong manufacturing and experience base that leads to further growth, but at a slower pace after the PTC and RPS expire. In the Advanced scenario, wind generation grows from 7.1 TWh in 2000 to 129 TWh in 2008, as a result of the PTC and RPS incentives, with help from the carbon permit penalty on other technologies and advances in technology. This 18-fold increase would require an unprecedented growth in production capacity of suppliers of wind generation equipment. In the Moderate scenario, with its shorter schedule for the PTC and no RPS or carbon permit price, wind quadruples by the time the PTC eligibility period expires (at the end of 2004). Other renewables are helped as well, but to a lesser extent. Biomass cofiring tax credits increase the use of biomass up to 50% in the Moderate scenario before the PTC expires, and biomass replaces up to 1.2% of coal consumption in 2004. Even higher amounts of cofiring occur in the Advanced scenario as other policies influence its use.

Improvements in technologies through R&D expand opportunities for carbon reductions. They provide effective alternatives to reducing demand or requiring higher prices to cover carbon permits. Without technology improvements, low- and non-carbon supplies are more expensive and less likely to displace current inefficient and carbon-intensive sources. Technology advances alone are generally insufficient to impact the overall carbon intensity of the production, but they are powerful in conjunction with the carbon permit price. In the BAU scenario, the carbon intensity of the overall electric sector by 2020 is 160 gC/kWh. The Moderate scenario, with only modest improvements in fossil technology efficiencies and lower demand growth, actually has 2.3% higher carbon intensity; lower demand means fewer opportunities to build low-carbon systems. Also, with no carbon permit price, there is little incentive to reduce carbon emissions. The Advanced scenario has higher fossil efficiencies but lower demand still. When the Advanced scenario was modeled without a $50/tC permit price, carbon intensity declined by 3% from BAU. With the carbon permit price, the intensity dropped 32% to 109 g/kWh.

Advances in non-hydro renewable technologies help increase the penetration of new technologies into the market and help make them a viable long-term supply. Production of non-hydro renewable energy in the Moderate scenario is 28% higher than in the BAU by 2020. But that figure represents only an increase from 3.7 to 5.4% of total production, so non-hydro renewable technology advances alone have a relatively small impact on carbon emission reductions. In the Advanced scenario, with other policies in place as well, non-hydro renewables double their production compared with BAU and represent almost 10% of production. Once again, the synergies of multiple policies contribute more than any one set of policies operating alone.

4.4. *Costs and benefits*

In both the Moderate and Advanced scenarios and in both timeframes (2010 and 2020), the nation pays less for its energy than in the BAU forecast. This is largely due to the accelerated development and deployment of energy-efficient technologies that reduce primary energy use. The technologies that produce these savings require incremental investment. In addition, there are costs to implement and operate policies and programs.

In this section, we report our estimates of these "direct" costs and benefits

- policy implementation and administration costs incurred by the public sector;
- R&D costs incurred by both the public and private sectors;
- incremental technology investment costs;
- changes in the energy bill, including the cost of carbon permits; and
- return of the carbon permit revenues to the public.

In the CEF scenarios, these costs and benefits rise and fall as follows. As policies are enacted, the government begins to incur direct costs for their implementation and administration. Energy prices then change as the market reacts to these policies, including higher fossil fuel prices in response to the purchase of carbon permits and lower energy costs due to reduced demand. Consumers react to the policies directly and to the changing energy prices by modifying their demand for energy services and investing in more energy-efficient and low-carbon technologies. With the annual auction of carbon permits, the government accrues revenues. These revenues are then distributed back to the public.

4.4.1. Policy implementation and administrative costs

Policy implementation costs include the costs of administering the public policies and programs that are modeled in each scenario, various fiscal incentives, and the incremental R&D costs. For the purposes of this project, *administrative costs* include the following costs to the public agencies implementing the policies and programs:

- program planning, design, analysis, and evaluation;
- activities designed to reach customers, bring them into the program, and deliver services such as marketing, audits, application processing, and bid reviews;
- inspections and quality control;
- staff recruitment, placement, compensation, development, training, and transportation;
- data collection, reporting, record-keeping, and accounting; and
- overhead costs such as office space and equipment, vehicles, and legal fees.

Preliminary cost increments were developed by estimating the administrative costs and energy savings associated with 12 policies and programs that have operated over the past decade or two. Administrative costs associated with these 12 policies range from $0.052 to $2.49 per MBtu saved. The average value was rounded up to $0.6 per MBtu, the increment used in the CEF study. It is added to the annualized incremental technology costs required to generate 1 MBtu of primary energy savings. This value is consistent with the findings of Berry (1991), who reviewed the cost of implementing demand-side management programs in the 1980s.

Based on these assumptions, the policy administration costs of the Moderate scenario are estimated to range from $3 to $7 billion per year in 2010 and 2020, respectively (Table 4). For the Advanced scenario, they range from $9 to $13 billion per year in 2010 and 2020. In addition to these administrative costs, two other policy implementation costs must be considered.

First, the fiscal incentives include the production tax credit for renewable energy in the power sector. In 2010, these amount to $0.4 billion in the Moderate scenario and $0.6 billion in the Advanced. These values are part of the "electric generators" row in Table 4. These costs do not occur in 2020, because all costs to the government end before 2020. (Note: Fiscal incentives for energy efficiency measures such as the credit for efficient new homes and vehicles are taken into account as incremental technology investment costs. These are shown in Table 6.)

Table 4
Annualized policy implementation and administration costs of the advanced scenarios in 2010 and 2020 (in billions 1997$ per year)

	Moderate scenario		Advanced scenario	
	2010	2020	2010	2020
Residential	0.5	1.5	1.0	2.7
Commercial	0.5	1.1	0.8	1.6
Industrial	1.0	2.2	2.3	3.9
Transportation	0.5	1.6	1.9	4.6
Electric generators	0.4	0	2.8	0
Total	2.9	6.4	8.8	12.9

Table 5
Research, development, and demonstration costs in 2010 and 2020 (in billions 1997$ per year)

	Moderate scenario		Advanced scenario	
	2010	2020	2010	2020
RD&D Costs	1.4	1.4	2.8	2.8

Second, the RPS in the Advanced scenario is modeled as a tax credit with costs that must also be taken into account. When actually implemented, the cost of an RPS would be captured within the energy bills of consumers. However, in our CEF-NEMS modeling of the RPS, we employed a 1.5¢/kWh tax credit as a surrogate for the RPS with its 1.5¢/kWh llowance cap. Thus in CEF-NEMS, the cost of the RPS is not captured by the utility bill but must be accounted for separately. The annual cost between 2010 and 2015, when the RPS terminates, is $2.2 billion. This value is part of the "electric generators" row for the Advanced scenario in Table 4.

4.5. RD&D costs

The Advanced scenario assumes that the federal government doubles its appropriations for cost-shared RD&D in efficient and clean-energy technologies; the Moderate scenario assumes a 50% increase (Table 5). Since these resources are spent in public/private RD&D partnerships, they are matched by private-sector funds. Altogether, the Advanced scenario assumes an increase of $2.8 billion per year by approximately 2005 (half as federal appropriations and half as private-sector cost share). This increment continues through 2020. The Moderate scenario assumes an additional $1.4 billion per year over the same period. Both scenarios assume a careful targeting of funds to critical research areas and a gradual, 5-year ramp-up of funds to allow for careful planning, assembly of research teams, and expansion of existing teams and facilities.

4.5.1. Incremental technology investment costs

Incremental technology costs refer to the additional investment in technology required by consumers and businesses to purchase more efficient equipment and energy services. Since we compute costs and benefits on an annual basis, we emphasize the annualized incremental technology costs for each year. The annualized cost for a particular year is the annualized cost of the total investment made to that time. We approximate the annualized cost by calculating an investment cost per unit of energy conserved and multiplying this cost of conserved energy (in \$/kWh or \$/MBtu) by the energy savings in that year.

For example, policies promoting more efficient residential refrigerators are projected to save 6 billion kWh in 2020 in the Advanced case. The cost of conserved energy for those savings is \$0.034/kWh (every kWh saved costs 3.4¢). In addition, the program implementation cost for capturing those savings is \$0.006/kWh. The annualized technology cost associated with these savings would be 6 billion kWh times \$0.034/kWh, or about \$0.2 billion per year. Including program costs, total annualized cost for capturing these savings would be 6 billion kWh times (\$0.034 + \$0.006), or \$0.24 billion per year.

Between 2010 and 2020, the annual incremental technology investment costs—totaled across all technologies and sectors—increase from \$11 to \$30 billion in the Moderate scenario, and from \$31 to \$66 billion in the Advanced scenario (Table 6). The transportation sector accounts for approximately half of these costs in both years.

Table 6
Annualized incremental technology investment costs in 2010 and 2020 (in billions 1997\$ per year)

	Moderate scenario		Advanced scenario	
	2010	2020	2010	2020
Residential	1.9	5.8	3.8	9.1
Commercial	2.0	4.6	2.7	5.8
Industrial	3.1	6.7	6.9	11.8
Transportation	4.3	13.4	16.2	39.1
Electric generators[a]	0	0	0	0
Total	11.4	30.5	29.6	65.9

[a] These investment costs are reflected in the price of electricity and hence in the bill savings calculation.

It is also useful to estimate the incremental capital outlays required each year to purchase the energy efficiency and clean energy technologies that are promoted by the CEF scenarios. These costs reflect the actual incremental expenditures needed for each scenario in each year. They can be calculated from the year-by-year annualized costs of these investments shown in summary in Table 6. The annualized cost calculations involve spreading the cost of capital across the operating lifetimes of new investments, while calculating the capital outlays requires removing that annualization and determining the change in actual capital investments from one year to the next. The actual capital outlays allow us to examine how the nation's investment capital would be affected by the CEF policies.

We are only able to estimate the incremental capital outlays for demand-side technologies and electricity supply side technologies from the outputs of the CEF-NEMS model. It is not possible to estimate these same requirements for all parts of the supply side investments that would come about in our policy scenarios. By limiting our estimates to the demand-side, we are likely overestimating the total net investment costs. Since the demand for electricity and fuels is reduced relative to the BAU forecast in both the Moderate and Advanced scenarios, investment capital required to build and operate new generation capacity, mines, and refineries will be avoided. The extent of these capital savings, however, cannot be estimated accurately. As a result, our estimates of incremental technology investments are based solely on the need to invest in improved demand-side technologies in the buildings, industry, and transportation sectors, with the recognition that these estimates are probably upper bounds to the net capital investments required in any given year.

The incremental capital outlays vary year-to-year in both the Moderate and Advanced scenarios. In the Moderate scenario they increase from several billion in 2000 to \$17 billion in 2015, after which they decline gradually. In the Advanced scenario, incremental technology investments increase more rapidly from \$4 billion in 2000 to \$30 billion in 2005; after that they decrease to \$17 billion in 2020. These energy-efficiency capital outlays are small relative to gross private domestic investments made in the US on an annual basis, which totaled to \$1.7 trillion in 1999 (Bureau of Economic Analysis, 2000). By comparison, the AEO99 reference case projects Real Investment at annual rates of \$2.0 trillion in 2010 and \$2.5 trillion in 2020 (in 1997\$).[6] Thus, the CEF capital outlays are no more than 2% of total capital investments in any year between 2000 and 2020.

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[6] The 1992 dollars of the AEO99 reference case are converted to 1997 dollars using the 1997 chain-type price index for Fixed Gross Private Domestic Investment (AEO99, Table 20; Council of Economic Advisers, 2000, Table B-7).

4.5.2. Changes in the energy bill

The total change in energy bill is a function of changes in energy prices, as well as changes in amounts and types of energy used. Generally, both factors are at work and are described below. The energy bill is calculated as the sum over all fuels (including electricity) in all end-use sectors of the fuel price times the amount of fuel used minus the pay-at-the-pump fee.[7] In the Advanced scenario, fossil energy prices include the \$50/tonne carbon permit charge that energy producers are assumed to add to energy prices as a result of the domestic carbon trading system.

The BAU scenario assumes that electricity prices will be 12% lower by 2010 than in 1997 and will decline another 8% by 2020 due to electricity restructuring in parts of the US (Note: Following the lead of EIA's Reference case, the BAU assumes that five regions of the US transition to competitive pricing with full consumer access and fully competitive prices beginning in 2008 (EIA, 1998a, p. 62).) The Moderate scenario results in even lower electricity prices in both 2010 and 2020, due largely to full national electricity restructuring and the decreased demand resulting from improved end-use energy efficiency. The Advanced scenario, on the other hand, produces electricity prices that are 9% higher than BAU in the two timeframes. This increase is largely due to the inclusion of the \$50/tC carbon permit price.[8] It is also affected by the greater use of renewable resources in power production.

The end-use price trajectories for natural gas are similar to those for electricity. In the BAU scenario, end-use prices are forecast to decline by 7% between 1997 and 2010 and by another 3% over the subsequent decade. The Moderate scenario results in even lower natural gas end-use prices in both 2010 and 2020, largely due to decreased demand resulting from energy-efficiency improvements. The Advanced scenario, on the other hand, results in 13% higher gas prices in 2010 (relative to BAU), but the relative increase drops to 6% by 2020. As with electricity prices, the increased natural gas prices in the Advanced scenario are primarily due to the domestic carbon trading system. Improved energy-efficiency reduces demand for natural gas in industry and buildings, which prevents price escalation as the result of rising natural gas demand in the power sector.

The same price trends occur for coal, but the effects of the Advanced scenario are more pronounced. Coal prices are forecast to decrease in the BAU scenario, and they decrease 1% further in the Moderate scenario because of decreased demand for electricity and steam coal. In the Advanced scenario, coal prices increase 120% in 2010 and 136% in 2020 relative to BAU.

Trends in prices for motor gasoline and other petroleum products are considered separately, because the pay-at-the-pump insurance charge applies only to gasoline. In the BAU scenario, gasoline and other petroleum product prices are forecast to grow only modestly over the next two decades. In the Moderate scenario, petroleum prices—especially gasoline prices—grow even more slowly because of dampened growth in demand. By 2020, gasoline prices have returned to 1997 levels. In the Advanced scenario, with its carbon permits and pay-at-the-pump fees, motor gasoline prices are 30% higher than the BAU forecast, both in 2010 and 2020. Prices for other petroleum products in the Advanced scenario are 11% higher than the BAU forecast in 2010 and 5% higher than the BAU in 2020.

While gasoline prices are higher in the Advanced scenario than in the BAU forecast, the cost of fuel per mile of travel is essentially unchanged. In 1997, gasoline prices averaged \$1.21 per gallon and the average light-duty vehicle got 20.5 miles to the gallon—resulting in a fuel cost of 5.90¢ per mile. In the Advanced scenario in 2020, paying \$1.69 per gallon of gasoline (including the pay-at-the-pump increment) and an average fuel economy of 28.3 miles to the gallon results in a fuel cost of 5.98¢ per mile traveled. Thus, consumers pay essentially the same per mile of travel in the Advanced scenario in 2020 as they do today, while also paying for a portion of their insurance premiums through the cost of their fuel.

The combination of evolving prices and demand for energy results in energy bill trajectories that vary widely across the scenarios (Table 7). Under BAU conditions, the US energy bill is forecast to increase 26%, from \$552 billion in 1997 to \$694 billion in 2020 (in 1997\$). In both

Table 7
Net energy bill savings in 2010 and 2020 (in billions 1997\$ per year)

	Moderate scenario		Advanced scenario[a]	
	2010	2020	2010	2020
Residential	12.6	19.3	2.8	20.1
Commercial	14.1	17.7	0.7	8.2
Industrial	13.5	19.3	−5.4	8.0
Transportation	15.0	44.0	18.3	85.6
Total	55.3	100.3	16.4	121.9

[a] The energy prices used to calculate the energy bill savings in the Advanced scenario include the cost of the carbon permit charges. They do not include the pay-at-the-pump fees for motor gasoline.

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[7] An additional \$44 billion is paid for motor gasoline in 2010 due to the 34¢ per gallon pay-at-the-pump increment for automobile insurance, and an additional \$56 billion is paid in 2020 due to the 51¢ per gallon increment. These costs are actually transfer payments (they offset other payments for insurance elsewhere in the economy) and are therefore, not treated as an addition to the nation's energy bill.

[8] The carbon allowance in the Advanced scenario adds 0.66¢ per kWh to the price of electricity in 2010. In 2020, it adds only 0.55¢ per kWh because of the lower carbon content of electricity in that year.

the Moderate and Advanced scenarios, the nation benefits from lower energy bills relative to the BAU increases. The energy bill is reduced in each of these scenarios, because the policies cause prompt efficiency increases and decreased energy use in the end-use sectors. In the Moderate scenario, US energy cost savings are $55 billion in 2010 and increase to $100 billion in 2020. In the Advanced scenario, efficiency increases in the end-use sectors are large enough to reduce the nation's energy bill in 2010 by $16 billion, even with increased energy prices. The savings rise to nearly $122 billion in 2020 as a result of improvements in the performance of energy-efficient technologies and their greater penetration in buildings, industry, and transportation. The transportation sector accounts for a large portion of the energy bill savings in both 2010 and 2020.

4.5.3. *Return of carbon permit revenues to the public*

The Advanced scenario assumes that each year beginning in 2005, carbon emissions permits are auctioned at a permit price of $50/tC. The government collects the carbon permit revenues and returns them to the public, offsetting revenues paid by the public in increased energy costs caused by the carbon permit. The idea of the carbon permit rebate is to leave people's "incomes" intact while changing the relative price of carbon.

As a result, the domestic carbon trading system imposes minimal first-order changes in the total income of "the public". Distribution of income will change, with some winners and losers, but aggregate income will change very little. This is a fairly gross system, but more refined rebate and allocation options are emerging (Bovenberg and Goulder, 2000; Center for Clean Air Policy, 1999; Weyant and Hill, 1999; Fischer et al., 1998a, b). The value of the transfer payments is shown in Table 8.

As with a tax, the carbon permit payments to the government reduce both consumer and producer surplus. Consumers pay a higher price and demand less fossil-fuel-derived energy, while producers see a lower demand, and, after subtracting the carbon payment to the government, a lower marginal price of supply. These price and quantity changes are reflected in the nation's energy bill. A small portion ($1.8 billion to $2.5 billion per year) of lost consumer and producer surplus is not captured in the energy bill calculation of the Advanced scenario. It is part of the macroeconomic costs that are discussed later in this section.

The method used to transfer carbon permit revenues back to the public will not affect the direct costs and benefits of the Advanced scenario, but it could affect the magnitude and nature of second-order impacts. Two fiscal policy approaches were analyzed in the Energy Information Administration's assessment of the Kyoto Protocol (EIA, 1998b):

Table 8
Net transfers to the public of the carbon permit revenues in 2010 and 2020 (in billions 1997$ per year)

	Moderate scenario		Advanced scenario	
	2010	2020	2010	2020
Total	0[a]	0[a]	72.9	67.4

[a] The domestic carbon trading system operates only in the Advanced scenario.

- returning collected revenues to consumers through personal income tax rebates, and
- lowering the social security tax rate as it applies to both employers and employees.

Both of these fiscal policies would ameliorate the short-term impacts of higher energy prices on the economy by bolstering disposable income.

4.5.4. *Net direct savings*

Table 9 shows the "net direct savings" of the two policy scenarios. The total savings are the difference between the direct benefits (i.e., net energy bill savings and carbon permit revenue transfers to the public) and the direct costs (i.e., annualized program implementation and administration costs, RD&D costs, and annualized incremental technology investment costs). The direct costs for both scenarios rise over time at a nearly linear pace. The energy bill savings of the Moderate scenario also rise at an essentially linear rate, as does the sum of the net energy bill savings (which includes the cost of carbon permits) and the carbon permit revenue transfers in the Advanced scenario.

In 2010, net energy bill savings and carbon permit transfer payments exceed direct costs by $39 billion in the Moderate scenario and by $48 billion in the Advanced scenario. By 2020, the gap has widened to an estimated $62 billion of direct savings in the Moderate scenario and $108 billion in the Advanced case.

Fig. 4 compares the annual gross energy savings from the Advanced scenario with the two measures of incremental technology investment costs: the annualized costs and the annual capital outlays. This figure shows that the investments spurred by the CEF policies quickly pay back in terms of reduced energy costs. This is true in both the Moderate and Advanced scenario.

4.5.5. *Externality costs and benefits*

A variety of externality costs and benefits would also accompany the CEF scenarios. The environmental externality benefits, for example, could be substantial. They include the possibility of reduced damages from global climate change and avoided costs of adapting to changing climates, such as avoided investments in

Table 9
Net direct savings of the clean energy future scenarios in 2010 and 2020 (in billions 1997$ per year)[a]

	Moderate Scenario		Advanced Scenario	
	2010	2020	2010	2020
Policy implementation and investment costs:				
Annualized policy implementation and administration costs	−3.2	−6.7	−9.1	−13.0
RD&D costs	−1.4	−1.4	−2.8	−2.8
Annualized incremental technology investments	−11.4	−30.5	−29.6	−65.9
Total investment costs	−16.0	−38.6	−41.5	−81.7
Net energy bill savings:				
Gross energy bill savings	55.3	100.3	89.2[b]	189.3[b]
Carbon permit costs	0	0	−72.9	−67.4
Net energy bill savings	55.3	100.3	16.4	121.9
Carbon permit revenue transfers to the public	0	0	72.9	67.4
Total	39.3	61.7	47.7	107.6

[a] These net direct savings do not account for the macroeconomic impacts of the scenarios. For example, the savings in the Advanced scenario are decreased by a small loss in consumer and producer surplus due to the domestic carbon trading system. These are estimated to be $2.5 billion in 2010 and $1.8 billion in 2020. Other macroeconomic costs are discussed below.

[b] The gross energy bill savings do not include pay-at-the-pump fees for automotive gasoline. These fees, which are part of the Advanced scenario policy portfolio, are treated as transfer payments and are therefore omitted from this table.

stronger physical infrastructures, more effective emergency preparedness programs, and increased air conditioning.

Other environmental externality benefits include cleaner air and water, which can produce significant public health benefits (Romm and Ervin, 1996). For example, in the Advanced scenario, in 2020, SO_2 emissions from the electric sector decline from 8.2 million metric tons in the BAU forecast to 4.1 million metric tons in the Advanced scenario.

The CEF policy scenarios also result in oil security benefits. In the Advanced scenario, petroleum consumption decreases more than 20% below the BAU forecast, thereby strengthening oil security. In addition, the nation benefits from significant reductions in annual wealth transfers from US oil consumers to world oil exporters.

A variety of ancillary or collateral costs and benefits would accompany the CEF policy scenarios. On the cost side are

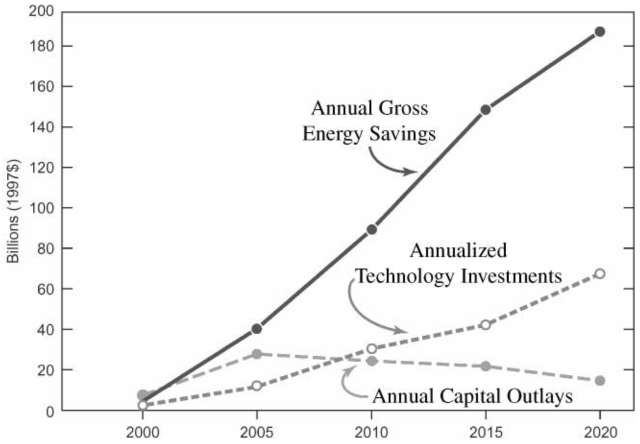

Fig. 4. Annual gross energy bill savings and incremental technology investments of the Advanced scenario: 2000 through 2020.

- amenity losses (e.g., from cars with lower hp) and
- opportunity losses (e.g., from investing in energy efficiency retrofits to manufacturing plants when more profitable investments such as creating a new product line may be available).

These costs are not captured in the analysis of direct costs and benefits, but could be considerable. On the benefits side are

- the productivity and product quality gains that have accompanied many investments in industrial efficiency improvements (Romm, 1999) and
- the growth in export markets for energy technologies.

Neither of these benefits is included in the analysis of direct costs and benefits, yet they could be considerable. Results reported in Elliott et al. (1997) and Laitner (1999) suggest that the average total benefits received from "energy-saving" projects in industry are typically two to four times the value of the energy savings alone.

4.5.6. Macroeconomic effects

The CEF study does not model the macroeconomic impacts of its two policy scenarios because of the difficulty of estimating transition and long-term macroeconomic effects on costs and investments that average less than 1% of national GDP over the study period. Instead, a review is conducted of previously published studies of the macroeconomic effects that might occur as a result of energy price changes from the domestic carbon trading policy included in the Advanced scenario.

Specifically, Sanstad et al. (2001) assessed the macroeconomic costs of a $50/tonne carbon permit price by examining the Energy Modeling Forum's recent compilation of results from simulations using seven of the leading energy/economic models (Weyant and Hill, 1999). These seven models provide alternative estimates of what it might cost to achieve carbon emissions at 1990 levels from energy use and generation. The scenarios varied according to how much (and among which countries) international trading was allowed to occur.

To estimate the GDP loss associated with a $50/tonne carbon permit price, a "GDP response curve" was calculated for each model indicating the expected response of GDP to various carbon permit prices. Each curve was determined by a quadratic extrapolation using the Annex I trading and global trading scenarios as reported by the Energy Modeling Forum (EMF-16), in Weyant and Hill (1999). (These are the scenarios with carbon permit prices that bracket or are close to the $50/tonne level.) For each model, the origin and the two estimates of implicit carbon permit price and GDP loss determine a unique quadratic response curve.

The estimated 2010 GDP losses (in 1997$) associated with $50/tonne carbon permit price range from $4 to $66 billion. These are the same order of magnitude as the $48 billion in net direct benefits estimated for the Advanced scenario in 2010.

Sanstad et al. (2001) also explores the transitional macroeconomic adjustment costs of the carbon permit price caused by the economy's reacting to higher energy prices in the CEF scenarios. As with the long-term macroeconomic costs described above, these findings show that even in the transition period, potential GDP losses can be mitigated—and indeed potential GDP gains may result—when revenue recycling is used to stimulate investment. In 2010, the net direct savings are of the same order of magnitude as the macroeconomic (transitional plus long-term) costs. Over the following decade, the net direct savings grow as energy-efficient technologies gain market shares, while the long-term macroeconomic impacts would likely remain steady and the transitional costs would likely decline.

4.5.7. Sectoral and regional impacts

Many sectors of the economy and regions of the United States would benefit from a transition to the type of clean energy future characterized in this study's two policy scenarios. For example, the growth of strong domestic wind and bioenergy industries could bring new employment opportunities to many regions and could revitalize the economies of rural America. A wide range of other business opportunities would thrive under the Advanced scenario. Specific sectors likely to see positive impacts on output include energy service companies, contractors, and consultants; light-weight materials and fuel cell manufacturing; the nuclear energy services industry; and electronic sensors and controls and advanced battery manufacturers.

Financial institution business could also expand along with the growth in third-party energy service companies, since many manufacturing companies and building owners may prefer to lower their debt-equity ratios through third-party investors when undertaking energy efficiency measures.

The enhanced energy technology innovation envisioned from the doubling of RD&D budgets in the Advanced scenario could lead to a stronger domestic economy through international cooperation. The development of advanced energy technologies could help expand the market share of US companies in the vast global market for efficient and clean energy technologies. It could also enhance long-term markets for other US exports by building the energy basis for sustainable prosperity in developing and transitional economies. Both of these goals are highlighted in the recent report from the PCAST Panel on International Cooperation in Energy Research, Development, Demonstration, and Deployment (PCAST, 1999).

The reduction of coal consumption in the Advanced scenario by 30% in 2010 and by nearly 50% in 2020 (relative to BAU) would have major negative consequences for the coal industry. Stricter policies to reduce SO_2 are anticipated to have a smaller negative impact on coal production in western states because of its lower sulfur content and its increasingly lower mining costs (EPA, 1999). Policies to reduce CO_2, on the other hand, are anticipated to have a smaller negative impact on coal production in Northern Appalachia and the Midwest because these mines are closer to coal markets and do not require long-haul, carbon-intensive transportation (EIA, 1998b).

Unequal regional impacts of CO_2 policies on the electricity industry are also anticipated because of regional differences in the resources used to generate electricity. In particular, interior states could suffer greater economic hardship than coastal regions based on the interior region's greater dependence on coal for electricity. Coastal regions have more readily available nuclear and hydroelectric power (Resourcedata International, Inc., 1999).

The reduced demand for coal would also adversely affect the transportation sectors (i.e., rail and barge) that draw sizeable fractions of their business from hauling coal. The viability of some rail links and barge routes would be weakened by the reduced freight.

Similarly, the 10–20% reduction in petroleum consumption in the Advanced scenario would dampen demand for petroleum products from the domestic refining industry. This could further challenge the US oil industry's ability to compete in world markets and to expand its production quickly in the event of oil supply shocks.

At a broader scale, cost-effective energy-efficiency measures free up real resources that otherwise would be needed for energy production. Because the energy efficiency measures are cost-effective, a net surplus remains for increased consumer and business investment spending. Increased consumer and business investment spending is the source of general benefits to most sectors in the economy (Hanson and Laitner, 2000).

5. Sensitivity analysis

We recognize that any effort to describe the future has a high degree of uncertainty. Even the BAU forecast is no more than a reasonable assessment of current trends and policies. As with all of the scenarios, it depends upon energy price projections that are highly uncertain.

The uncertainty associated with the results of the Moderate scenario is exacerbated by the presumption of new policies to promote energy efficiency. However the uncertainty is moderated by the fact that most of the technologies required to achieve the demand reductions for this scenario are already available and economic today, if the stream of energy savings over their operating lives is considered. These technologies have not penetrated the market more completely in large part because of various market imperfections and barriers that the CEF policies are designed to overcome.

The Advanced scenario, with its aggressive policies and advanced technologies, has even greater uncertainties. The first concerns technology. In many cases, technology is not presently available to achieve the scenario results. In particular, the scenario requires substantial progress toward more efficient vehicles, as well as important evolutionary improvements in renewable and fossil-fueled electricity technologies. It is also possible that technology innovation in response to the Advanced policies in combination with similar or more aggressive policies enacted in other countries and not analyzed, could lead to greater technical progress than assumed. The second major uncertainty is in the effectiveness, benefits, and costs of policies. This is closely tied to the success of R&D. If efficient and clean energy technologies become increasingly cost-effective, as the authors suggest, then the policies driving them to market in the Advanced scenario are much easier to pursue and much more likely to generate net economic gains.

Many types of uncertainties can be captured through quantitative sensitivity analyses, in which one or more key input assumptions are varied and the results studied. Other uncertainties are more difficult to capture—e.g., uncertainties in the specification of basic data and underlying assumptions, in the realism of the models and related forecasting approaches, and in the assessment of impacts of policies. Recognizing that sensitivity analysis captures only a portion of the uncertainty, we carried out a range of sensitivities on a number of important variables. The sensitivity cases include: (1) higher natural gas and petroleum prices, (2) shorter duration of the Renewable Portfolio Standard or higher cost of renewable energy technology, (3) no penetration of light-duty diesel engines, and (4) higher cost of advanced fossil fuel technologies.

Overall, the results show impacts on the order of 3 to 20 MtC in 2020 for each of the sensitivities. These results are to be compared with the reduction in carbon emissions in 2020 of approximately 180 MtC in going from BAU to the Moderate scenario, and a reduction of 565 MtC in going to the Advanced scenario. In short, each of the particular sensitivities analyzed has an impact on carbon emissions that is less than 4% of the reduction achieved in moving from BAU to the Advanced scenario. These sensitivities underscore the robustness of the CEF scenarios that results from the broad portfolio of policies and technologies that is included.

Koomey et al. (2001b) present the results of these sensitivities. They also describe the results of sensitivity cases that involve the system-wide variations in policies—comparing and contrasting demand-side versus supply-side policies and examining cases that rely strictly on domestic carbon trading. One important finding from this analysis is that the domestic carbon trading policy in the Advanced scenario accounts for approximately half of the carbon reductions in 2010; its contribution is reduced to about one-third in 2020 as other policies such as RD&D gain in overall impact.

6. Summary

This study makes a strong case that a vigorous program of energy technology research, development, and demonstration coupled with an array of public policies and programs to overcome market failures and organizational barriers can be an effective public response to the energy-related challenges facing the United States. Smart public policies can significantly reduce not only carbon dioxide emissions, but also air pollution, petroleum dependence, and inefficiencies in energy production and use. In addition, the study indicates that the overall economic benefits of these policies could be comparable to their overall costs. Finally, while it is important to mention the imprecision of policy analysis, sensitivity analyses show that the uncertainties in the CEF assessment are unlikely to alter the study's fundamental conclusions. The policy and technology opportunities modeled in the CEF study are so abundant that they compete with each other to reduce carbon emissions. We would expect enough of them to be successful to achieve the results we claim.

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