EXECUTIVE SUMMARY

As we move into the 21st century, a number of key energy-related challenges face the nation. U.S. dependence on imported oil is growing, increasing the nation's vulnerability to supply and price disruptions. Electricity outages, power disturbances, and price spikes threaten U.S. 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. And 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.

Following a 1997 study, *Scenarios of U.S. Carbon Reductions*, the U.S. Department of Energy (DOE) commissioned an Interlaboratory Working Group to examine the potential for public policies and programs to foster efficient and clean energy technology solutions to these energy-related challenges[1]. This document reflects the best efforts of the Interlaboratory Working Group to understand and present that potential. The three key conclusions of the CEF study are summarized below.

The Study's Key Conclusions

Smart public policies can significantly reduce not only carbon dioxide emissions, but also air pollution, petroleum dependence, and inefficiencies in energy production and use. A range of policies exists – including voluntary agreements; efficiency standards; increased research, development, and demonstration (RD&D); electric sector restructuring; and domestic carbon trading – that could move the United States a long way toward returning its carbon dioxide emissions to 1990 levels by 2010. Additional means would be needed to achieve further reductions, such as international carbon trading and stronger domestic policies.

The overall economic benefits of these policies appear to be comparable to their overall costs. The CEF policies could produce direct benefits, including energy savings, that exceed their direct costs (e.g., technology and policy investments). Indirect macroeconomic costs are in the same range as these net direct benefits. The CEF scenarios could produce important transition impacts and dislocations such as reduced coal and railroad employment; but at the same time, jobs in wind, biomass, energy efficiency, and other "green" industries could grow significantly.

Uncertainties in the CEF assessment are unlikely to alter the overall conclusions. The policy and technology opportunities identified in the CEF 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. Furthermore, a broad range of technology options, with sufficient research, could provide additional solutions in the long run.

In the end, the authors take advantage of the data available, use their best judgment informed by external expert review, and employ scenarios and sensitivity analysis to bound the uncertainties. The overall conclusion from this analysis is that the existence of a wide array of policy and technology options

[1] Members of the working group were drawn from Argonne National Laboratory (ANL), Lawrence Berkeley National Laboratory (LBNL), National Renewable Energy Laboratory (NREL), Oak Ridge National Laboratory (ORNL), and Pacific Northwest National Laboratory (PNNL).

provides many low-cost pathways to a cleaner energy future. In reviewing the study's results, however, it is important to remember the imprecision of policy analysis; uncertainties derive from such diverse issues as the likely pace of technology advancements and the response of consumers to market-based incentives.

CEF SCENARIOS

This study does not make policy recommendations. Rather, the purpose of the study is to better understand the costs and benefits of alternative sets of policies to accelerate clean energy technology solutions. Some of these policies are not the policies of the current Administration. In addition, the policies do not address the complete range of policy options. For example, the scenarios do not include international emissions trading which could be important to meeting possible carbon emission targets.

The structured development of energy scenarios allows a way to examine a range of public policies and to consider alternative possibilities. The CEF study develops three scenarios: Business-as-Usual (BAU), Moderate, and Advanced. 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 solving 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) and assessed for impacts to 2020.

The CEF scenarios address U.S. energy and environmental issues for the next 20 years. They are not long-term, global, integrated assessments. As such, the CEF scenarios are not necessarily responsive to energy needs, environmental conditions, and technology opportunities that emerge after 2020 or elsewhere in the world. The scope of this quantitative analysis is limited to near-term domestic issues to illustrate specific clean energy technology and policy opportunities for the United States today. "Clean energy technologies" include:

- measures that reduce the energy intensity of the economy (e.g., more efficient lighting, cars, and industrial processes),
- measures that reduce the carbon intensity of the energy used (e.g., renewable energy resources, nuclear power, natural gas, and more efficient fossil-fueled electricity plants), and
- measures that integrate carbon sequestration into the energy production and delivery system (e.g., integrated gasification combined cycle plants with carbon separation and storage).

To place the CEF scenarios within an expanded context that considers the post 2020 period, we qualitatively describe energy technology breakthroughs that could occur by mid-century. With successful research and supportive policies, such breakthroughs could provide additional solutions to long-term and global energy problems. These technologies include carbon sequestration from coal, a new generation of nuclear power plants, advanced gas and chemical separation technologies, hybrid electric systems deploying wind power and gas turbines in combination with low-cost storage and advanced power electronics, and a host of highly efficient and advanced renewable energy technologies.

Following a detailed assessment of market failures and institutional barriers to the market penetration of clean energy technologies, numerous policies were chosen for examination in the CEF study. These policies 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 that promote 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. Delays in implementation would miss immediate capital replacement opportunities.

The policies identified as most important in the Advanced scenario are summarized in Table 1. A key policy mechanism for the Advanced scenario across all of the sectors is the addition of a domestic carbon trading system. In this system, which is assumed to be announced in 2002 and implemented in 2005, permits are sold annually in a competitive auction run by the federal government. The carbon emissions annual limit is set so that the permit price equilibrates at $50/tC (in 1997$) throughout the period. A $25/tC case is also analyzed. The second key policy mechanism in the Advanced scenario for all of the sectors is the doubling of federal government appropriations for cost-shared RD&D in efficient and clean energy technologies. As these resources are spent in public/private RD&D partnerships, they are matched by private-sector funds, resulting in an assumed increase of $1.4 billion per year by 2005, bringing the total to $2.8 billion (in 1997 $) in 2005 and each year after that. Half of these expenditures are federal appropriations and half are from private-sector cost sharing.

Table 1 Key Policies in the Advanced Scenario*

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

*The scenarios are defined by approximately 50 policies. The 10 in this table are the most important ones in the Advanced scenario. 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.

[a] 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.

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 CEF scenarios are based on a limited set of policies, many of which are relatively non-intrusive policies. Inclusion of stronger, more intrusive policies would result in more rapid progress toward meeting the nation's energy and environmental goals, though probably at higher cost. Many of these additional policies are explored in other studies, which could be consulted if the nation requires acceleration beyond the transitions described here. Further, the CEF scenarios omit policies that some policymakers might consider attractive. Some policies are omitted because their impacts are redundant. Others are left out because of modeling difficulties. Additional policies are excluded because the authors concluded that the required levels of public commitment or costs exceed CEF scenario guidelines.

METHODOLOGY

A scenario-based approach is used to allow examination of alternative portfolios of public policies. A scenario is a story – not a prediction – of how the future might unfold. Scenarios are useful for organizing scientific insight, gauging emerging trends, and considering alternatives.

We have used 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. Macroeconomic impacts and feedback are separately assessed through an analysis of previous published modeling results.

The EIA's Reference case from the *Annual Energy Outlook 1999* is used as the starting point for the CEF BAU forecast (the most recent available from the EIA at the time of this analysis). 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[2].

The CEF BAU forecast and the EIA Reference case forecast 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 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 scenario (and therefore from the EIA's Reference case). 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 analysis is unable to incorporate the full impact of market-wide behavioral responses to the CEF 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

[2] 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.

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.

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 a carbon 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. 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

Table 2 Selected Results for 2010 and 2020*

			2010 Scenarios			
	1990	**1997**	**BAU Forecast**	**Moderate**	**Advanced ($25/tC)**[a]	**Advanced ($50/tC)**[b]
U.S. Primary Energy Use in Quadrillion Btu (Percent Change from BAU)	84.2 –	94.0 –	110.4 –	106.2 - 106.5 (-4%)	101.0 (-9%)	98.2 - 99.3 (-11% to -10%)
U. S. Energy Bill in Billion 1997$ (Percent Change from BAU)	516 –	552 –	651 –	595 (-9%)	598 (-8%)	634[c] (-3%)
U.S. Carbon Emissions in Million Metric Tons (Percent Change from BAU)	1,346 –	1,480 –	1,769 –	1,679 - 1,684 (-5%)	1,539 (-13%)	1,437 - 1,463 (-19 to -17%)
			2020 Scenarios			
	1990	**1997**	**BAU Forecast**	**Moderate**	**Advanced ($25/tC)**[a]	**Advanced ($50/tC)**[b]
U.S. Primary Energy Use in Quadrillion Btu (Percent Change from BAU)	84.2 –	94.0 –	119.8 –	109.6 - 110.1 (-9% to -8%)	98.8 (-18%)	94.4 - 96.8 (-21% to -19%)
U. S. Energy Bill in Billion 1997$ (Percent Change from BAU)	516 –	552 –	694 –	594 (-14%)	541 (-22%)	572[c] (-18%)
U.S. Carbon Emissions in Million Metric Tons (Percent Change from BAU)	1,346 –	1,480 –	1,922 –	1,730 - 1,740 (-10% to -9%)	1,472 (-23%)	1,307 - 1,347 (-32% to -30%)

*A number of key technologies were not modeled within the CEF-NEMS framework, including combined heat and power (CHP), solar domestic hot water heaters, and fossil fueled on-site generation in buildings. An off-line analysis of policies to tackle barriers to CHP in industry was completed. It produced estimates of energy and carbon impacts for the Moderate and Advanced scenarios. These estimates are included in the lower numbers in the ranges shown in this table. Estimates of impacts of CHP policies on the U.S. energy bill are not available.

[a] This variation of the Advanced scenario has a domestic carbon trading system that equilibrates at a carbon permit value of $25/tC.

[b] The Advanced scenario includes a domestic carbon trading system that equilibrates at a carbon permit value of $50/tC.

[c] The energy prices used to calculate this energy bill include the cost of the carbon permit.

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.

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 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. 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 the transportation sector, RD&D is estimated to drive down the cost of a hydrogen fuel cell system from $4,400 more than a comparable gasoline vehicle in 2005 to an increment of only $1,540 in 2020. In the electric sector, capital costs for wind power drop to $611/kW in 2016 as a result of RD&D. Even reductions in primary energy use in all sectors can be expected after 2020 as technology improves further and utilization expands.

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 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. An off-line analysis of combined heat and power in industry suggests that policies tackling barriers to this technology could increase energy savings by an additional quad in 2010 and by an additional 2.4 quads in 2020.

Carbon Emissions[3]. By 2020, carbon emissions in the Advanced scenario are 30 to 32% lower than in the BAU forecast. These emission reductions are nearly three times those of the Moderate scenario (Figures 1 and 2). 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 power generation as well as wind, biomass, and geothermal power. The off-line analysis of combined heat

[3] 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 will follow this convention here.

and power in industry suggests the potential to reduce carbon dioxide emissions by an additional 40 MtC in 2020.

Fig. 1 Carbon Emission Reductions, by Sector, in the Moderate Scenario

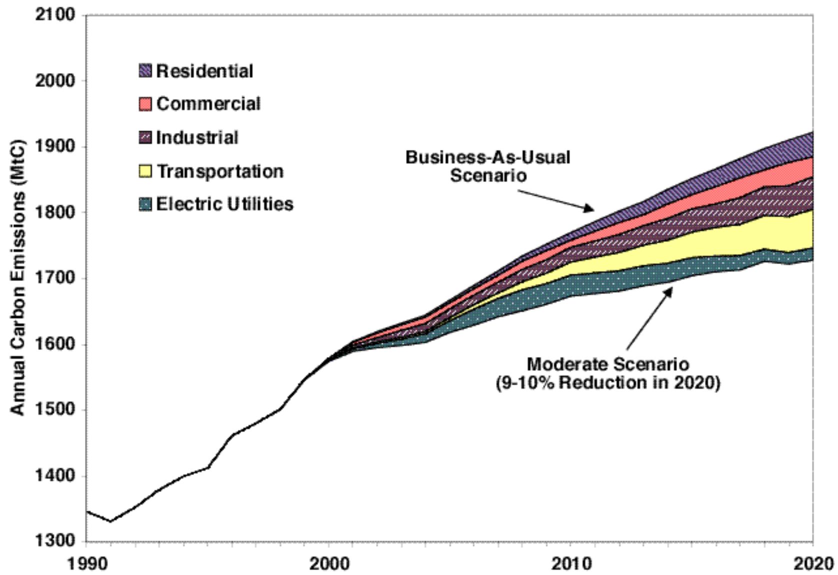
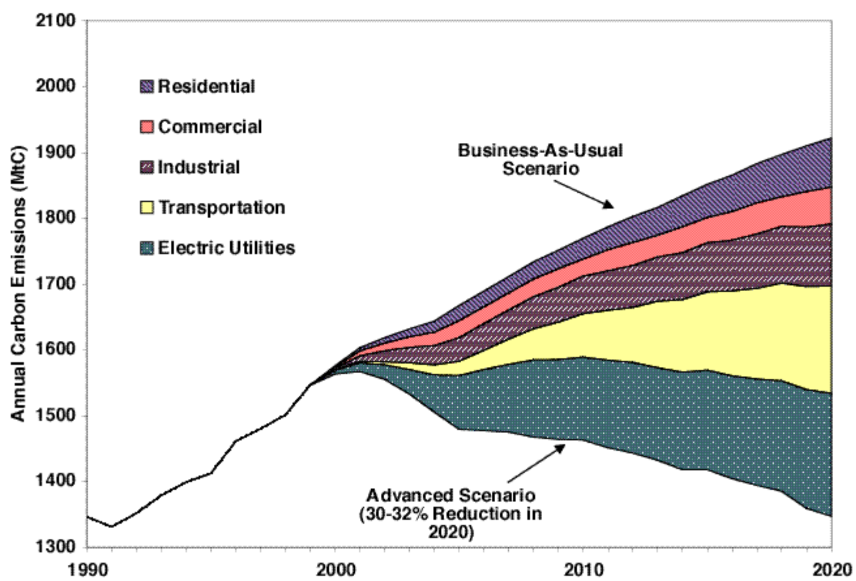


Fig. 2 Carbon Emission Reductions, by Sector, in the Advanced Scenario



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. In the context of the U.S. 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/or stronger domestic policies. In the Advanced scenario, carbon emissions drop fully to 1990 levels by the year 2020.

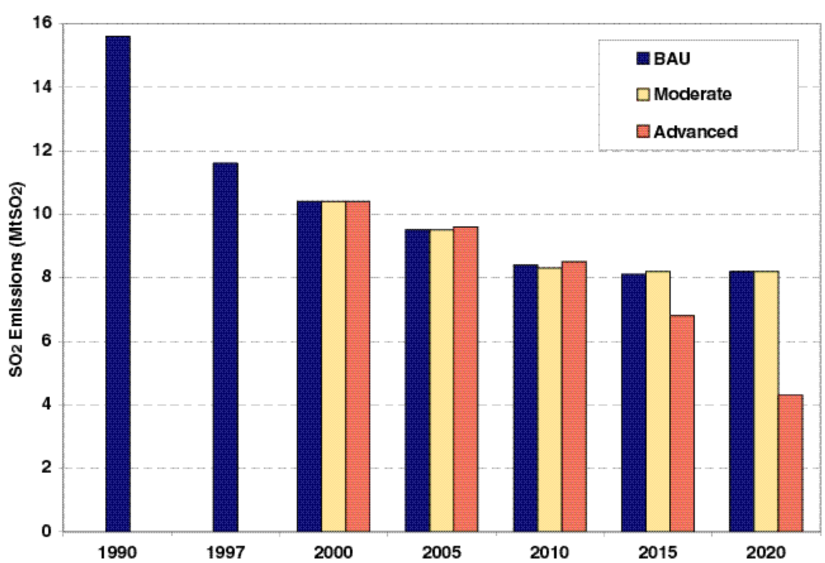
Costs and Benefits. In both the Moderate and Advanced scenarios and in both timeframes (2010 and 2020), the nation pays less for its energy than in the BAU forecast. This is largely due to the accelerated development and deployment of energy-efficient technologies that reduce primary energy use. In 2010, the Advanced scenario bill is higher than the Moderate scenario bill because energy producers increase energy prices to recover their cost of purchasing carbon permits. The increased use and improved performance of efficient and low-carbon energy technologies in the Advanced scenario place downward pressure on energy prices throughout the 20-year period. The net effect is that by 2020 the Advanced scenario's energy bill is $23 billion lower than that in the Moderate scenario and $124 billion lower than in the BAU forecast, even with the costs of carbon permits included.

While consumers benefit from lower energy bills, the technologies that produce these savings require incremental investment. In addition, there are costs to implement and operate policies and programs. In both policy scenarios, the energy bill savings, in combination with recycled revenues from the domestic carbon trading system, exceed the annualized direct costs of the technologies and policies. The Moderate scenario produces direct benefits of approximately $40 billion compared to the Advanced scenario of $48 billion in 2010. By 2020, these benefits grow to more than $60 billion per year in the Moderate scenario and to more than $100 billion per year in the Advanced scenario.

Against these direct benefits is the possibility of macroeconomic costs arising from distortions induced by domestic carbon trading. An integrated macroeconomic analysis was not undertaken for this study. However, an assessment of these costs, based on a review of the quantitative modeling of other researchers, shows them to range from a $4 billion to a $66 billion loss in Gross Domestic Product (GDP) in 2010. These costs are the same order of magnitude as the direct benefits described above.

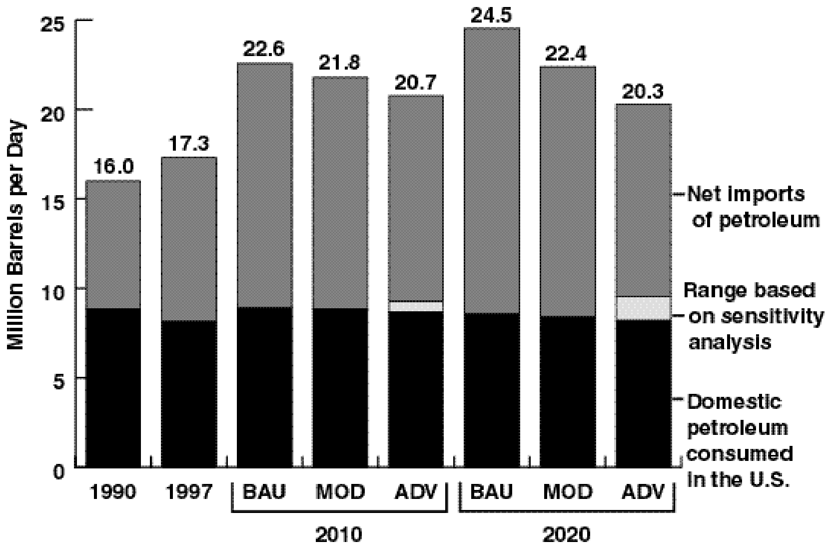
The impacts summarized above do not reflect several important other benefits: reduced vulnerability to oil supply disruptions, cleaner air, and improved balance of payments. For example, in the Advanced scenario, in 2020:

Fig. 3 SO_2 Emission Reductions in the Electric Sector



· 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, resulting in substantial environmental and health benefits (see Fig. 3).

Fig. 4 U.S. Consumption of Domestic and Imported Crude Oil and Petroleum Products



· Petroleum consumption decreases 23% below the BAU forecast, thereby strengthening oil security. In addition, the nation benefits from significant reductions in annual wealth transfers from U.S. oil consumers to world oil exporters (see Fig. 4).

In spite of the overall net economic and environmental benefits of the scenarios, implementation of the CEF policies could produce important transition impacts and dislocations, and some regions are likely to be disproportionately impacted[4]. The impact of the Advanced scenario on the coal and coal transport industry is of particular note. Overall coal production in the United States decreases by 2020 to 50% of the BAU forecast, causing significant adverse impacts on that industry. On the other hand, the growth of strong domestic wind, bioenergy, energy efficiency, and other "green" industries envisioned in this scenario would bring new employment opportunities to many regions and could contribute to a revitalization of the economies of rural America. Efficiency technologies could boost output over a range of industries located throughout the United States, such as agriculture and bioprocessing, lightweight materials fabrication, sensor and control systems, and energy service companies.

As is true of any study that estimates future impacts of technology and policy, these scenarios have many uncertainties. The first concerns RD&D. On one hand, the Advanced scenario depends on technologies not currently available or cost-effective. For instance, substantial progress toward more efficient vehicles is assumed, as well as important evolutionary improvements in renewable and fossil-fueled electricity technologies. The degree of success for RD&D is inherently uncertain, however, and it is not possible to be sure that the results would turn out as estimated. On the other hand, the broad portfolio of technologies adds to the robustness of the results and, conceivably, the Advanced policies 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 RD&D. If efficient and clean energy technologies become increasingly cost-effective, 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.

LONG-TERM AND GLOBAL CONTEXT

The CEF scenarios cover a near-term timeframe – the next two decades – and focus primarily upon domestic energy challenges and issues. This scope is not meant to minimize the importance of longer-term and global energy issues such as the severe air pollution problems in many countries throughout the world, access to electricity for the third of the world's population that is currently unserved, and long-term fossil fuel resource limitations.

[4] Policies to mitigate these regional impacts are not explored in this report.

A consideration of the longer term makes clear the tremendous variety of possible energy futures. In spite of this diversity, two observations appear likely. First, developing nations will account for a high percentage of energy demand growth and will play an increasingly dominant role in world energy markets. Second, there is a broad range of longer-term technology options which, with successful research, would provide additional solutions to the nation's – and the world's – energy-related problems. Given uncertainties in global economic trends, demographics and lifestyles, air quality, and climates, an expanded R&D effort in most energy technology arenas would appear to be warranted.

SUMMARY

This study makes a strong case that a vigorous program of energy technology research, development, demonstration and deployment coupled with an array of public policies and programs to overcome market failures and organizational barriers hindering technology utilization can be an effective public response to the nation's energy-related challenges. This study helps move the nation toward developing the analysis and public process needed to identify smart, sustainable energy policies and programs. This study shows that policies exist that could significantly reduce inefficiencies, oil dependence, air pollution, and greenhouse gas emissions at essentially no net cost to the U.S. economy.