

Scenarios for a Clean Energy Future

Briefing to the
White House Climate Change Task Force

Washington, DC ~ January 28, 2000

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BRIEFING OUTLINE

1. Background
2. Scope and Approach
3. Key Findings
 - Key Policies
 - Limitations
 - Energy and Carbon Impacts
 - Costs and Benefits
 - Sensitivity Analysis
4. Insights and Conclusions to Date

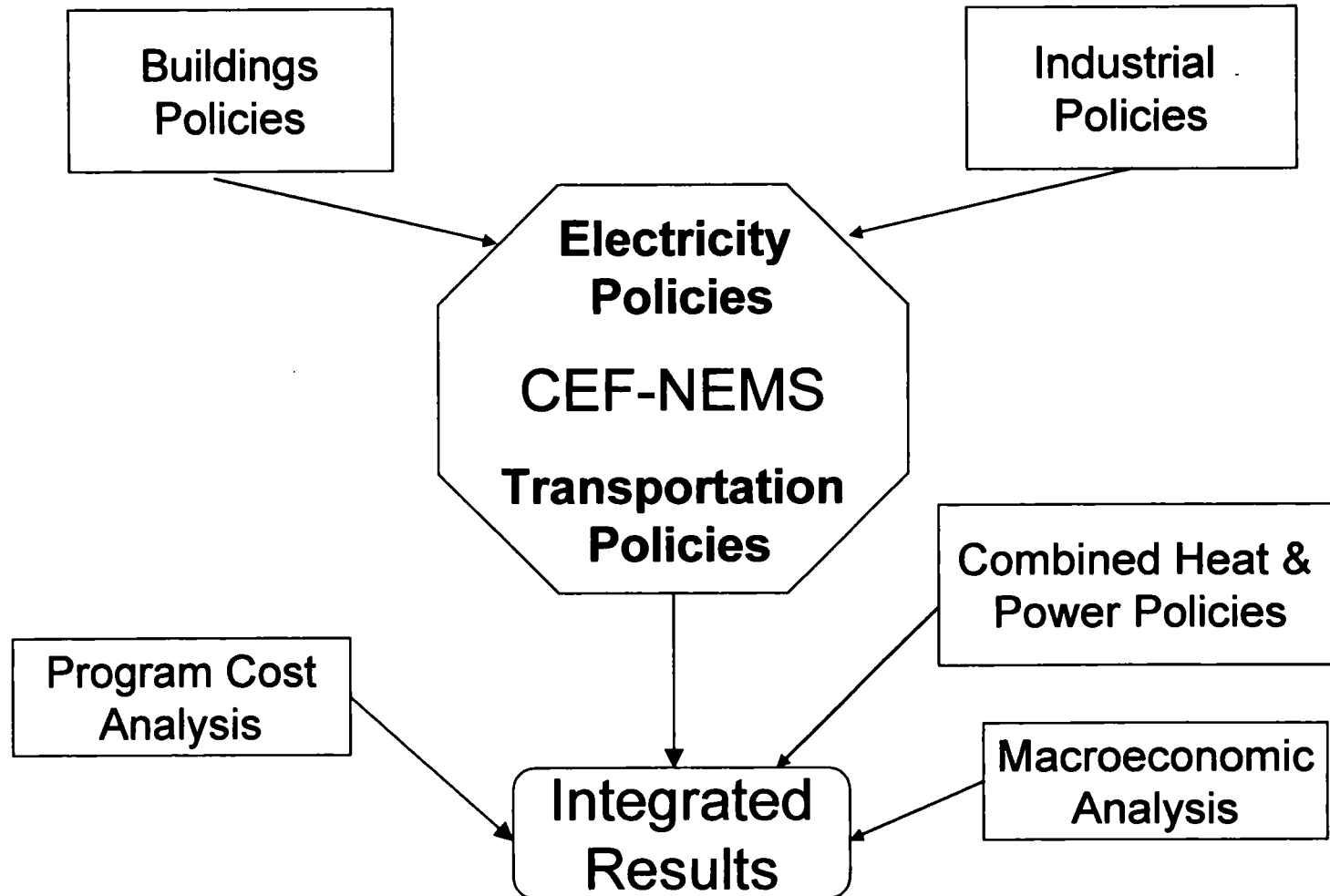
BACKGROUND

- Initiated by DOE/EE in November 1998
- **Goal:** to identify and analyze policies that promote efficient and clean energy technologies to reduce CO₂ emissions and achieve other energy-related goals (e.g., oil security and air quality)
- **Structure:** Analysis undertaken by 5 national laboratories with input from experts groups
- **Status:** Final analytical runs being completed and drafts being revised accordingly
- **Reviews:** DOE, EIA, EPA, External Review Committee, and Sector Expert Groups

SCOPE

- Focus on domestic carbon dioxide emissions
- Quantitative analysis through 2020; brief qualitative analysis of global, long-term energy needs and opportunities (2050)
- **Not a forecast or prediction; rather, two pathways towards a cleaner energy future**
- Policy opportunities, not policy recommendations

APPROACH



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Two Scenarios are Modeled

They reflect increased levels of national commitment to energy and environmental goals.

- (1) **Moderate Scenario:** enhanced national commitment if costs can be kept low.
 - assumes some shift in political will & public opinion
 - excludes fiscal policies that involve taxing energy
- (2) **Advanced Scenario:** nationwide sense of urgency to meet these goals.
 - more vigorous fiscal and non-fiscal policies
 - includes a domestic carbon cap and trade system with assumed permit price of \$50/tC.

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 Utilities
-Voluntary fuel economy agreements with auto manufacturers -“Pay-at-the-pump” auto insurance	-Renewable energy portfolio standards and production tax credits -Electric industry restructuring
Cross-Sector Policies - Doubled federal R&D -Domestic carbon cap and trade system	

mpg
 2010: 40
 2020: 50

AS

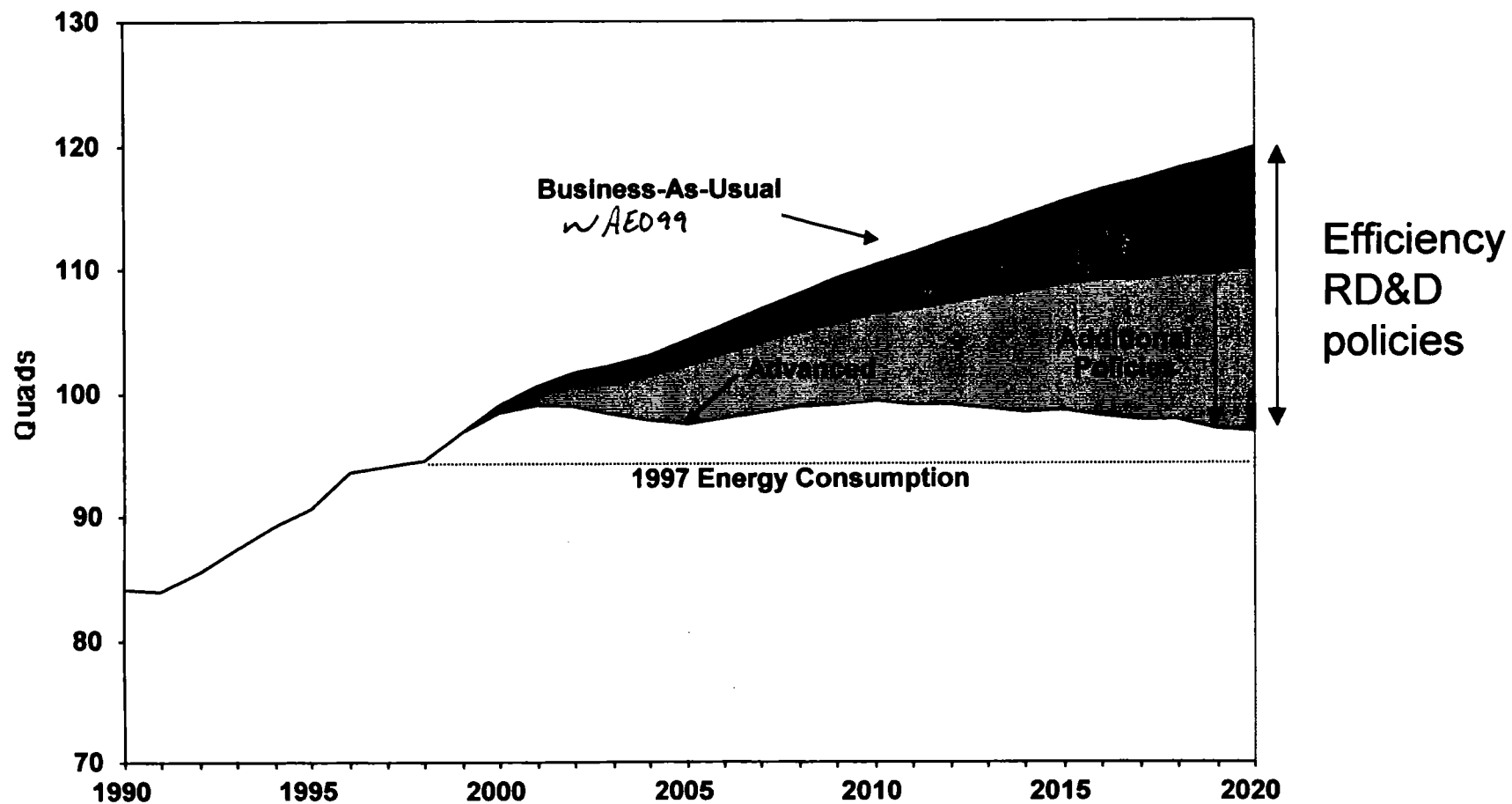
*The scenarios are defined by approximately 50 policies. These 10 are the most important ones in the Advanced scenario. Each policy is specified in terms of magnitude and timing (e.g., “431 kWh/year dishwasher standard implemented in 2010”).

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LIMITATIONS

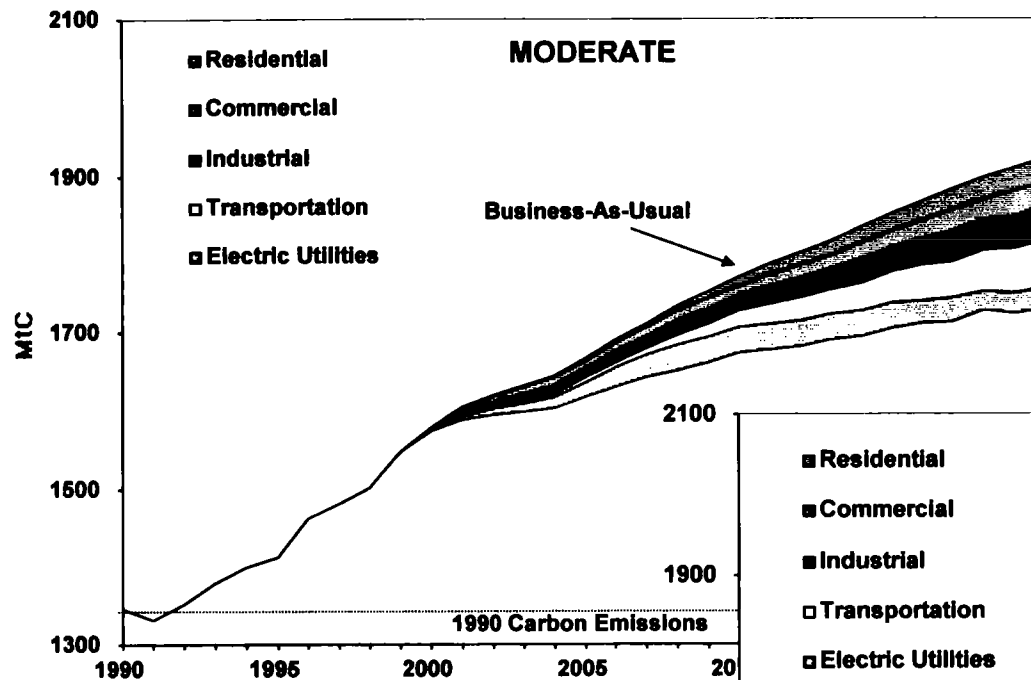
- Not all policy opportunities have been analyzed
- Modeling of non-fiscal policies
- Forecasting technology improvements
- Modeling of macroeconomic costs *- did not evaluate; make claim of energy efficiency gap, thus negative cost actions are available; did compare with some CGE models*
- NEMS limitations: DG, CHP, green power, federal facilities, co-benefits
- Point estimates do not reflect range of uncertainties

Scenario Energy Reductions



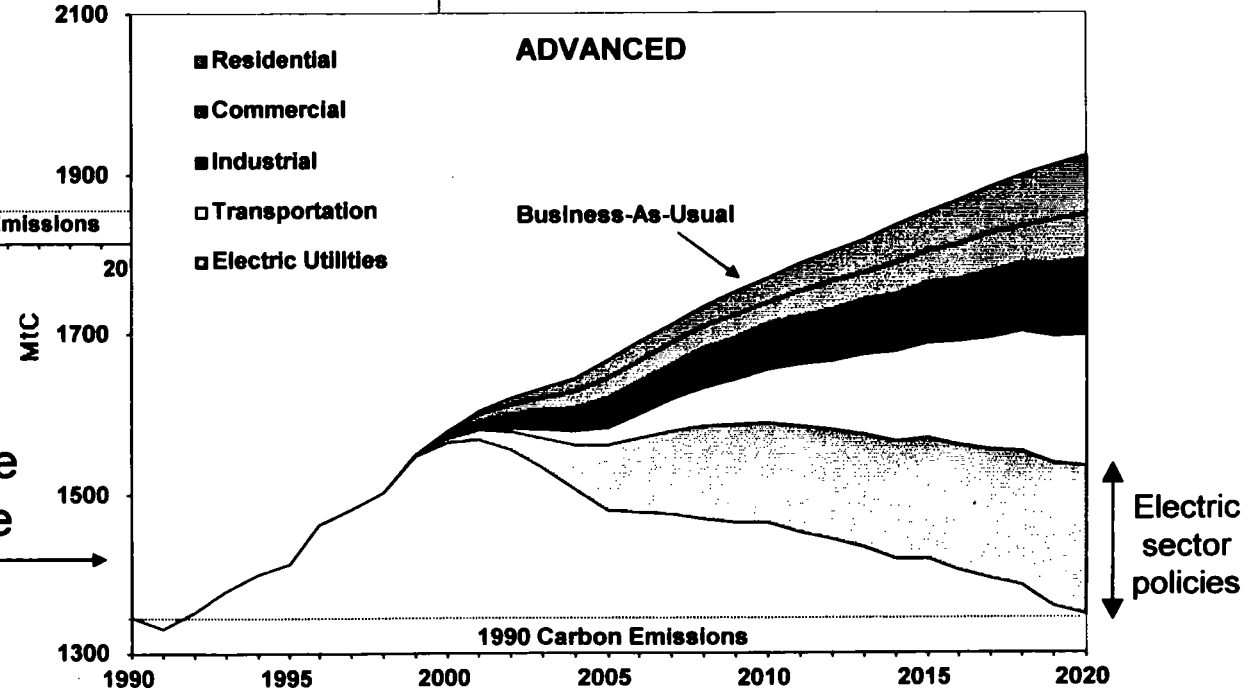
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Sectoral Contributions to Carbon Reductions



Reliance on R&D delays carbon reductions from the transportation sector, but by 2020 emission reductions are large.

Electric sector policies account for a third of the carbon reductions in the Advanced scenario.



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Costs and Benefits

- Premises of study:
 - Market failures and barriers prevent the efficient provision of energy services.
 - Policies can serve to ameliorate this.
 - Nonetheless, energy price changes can have macroeconomic costs associated with them.
- Current models not designed to address both issues.
- Approach:
 - Estimate net (direct) costs and savings from individual policies utilizing CEF-NEMs.
 - Utilize a meta evaluation of Energy Modeling Forum results to reflect (indirect) macroeconomic effects of changes in energy prices.

Estimation of Net Direct Savings in 2010

(units: Billions US \$)

Moderate Scenario		Advanced Scenario	
Energy bill savings:	+\$55	Reduced energy costs:	+ \$89
Investment costs:	- \$11	Carbon permit costs:	<u>- \$73</u>
Program costs:	- \$4	= Energy Bill Savings:	+\$16
Recycle of carbon charge revenues to public	<u>\$0</u>	Investment Costs:	-\$30
Net Direct Savings:	+\$40	Program Costs:	-\$12
		Recycle of carbon charge revenues to public*	<u>+\$71</u>
		Net Direct Savings:	+\$46
		* Adjusted for loss of consumer/producer surplus	

Adding Indirect Costs

(units: billions US \$)

Moderate Scenario

Net Direct Savings: **+\$40**

Est. macro-
economic impact: ---

Net Savings: **+\$40**

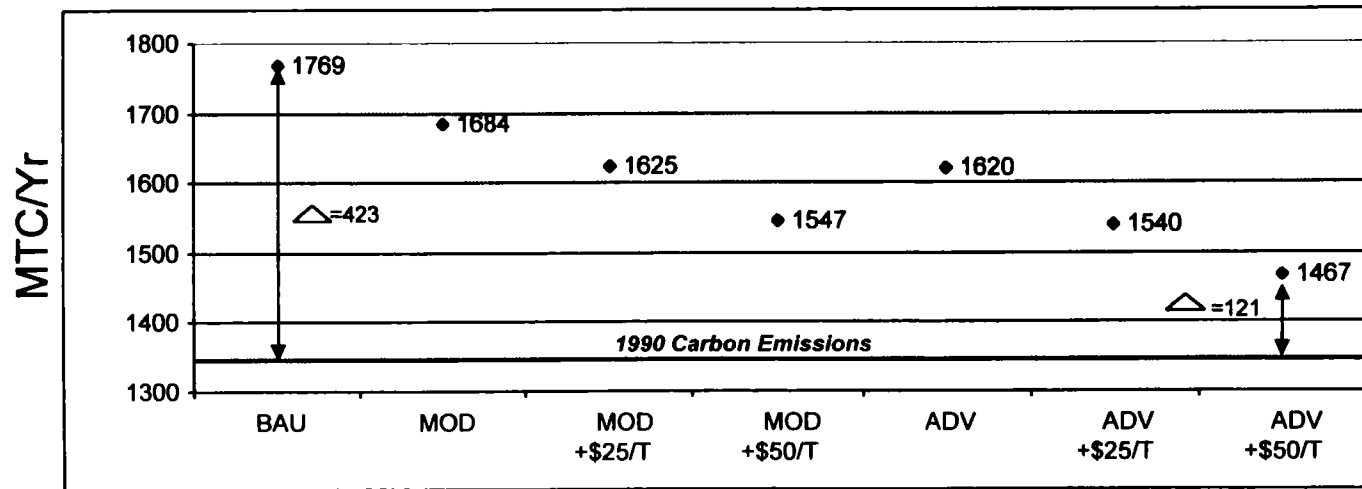
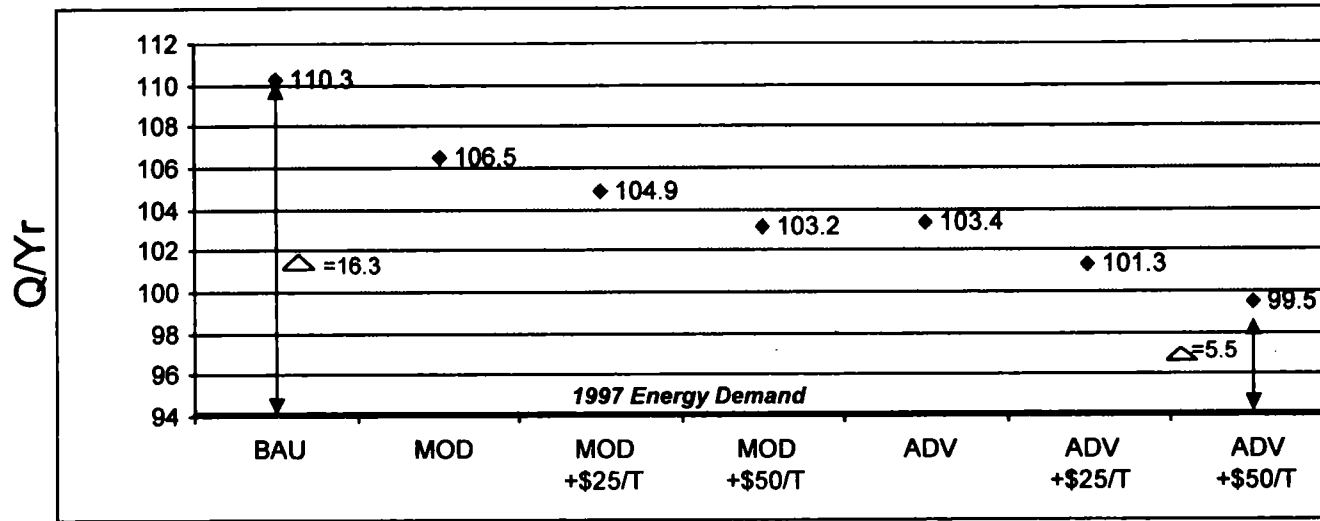
Advanced Scenario

Net Direct Savings: **+\$46**

Est. macro-
economic impact: -\$30 to -\$40

Net Savings: **+\$6 to \$16**

Sensitivity Cases for 2010



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Insights & Conclusions to Date

- Success in implementing the CEF policy pathways would significantly reduce:
 - ⇒ energy costs,
 - ⇒ oil dependence,
 - ⇒ air pollution, and
 - ⇒ carbon dioxide emissionsat essentially no net cost to the U.S. economy.
- By 2020 CEF policies drive CO₂ emissions to 1990 levels (9% above 1990 levels in 2010).
- The strong performance of energy-efficient technologies limits opportunities for clean energy supply options through 2020.

FROM
FUELS?
OR WCCVONG
SINKS?

Insights & Conclusions to Date (cont.)

- Macroeconomic studies suggest that the costs associated with energy price changes due to carbon permits are on the order of, or smaller than, the direct savings.
 - ⇒ The strong growth of “green” industries could create new employment opportunities. *wind, CHP, fuel cell*
 - ⇒ Additional policies may be needed to ameliorate transition impacts such as reduced coal and rail employment.
- Large uncertainties are inherent in policy assessment, but the existence of a range of supply and demand “backstop” technologies increases confidence in results.

Policy Insights

- The CEF policies have positive synergisms:
 - R&D, restructuring, renewable production tax credits
 - Voluntary agreements & information/ technical assistance
- Time matters
 - Policy implementation
 - R&D and stock turn over
- Additional/stronger policy opportunities exist
 - CEF policy sets modeled were selected through peer consultation
 - Additional or quicker savings possible through additional or stronger policies

Scenarios for a Clean Energy Future

Overview and Preliminary Findings

Washington, DC ~ September 1, 1999

Dr. Marilyn A. Brown
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OVERVIEW AND PRELIMINARY FINDINGS

Goal of the Clean Energy Future Study

To produce fully documented scenarios assessing how energy efficient and clean energy technologies can address key energy and environmental challenges of the next century while enabling continued economic growth.

The scenarios are “driven” by sets of public policies and programs that are designed to be credible, flexible, and low-cost mechanisms for fostering energy technology solutions, with an emphasis on climate change issues.

OVERVIEW AND PRELIMINARY FINDINGS

Two scenarios are modeled.

They reflect increased levels of national commitment to energy and environmental goals.

(1) **Moderate Scenario:** national commitment to address these goals if costs can be kept low.

- assumes some shift in political will & public opinion
- excludes fiscal policies that involve taxing energy, directly or indirectly

(2) **Advanced Scenario:** nationwide sense of urgency to meet significant energy and environmental goals.

- more vigorous fiscal and non-fiscal policies
- includes a domestic carbon cap and trade system with assumed permit price of \$50/tC.

OVERVIEW AND PRELIMINARY FINDINGS

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OVERVIEW AND PRELIMINARY FINDINGS

Illustrative Buildings Policies

Moderate Scenario	Advanced Scenario
➤ Implement new efficiency standards for equipment beyond those already planned.	➤ More end-uses covered by standards
➤ Increase enforcement and adoption of current building codes (Model Energy Code and ASHRAE 90.1R)	➤ Same, but adding a new more stringent residential building code in 2009 that is gradually adopted by states in preference to the less stringent codes that already exist
➤ Expand voluntary labeling and deployment programs such as Energy Star, Building America, Rebuild America	➤ More penetration, more end-uses covered
➤ Implement tax credits as proposed by Clinton Administration (e.g., \$1,000 tax credit for new homes that are at least 30% more energy efficient than the International Energy Conservation Code, through 2004)	➤ Same credits but with longer time periods before phase out. Size of tax credit increased for heat pump water heaters as well

OVERVIEW AND PRELIMINARY FINDINGS

Illustrative Building Policies (continued)

Moderate Scenario	Advanced Scenario
➤ Expand cost-shared, federal R&D expenditures by 50%	➤ Double cost-shared, federal R&D expenditures. More end-uses covered, more advanced technologies
➤ Line charges for states implementing electricity restructuring (full national restructuring in 2008)	➤ Higher line charges
➤ Government procurement assumed to increase in scope over current efforts. Increase Federal Energy Management Program (FEMP) efficiency goals by executive order. Adopt renewable power purchase requirement for Federal facilities.	➤ Significant efforts beyond moderate case, including more rapid implementation of FEMP efficiency goals and faster expansion of Energy Star purchasing to state and local governments as well as large corporations. Adopt more stringent renewable power purchase requirement for Federal facilities.
	➤ Domestic carbon cap and trade system with assumed permit price of \$50 per metric ton of carbon, announced in 2002 and implemented in 2005.

OVERVIEW AND PRELIMINARY FINDINGS

Illustrative Industrial Policies

Moderate Scenario	Advanced Scenario
➤ Build upon existing voluntary agreements with associations and companies to achieve an energy efficiency improvement of 0.5% per year over the business-as-usual scenario	➤ Build upon existing voluntary agreements with associations and companies to achieve an energy efficiency improvement of 1.0% per year over the business-as-usual scenario
➤ Information and technical assistance: expanded Challenge programs, expanded labeling programs for industrial buildings and products	➤ Information and technical assistance: expanded Challenge programs to smaller companies and activities, expanded labeling to cover greater industrial floor space and additional products
➤ Regulation: Mandate upgrades of all motors to EPACT standards by 2020	➤ Regulation: Mandate upgrade of all motors to Consortium for Energy Efficiency standards by 2020

OVERVIEW AND PRELIMINARY FINDINGS

Illustrative Industrial Policies (continued)

Moderate Scenario	Advanced Scenario
➤ Investment enabling: Clean Air Partnership and line charges expanded to 30 states, provide tax rebates of 50% of the salary of 5,000 energy managers by 2020	➤ Investment enabling: Extended Clean Air Partnership and line charges expanded to 50 states, provide tax rebates of 50% of the salary of 10,000 energy managers by 2020
➤ CHP Policies: CCTI tax credits, expedited siting and permitting, interconnection standard in 2002	➤ CHP Policies: Extend tax credits beyond 2003, increase state grants through Clean Air Partnership Fund, further reduce expense associated with interconnection
➤ Expand cost-shared federal R&D expenditures by 50%; increase industries-of-the-future effort and cross-cutting industrial efficiency R&D programs	➤ Double cost-shared federal R&D expenditures: include new industries-of-the-future effort and further expand cross-cutting industrial efficiency R&D programs
	➤ Domestic carbon cap and trade system with assumed permit price of \$50 per metric ton of carbon, announced in 2002 and implemented in 2005.

OVERVIEW AND PRELIMINARY FINDINGS

Illustrative Transportation Policies*

Moderate Scenario	Advanced Scenario
➤ Expand cost-shared, federal R&D expenditures by 50% (e.g., achieving 7.4 mpg for heavy trucks in 2020)	➤ Double cost-shared, federal R&D expenditures (e.g., achieving 7.9 mpg for heavy trucks in 2020)
➤ Implement vehicle purchase tax credits as proposed in the CCTI (e.g., \$2,000 credit for vehicle that is two-thirds more fuel efficient than a comparable vehicle, for purchases in 2003 through 2006)	➤ Tax credits are extended
➤ Acceleration of air traffic management improvements	➤ Same

*A side analysis examines the potential reduction in vehicle miles of travel from policies that alter (1) the spatial pattern of traffic generating infrastructure, (2) the nature of transportation infrastructure supply, and (3) travel demand within a given urban infrastructure.

OVERVIEW AND PRELIMINARY FINDINGS

Illustrative Transportation Policies

(continued)

Moderate Scenario	Advanced Scenario
➤ Accelerated cellulosic ethanol program	➤ Same
➤ Invigorated government fleet program promoting alternative fuels and efficiency	➤ Same, with more rigorous requirements
	➤ Voluntary agreements for light-duty vehicles (40 mpg autos, 30 mpg light trucks in 2010; 50 mpg autos, 35 mpg light trucks in 2020)
	➤ "Pay-at-the-pump" automobile insurance
	➤ Domestic carbon cap and trade system with assumed permit price of \$50 per metric ton of carbon, announced in 2002 and implemented in 2005.

OVERVIEW AND PRELIMINARY FINDINGS

Illustrative Electricity Policies

Moderate Scenario	Advanced Scenario
➤ Wind deployment facilitation (e.g., to facilitate siting on Federal land, to design operator protocols to accommodate wind intermittency)	➤ Same
➤ 1.5¢/kWh production tax credit for the first 10 years of operation for wind and biomass power installed through 2004.	➤ Same, for all non-hydro renewable electricity options
➤ 1¢/kWh credit for biomass cofiring during the years 2000-2004 (not yet implemented)	➤ Same
➤ Enhanced R&D – represented by the technology cost and performance assumptions of the AEO99 high renewables and high fossil cases	➤ Limited additional technology advances for renewable and fossil technologies

OVERVIEW AND PRELIMINARY FINDINGS

Illustrative Electricity Policies (continued)

Moderate Scenario	Advanced Scenario
➤ Up to 1% net metering.	➤ Up to 5% net metering.
➤ Full national restructuring of the electricity industry in 2008, resulting in marginal cost pricing, lower reserve margins, etc.	➤ Same
	➤ SO ₂ ceiling reduced in steps by 50% between 2010 and 2020 to represent tighter particulate matter emission standards.
	➤ Domestic carbon cap and trade system with assumed permit price of \$50 per metric ton of carbon, announced in 2002 and implemented in 2005.

OVERVIEW AND PRELIMINARY FINDINGS

Energy Use in the Advanced Scenario

- By the end of the first decade of aggressive policies, energy use in buildings and industry is declining.
- Transportation is the only sector that increases between 1997 and 2010. All sectors decrease in the second decade.

OVERVIEW AND PRELIMINARY FINDINGS

Sources of Energy in the Advanced Scenario

- A significant shift away from coal consumption occurs by 2020.
- Natural gas demand grows, but slower than in the BAU scenario.
- Petroleum use decreases relative to the BAU.
- Non-hydro renewables increase relative to BAU.
- Nuclear power remains steady over the 20 years, compared to an accelerating decline in the BAU.

OVERVIEW AND PRELIMINARY FINDINGS

Carbon Emissions in the Advanced Scenario

There are much greater reductions in carbon emissions than in energy use.

- Carbon emissions in 2020 are down to 1990 levels.
- Carbon emissions, from electric utilities, in 2020 are half of the BAU forecast.
- The transportation sector contributes least to these reductions, partly because the carbon content of its fuels declines only slightly.

OVERVIEW AND PRELIMINARY FINDINGS

Key Policies and Technologies

Residential Buildings: End uses with the greatest energy and carbon savings are “all other,” space heating, water heating, and cooling.

End-Uses:	1990 Q	1997 Q	2010			2020		
			BAU Q	Advanced Q	% Δ	BAU Q	Advanced Q	% Δ
Space heating	5.1	6.9	6.9	6.6	-4.1%	7.1	6.6	-8.2%
Space cooling	1.7	1.5	1.6	1.4	-17.1%	1.7	1.2	-28.7%
Water heating	2.4	2.6	2.7	2.3	-13.4%	2.8	2.2	-20.0%
Refrigerators/ freezers	2.2	1.6	1.1	1.0	-8.4%	1.0	0.8	-21.4%
Lighting	1.0	1.1	1.2	1.0	-15.1%	1.3	0.9	-29.9%
All other	4.4	5.3	7.6	6.6	-13.4%	8.9	6.3	-29.5%
Total	16.7	19.0	21.1	18.9	-10.5%	22.8	18.0	-21.3%

OVERVIEW AND PRELIMINARY FINDINGS

Key Policies and Technologies

Commercial Buildings: End uses with the greatest energy and carbon savings are “all other” and lighting.

End-Uses:	1990 Q	1997 Q	2010			2020		
			BAU Q	Advanced Q	% Δ	BAU Q	Advanced Q	% Δ
<i>Commercial</i>								
Space heating	1.9	1.9	1.9	1.8	-8.3%	1.9	1.7	-11.1%
Space cooling	1.8	1.1	1.1	0.9	-16.6%	1.0	0.8	-24.2%
Water heating	1.1	0.9	0.9	0.8	-11.1%	0.9	0.8	-11.2%
Office equipment	0.6	1.3	1.9	1.8	-4.8%	2.2	2.1	-5.9%
Lighting	3.7	3.9	3.8	3.2	-15.3%	3.7	2.8	-24.9%
All other	3.8	6.1	7.6	6.7	-11.5%	8.2	6.4	-21.8%
Total	13.0	15.2	17.2	15.2	-11.6%	18.1	14.6	-19.0%

OVERVIEW AND PRELIMINARY FINDINGS

Key Policies and Technologies

Industrial:

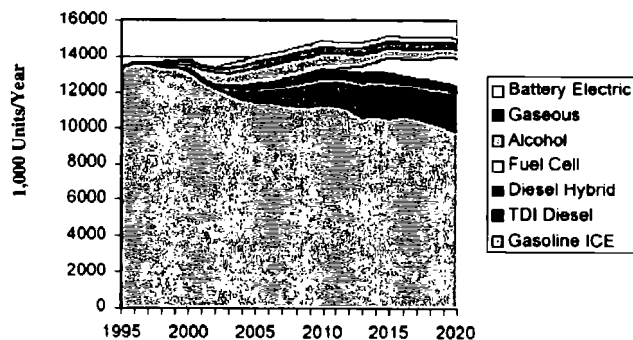
- Voluntary agreements
- Crosscutting technologies: Combined heat and power, preventive maintenance, pollution prevention, waste recycling, process control, stream dist., motor and drive system improvements
- Numerous subsector-specific technologies

OVERVIEW AND PRELIMINARY FINDINGS

Key Policies and Technologies

Transportation: Hydrogen fuel cell vehicles and TDI diesels play a major role by 2020.

Figure 6.10 Sales of New Light-Duty Vehicles by Technology: Advanced Scenario



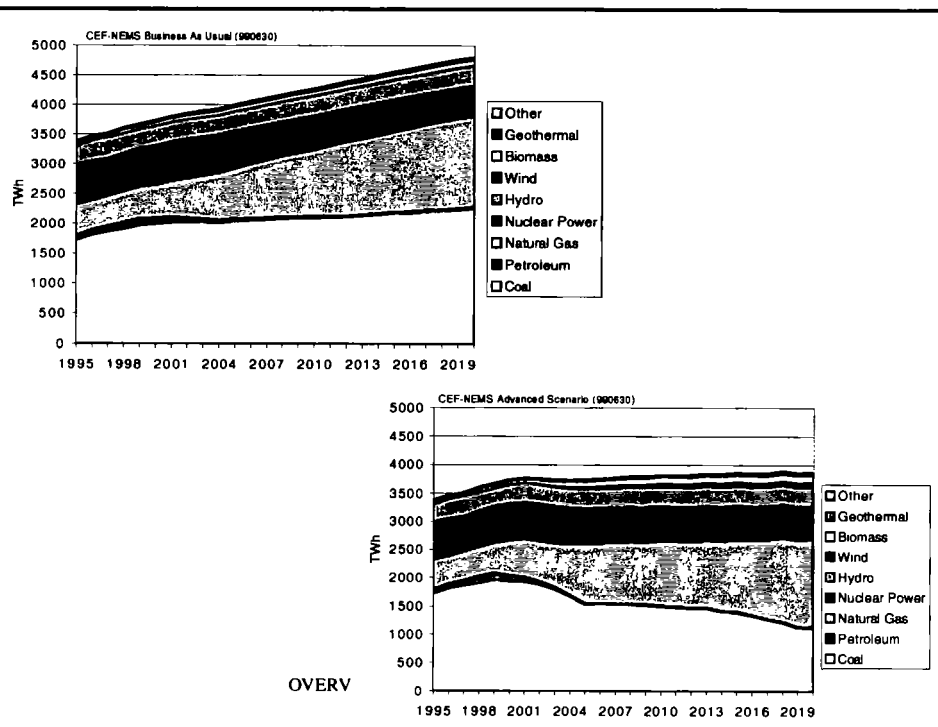
OVERVIEW AND PRELIMINARY FINDINGS

Key Policies and Technologies

Electricity:

- Policies: domestic carbon cap and trade system, restructuring, production tax credit
- Technologies: natural gas combined cycle plants, wind power, nuclear relicensing

OVERVIEW AND PRELIMINARY FINDINGS



Energy Prices

- The Moderate Scenario results in lower energy prices relative to BAU in 2010 and 2020.
- The Advanced Scenario results in higher energy prices relative to BAU in 2010 and 2020.
- When the carbon charge is treated as a transfer payment, these prices resemble the Moderate Scenario.

OVERVIEW AND PRELIMINARY FINDINGS

Costs

Two types of “direct costs” are estimated.

- Incremental technology investment costs
 - in the end-use sectors, this is the annualized additional technology investment required to purchase the more efficient equipment or energy service.
 - in the power sector, incremental technology investment costs are reflected in electricity prices.
- Policy implementation and administration costs
 - the costs of administering the public policies and programs.
 - the incremental R&D costs (both the federal appropriations and the matching private-sector R&D resources).
 - the production tax credit for renewable resources.

OVERVIEW AND PRELIMINARY FINDINGS

Energy Bill Savings and Net Direct Costs

- Energy bill savings are a function of changes in:
 - energy prices, amounts of energy consumed, & types of energy used.
- It appears that energy bill savings will exceed (or approximately equal) direct costs in both decades and for both Scenarios.

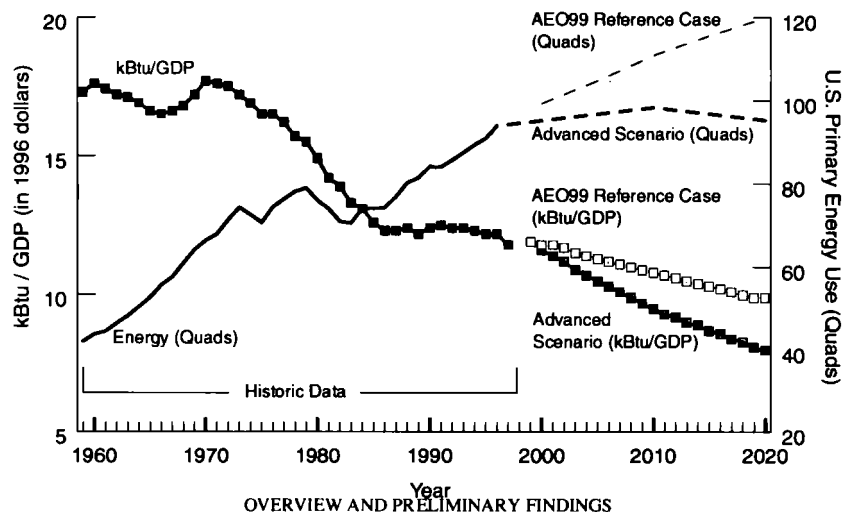
OVERVIEW AND PRELIMINARY FINDINGS

Macroeconomic Costs

- Premise:
 - Large-scale market and organization failures and transaction costs prevent consumers and firms from obtaining energy services at least cost.
 - Policies exist that can correct these market failures and reduce transaction costs.
- Conclusion:
 - A Pareto improvement is available from these policy measures.
 - Whatever the inter-sector shifts or temporary adjustments in factor markets, the aggregate result is a gain in economic efficiency.

OVERVIEW AND PRELIMINARY FINDINGS

Figure 1.7 Energy/GDP Ratios



Other Benefits

- Both Scenarios reduce U.S. petroleum consumption and, hence, imports. Significant wealth transfers are thereby avoided.
- Improved oil security also results, by reducing oil imports and U.S. oil consumption.
- Another significant benefit is improved air quality. These are being quantified for the electric sector. With EPA assistance we hope to do a more complete analysis.
- The development of advanced energy technologies could expand the market share of U.S. companies in the vast global market for efficient and clean energy technologies.

OVERVIEW AND PRELIMINARY FINDINGS

Possible Sectoral and Regional Impacts of the Advanced Scenario

- The reduction in coal consumption would have negative consequences for the coal industry and related transportation sectors--rail and barge.
- The reduced demand for petroleum would negatively impact the domestic refining industry.
- The growth of wind power and bioenergy would create new employment opportunities.
- Other business opportunities would also develop (e.g., fuel cell and microturbine manufacturing).
- The viability of the U.S. nuclear industry would be strengthened.

OVERVIEW AND PRELIMINARY FINDINGS

Next Steps

- The following steps are being pursued to prepare the report for inter-agency review.
 - **Modeling and Analysis** - combined heat and power, cofiring tax credit, macro-economic impacts, etc.
 - **Sensitivities** - Natural gas prices, discount rates, development of ranges to represent uncertainty, etc.
 - **Report** - Addition of side bars to broaden context - the longer term view, the role of sequestration, international trading, the clean development mechanism, etc.

OVERVIEW AND PRELIMINARY FINDINGS

APPENDIX E-4: ESTIMATING BOUNDS ON THE MACROECONOMIC EFFECTS OF THE CEF POLICY SCENARIOS

by

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January 31, 2000

The purpose of this Appendix is a) to review the issue of macroeconomic (or “second-order”) effects that might occur under the types of scenarios analyzed in the CEF, and b) to present bounds on these effects that might be associated with the Moderate and Advanced scenarios as described in the CEF study. It should be noted that the term “macroeconomic” has been used in several, not always consistent, ways in this context. Beyond meaning “economy-wide” in general, “macroeconomic” has several connotations in contemporary economics. First, there is the Keynesian idea of short-run, disequilibrium dynamics, with particular emphasis on involuntary unemployment. A leading example of this approach is the DRI model. Second is the point of view that treats the entire economy in *microeconomic* terms, by assuming market equilibrium and completely rational consumers and firms. This paradigm underlies the “computable general equilibrium” models such as those of Jorgenson-Wilcoxon (1993), Goulder (1995), or Edmonds et al. (1992).¹ The calculations we present later will be based on the CGE models, because the conventional macroeconomic models are designed and suited for short-term forecasting rather than for projecting trends on scales of a decade or more as required for estimating the second-order effects of CEF policies through 2010 or 2020.

1. *The nature of the exercise*

The *Scenarios for U. S. Carbon Reductions* (or “5-Lab”) study (1997) was criticized, in part, for not considering what were generically referred to as “second-order feedback effects” that would result from the introduction of policies to accelerate the diffusion of energy efficiency in the U.S. economy. The implication of this line of criticism was that such effects, if properly estimated and included in the analysis, would qualify – perhaps substantially – the claim that no-cost or low-cost energy and carbon savings are possible on a large scale.

The economy-wide impacts of energy or carbon policies are unquestionably important in general, and no less so in the particular case of technology-oriented policies as envisioned

¹ For additional discussion of this model, see Fisher-Vanden et al. (1993), MacCracken et al. (1999).

(implicitly) in the 5-Lab study and (explicitly) in CEF. This point, however, should not obscure the purpose and methodology underlying the technology-based studies. The essential premise of the 5-Lab study and the CEF is that there are large-scale market and/or organizational failures, in addition to potentially substantial transactions costs, that prevent consumers and firms from obtaining energy services at least cost. The essential conclusion is that this general problem can, to a considerable extent, be overcome through policies that correct the market failures, induce positive organizational change, and reduce the transactions cost barriers to the diffusion of energy-efficient technologies.

Seen in this light, the point of these studies is that the economy is not on its aggregate production-possibilities frontier and that, at the aggregate level, a Pareto improvement is available through intervening in markets for energy services and by adopting other policy measures.² Hence, whatever inter-sectoral shifts, or temporary adjustments in factor markets, might take place as a result of the policies in question, *the aggregate result is a gain in economic efficiency*. Investments that show rates of return that are equal to or greater than the returns available on other investments of comparable risk are investments that contribute positively to macroeconomic performance.

We believe that the real issue behind the “macroeconomic-based” criticisms of the 5-Lab study was a disagreement with the premise that the economy might be inside its aggregate production frontier, and of the effectiveness of policies to overcome this situation, or both. While there are reasonable grounds for debate here, it is important not to confuse this dispute with the general problem of modeling general equilibrium aspects of the policies contemplated in the studies.

2. *Bounds on magnitude of potential macroeconomic effects.*

In light of the point made above, a way to combine results from CGE models with the findings of the technology-based studies such as the CEF is to account separately for movements *towards* the production possibilities frontier (as calculated by the bottom-up methodology) and movements *along* the production-possibilities frontier (as estimated by the CGE models). Here, the “production possibilities frontier” is an abstract representation of the fact that the economy jointly produces desirable products and services (“goods” of the kind measured by the GDP) as well as environmentally undesirable by-products (“bads” as indicated by carbon emissions, for example). “Good” outputs have a value, or price, in the market, while “bads” frequently are not priced by the market. When “bads” are priced along with “goods,” their prices are negative.³ In order to place bounds on the effect of the CEF policies on GDP alone, we suggest a thought experiment having three steps:

² There is a substantial economic literature measuring the divergence of firms and even countries from their production frontiers. For just one example of such a study of macro level data see Färe et al. (1994).

³ For an application of this approach in the context of production frontiers see Färe et al. (1993).

(1) Estimate the size of the GDP enhancement resulting from the policies of the CEF's Moderate Scenario. This scenario does not include any carbon charge, hence its economic effects are due entirely to its removal of market and organizational barriers to profitable investments and its lowering of transactions costs throughout the economy. These improvements in economic performance represent a pure gain to the economy, a gain that is possible because the economy is initially inside its production-possibilities frontier.

(2) After the Moderate Scenario's GDP increment has been realized, introduce the \$50/tonne carbon charge that is part of the Advanced Scenario, but include none of the other policies included in the Advanced Scenario. The literature on CGE models reports the results of various runs of those models with alternative carbon charges. Using these estimates, it is possible to calculate a predicted drop in GDP resulting from the carbon charge alone. The difference between the GDP gain of the Moderate Scenario and this estimated GDP loss from the carbon charge is a *lower bound* for the GDP gain that could be achieved from the Advanced Scenario, because none of the other productivity-enhancing policies of the Advanced Scenario is included in the calculation.

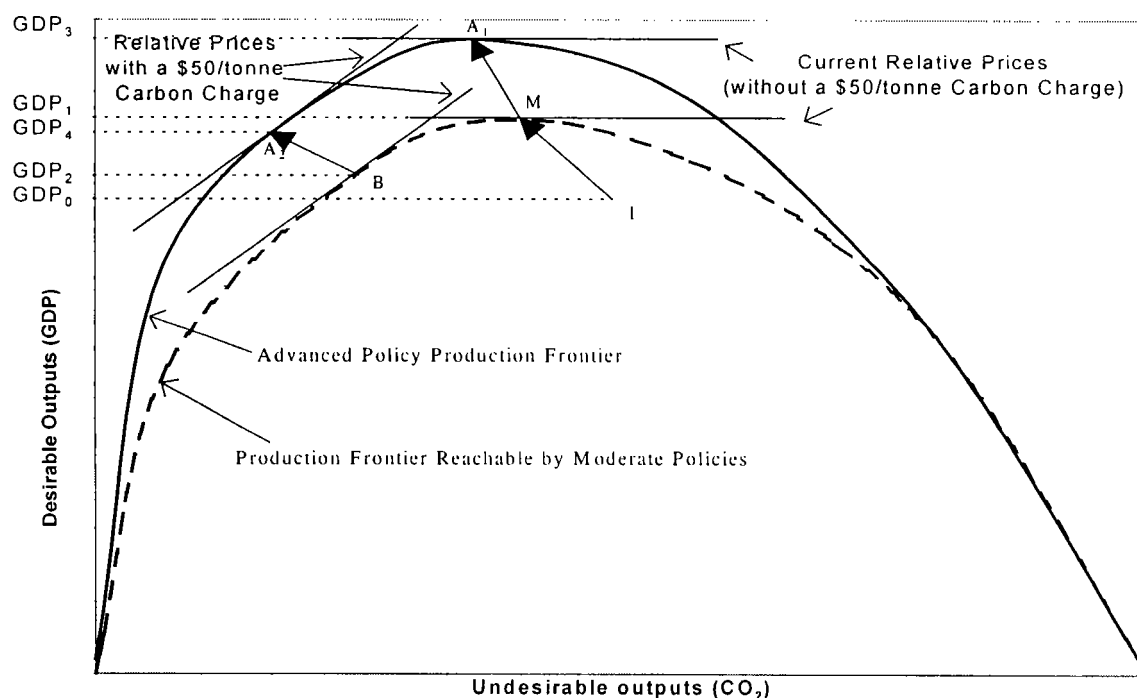
(3) The potential GDP gain from the Advanced Scenario depends on how the Net Direct Savings⁴ calculated for the Advanced Scenario are interpreted. The CEF Advanced Scenario includes technological change induced by the \$50/tonne carbon charge in addition to the effects of other policies that shift the production-possibilities frontier beyond what it is under the Moderate Scenario. This additional outward shift of the production-possibilities frontier could not be achieved without the carbon charge. However, the Net Direct Savings estimated by the CEF do not account for a possible shift along the production-possibilities frontier brought about by the carbon charge. (It is a premise of both the Moderate and Advanced scenarios that the energy services provided under the scenarios remain the same as in the baseline case.) Hence, the Net Direct Savings calculated under the Advanced Scenario are an upper bound for the GDP augmentation effect of the Advanced Scenario. Subtracting the same percentage GDP loss associated with the \$50/tonne carbon charge as in step (2) gives an intermediate estimate of the GDP gain under the Advanced Scenario.

This methodology is illustrated in Figure 1. This Figure displays the different possibilities in schematic form. The economy initially is at point I, inside the production-possibilities frontier that can be reached by the Moderate Scenario's policies. Implementation of the Moderate Scenario moves the economy to point M, with a corresponding increase in GDP from GDP_0 to GDP_1 . The line depicting "current relative prices" is tangent to the p-p frontier at M, and represents the current situation with no carbon charge. A \$50/tonne carbon charge shifts the relative price line and makes it

⁴ Net Direct Savings is defined as "[t]he difference between the energy bill savings and the direct costs (annualized incremental technology investment costs plus the program implementation and administration costs)" (CEF 1999).

upward sloping. The tangency of the new price line to the p-p frontier is at point B, which represents the best the economy can do under the Moderate Scenario but with a \$50/tonne carbon charge. GDP falls from GDP_1 to GDP_2 , reflecting the tradeoff between carbon emissions and GDP that comes about when there is a charge for carbon emissions.⁵ The points A_1 and A_2 represent the two possible interpretations of the Advanced Scenario. At A_1 there is no substitution of carbon reductions for GDP caused by the carbon charge, while at A_2 this substitution is taken into account.⁶ The Net Direct Savings of the Advanced Scenario is represented by the quantity $GDP_3 - GDP_0$, this quantity represents the upper bound on the GDP effect of the Advanced Scenario. The difference $GDP_4 - GDP_0$ gives the intermediate estimate of the GDP gain of the Advanced Scenario when substitution is taken into account.

Figure 1 –CEF Scenarios and Substitution Effects



⁵ Note that although measured GDP falls as the economy moves from M to B, economic *welfare* can improve because society values the additional environmental services that are obtained at point B. See DeCanio (1997) for a full discussion.

⁶ A recent study of productivity in OECD countries supports the notion that countries are inside their GDP - CO₂ production frontier and that this frontier has been shifting as shown during the decade of the eighties, see Boyd et al. (1998).

It remains to estimate the magnitude of the substitution effect resulting from implementation of the \$50/tonne carbon charge. In doing this, it is important to make a distinction between whether the revenue raised by the carbon charge is used to reduce other marginal tax rates or it returned to consumers in the form of lump-sum payments that do not affect marginal tax rates. It is well-understood that using the carbon charge revenues to reduce marginal tax rates will have a *less negative* effect on GDP than if the revenues are returned as lump-sum payments. In some models, the economic gains from a reduction in the marginal tax rates on capital and/or labor can even outweigh the distortionary losses caused by the carbon charge. This is the “double dividend” hypothesis, that a well-designed carbon charge may be able to boost economic performance even without accounting for the pollution-reduction benefits (Shackleton et al. 1992). In order to obtain the most conservative estimate of the GDP effect (that is, the largest substitution effect attributable to the increase in the carbon price), we based our calculation on the results obtained from lump-sum recycling of the carbon revenues.

In its 1995 Assessment, the IPCC Working Group III reports the results of a study conducted by the Stanford University Energy Modeling Forum that calculated 2010 GDP losses associated with different carbon charges, as estimated by the leading CGE models (IPCC 1996; EMF 1993). The model runs were standardized to reflect common assumptions about GDP growth, world oil prices, population projections, the oil and gas resource base, and the cost of backstop technologies. According to the IPCC, “[t]he harmonization of key exogenous inputs makes it possible to verify to what extent the disagreements were due to differences in methodologies and to understand better the economic meaning of these differences” (IPCC 1996, p. 305). These model runs are also comparable in that the modelers *assumed a lump-sum redistribution of the tax revenues*. Therefore, these estimates are upper bounds on the potential GDP losses associated with the carbon tax rates assumed in the runs. The results are summarized in Table 1, adapted from Table 9.4 of the IPCC Assessment (1996, p. 306).

**Table 1 - Comparison of Carbon Taxes and
Hypothetical Percentage GDP Losses in 2010**

Model	<u>Carbon tax (1990\$/tonne of C)</u>		<u>GDP Loss (% of GDP)</u>	
	Stabilization	20% Reduction	Stabilization	20% Reduction
CRTM	150	260	0.2	1.0
DGEM	20	50	0.6	1.7
ERM	70	160	0.4	1.1
Global 2100	110	240	0.7	1.5
Goulder	20	50	0.3	1.2
GREEN	80	170	0.2	0.9
MWC	70	180	0.5	1.1

Source: EMF (1993). Data points from the Fossil 2 model (which was one of those models included in the Energy Modeling Forum's comparison) were not included because Fossil 2 is not a CGE model. Note that both the "Stabilization" and the "20% Reduction" cases are relative to 1990 levels.

We employed two distinct methods to obtain an estimate of the effects of a \$50/tonne carbon charge.⁷ First, we regressed the GDP loss on the tax level for the stabilization case, and then calculated the predicted GDP loss for a \$50/tonne charge. The regression was constrained to pass through the origin, as required by the theory of the CGE models (i.e., that a zero carbon charge would produce no deviation from the 2010 GDP baseline).⁸ The estimated equation was

$$\Delta \% \text{ GDP} = -0.003953 T \quad (1)$$

(0.001419)

where $\Delta \% \text{ GDP}$ is the *percentage* change in GDP, T is the carbon tax in 1990 dollars/tonne, and the standard error of the estimated coefficient is in parentheses. The Probability-value of the estimated coefficient under the null hypothesis of no relationship is 0.0317.⁹ The 95% confidence interval for the coefficient is (-0.007426, -0.000481).

⁷ The timing of introduction of the carbon charge is important in calculating the loss of GDP associated with that charge in any particular year such as 2010. The EMF model runs incorporated, on average, steadily rising carbon taxes through 2010. This corresponds roughly to the phase-in schedule of the carbon charge in the CEF Advanced Scenario (IPCC 1996, p. 307).

⁸ Of course, the zero-intercept specification means that the standard R^2 measure no longer necessarily lies between zero and one, and is therefore not an appropriate indicator of the "goodness of fit" of the regression. The " R^2 " of equation (1) is indeed negative, but this does not affect the validity of the estimates of the coefficient of the tax rate and of the standard error of that coefficient. See Aigner (1971) for a discussion of R^2 when the intercept coefficient is constrained to be zero.

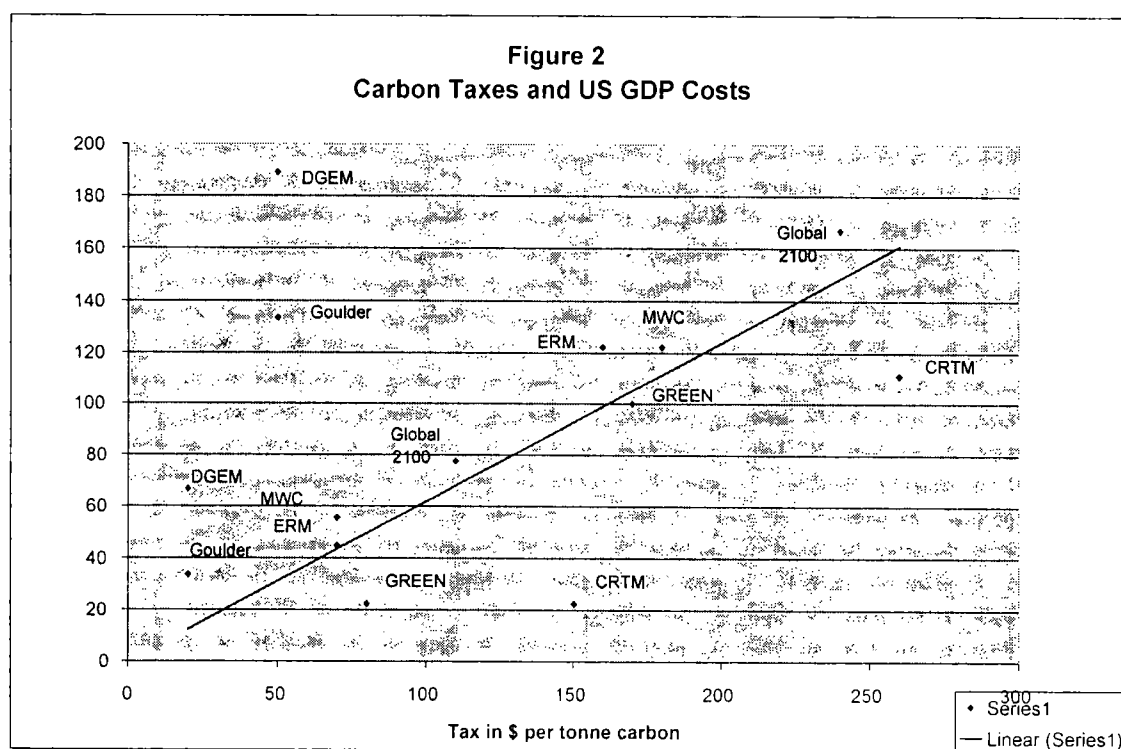
⁹ We used the stabilization case for estimating the relationship because that case is more comparable to the carbon reductions of the CEF scenarios than the 20% reduction (from 1990 levels) case. The observations for the stabilization case and the 20% reduction case are not independent because the same models were used to calculate both estimates. We also estimated the relationship between the carbon tax and the percentage GDP reduction from a two-equation model in which the stabilization case was represented by the first equation and the 20% reduction case by the second. We used the Zellner seemingly unrelated regression (SUR) estimation technique (Greene 1997; Quantitative Micro Software 1997) that allows the disturbances to be correlated across equations, thereby accounting for the fact that each model generated an observation for each of the two cases. The coefficients of the tax variable were constrained to be equal across the two equations. The result of this procedure was:

$$\Delta \% \text{ GDP} = -0.004761 T \quad (1a)$$

(0.001337)

with a probability-value under the null hypothesis of no effect of 0.0035.

Translating this estimated relationship into the effect of a \$50/tonne carbon charge (1997\$) on 2010 GDP requires first that the \$50/tonne charge (1997\$) be converted into the equivalent \$41.95/tonne carbon charge in 1990 dollars.¹⁰ The result is an estimated GDP loss of \$18 billion, with a 95% confidence interval of \$2 billion to \$35 billion (the 2010 GDP baseline figure is \$11123 billion from AEO99 as reported in CEF, Table 8.11).



The data in Table 1 are illustrated graphically in Figure 2. It is worth noting the relatively high GDP costs associated with both the Stabilization and 20% Reduction scenarios in the results from the DGEM and Goulder models. The explanation for this pattern is that these models embody a relatively higher responsiveness of the economy to a given level of carbon tax. This is seen by noting that, in these two models, the carbon tax levels required to achieve the reductions in the two scenarios are the lowest among the models represented.

Second, we used the two runs for each model reported by the EMF, plus the origin, to extrapolate a quadratic "GDP response curve" for each model indicating the expected response of GDP to various carbon tax levels. (Again, the GDP response curve must pass through the origin because, by construction, CGE models show no deviation of GDP from the baseline if no carbon tax is imposed.)¹¹ We then calculated the GDP loss

¹⁰ The price level ratio was that of the GDP deflator (Council of Economic Advisers 1999, Table B-3).

¹¹ The unique quadratic passing through the three points (0,0), (x_1, y_1), and (x_2, y_2) is given by the equation

associated with each model's GDP response curve for a tax of \$50/tonne.¹² The values are shown in Table 2, along with the mean and median estimates of the central tendency of the seven estimates.

Table 2 – Estimated 2010 GDP Loss (%) Associated with \$50/tonne Carbon Tax, GDP Response Curve Method, EMF-12 Data	
Model	Estimated GDP Loss (%)
CRTM	- 0.047610
DGEM	1.381274
ERM	0.224539
Global 2100	0.269450
Goulder	0.905491
GREEN	0.055320
MWC	0.310680
Mean	0.442735
Median	0.269450
Source: EMF-12 (1993); see text.	

Converting these percentage GDP losses to dollar amounts, this GDP response curve method yields an estimate of a \$49 billion GDP loss if the mean is taken as the estimator of the central tendency, and a \$30 billion loss if the median is used to estimate the central tendency. As noted above, the Goulder and DGEM models are the most sensitive to a given level of the carbon tax. Because of the dispersion of the estimates and the presence of outliers, the median may be a better estimator of the central tendency of these data.

We used both methods to estimate the effect of a \$50/tonne carbon charge on 2010 GDP using reported outputs of model runs from EMF-16. The EMF-16 runs calculated (among other things) the GDP effects of various carbon reduction scenarios, with the scenarios differing according to the extent of international trading in carbon permits. EMF-16 considered four scenarios: no trading, trading between Annex 1 countries only, the double bubble (which considers separate EU and rest of Annex 1 trading blocs), and

$$y = \left[\frac{y_1 x_2 - y_2 x_1}{x_1^2 x_2 - x_2^2 x_1} \right] x^2 + \left[\frac{x_1^2 y_2 - x_2^2 y_1}{x_1^2 x_2 - x_2^2 x_1} \right] x.$$

¹² As in the case of the regression method, the \$50/tonne carbon charge (1997\$) has to be converted to 1990\$ to make it compatible with the 1990\$ prices used in the EMF-12 runs.

full global trading (with the non-Annex 1 countries constrained to their reference case scenarios) (Weyant and Hill 1999). Each model generated a different marginal cost of carbon reductions (equivalent to an implicit carbon tax) associated with each of the scenarios. The EMF-16 results are summarized in Table 3.

Table 3: GDP Effects and Implicit Carbon Charges, Various Emissions Trading Scenarios

<u>Model</u>	<u>Implicit Carbon Charge, 1990\$</u>				<u>GDP Loss in 2010, billions of 1990\$</u>			
	No trading	Annex 1 trading	Double bubble	Global trading	No trading	Annex 1 trading	Double bubble	Global trading
ABARE-GTEM	\$322	106	100	23	\$182	75	71	19
MS-MRT	236	77	N/A	27	181	88	N/A	28
CETA	168	46	N/A	26	170	59	N/A	38
MERGE3	265	135	N/A	86	90	43	N/A	17
RICE	132	62	N/A	18	84	61	N/A	22
AIM	153	65	45	38	38	26	19	17
G-Cubed	76	53	28	20	35	20	- 4	5

Sources: EMF-16; Weyant and Hill 1999; Weyant 1999. The Oxford model was not included because it is not a CGE model. Some other EMF-16 model results are not listed because they did not calculate GDP effects.

Most of the EMF-16 modelers were “uncomfortable” about running the Full Global Trading scenario, because they did not believe it is a realistic outcome of the negotiating process, given the time remaining between now and 2010. Similarly, the No Trade scenario has carbon charges rising to a level that made the modeling teams “question whether the macro-economic constraints left out of most of the models...might lead to economic impacts that are on the order of the equilibrium impacts that are considered” (Weyant and Hill 1999, p. xxx). Hence, for our regression method estimate, we used the GDP change and the carbon tax levels from the Annex 1 trading scenario only (the Double Bubble scenario only has three data points). The estimated regression (where Δ GDP is the change in GDP and T is the implicit carbon charge) was

$$\Delta \text{ GDP} = -0.6113 \text{ T} \quad (2)$$

(0.1331)

with a Probability-value under the null hypothesis of no relationship of 0.003714. The 95% confidence interval for the estimated carbon charge coefficient was (-0.9369, -0.2857).¹³

Translating this into the 2010 effects of a \$50/tonne (1997\$) carbon charge yields an estimate of the GDP loss of \$31 billion. (No price level correction needs to be made because the regression relationship is linear in dollars.) The 95% confidence interval for the estimated effect is \$14 billion to \$47 billions of 1997 dollars.

To implement the GDP response curve method, we carried out the quadratic extrapolation using the Annex I trading and global trading scenarios as reported by EMF-16. (These are the scenarios with carbon tax levels that bracket or are close to the \$50/tonne level.) The results of this method, with mean and median estimates of the central tendency, are displayed in Table 4.

Table 4 – Estimated 2010 GDP Loss (1997\$) Associated with \$50/tonne Carbon Tax, GDP Response Curve Method, EMF-16 Data	
Model	Estimated GDP Loss (billion 1997\$)
ABARE-GTEM	22
MS-MRT	66
CETA	16
MERGE3	39
RICE	4
AIM	54
G-Cubed	55
Mean	37
Median	39
Source: EMF-16; see text.	

¹³ We also used the Zellner technique to estimate a 3-equation SUR model allowing for correlation of the disturbances across equations to account for the fact that the same models were used to calculate the estimates for the three scenarios (we did not include the Double Bubble scenario because of the paucity of data points for that scenario). Again, the coefficients of the tax variables were constrained to be equal across the three equations. The resulting estimate was

$$\Delta \text{ GDP} = -0.5530 \text{ T} \quad (2a)$$

(0.0525)

with a Probability-value under the null hypothesis less than 0.0001.

Finally, these estimated GDP losses by the two methods (and from each of the two EMF samples) can be compared to the GDP *gain* from the Moderate and Advances Scenarios as calculated by the CEF (Table 8.9). The net result is that the gain in GDP brought about by the efficiency-improving policies of the Moderate Scenario offsets or is roughly equal to the potential loss of GDP caused by the substitution induced by the \$50/tonne carbon charge. The effect of the Advanced Scenario and the substitution effect combined is a slight GDP gain. The comparisons are shown in Table 5.

Table 5 – Estimated GDP Changes from Different Policy Combinations				
Change Estimated (in Notation of Figure 1)	GDP Change (billions of 1997\$)			
	<i>Regression Method</i>		<i>GDP Response Curve Method</i>	
	EMF-12 Sample	EMF-16 Sample	EMF-12 Sample (Median)	EMF-16 Sample (Median)
$GDP_1 - GDP_0$ (CEF Moderate Scenario)	\$ 40	\$ 40	\$ 40	\$ 40
$GDP_2 - GDP_1$ (GDP Substitution Effect)	- 18	- 31	-30	-39
$GDP_2 - GDP_0$ (CEF Moderate + Substitution)	22	9	10	1
$GDP_3 - GDP_0$ (CEF Advanced Scenario)	47	47	47	47
$GDP_4 - GDP_0$ (CEF Advanced + Substitution)	29	16	17	8
Source: See text, Figure 1.				

The Advanced Scenario projects Net Direct Savings in 2010 of \$47 billion. Thus, the net GDP gain after accounting for macroeconomic substitution effects lies between \$1 billion (the lower of our two estimates of $GDP_2 - GDP_0$) and \$47 billion (the estimate of the GDP gain from the Advanced Scenario without any GDP substitution effect). If substitution between carbon reductions and GDP under the Advanced Scenario is calculated using the regression estimates, the GDP gain in the Advanced Scenario will be \$16 billion or \$29 billion, depending on which regression coefficient is used. If the median is used to measure the central tendency from the GDP response curve method, the GDP gain under the advanced scenario will be between \$8 billion and \$17 billion, depending on which EMF sample is used to calculate the response curves.¹⁴

¹⁴ If the means of the response curve estimates are used, the GDP gain under the Advanced Scenario would be either – \$2 billion (a loss of \$2 billion) or \$10 billion, depending on whether the EMF-12 mean or the EMF-16 mean is used.

3. Relative size of CEF investments

It is worth pointing out that, as a practical matter, the magnitude of the potential economy-wide energy-efficiency investment contemplated in CEF is small relative to aggregate total investment. The annual total cost (Annualized Incremental Investment Costs + Program Costs) of the Moderate Scenario is \$13 billion in 2010 and \$36 billion in 2020 (1997\$). The annual total cost of the Advanced Scenario is \$35 billion in 2010 and \$78 billion in 2020. By comparison, the AEO99 reference case projects Real Investment at annual rates of \$2011 billion in 2010 and \$2508 billion in 2020 in 1997 dollars, converting the 1992 dollars of the AEO99 reference case to 1997 dollars using the 1997 chain-type price index for Fixed Gross Private Domestic Investment (FGPDI) of 1.0445 (AEO99, Table 20; Council of Economic Advisers 1999, Table B-7). Thus, the CEF scenario costs range between 0.6% (2010, Moderate Scenario) and 3% (2020, Advanced Scenario) of projected total Real Investment. The ratios indicate that the investments induced by the CEF policies are quite small relative to total investment, and that any second-order macroeconomic effects resulting from CEF policies would be swamped by other sources of macroeconomic fluctuation.

4. Transitional Effects and the role of the Fed

Finally, the CGE models upon which the above calculations are based assume clearing of labor markets: there is, there is no unemployment in these models even though employment in particular sectors may rise or fall. While this is clearly an idealization, it is the case that any unemployment during the transitional adjustment to carbon-reducing policies would be of short-run duration, and its magnitude would depend on (among other things) Fed policy. If, for example, it were to be the case that implementation of the CEF policies had an initial impact of slowing the economy's expansion, the Fed might react by doing nothing (if it had been intending to impose economy-slowng policies absent the CEF policies) or by loosening monetary policy (if the Fed had been satisfied with the growth and price-level performance of the economy prior to the CEF policies). It is unrealistic to think that the Fed would not be cognizant of CEF policies, should those policies have any kind of short-run macroeconomic impact. No one can predict exactly what the Fed would do under various circumstances, but it is reasonable to assume that the Fed would act to offset any perturbation of aggregate employment that might be set off by CEF policies.

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The Uses and Misuses of Technology Development as a Component of Climate Policy

Henry D. Jacoby

INTRODUCTION

The search for low-carbon technology for the long run must be a central element in the global response to the threat of climate change. Unfortunately, actions taken by both the U.S. Congress and the Administration run the risk of crippling the U.S. effort to explore this avenue, in effect throwing out the baby with what is perceived by some to be policy bath water. In its current focus on short-term Kyoto-type emissions targets, and Congress's reaction to the process, the United States is wasting time and effort that could be applied to the search for cost-competitive, low-carbon ways of powering the modern economy. This is a tragic mistake. At the heart of the problem is a push for a short-term technical fix, driven by domestic political exigencies and unfortunately supported by badly flawed analyses of the process of technical change. The focus of this paper is one widely cited study of technology options by five U.S. national laboratories, and the uses and misuses of this work as a guide to policy.

Failure to harness technology development intelligently in response to the climate issue could have serious consequences. Although the possible magnitude of potential change is very uncertain, the risk of human influence appears substantial. Our own analysis at the Massachusetts Institute of Technology (Prinn et al. 1998) shows that the range of possible outcomes over the next century is very wide. We only partially understand climate system behavior, and our ability to forecast economic growth and technical change, and the resulting greenhouse emissions, is limited as well. Our understanding of the ecosystem effects of rapid climate change

is even weaker. The magnitude of the combined uncertainties is so great that the problem could prove either not so important as we imagine, or much worse. Thus, whatever one's position regarding the current conflict over near-term emission controls, we should, in my view, be able to agree that we are taking considerable risks with global climate in the long term.

Unfortunately, even the emergence of universal consensus that the problem is serious, and that something dramatic should be done, may not lead to meaningful action. Nations have very different interests and priorities. A treaty that could meet the needs of each, and suppress the incentive for free-riding, is difficult to formulate even as a theoretical exercise, much less to negotiate among dozens of nations. In principle, rich countries could use various forms of foreign aid, trade in emissions permits, or other side payments to gain the participation of holdouts, but the amounts of money that would be needed are very large in relation to anything seen before, or to what would seem politically feasible.

It may well be, therefore, that the key to future response capability is the development of low-carbon energy supply technologies that can compete head-to-head with conventional fossil-fuel burning, and use technologies that can deliver the same services as today with much lower energy input. We do not have these options in hand now, and their development is a long-term, multi-decade process. Moreover, at least within the next few decades we cannot look to resource depletion to have a substantial effect on the prices of conventional fossil fuels, allowing market penetration by today's relatively costly alternatives. Thus, a shift of limited R&D resources and managerial and political attention to short-term policy targets may come at the cost of long-term technical developments, to our considerable regret in the future. Unfortunately, in recent months a few prominent technology studies have lent support to just this outcome.

TWO APPROACHES TO ANALYZING EMISSIONS CONTROL POLICY

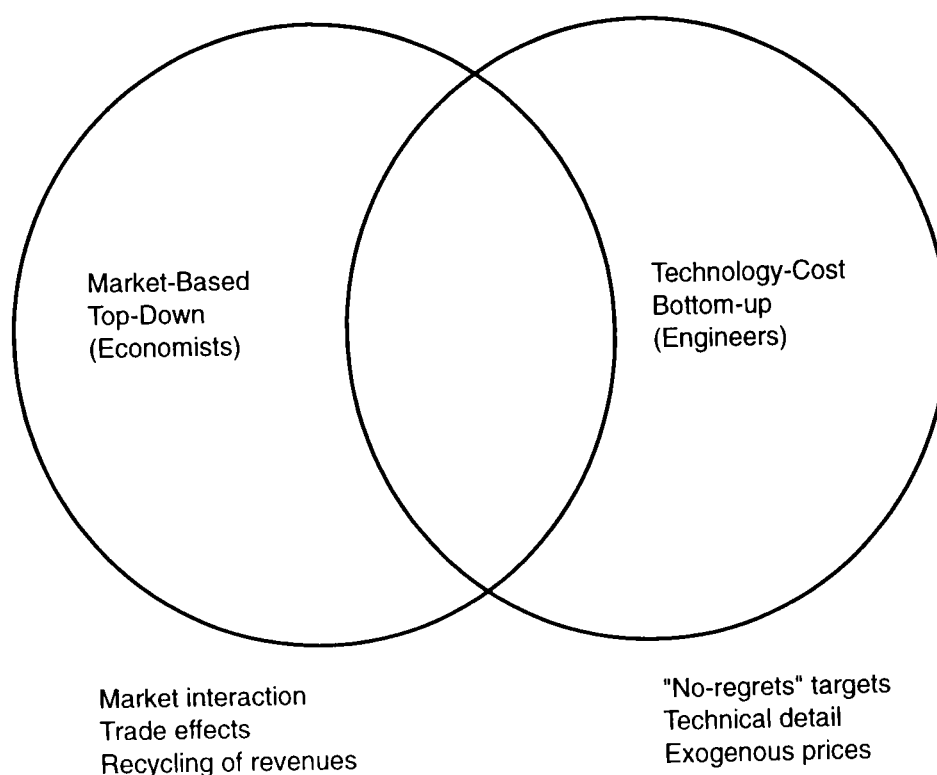
To provide a context for discussion of these studies, it is helpful to have a map of the methods usually applied to studies of emissions control. As illustrated in Figure 1, they fall into two rough categories, each encompassing a rich variety of detailed methods. As the figure suggests, some analytical efforts involve a mix of the two so that the categories overlap, but the distinction nonetheless remains a useful one.

One approach, usually carried out by economists, might be called "market-based." Its concern is with how markets respond under assumed policy intervention, and the essential question is, "At what price?" That is, the focus is on market price as the essential mechanism through which policy acts. Frequently, this approach also is referred to as "top-down" analysis, meaning that it encompasses

the economy as a whole (or at least a number of interacting sectors), and it analyzes the interplay of policies within this larger system. The most common alternative is "technology-cost" analysis. Often associated with studies dominated by engineers, its essential question is, "At what cost?" Its focus is on estimation of the cost of particular supply technologies and/or end-use devices, and comparison of these costs with reduced energy expenditures and other environmental benefits. It is frequently referred to as "bottom-up," in that assessment of a policy involves the adding up of energy savings or emissions reductions from various technologies, each considered independently.

Each of these two approaches to analysis has its strengths and weaknesses. Market-based methods take account of interactions in the markets for intermediate and final goods and inputs to production such as capital, labor, and natural resources, and they can take explicit account of consumer preferences and how they change with increasing wealth. They can consider the fiscal effects of policy measures such as carbon taxes or permit auctions. They also can be formulated to reflect the ways that policy impacts are mediated through international trade. In short, they can be designed to consider the side effects, spillovers, and feedbacks

Figure 1 Different Approaches to Control Cost



that flow from a policy change, the so-called "general equilibrium" adjustment of the economy.

There is a trade-off, of course. Gaining multi-sector, multi-region interactions requires a sacrifice in technical detail, through the need to use simplified representations of production processes and to aggregate industrial sectors. However, for an economic change as large as the emissions reductions under the Kyoto Protocol, these market interactions are crucial, and so these market-based methods offer significant advantages for addressing the implications of such a commitment.

The chief advantage of the technology-costing methods, naturally, is their technical detail, which makes it possible to study specific cases where markets may not be working efficiently, and to guide expenditures on technology research and development to the areas of greatest payoff. To gain this detail they usually must assume prices of energy and other key inputs rather than analyze them, and omit consideration of the many substitutions that take place among goods and processes in response to any policy action.

If done well, studies following a technology-costing approach can offer insight into larger economy-wide questions, like the implications of climate agreements. In the attempt, however, these studies frequently encounter one of several pitfalls, which can make them positively misleading as a guide to broad policy. Three of these are of particular relevance to this discussion.

Pitfalls of Technology-Costing

Confusion of Market Failures With Other Market Barriers.

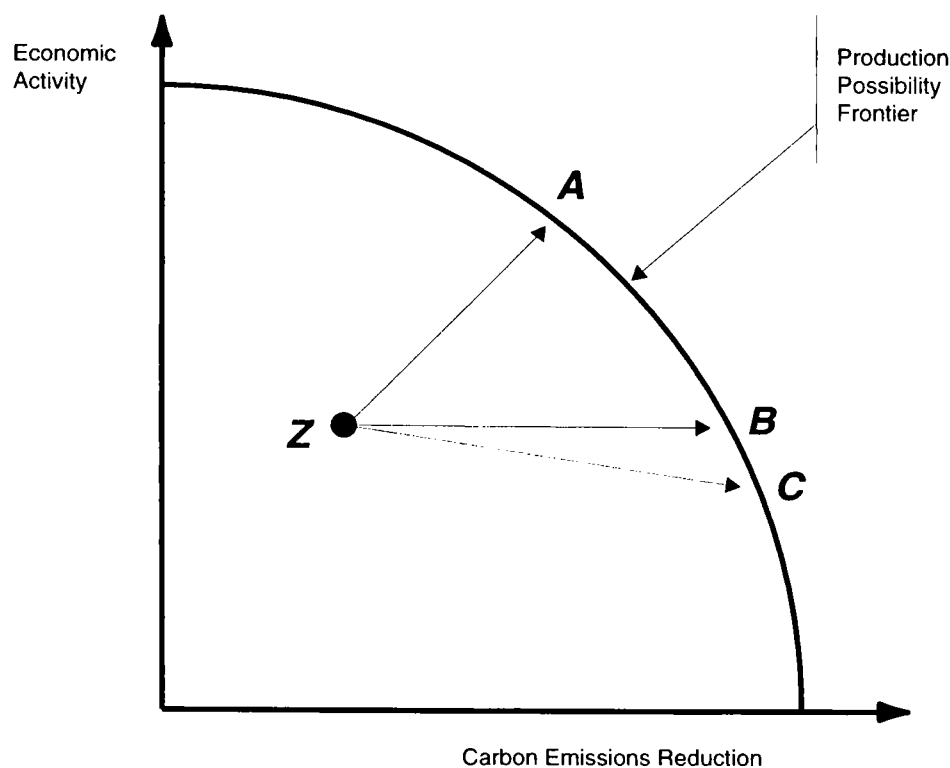
Technology-costing studies usually start with a list of particular technologies, such as energy-saving end-use devices or low-carbon energy sources, which look attractive but are "under-used." An analytical basis for this judgment is constructed by means of a calculation of net present value (NPV), taking account of capital and other components of cost and the savings to be realized in energy expenditures. Examples of such opportunities include highly efficient windows or higher mile-per-gallon cars, and wind and solar power supplies. If such "good" technologies go wanting, then something must be wrong in the economy, so the argument goes. The analysis proceeds to show how much improvement could be gained at a low cost, or even a net benefit, with only small changes in policy or perhaps just general encouragement.

The question is, what is the barrier to use of a technology which is to be corrected by policy intervention? Here it is helpful to distinguish two possible reasons why an apparently attractive technology may not be quickly adopted. One is appropriately classified as a market "failure"; the other is not attributable to failure in market

function but to some inhibiting feature of market preferences or normal market activity (Jaffe and Stavins 1994; Sutherland 1991). The difference between the two circumstances can be illustrated using Figure 2, which is adapted from the Intergovernmental Panel on Climate Change (1996). An economy cannot produce everything its citizens want; there are always trade-offs. Here the textbook choice of "guns vs. butter" is restated in terms of some traditional measure of economic welfare vs. climate-related environmental quality. In this example, the vertical axis includes output of market-priced goods plus all environmental benefits *except* those of reducing the risk of climate change; the horizontal axis is the level of greenhouse gas emissions. The figure thus illustrates the components of a cost-effectiveness analysis of climate policy, which is the type of calculation being reviewed here. An economy is said to be "efficient" when it is not possible to lower greenhouse gas emissions without incurring welfare losses elsewhere. In the economist's jargon, an efficient economy is on its production possibility frontier, at points like A, B, or C in the figure.

A market "failure" occurs when there is some flaw in the way markets are organized, which leads consumers and/or producers to respond to the wrong price signals. That is, the economy is operating in a state like point Z, where there may be

Figure 2 Trade-Off of Economic Welfare vs. Emissions Reductions



so-called "no regrets" opportunities to move to point B, or even A, thereby achieving environmental improvement at no cost or even a net benefit. Or it may be possible to move from Z to point C, which would involve economic costs but which might be justified on a benefit-cost basis. Such failures include situations where decision makers have insufficient or incorrect information (consumers do not perceive how costly it is to own a power-guzzling air conditioner), where there is an asymmetry between the person making the energy-use decisions and the one paying the bills (the landlord-tenant problem), or where there is some form of non-priced externality (such as urban air pollution). These conditions lead to calls for government action, in the interest of economic efficiency, ranging from labeling rules to device performance standards to various forms of direct government expenditure or tax subsidy.

In contrast to these market failures are another set of barriers that may retard the spread of a technology, even when analysts' calculations show it has a positive NPV, that are better thought of as an unfortunate set of normal market preferences. In these cases, the economy is operating efficiently, and emissions reduction (perhaps through the use of a new technology) can be had only at some cost, as with a move from A to B, or B to C, in the figure. In other words, the technology is not economically competitive apart from possible expected benefits from reduced climate risk.

A wide range of normal market conditions can contribute to this result, where technology-costing analysis shows the move is costless (or a net benefit) but buyer behavior indicates otherwise. First, potential buyers simply may not like the technology. That is, it may have undesired attributes that matter to users but are not priced in the technology-cost analysis.¹ Or there may be transactions costs or other expenses of adoption that are hard to include in the calculations. Uncertainty about performance, or about energy prices, may lead users (quite rationally) to exercise their option to wait and reconsider the opportunity next year. And most significant is the issue of discount rates. Consumers and industry decision makers may appear to operate at discount rates higher than those that analysts choose for their NPV calculations. Sorting out the influence of discount rates from that of un-priced attributes and options behavior is a very complex matter. (Do I decide not to buy more energy-efficient fluorescent light bulbs because I over-discount the electricity savings, or because they do not look good in my existing appliances?) Still, technology-costing studies that apply discount rates below the levels generally seen in practice do not reveal a market failure so much as an analyst's disagreement with market preferences.

The key difference between these two causes of non-use is that correcting failures may in some circumstances offer a net benefit, whereas overcoming non-failure or market-preference barriers always involves cost. The distinction is of concern in this discussion because in some technology studies these two effects are mixed indiscriminately. Too often market intervention to advance a particular

technology is implicitly assumed to be correcting failures, and therefore the analysts feel no need to dig into specific policy instruments and their costs. An example of this phenomenon will be seen later.

Lack of Attention to Market Structure

In analyzing a new technology, such as a consumer device or production process, it may be difficult to account for all the conditions (besides engineering NPV) that must be met before it can take market share. It can be even harder to estimate how long the process may take. Aspects of market structure, which are outside the usual boundaries of technology-cost analysis, are crucial at this point. These factors include the structure of distribution channels and industries supplying key (and perhaps new) inputs, and they may involve regulatory and legal liability issues particularly regarding health, safety, and environmental quality. Most important, they include the internal organization of the particular industry—firms, consumers, and intervening markets—that is to adopt the technology.

These aspects of detailed market structure may or may not determine the fate of a new technology in the long run, but they have a huge influence on the likely pace of adoption. Failure to consider them may lead (incorrectly) to a judgment that something is "wrong" with the market, or if truly wrong that it is fixable at reasonable cost. Such faulty analysis can lead to bad policy advice.

Failure to Account for Inter-Market Adjustments

Finally, in a partial analysis built up from assessments of individual technologies, and policies to foster them, it is very difficult to consider interactions across markets. If the changes are small, then this aspect can be ignored. If these effects are large in relation to the markets at issue, however, then failure to consider them can lead to serious flaws in the analysis. Proposed climate policies, which involve major shifts in the structure of energy supply and use, present such a case. An obvious source of concern is the evaluation of a large-scale policy-induced change in use of a particular fuel or other input, when the study assumes an exogenous (and constant) estimate of its domestic price. Some changes in technology may also influence the prices of capital and specialized labor. Less obvious, but nonetheless significant in some cases, are interactions through international trade.

THE DEPARTMENT OF ENERGY'S FIVE-LABS STUDY

An example of how a study can suffer from the ills above, and yet be applied to an important policy issue, is the analysis of U.S. carbon reductions prepared by

a consortium of five U.S. Department of Energy laboratories, frequently referred to as the Five-Labs report (Interlaboratory Working Group 1997). Beginning with an observation that many energy-efficient technologies remain "underutilized," it sets out to "...quantify the reductions in carbon emissions that can be attained through the improved performance and increased penetration of efficient and low-carbon technologies by the year 2010" (p. 1.1). It has proved an influential piece of work, as discussed below. Its dominant and much-publicized conclusion is that, by pursuing a technology path, the United States could stabilize carbon emissions at 1990 levels, at no cost or even a positive net benefit. As stated in the report, if certain measures discussed are taken, "...the cases analyzed in the study are judged to yield energy savings that are roughly equal to or greater than the costs" (p. 1.1).

The Study's Structure

The Five-Labs study divides the U.S. energy economy into four sectors (buildings, industry, transportation, and electric utilities) and compiles estimates of how carbon emissions in 2010 could be reduced by means of a technology push. Reductions in energy and carbon emissions are calculated from a baseline or "Business as Usual" case drawn from forecasts in the Energy Information Administration's 1997 *Annual Energy Outlook*. Possible carbon reductions are described for three policy cases:

- **Efficiency case.** This case presumes "...an invigorated public- and private-sector effort to promote energy efficiency through enhanced R&D and market transformation activities."
- **High-Efficiency/Low-Carbon (HE/LC) Case with a \$25 price per ton of carbon (\$/tC).** This case presumes that the carbon premium is attained through a cap-and-trade system. This policy is accompanied by a "greater commitment" through federal programs, strengthened state programs, and "very active" private-sector involvement.
- **High-Efficiency/Low-Carbon (HE/LC) Case with a \$50/tC price.** This case doubles the carbon price but is otherwise the same.

Given the "Business as Usual" Department of Energy forecast of emissions which the study uses, a return to 1990 levels would require a reduction in 2010 emissions of 390 million metric tons of carbon annually.²

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The sector breakdown of these reductions is shown in Table 1, which is drawn from Table 1.2 of the Five-Labs report. Before looking at some of the assumptions behind these estimates, two general points should be made about the analytical method. First, only in the case of the electric sector has the Five-Labs group conducted any numerical analysis of the potential effects of carbon prices. For all other sectors, the net decreases in carbon emissions are the result of "expert" judgments about the effects of price and the assumed effect of a "greater commitment" by government and the "very active" private sector that might accompany the imposition of a permit scheme.

Second, the study does not describe the policies that might be used to accomplish higher penetration of energy-efficient and/or low-carbon technologies. There is not even any explicit treatment of the reasons why emissions should be lower in the Efficiency case than under Business as Usual. The report simply posits a "host of market barriers [that] account for the lost opportunities," with no attempt to sort out the failures-vs.-preferences puzzle discussed above.

The Study's Shortcomings

Based on these observations, and others below, many criticisms can be leveled at the Five-Labs study (for example, see Sutherland 1998, U.S. General Accounting Office 1998). It also should be noted that the authors were aware of many of its shortcomings and cite them in the body of the study and its appendices. The argument here is not that the staffs of these national laboratories did not know what they were doing, or that they hid the blemishes from the diligent reader. The central critique is that the Five-Labs study is not an appropriate vehicle for analysis of the policy question which its main conclusion addresses, i.e., how costly it would be to return to 1990 U.S. carbon emissions by 2010. A look at the details of just three of the many components of the analysis—for automobile fuel economy,

Table 1 Forecast for Carbon Reduction Below the 2010 Baseline
Millions of metric tons of carbon

	Efficiency	High Efficiency/Low Carbon	
		\$25/tC	\$50/tC
Buildings	25	44	62
Industry	28	54	93
Transportation	73	88	103
Electricity	0	48	136
Total (rounded)	120	230	390

building efficiency, and reduction of coal use in electric power—will illustrate the cause for concern.

Automotive Fuel Efficiency: Regulation Is Costless

As can be seen in Table 1, over half of the carbon reduction in the Efficiency case is realized in the transport sector. Of the 73 million metric ton reduction, 61 million metric tons or 84 percent is from increases in vehicle efficiency and the remainder results from the assumed introduction of ethanol from biomass. Here we focus on just the main component of this estimate. The increase in efficiency is the result of the assumed market penetration of new technologies such as direct-injection stratified charge engines, direct-injection diesels, and gasoline- and/or diesel-electric hybrids, in addition to other changes in vehicle design and materials. In the overall cost analysis, the additional capital cost of these vehicles is weighed against the assumed fuel savings, with market penetration rates and other calculations performed using the Energy Information Administration's National Energy Modeling System (NEMS) model.

The question is, why should these efficiencies appear in the Efficiency case but not in the baseline, when there are no price incentives such as higher gasoline prices? The answer comes in two parts. First, vastly increased R&D is assumed to reduce the time required for market introduction of new technologies by 25 percent (by a mechanism that is not explained). But second and most important is the following:

[The study] assumes that policies necessary to draw energy-efficiency technology into the market are implemented as needed...[including] fuel economy standards, revenue neutral feebates, fuel taxes, public information, or some other initiative (p. 5.3).

That is, underlying the analysis, which is supposedly about technology, is a regulatory and tax program. The components of such a policy program receive no analysis in the study, and only the barest description beyond what is quoted here. As noted earlier, the study is explicit about its lack of analysis of specific policies, but less obvious is the fact that any costs of such a regulatory and tax program are omitted from the benefit-cost analysis. In effect, regulation and tax programs are treated as politically acceptable and free of economic cost. Thus, the analysis is best described as a scenario exercise gone haywire, not a plausible economic forecast as implied by the study's conclusions and the way they have been interpreted in policy discussions.

When the report comes to the HE/LC cases, the analysis descends even deeper into the imaginary world of "what if." As noted earlier, there is no analysis of the

potential effect of the \$25 or \$50 per ton carbon price (\$50 per ton of carbon would add roughly \$0.125 per gallon to the gasoline price). Instead, the additional reductions derived for these cases, shown in Table 1, are based on "technological breakthroughs" and "a certain degree of luck" (p. 5.3). Lost in references to this study in policy discussions is the fact that the report itself declares that the HE/LC case is best described as "optimistic" or "possible," and that in addition to a major intensification of R&D it presumes the adoption of "...significant policy measures aimed at pushing the market towards giving fuel efficiency a much higher priority" (p. 5.3). In the terms introduced above, the study implicitly assumes that regulatory or tax intervention is justified by the correction of (unspecified) market failures, so the costs are not important to the analysis. As a result, the economic cost analysis is not correct, the considerable political difficulties of "pushing the market" are hidden, and thus the future the report lays out is not realistic. Moreover, little evidence is presented that this market push could produce the promised magnitude of energy and carbon savings, even if it were somehow carried out.

Building Efficiency: Arbitrary Assumptions About Markets

The study's handling of the building sector provides a disturbing example of the failure to consider the structure of markets when preparing this form of technology-cost analysis. To arrive at the carbon reductions presented in Table 1, the study first constructed an estimate of how much energy and carbon would be saved if maximum cost-effective energy improvements were installed in 100 percent of U.S. homes and commercial and public buildings. These improvements include appliances such as lighting, refrigeration, and space-conditioning equipment, and more effective building design and construction. The definition of "cost effective" for this analysis is a positive NPV to the user, assuming a 7 percent real discount rate.

For the Efficiency case, it is assumed that 35 percent of this maximum reduction is achieved. Why the Efficiency case should differ from the baseline in this way (with no price incentives) is not discussed, except to say that the expected savings result from a "moderately vigorous" effort to reduce energy use by "[a] combination of mechanisms that may include higher prices...energy-efficiency standards and information programs" (p. 3.11). The HE/LC cases assume that 65 percent of the maximum is achieved. Again, prices of energy, as they might be influenced by the carbon permit system, are not considered explicitly. Rather, the 65 percent result flows from a judgment as to the effect of a "vigorous effort" to reduce energy use (in contrast to a "moderately vigorous" effort in the Efficiency case). That is the extent of the reported analysis.

The study imagines an appliance and construction market with a structure quite different than the one we actually have. With a straight face, the Five-Labs

authors justify the 7 percent discount rate on the basis that, "The long term average return for the utility industry is about 6 percent real and the typical rates for auto loans and business loans are also in this range" (Appendix C, p. 1.5). Controversy over the economics of demand-side management programs conducted by U.S. electric utilities spawned a large amount of careful work on consumer and industry behavior in the area of energy-efficiency investments (e.g., Joskow and Marron 1992; Levine and Sonnenblick 1994; Nichols 1994). In the light of this work it is clear that 7 percent is far below actual experience, and any analysis using such a low rate is seriously misleading.

Also included in the savings in building efficiency is the effect of "vigor" and "moderate vigor" on the design, construction, and equipping of new residential and commercial structures. Here again, forecasting the response of this industry to heightened societal concern for conservation, and perhaps to price incentives flowing from the carbon permit scheme, requires consideration of its peculiar structure. The U.S. construction industry is notorious for the fragmentation of its various components such as local building codes, development and finance, design, construction (with its various layers of subcontractors), materials manufacture and supply, certification, and training of construction trades. To be realistic, any analysis of response to policy must reflect the inertia of this system (Hansen 1998). It is an issue that the study does not address.

Thus, the 35 percent or 65 percent numbers, which reflect progress toward some maximum potential, involve seriously flawed assumptions about the structure of markets in this sector, and unspecified policy intervention. As such, it may be a start toward an analysis of long-term potential and sector-specific policies, but it is not a reasonable approach to estimation of likely developments by 2010.

Electricity: Ignore Inter-Market Adjustments

The electric sector is the one place in the Five-Labs Study where explicit account is taken of the potential effect of a cap-and-trade system. As Table 1 shows, 136 million metric tons of carbon or one-third of the reduction needed to achieve the 390 million metric ton reduction in 2010 comes from the electric sector. Here, we focus on the shift from coal to natural gas in existing generators, which accounts for 70 percent of the total. The remainder of the savings come from a combination of small contributions from biomass, wind, hydro, and nuclear sources, and various improvements in other parts of the electric system.

The results in Table 1 are calculated on the basis of only one case of an emissions permit system, i.e., the one yielding a carbon price of \$50 per ton of carbon. (The \$25 case was constructed using analysts' judgment.) System calculations were made using a simulation model of the generation sector. A base case was constructed to

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approximate the results under the Energy Information Administration's 1997 *Annual Energy Outlook*, which underlies the analysis of other sectors, and an attempt was made to adjust the model for market changes that will accompany the current process of electricity deregulation. Then analysis of the \$50 per ton carbon case was conducted in two parts: adjustments on the demand side, and changes in the supply structure. First, as a result of lowered end-use of electricity in the Building and Industry sectors, the demand for electric generation will be reduced. Some of this effect is already accounted for in these other sectors, but not counted there is the fact that, with lower overall electricity demand and the new carbon emissions charge, there will be a re-dispatching of existing generating units, in general away from coal. Second, whatever the demand level, coal-fired units will be re-powered with lower-carbon-emitting natural gas.

Unfortunately, at this point the study drops into the third of the pitfalls laid out above. Underlying all of the model results is the key assumption that the prices of oil, natural gas, and coal are constant. This condition holds across all cases (Appendix F-2). This of course means that the coal-gas price ratio, which is a crucial input to the calculation of coal to gas conversion, also is constant. In reality, if coal demand falls domestically because of climate policy (electric generation accounts for about 80 percent of U.S. coal use), coal prices will fall as well. Since the United States is a net exporter of coal, and any U.S. domestic carbon control policy presumably will have counterparts in other countries, this price response will be augmented through international trade. Also, the conversion of coal plants to natural gas will cause a substantial increase in gas demand, driving up its price. In omitting these intermarket effects, the Five-Labs analysis overestimates the carbon reductions from re-dispatch and re-powering. In addition, the calculated fuel shift is strongly influenced by assumed prices of emissions permits under sulfur and nitrogen oxides control programs, but these prices also are held constant even with drastic reductions in coal use.

Without reanalysis, taking account of the changing market equilibria in these closely related markets, it is not possible to say how big an error is introduced by this procedure. Note, moreover, that this assumption of constant prices will bias the estimates of the penetration of other contributors to carbon reduction in the electric sector such as biomass, wind, and solar power.

In short, it is not correct to calculate these changes in generation patterns in a partial or one-sector analysis, ignoring the response of fuel prices. To be fair to the Five-Labs effort, it should be said that the authors do describe their method in one place or another, and they are explicit about the fact that they did no analysis of natural gas or coal prices (p. 7.3 and Appendix F-1). It is not that work underlying the sector chapters and appendices is misrepresented, or that an effort was not made to lay out a set of interesting scenarios. The problem is that this technology-costing

analysis, with its particular structure, is simply inappropriate for the policy question at which it is directed.

APPLICATION TO ADMINISTRATION POLICY, AND ITS CONSEQUENCES

It would be easy to overstate the influence on government policy of any particular piece of analysis. Diverse forces come to bear, many of them much more powerful than the computer model and the word processor. However, recent U.S. climate policy, particularly as it concerns the role of new technology, is a case where this influence merits greater attention. By the same token, it is not altogether fair to single out the Five-Labs report for criticism, because it is only one of a number of studies that offer a similar brand of technological optimism (e.g., National Academy of Sciences 1991; Alliance to Save Energy et al. 1997). On the other hand, the Five-Labs study has proved to be an influential piece of work, frequently cited as justification for a technology-based approach to climate change in the short term. Of course, the policy consequences should not be attributed to the Five-Labs study alone, but equally to those who misapply its results (and those of other studies like it) in climate discussions.

U.S. Climate Policy and Its Analytical Justification

The outlines of U.S. climate policy were stated by President Clinton in an October, 1997, speech at the National Geographic Society (White House 1997a). The President instructed U.S. negotiators to seek agreement to a legally binding target of returning to 1990 emissions by a 2008–2012 budget period, a target tightened to *minus* 7 percent in the subsequent Kyoto Conference of Parties (United Nations 1997). Further, the President's speech laid out a three-stage approach to attaining this goal. The first and key stage was a technology initiative. The plan involved \$5 billion in additional federal expenditures over five years for tax incentives, R&D spending, and various federal energy initiatives, plus a program of jawboning of U.S. industry. No additional actions were foreseen for seven years or more! Only after "...a decade of experience, a decade of data, a decade of technical innovation" did the plan foresee a need to impose significant economy-wide economic incentives. These are to be in the form of a system of tradable emissions permits, "to insure that we hit the binding targets."

Most forecasts show U.S. carbon emissions, without policy, to be one-quarter to one-third above 1990 levels by 2010, yet at the time of the anticipated "launch" of this permit system the start of the first budget period would be less than three years away. At one point in the press briefing that followed the President's announce-

ment, the chair of the National Economic Council, Gene Sperling, declared, "The plan that we have as you look forward does not include increased energy prices" (White House 1997b). Thus, the plan had to assume great success from the technology initiative. As one wag put it, "It was the tooth fairy in reverse: put \$1 billion per year under your pillow, and in the year 2010 you'll find teeth capable of eating 400 million tons of carbon!"

How could this proposal pass the laugh test? One justification was the Five-Labs study, with its forecast that emissions stabilization could be achieved at a net gain to the economy (Interlaboratory Working Group 1997; Romm et al. 1998). Indeed, when questioned in the briefing about the analytical basis for the plan, Sperling replied,

But we have certainly been locked in doing a tremendous amount of economic analysis...for example there is the Five-Labs study...from the Energy Department, there is very careful analysis on what the potential is for reducing metric tons of carbon through the efficiencies in three main sectors—the building, the transportation, and the industrial sectors (White House 1997b).

As the year wore on, the Five-Labs analysis continued to be used as a validation of the proposed policy. In Senate committee hearings in the wake of the Kyoto meeting, the chief U.S. negotiator, Undersecretary of State Stuart Eizenstat, was questioned about the analytical basis for the positions the United States had accepted. In part, his response was

We also have...something called a Five-Labs study that was done by the five national labs. They're totally independent—you know, nobody told them what to come up with—and they made some findings about what technology can do and how we can reduce the burdens and costs on coal miners and others by coming up with what is the hallmark of America, and that is ingenuity and technology (U.S. Senate 1998).

As recently as June 1998, a top Department of Energy official testified that R&D was a key element of our response to climate change, and that

Last year, a peer-reviewed study conducted by five national laboratories recognized that the United States can hold down the costs of meeting climate change goals...In fact, the study concluded that significant progress in reducing greenhouse emissions could be achieved without increasing the nation's total energy bill (U.S. House of Representatives 1998b).

Later, in an effort led by the President's Council of Economic Advisors, the Administration presented a full analysis of its Kyoto position, this time based on top-

down models (Executive Office of the President 1998). The study included unreasonably optimistic assumptions about the extent of an international permit trading system to be in place in time for the first budget period, but at least the paper is clear about the policy measures to be used and their economic basis. Interestingly, the Five-Labs study merited only a passing reference in this later Administration analysis. This type of technology-costing study nonetheless continues to be influential in public discourse, because it makes a point that many players want to hear: that is, that even large-scale, short-term carbon reductions will be cheap.

The Consequences

An important consequence of this approach to technology development is the subversion of what is essentially a long-term policy tool to the service of short-term emissions goals. In February, 1998, when the 1999 budget was put forward, the Administration's October proposal emerged as a five-year \$6.3 billion Climate Change Technology Initiative (CCTI). The major portion of this funding was proposed not for R&D but for tax expenditures and other measures intended to spur adoption of existing technologies. That is, "...to stimulate adoption of more efficient technologies in buildings, industrial processes, vehicles, and power generation" (OMB 1998). The plan is heavily biased toward resolving problems of market barriers, as described above, based on justifications that sound a lot like the assumptions in the Five-Labs Report.

By coincidence, it was also in the fall of 1997 that a study by a panel of the President's Committee of Advisors on Science and Technology (PCAST) presented its carefully reasoned recommendations for a program of long-term R&D focused on climate issues (PCAST 1997). However, although the CCTI contains useful expansions of some existing federal R&D programs, the PCAST report and other studies of the long-term climate issue appear to have had little effect on the overall allocation of the proposed new resources. To the contrary, the desire to produce results by a technology path within the 2008–2012 budget period appears to have been the stronger influence on the design of the CCTI.³

Even worse, this focus on short-term emissions goals threatened the loss of or drastic reduction in the CCTI program itself, including the portion that *does* contribute to long-term R&D. This is because of a backlash in the Congress over "implementation without ratification." Some members express a fear that the Administration is trying to achieve the goals of the Kyoto Protocol even though it has not been ratified (or even submitted for ratification), ignoring the stringent conditions for approval set by the Senate (U.S. Senate 1997).

This larger issue of ratification and implementation are beyond the scope of this paper. The one aspect that is of concern here, however, is the fact that long-term

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R&D, which might receive widespread congressional support as prudent preparation for an uncertain and risky future, has become caught in the fray. Happily, a cut-down version of the first year's funding for Administration's CCTI proposal survived the 1999 omnibus spending compromise, reached in fall 1998. But this achievement came in the face of opposition by key members of Congress on the grounds that "...[the] \$6.3 billion initiative is intended to help meet emissions reductions mandated in the Kyoto Protocol" (U.S. House of Representatives 1998a). It is lamentable that key preparations for the long road are so deeply tangled in a debate about the first steps.

CONCLUSION

Technology-costing studies, like the Five-Labs report and its cousins, can be a useful input to climate policymaking. They point to possible market failures; they help sort out the most important targets for R&D and perhaps for selected technology-push investments; and they help provide justification for these activities. However, it is very important to avoid misuse of these studies. There is no technical fix in the short run of a decade or so, readily available at little or no cost, as implied by the Five-Labs report. Science does not run on the policymakers' clock; new technologies frequently require breakthroughs and they take time to develop; markets for new consumer devices and industrial processes, including needed distribution and materials supply systems, require time to evolve. Further, capital turnover has its own internal dynamics, particularly in the heavily capital-intensive subsectors of energy supply. In the long run of several decades, and with a well-designed effort, the prospects are brighter. Indeed they must be brighter if we are to have any hope of an effective response, should the climate picture darken. For example, the Kyoto commitments are just an easy first step compared to the carbon reductions needed to achieve ultimate stabilization of atmospheric concentrations (Jacoby, Schmalensee, and Reiner 1997).

However, enthusiasm for the task does not mean that it will be easy to do well, or even that we know very clearly how to proceed. At the level of basic science, with its public good characteristics, the role of government expenditure is clear. At subsequent stages of technology development and application—such as pilot facilities, commercial demonstration plants, and subsidy schemes to seek benefits of economies of scale and learning—the history is mixed. Picking winners is a difficult art, and spending money effectively is a daunting challenge in the midst of regional and industrial demands for a share of the pie. Most important, the expertise in many technical areas resides in private industries—particularly oil, chemicals, and electric power. Government-industry partnerships and tax subsidies can help direct their efforts, and useful experiments are now being tried. But the only way to

truly attract industry attention is through an influence on the bottom line, which necessarily involves (among other things) price expectations. In the energy sector, at least, large-scale technical change with no price incentive is a non sequitur.

Precisely because it is such a complex task to devise policies that can hasten major technical advances in energy supply and use, it is important to free decisions about these important long-term measures from disputes over short-term policy issues. Our long-term outlook can be hopeful, provided a well-designed effort is launched and sustained. A key step in this process is to put studies of technology cost in their proper place, and avoid their misuse as guides to short-term policy development.

NOTES

1. A classic example is the finding that a highly cost-effective energy-saving technology would be to cover the roofs of all U.S. residences with white paint (National Academy of Sciences 1991). The analysis does not ask the question whether people want to do this and how they might be encouraged to carry it out, or what they might pay to avoid it.
2. The size of the needed reduction is subject to considerable uncertainty (Webster 1997). Our MIT reference forecast implies a 470 million metric ton reduction would be needed to achieve 1990 levels, and the latest Administration analyses use 2010 baselines which would yield a number in the same range (Executive Office of the President 1998, U.S. Department of Energy 1998). The larger the number, the higher the cost.
3. As argued by Jacoby, Prinn, and Schmalensee (1998), long-term R&D was only one of several long-term tasks that have taken a back seat to the push for short-term targets for the richer countries.

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EXECUTIVE SUMMARY

The goal of this study by five U.S. Department of Energy National Laboratories is to produce well-documented scenarios or pathways that assess how public policies and programs can foster efficient and clean energy technologies to meet the nation's energy-related challenges.¹ These challenges include global warming, air pollution, oil supply vulnerability, and economic inefficiencies in energy end-use systems. Some of these concerns are visible today and are clear public priorities; others are emerging as issues or are possible outcomes of an uncertain future. How the nation responds to them will affect the prosperity and well-being of future generations.

Scenarios for a Clean Energy Future (CEF) documents the valuable role that efficient, clean energy technologies could play in meeting these challenges, and describes portfolios of policies that could motivate consumers and businesses to invest in them. Five key conclusions from this study are summarized below.

Box ES1. Five Key Conclusions

- We have described a number of policies and measures (such as voluntary agreements, efficiency standards, increased R&D, electric sector restructuring, and a domestic carbon cap and trade system) that could lead to the faster development and increased market deployment of energy-efficient and low-carbon technologies. Success in implementing these policies and measures would significantly reduce energy inefficiencies, oil dependence, air pollution, and carbon emissions, at essentially no net cost to the U.S. economy.
- The CEF policy pathways would move the U.S. a long way towards meeting the U.S. greenhouse gas reduction goals set by the Kyoto protocol. However, they do not provide a complete response; other means would be needed to reach these goals (e.g., international carbon trading, reductions in gases other than carbon dioxide, stronger domestic policies).
- The strong performance of energy-efficient technologies limits the need for new supplies and therefore, the opportunities for many environmentally attractive energy supply options in the 2020 time frame. Improved energy-efficiency also reduces demand for natural gas in industry and buildings, which prevents price escalation from rising natural gas demand in the power sector.
- The energy cost savings from the more efficient use of energy throughout the economy can exceed the direct costs of these policies and technologies. At the same time, the strong growth of domestic wind, bioenergy, and other "green" industries could create new employment opportunities. On the other hand, additional policies may be needed to ameliorate possible transition impacts such as reduced coal and railroad employment.
- Large uncertainties are inherent in policy assessments, but the existence of a range of supply and demand technologies provide "backstop" opportunities that add confidence to the CEF scenarios. In addition, there is a broad array of technology options which, with successful research, would provide additional pathways to address longer-term, national and global energy challenges (ranging from sequestration of carbon from coal, to a new generation of nuclear plants, to a host of efficient and renewable energy technologies).

THE CEF SCENARIOS

¹ The five national laboratories that participated in this study are: 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).

The 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 increasing levels of public commitment to solving the nation’s energy-related challenges and a strong political and public resolve that enables policies to be implemented that may be politically infeasible today. These two scenarios are delimited by sets of public policies and programs – some of these apply economy-wide while others are specific to an individual sector (buildings, industry, transportation, and electric generators). The public policies and programs are assessed for impacts to 2020.

The 20-year, domestic scope of the CEF scenarios is not meant to minimize the importance of longer-term global energy issues such as:

- air pollution problems in many countries around the world,
- access to electricity for the third of the world’s population that is currently unserved, and
- long-term fossil fuel resource limitations and distribution.

To place the CEF scenarios within this expanded context, we qualitatively describe an array of additional technology options that, with successful research, could provide additional pathways to address global energy-related challenges beyond 2020. These include novel nuclear reactor designs, advanced gas and chemical separation technologies, and fuel cell/turbine hybrids. However, the scope of our quantitative analysis is limited to near-term domestic issues to illuminate specific technology and policy opportunities for the U.S. today.

Numerous policies are examined, including fiscal incentives, voluntary programs, regulations, and research and development. Most of the policies were selected on the basis of their potential to reduce carbon emissions.² Others were designed specifically to improve air quality (e.g., reducing SO₂ emissions in the electric sector by 50%) or for economic efficiency (e.g., restructuring of the electricity industry). Regardless of the driving force behind them, almost all reduce carbon emissions and improve air quality. Policies are generally stronger in the Advanced than the Moderate scenarios, with larger expenditures on public-private R&D partnerships, stricter standards, higher tax incentives, and greater government investment in programs that promote efficient and clean technologies.

The policies identified as most important in the Advanced scenario are summarized in Table ES1. A key policy mechanism for the Advanced scenario for all of the sectors is the addition of a domestic carbon cap and trade system. In this system, assumed to be enacted 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. The second key policy mechanism in the Advanced scenario for all of the sectors is the doubling of federal government appropriations for cost-shared research development, and demonstration (RD&D) in efficient and clean-energy technologies. Since 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 approximately 2005 (half as federal appropriations and half as private-sector cost share) and continuing through 2020.

² Throughout this report, emissions are reported in terms of metric tons of carbon. To convert metric tons of carbon to metric tons of carbon dioxide, multiply the amount of carbon by 44/12.

Table ES1. 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 –“Pay-at-the-pump” auto insurance	–Renewable energy portfolio standards and production tax credits –Electric industry restructuring
Cross-Sector Policies	
– Doubled federal R&D	–Domestic carbon cap and trade 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.

* These voluntary agreements, because they are met in the Advanced scenario, would have the same effect as a CAFE standard of the same level.

Several of the policies in the CEF scenarios are coupled to produce significant positive synergies. For instance, R&D positions clean energy technologies to respond to opportunities created by incentives and to meet subsequent codes and standards. Because more than 50 policies are modeled, it is not possible to estimate the impacts of each policy in isolation of the others. As a result, we focus on the effects of policy pathways which involve collections of policies, tailored to meet the needs of each sector.

The CEF Scenarios omit policies that some policymakers might consider attractive. Some policies are not included because of modeling difficulties. Several others are omitted because their impacts are redundant or the required levels of public commitment or costs exceed CEF scenario guidelines. The CEF scenarios are based on relatively non-intrusive, virtually no-regrets policies. Inclusion of stronger policies would result in accelerated progress toward meeting the nation’s energy and environmental goals. Thus, if the nation requires acceleration beyond the transitions described here, other policy studies exist that should be consulted.

METHODOLOGY

This study uses an integrated national energy model based on the Energy Information Administration’s (EIA) National Energy Modeling System (NEMS), along with supporting analyses to assess the effects of each policy and to account for impacts across sectors. This model, which we call CEF-NEMS, simulates the behavior of U.S. energy markets. It achieves a supply/demand balance in nine end-use demand regions by solving for the prices of each energy product that will balance the quantities producers are willing to supply with the quantities consumers wish to consume. The model reflects market economics, industry structure, and many energy policies and regulations that influence market behavior. The impacts of standards and fiscal policies are generally assessed within CEF-NEMS, while the impacts of policies such as voluntary agreements, enhanced R&D, and technical assistance have been largely evaluated outside CEF-NEMS and translated into inputs for CEF-NEMS. The integration step of CEF-NEMS allows the estimated effects of changes in energy use in each sector to be taken into account in the energy use patterns of the other sectors. For instance, if electric generators should shift significantly to natural gas while at the same time energy consumption in buildings and industry continued to grow, natural gas prices would rise and some switching to other fuels would result.

We employed the EIA's reference case from the *Annual Energy Outlook 1999* (EIA 1998) as the starting point for the CEF Business-As-Usual (BAU) forecast. Thus the EIA's reference case assumptions on fossil fuel supplies, world oil prices, energy transport, end-use service demands, and macro-economic growth underlie the three CEF scenarios.³ To capture the policies of the Moderate and Advanced scenarios, CEF-NEMS inputs associated with process economics, stock turnover rates, consumer discount rates, and fuel prices are changed from the BAU scenario (and therefore from the EIA's Reference case). The translation of these policies to the inputs required by CEF-NEMS was conducted through off-line analysis, reference to past studies, expert judgment, and outside review. This process has the essential advantage that it quantitatively estimates the impacts of key non-fiscal policies.

RESULTS

Key results of the study derived through the above approach are presented in Table ES2 for the Moderate and Advanced scenarios.⁴ 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 cap and trade system that equilibrates at a carbon price of \$25/tC.

Primary Energy Use. The reductions in primary energy use shown for these scenarios result from the many CEF policies that are directed at the adoption of energy-efficient technologies in the end-use sectors. Efficiency standards are shown to be highly effective 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 capital stock turnover occurs. Thus the reduction in primary energy use takes considerable time to materialize, with the 2020 percentage reductions in energy use relative to the BAU being twice as large as the 2010 reductions for both the Moderate and Advanced scenarios.

The 2020 reductions are also larger because of continuing technology improvements with enhanced R&D programs. For example, in the transportation sector much of the stock turns over relatively quickly, but the reductions in energy use are even larger in the second decade as R&D and voluntary agreements with automobile manufacturers make more efficient vehicles available. Reductions in primary energy use in all sectors can be expected to grow even larger after 2020 as R&D improves technology further and additional stock turns over, synergistically providing a market for the improvements.

Primary energy use reductions in the Advanced scenario (with carbon permit charges of both \$25/tC and \$50/tC) 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, R&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. Key amongst these are the carbon cap and trade policy, voluntary agreements to improve the fuel economy of light-duty vehicles, and pay-at-the-pump automobile insurance.

³ The CEF BAU forecast and the EIA reference case forecast differ slightly. The BAU forecast uses different base year values and stock turnover rates for several industries, which results 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. 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.

⁴ The presentation of these values with three or more significant figures here and throughout the 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 our resources and the process described above.

Table ES2. Selected Results for 2010 and 2020*

	2010					
	1990	1997	BAU	Moderate	Advanced (\$25/tC) ^a	Advanced (\$50/tC) ^b
U.S. Primary Energy Use (Quadrillion Btu)	84.2	94.0	110.4	106.5	101.0	99.3
Energy Use Reductions (Percent Change from BAU)	–	–	–	(-4%)	(-9%)	(-10%)
U. S. Energy Bill (Billion 1997\$)	563	553	650	595	598	634 ^c
Energy Bill Reductions (Percent Change from BAU)	–	–	–	(-9%)	(-8%)	(-3%)
U.S. Carbon Emissions (Million Metric Tons)	1,346	1,480	1,769	1,684	1,539	1,463
Carbon Emissions Reductions (Percent Change from BAU)	–	–	–	(-5%)	(-13%)	(-17%)
	2020					
	1990	1997	BAU	Moderate	Advanced (\$25/tC) ^a	Advanced (\$50/tC) ^b
U.S. Primary Energy Use (Quadrillion Btu)	84.2	94.0	119.8	110.1	98.8	96.8
Energy Use Reductions (Percent Change from BAU)	–	–	–	(-8%)	(-18%)	(-19%)
U. S. Energy Bill (Billion 1997\$)	563	553	694	592	541	570 ^c
Energy Bill Reductions (Percent Change from BAU)	–	–	–	(-15%)	(-22%)	(-18%)
U.S. Carbon Emissions (Million Metric Tons)	1,346	1,480	1,922	1,740	1,472	1,347
Carbon Emissions Reductions (Percent Change from BAU)	–	–	–	(-9%)	(-23%)	(-30%)

*A number of key technologies were not modeled within the CEF-NEMS framework and are therefore not reflected in these numbers, including: combined heat and power (CHP) in industry, CHP-district energy systems in buildings, solar domestic hot water heaters, and fuel cells in buildings. The first two of these are modeled in off-line analyses and show considerable potential for further reductions in energy use, energy bills, and carbon emissions.

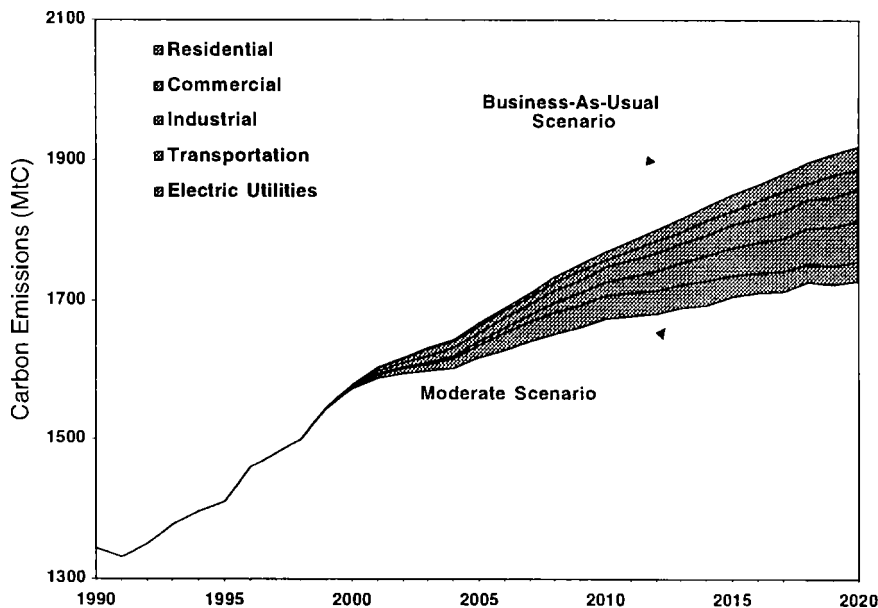
^a This variation of the Advanced scenario has a domestic carbon cap and trade system that equilibrates at a carbon permit charge of \$25/tC.

^b This "standard" Advanced scenario includes a domestic carbon cap and trade system that equilibrates at a carbon permit charge of \$50/tC.

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

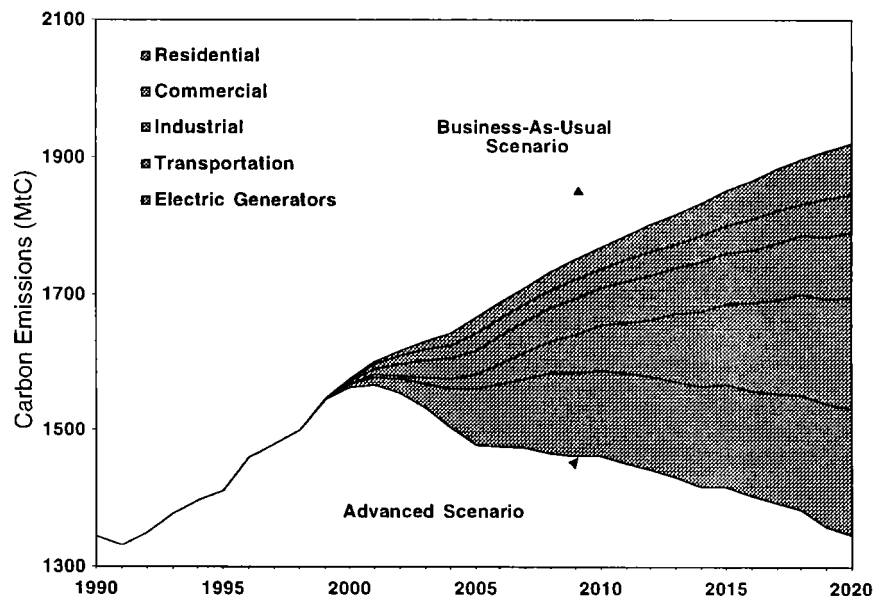
Carbon Emissions. The difference between the Moderate and Advanced scenarios is even more pronounced with respect to carbon emissions (see Figures ES1 and ES2). In both 2010 and 2020, the carbon emission reductions of the Advanced scenario are more than three times those of the Moderate scenario. The Advanced scenario carbon emissions do not grow at all between 1997 and 2010, and by 2020 they have dropped to 1990 levels. By 2010, the Moderate scenario brings CO₂ emissions 20% of the way back to 1990 levels, the Advanced scenario with a carbon permit charge of \$25/tC brings them 54% of the way down, and the Advanced scenario at \$50/tC closes 72% of the gap. Thus, to meet the Kyoto goal, 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.

Fig. ES1. Carbon Emission Reductions, by Sector, in the Moderate Scenario Carbon Emissions



electric sector of 47%, versus only 12% in the Moderate scenario. The largest portion of these reductions come from the replacement of coal-fired by natural gas-fired power plants as well as wind, biomass, and geothermal power.

Fig. ES2. Carbon Emission Reductions, by Sector, in the Advanced Scenario



Against these direct benefits is the possibility of macroeconomic costs arising from distortions induced by the carbon charges. Our assessment of these macroeconomic costs, based on a review of the quantitative modeling of other researchers, shows them to be no more than the net direct benefits of the scenarios. Hence, it appears that implementation of the policies in the CEF scenarios would produce, at worst, no net harm to the economy as a whole, and at best their net impacts would be beneficial.

Costs and Benefits. In both the Moderate and the Advanced scenarios and in both time frames (2010 and 2020), the national energy bill is lower than in the BAU forecast. This is largely due to the accelerated development and deployment of energy-efficient technologies, which reduces 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. Energy prices in the Advanced scenario drop between 2010 and 2020 due to the increased use and improved performance of efficient and

low-carbon energy technologies. 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.

While consumers see the energy bill and must pay for any incremental investment costs of the energy-efficient and clean energy technologies they purchase, there are also public costs to implement policies and programs and to recycle revenues to the public from the auction of carbon allowances. In both the policy scenarios the energy bill savings from investments in energy efficiency, in combination with recycled revenues from the cap and trade system, exceed the annualized direct costs of the technologies and policies (including an estimate of incremental investment costs and policy implementation costs). The annualized net direct benefits are estimated to be over \$40 billion dollars per year for both scenarios by 2010, and growing to more than \$100 billion per year in the Advanced scenario by 2020.

Against these direct benefits is the possibility of macroeconomic costs arising from distortions induced by the carbon charges. Our assessment of these macroeconomic costs, based on a review of the quantitative modeling of other researchers, shows them to be no more than the net direct benefits of the scenarios. Hence, it appears that implementation of the policies in the CEF scenarios would produce, at worst, no net harm to the economy as a whole, and at best their net impacts would be beneficial.

In addition to reducing carbon emissions and cutting energy bills, a clean energy future could produce important collateral benefits: reduced threat of disruptions in oil supply, cleaner air, and increased opportunities to export energy technologies. For example, in the Advanced scenario, in 2020:

- SO₂ 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.
- Petroleum consumption decreases 23% below the BAU forecast, thereby strengthening oil security. In addition, the U.S. benefits from significant reductions in annual wealth transfers from U.S. oil consumers to world oil exporters.

In spite of the overall net economic and environmental benefits of the scenarios, implementation of the policies in the CEF scenarios could produce important transition impacts and dislocations. The impact of the Advanced scenario on the coal industry is of particular note. Overall coal production in the United States decreases by 2020 to 60% of today's production or 50% of the BAU estimate for 2020, causing major adverse impacts on that industry. On the other hand, the growth of strong domestic wind, bioenergy, and other "green" industries envisioned in this scenario would bring new employment opportunities to many regions and could lead to a revitalization of the economies of rural America.

UNCERTAINTIES

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

The uncertainty associated with the results of the Moderate scenario is somewhat larger as policies to promote energy efficiency are included. 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, on the other hand, with its carbon charges, 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 benefits.

SUMMARY

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 responsive to energy needs, environmental conditions, and technology opportunities that emerge after 2020. Their scope is limited because we wanted to illuminate specific technology and policy opportunities for the United States today and in the near-term. By doing so, we show the importance of taking advantage of stock turnover to increase efficiency and clean fuel use. The lifetimes of energy supply technologies, energy distribution systems, and many other infrastructures such as refineries, highway infrastructures, and new subdivisions are five decades or longer. At most one or two replacements can occur over the course of a half-century. As a result, decisions made over the next two decades that impact these infrastructures will have far-reaching implications.

Our emphasis is on the importance of optimizing decisions at the point of major stock turnover while simultaneously continuing research to develop new and improved technology options for the future. In fact, given the uncertainties in global economic trends, export markets, energy technology development, air quality, and global climates, an expanded R&D effort in many energy technology arenas would appear to be warranted. There is a broad range of longer-term technology options that, with successful research, could provide additional pathways to address long-term, global, energy-related challenges. These include technologies for sequestering carbon from coal, a new generation of nuclear plants, and a host of efficient and renewable energy technologies.

This study makes a strong case for the value of energy technology research, development, demonstration and deployment as an effective public response to the nation's energy-related challenges. Many efficient and clean energy technologies are currently available and are cost-effective, but they need public policies and programs to overcome market and organizational barriers hindering their widespread utilization. Other potential technology solutions require further R&D to ready them for commercial introduction. This study helps move the nation toward developing the analysis and public process needed to identify, specify, and implement smart, sustainable energy policies and programs. We have shown that policies exist that can significantly reduce energy inefficiencies, oil dependence, air pollution, and carbon emissions at essentially no net cost to the U.S. economy.

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- John Stamos and Carolyn Heising (DOE Office of Nuclear Energy, which also provided funding for some supplemental analysis)
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Additional funding from the U.S. Environmental Protection Agency's Office of Atmospheric Programs enabled the completion of several important analyses. These included:

- the estimation of policy and program administrative costs,
- the assessment of travel reduction options,
- analysis of transportation technology supply curves, and
- assessment of non-CO₂ greenhouse gas opportunities.

Skip Laitner was the EPA manager for these analyses and was also an active participant in all aspects of the CEF Study.

The completion of this study was guided by an External Review Committee of experts from industry, universities, and utility research organizations. The committee was chaired by Bill Fulkerson (University of Tennessee, Joint Institute for Energy and Environment) and included:

- Douglas Bauer, National Research Council
- Morton H. Blatt, Electric Power Research Institute
- Stephen DeCanio, University of California-Santa Barbara
- Jae Edmonds, Global Change, Battelle Washington Operations
- Dan Lashof, Natural Resources Defense Council
- Trevor O. Jones, BIOMECH Inc.
- Manoj Guha, American Electric Power
- Thomas R. Roose, Gas Research Institute

Staff members of DOE's Energy Information Administration (EIA) participated in the planning process for this report, provided advice and assistance with the modelling described in the report, and offered useful comments on previous drafts. Leading this group were Mary Hutzler and Andy Kydes.

"Sector Expert Groups" were created to broaden the review process for the individual sector analyses. These groups reviewed the portions of the work plans and draft reports that pertain to their sectors and provided additional views and feedback. Participants in these groups are listed below.

Chapter 4 (Buildings):

- Gerald Auten, Department of the Treasury, Office of Tax Analysis
- Steve Bernow, Tellus Institute
- Erin Boedecker, EIA
- John Cymbalsky, EIA
- Sara Dill, BJ's Wholesale Club, Inc.
- Howard Geller, American Council for an Energy-Efficient Economy
- Mark Hanson, Energy Center of Wisconsin
- Kristin Heinmeier, Honeywell Home & Building Controls
- Skip Laitner, EPA
- Michael McCabe, DOE/EE
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- Howard Geller, American Council for an Energy-Efficient Economy
- Skip Laitner, EPA
- Steven Rosenstock, Edison Electric Institute

By acknowledging the involvement of the above individuals and the extensive review process in which they participated, we do not mean to imply their endorsement of the report. Final responsibility for the content of this report lies solely with the authors.

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Chapter 1

INTEGRATED ANALYSIS AND CONCLUSIONS¹

This report presents the results of a study conducted by five U.S. Department of Energy national laboratories that quantifies the potential for efficient and clean energy technologies to address a number of energy-related challenges facing the United States.² These challenges include global warming, air pollution, oil supply vulnerability, and economic inefficiencies in energy end-use systems. Some of these concerns are visible today and are clear public priorities; others are emerging as issues or are possible outcomes of an uncertain future. How the nation responds to them will affect the prosperity and well-being of future generations.

The stimulus for this study derives from the recognition that any national effort to address these challenges must consider ways of increasing the productivity, while decreasing the carbon content, of the energy that powers the U.S. economy. The results of this study make a strong case for the value of energy technology research, development, demonstration, and deployment as an effective public response. The study's unique contribution is its identification of specific public policies and government efforts that can foster solutions with positive economic impact.

1.1 STUDY OBJECTIVES

The principal goal of this study is to produce well-documented scenarios or pathways that assess how public policies and programs can foster efficient and clean energy technologies to meet the nation's energy-related challenges. The energy-related challenges addressed in this study include

- the threat of global warming and the possibility that human activities are contributing significantly to long-term climate change with potentially large economic and social costs;
- the possibility of increased acid rain, urban ozone, and other air pollution problems resulting from the continued growth in coal and petroleum use forecast for the next two decades;
- oil supply vulnerability and price volatility associated with the continued concentration of oil supplies in politically unstable parts of the world; and
- the difficulty of improving the efficiency of end-use energy systems in an era of cheap and plentiful energy.³

Scenarios for a Clean Energy Future (a.k.a., the CEF study) concentrates primarily upon the challenge of global warming—this is the principal focus of the supporting policies. In this context the term “clean energy technologies” refers to technologies that result in fewer carbon emissions per energy service delivered (e.g., lighting, mobility, and industrial heating). Using the framework of the 11-Lab study (DOE National Laboratory Directors, 1998), these technologies include:

¹ Authors: Marilyn A. Brown (ORNL), Mark D. Levine (LBNL), and Walter Short (NREL).

² The five national laboratories that participated in this study are: 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). This study has benefited greatly from reviews by representatives of the business, government, university, and nonprofit segments of the scientific community who provided important advice and feedback. Their assistance does not imply endorsement. The final responsibility for the content of this report lies solely with the authors.

³ These challenges, and their relationship to DOE's energy R&D portfolio and its Comprehensive National Energy Strategy are described in DOE (1998 and 1999).

- 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, 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).

The other energy-related challenges (i.e., air pollution, oil supply vulnerability, and economic inefficiencies) are addressed both as co-benefits of climate change mitigation and as the target of policies specifically designed to tackle them.

This study builds upon the results of a previous report, *Scenarios of U.S. Carbon Reductions*—also known as the “Five-Lab study” (Interlaboratory Working Group, 1997). This earlier report quantified the potential for energy-efficient and low-carbon technologies to reduce carbon emissions in the United States by the year 2010. Key sectors of the economy were examined independently: buildings, transportation, industry, and electric generators. The report identified a set of technologies with the potential to restrain the growth in U.S. energy consumption and carbon emissions so that levels in 2010 could be close to those in 1997 (for energy) and 1990 (for carbon). The report concluded that if feasible ways could be found to implement these technologies, the resulting reduction in energy costs would be roughly equal to or exceed the direct costs of implementing the technologies.⁴

The Five-Lab study did not identify specific policies and programs needed to motivate consumers and businesses to purchase the technologies that make up its scenarios. The current study does so. Specifically, it examines the potential impacts of different packages of public policies and programs in an effort to identify feasible, low-cost policy pathways to a clean energy future. As such, 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 also did not conduct an integrating analysis and was therefore unable to assess the full range of effects of its technology scenarios on the U.S. economy.⁵ The need for an integrating analysis was recognized by the authors and was addressed in a subsequent peer-reviewed report sponsored by the U.S. Environmental Protection Agency (Kooimey, et al., 1998). An integrating analytical framework is also used in the CEF study. In particular, a variant of the Energy Information Administration’s (EIA’s) National Energy Modeling System (NEMS)—called the Clean Energy Future-NEMS (CEF-NEMS)—provides integrated results across individual sectors.⁶ The integration step 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. For example, if electric generators should shift significantly to natural gas while at the same time energy consumption in buildings and industry continued to grow, natural gas prices would rise and some switching to other fuels would result. Through the integration process, such interactions can be assessed.

Although this study builds on the Five-Lab study, it stands on its own. Its purpose, scope, and methodology are different, and as a result its findings, while complementary, are distinct. In addition to the differences noted above, the CEF scenarios extend beyond the Five-Lab study’s horizon—by looking

⁴ Direct costs include the increased technology cost plus an approximate estimate of the costs of program and policy implementation.

⁵ This limitation and the lack of specific policies and programs were noted in a General Accounting Office review of the Five-Lab study (GAO, 1998, pp. 5–6).

⁶ Kooimey, et al. (1998) was based on many of the technology assumptions of the Five-Lab study. It used the NEMS integration module but changed the characterization of consumer behavior, the technology characteristics, and many assumptions of the end-use models. It found that the results were not significantly altered by the integration step.

quantitatively to 2020 and qualitatively to 2050—and they address an array of multiple challenges, not just global warming.

1.2 STUDY METHODOLOGY

The methodology developed for this study is driven largely by the objective of assessing national policies to address the multiple energy and environmental challenges facing the United States. This objective requires that the methodology be scenario-based, integrated across sectors, and flexible (yet consistent) in handling a variety of policy options, market sectors, and technologies. The methodology developed here meets these requirements by employing a combination of tools and analytical approaches.

1.2.1 CEF Scenarios

A scenario-based approach is used to allow examination of a range of public perceptions of the severity of energy-related challenges including global climate change. Each scenario includes a package of policies compatible with that public perception. The central tool employed to analyze the policy set of each scenario is the CEF-NEMS model. For flexibility in addressing specific policies, additional assessment methods and tools specific to sectors and end-uses have been exercised and their results integrated within the CEF-NEMS framework. Macro-economic impacts and feedback have also been assessed through a qualitative discussion and an analysis of previous modeling results.

The study employs three scenarios—Business-as-Usual (BAU), Moderate, and Advanced. The BAU forecast assumes a continuation of current energy policies and a steady pace of technological progress. In contrast, the Moderate and Advanced scenarios represent increasing levels of public commitment to solving the nation's energy-related challenges and a strong political resolve that enables policies to be implemented that are politically infeasible today. These scenarios are defined by public policies and programs, designed individually for each sector (buildings, industry, transportation, and electric generators) and assessed for impacts out to 2020. A wide range of policies is examined, including fiscal incentives, voluntary programs, regulations, and research and development.

The CEF scenarios are assessed as a package in terms of both benefits and costs projected out to 2020. The benefits include not only lower greenhouse gas emissions, but also reduced local air pollution, the benefits to national security of reduced oil imports, and more efficient energy production and use. The costs include direct costs of the private-sector investment in efficiency and low-carbon technologies and of federal programs designed to encourage such technologies, as well as the indirect costs of shifts in energy supply that will lead to changes in employment and economic activity.

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 responsive to energy needs, environmental conditions, and technology opportunities that emerge after 2020. Their scope is limited because we wanted to illuminate specific technology and policy opportunities for the United States today and in the near-term. The 20-year scope of the CEF study is not meant to minimize the importance of longer-term, global issues, or of alternative technology pathways that emerge in later decades. In order to place the CEF scenarios in this broader context, we qualitatively describe an array of additional technology options that, with successful research, could provide additional pathways to address the nation's and the world's energy-related challenges.

1.2.2 Treatment of Uncertainties

The use of scenarios in our study addresses one key uncertainty – the public response to the nation's energy-related challenges. However, there are many additional uncertainties associated with any study of this sort that estimates future impacts of technology and policy. Principal among these is the assumed cost and performance of technologies that are still under development. Uncertainties also arise from the

imprecision in modeling consumer behavior and policy impacts on that behavior. Consumer preferences for new technologies are unreliable and subject to change. And certainly, the connection between public policy and such consumer preferences is even more tenuous.

Based on the scenario definitions and modeling approach used in this study, the CEF scenarios do not have “inflection points” caused by sudden shifts in policies, technologies, or market preferences. Rather, the scenarios are more incremental and continuous, based on an accumulation of policies impacting numerous technologies, sectors, and markets. To the extent we have failed to anticipate major technology- and market-driven breakthroughs, the CEF characterization of policy impacts over the next 20 years will be imprecise.

All scenario-building exercises run this risk. History has experienced numerous transformations that were unanticipated by qualified planners. For instance, energy analysts in the 1970’s failed to predict America’s love affair with sports utility vehicles in the 1990s—an inflection point that interrupted the post-oil embargo’s decade of steady gains in automobile efficiency. Similarly, electricity analysts in the 1970’s failed to foresee the extraordinary consequences of the gas turbine technologies developed for the defense industry, which became the “technology of choice” in the 1990s—an inflection point that transformed the electricity industry and led to the elimination of many demand-side management programs.

We may also have failed to anticipate transformational trends. The scenarios do not, for instance, take into account the exploding growth of e-commerce and the Internet economy, which could fundamentally reshape the nation’s demand for energy services. As Romm (1999, p. 9) explains, “The Internet has the ability to turn retail buildings into Web sites and to turn warehouses into better supply chain software, to dematerialize paper and CDs into electrons, and to turn trucks into fiber optic cables.”

Despite this omission, the CEF study does undertake a diverse array of sensitivity cases to examine a number of key “what if’s.” These range from analysis of:

- energy prices (e.g., what if natural gas prices were to rise by 25% over the next two decades),
- technology breakthroughs (e.g., what if international markets could significantly drive down the price of new nuclear plants in the U.S.?),
- technology failures (e.g., what if research is unable to produce a clean diesel engine for automobiles?),
- policy limitations (e.g., what if policies to promote energy efficiency become politically incorrect and the nation’s energy challenges must be addressed entirely through the use of cleaner energy?).

These sensitivity cases allow the reader to examine numerous possible future scenarios and to determine the degree to which the “core” ones (i.e., the Moderate and Advanced scenarios) are robust over a multitude of circumstances. The overall conclusion of these sensitivities is that the existence of a wide array of policy and technology options provides many low-cost pathways to a cleaner energy future.

In the end, we take advantage of the data available, use our best judgment tempered by external expert review, and employ scenarios and sensitivity analysis to bound the uncertainties. For example, in addition to our three scenarios, we include high-level sensitivities in which we consider only demand-side policies or only supply-side policies (i.e. policies that impact electricity supplies). We also have examined the sensitivity to a limited number of specific major policies such as the carbon cap and trade system, the renewable portfolio standard, and tougher corporate average fleet efficiency standards.

In spite of our scenarios, sensitivities, caveats, and protests to the contrary, it is tempting to use point estimates provided by the individual scenarios as “the estimate.” In hindsight, we might have devoted

more of our limited resources to developing a range of estimates for each scenario. For now, the reader is cautioned to consider the values shown as simply representative of a range of possible outcomes.

The only remaining question is whether this range of possible outcomes might be large enough to reverse some of the principal findings of the study. In the end, each reader must weigh the data, the methods, the results, and the sensitivities to answer this question. However, the size of the net “direct” benefits of the Advanced scenario, the robustness of the findings with respect to the sensitivities conducted, and the market’s inherent ability to innovate beyond that which can be anticipated by any study all lend credence to the conclusions drawn. While the authors of this report have a range of views about the results, they all believe that with sufficient commitment, the United States could achieve all or a substantial portion of the future portrayed by the Advanced Scenario.

1.3 POLICY IMPLEMENTATION PATHWAYS

As noted, the analysis focuses on three scenarios: Business-As-Usual, Moderate, and Advanced. The BAU forecast describes a future in which policies and the implementation of energy efficiency and low-carbon technology are not greatly different from today. It is based on the Reference Case developed by EIA and published in the *Annual Energy Outlook 1999* (EIA, 1998). To follow a path that leads to the Moderate and Advanced Scenarios, new or strengthened policies and programs will be needed.

Tables 1.1 through 1.4 illustrate the types of policies and programs that define the Moderate and Advanced scenarios for buildings, industry, transportation, and electricity supply, respectively. The lists simply summarize each policy; a complete description of the policies can be found in each of the sector chapters that follow.

Most of the policies were selected on the basis of their potential to reduce carbon emissions. Others were designed specifically for other emissions (e.g., reducing SO₂ emissions in the electric sector by 50%) or for economic efficiency (e.g., restructuring of the electric sector). Regardless of the driving force behind them, almost all reduce carbon emission and improve air quality. Policies are generally stronger in the Advanced than the Moderate Scenarios, with larger expenditures on public-private R&D partnerships, stricter standards, higher tax incentives, and greater government investment in programs that promote efficient and clean technologies. Two key differences for all of the sectors is the addition of a domestic carbon cap and trade system to the Advanced scenario and increased R&D resources in both the Moderate and Advanced scenarios.

- **Domestic carbon cap and trade system.** Emissions trading programs work by allocating allowances that permit the emission of limited quantities of pollution during a specified period (e.g., annually). They allow sources to comply with the cap by either reducing emissions or purchasing permits from other sources so that they can continue to emit carbon. A firm’s response will depend on its costs of control compared with the market price of allowances. We assume that the domestic carbon-trading program is announced in 2002 and is implemented in 2005. 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.⁷ The federal government collects all of the carbon charge revenues and transfers them back to the public.

⁷ \$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).

Table 1.1 Illustrative Buildings Sector Policies, By Scenario

Moderate Scenario	Advanced Scenario
→ Implement new efficiency standards for equipment, beyond those already planned.	→ More end-uses covered by standards
→ Increase enforcement and adoption of current building codes (Model Energy Code and ASHRAE 90.1R)	→ More stringent residential building code in 2009 that is gradually adopted by states
→ Expand voluntary labeling and deployment programs such as ENERGY STAR, Building America, PATH, Rebuild America to increase the penetration of efficient technologies in the market and to raise the efficiency level for certain programs	→ Enhanced programs, more end-uses covered
→ Implement tax credits as proposed by the Clinton Administration in the Climate Change Technology Initiative (CCTI) (e.g., \$1,000 tax credit for new homes that are at least 30% more energy efficient than the International Energy Conservation Code, through 2004)	→ Same credits but with longer time periods before phase-out. Size of tax credit increased for heat pump water heaters as well
→ Expand cost-shared, federal R&D expenditures by 50%	→ Double cost-shared, federal R&D expenditures, leading to greater cost reductions, more advanced technologies, more penetration associated with R&D
→ "Public benefits" (lines) charges for states implementing electricity restructuring (full national restructuring in 2008)	→ Higher line charges
→ Government procurement assumed to increase in scope over current efforts. Increase Federal Energy Management Program (FEMP) efficiency goals by executive order. Adopt renewable power purchase requirement for federal facilities.	→ More rapid implementation of FEMP efficiency goals and faster expansion of ENERGY STAR purchasing to state and local governments as well as large corporations. More stringent renewable power purchase requirement for federal facilities.
	→ Domestic carbon cap and trade system with assumed permit price of \$50/tC

- **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. Since these resources are spent in public/private RD&D partnerships, they are matched by private-sector funds. Altogether, the Moderate scenario assumes an increase of \$1.4 billion per year by approximately 2005 (half as federal appropriations and half as private-sector cost share). This increment continues through 2020. The Advanced scenario assumes that the federal government doubles its appropriations for cost-shared RD&D, resulting in an increase of \$2.8 billion per year. 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.

Table 1.2 Illustrative Industrial Sector Policies, by Scenario

Moderate Scenario	Advanced Scenario
Build upon existing voluntary sector agreements with associations and companies to achieve an energy efficiency improvement of 0.5% per year over the business-as-usual scenario	Build upon existing voluntary sector agreements with associations and companies to achieve an energy efficiency improvement of 1.0% per year over the business-as-usual scenario
Voluntary programs: increase motor, compressed air, steam, and combined heat and power (CHP) challenge programs; expand floorspace covered by Energy Star Building program by 50%	Voluntary programs: extend challenge programs to smaller companies and other activities; increase floorspace covered by Energy Star Building program by 100%; expand number of pollution prevention program partners grows to 1600 by 2020 (from 700 in 1997)
Information and technical assistance: expand audit programs (Industrial Assessment Centers–IACs) and labeling programs	Information and technical assistance: expand audit programs (IAC) and labeling programs
Regulation: Mandate upgrades of all motors to EPACT standards by 2020	Regulation: Mandate upgrade of all motors to Consortium for Energy Efficiency standards by 2020
Investment enabling: expand Clean Air Partnership and line charges to 30 states, provide tax rebates of 50% of the salary of 5,000 energy managers by 2020. Investment tax credit for CHP systems.	Investment enabling: Extend Clean Air Partnership and expand line charges to 50 states, provide tax rebates of 50% of the salary of 10,000 energy managers by 2020
CHP Policies: CCTI tax credits, expedited siting and permitting, interconnection standard in 2002	CHP Policies: Extend tax credits beyond 2003, increase state grants through Clean Air Partnership Fund, further reduce expense associated with interconnection
Expand cost-shared federal R&D expenditures by 50%: increase industries-of-the-future effort and cross-cutting industrial efficiency R&D programs	Double cost-shared federal R&D expenditures: include new industries-of-the-future effort and further expand cross-cutting industrial efficiency R&D programs
	Domestic carbon cap and trade system with assumed permit price of \$50/tC

A set of guidelines was developed for selecting policies for each sector and scenario (see Chapter 3). For buildings, the policies and programs include additional appliance efficiency standards; expansion of voluntary programs such as ENERGY STAR, Building America, and Rebuild America; increased efforts on building codes; expanded R&D; tax credits; continuation of market transformation programs; and related public interest programs financed by electricity line charges.

Table 1.3 Illustrative Transportation Sector Policies, by Scenario*

Moderate Scenario	Advanced Scenario
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Moderate Scenario	Advanced Scenario
→ Expand cost-shared, federal R&D expenditures by 50% (e.g., achieving 7.4 mpg for heavy trucks in 2020)	→ Double cost-shared, federal R&D expenditures (e.g., achieving 7.9 mpg for heavy trucks in 2020)
→ Implement vehicle purchase tax credits as proposed in the CCTI (e.g., \$2,000 credit for vehicle that is two-thirds more fuel efficient than a comparable vehicle, for purchases in 2003 through 2006)	→ Tax credits are extended
→ Accelerate air traffic management improvements to reduce the time spent waiting “on line” on the ground and circling around airports.	→ Same
→ Program to promote investment in cellulosic ethanol production.	→ Same
→ Invigorated government fleet program promoting alternative fuels and efficiency	→ Same, with more rigorous requirements
	→ Voluntary agreements to improve fuel economy for light-duty vehicles (40 mpg autos, 30 mpg light trucks in 2010; 50 mpg autos, 35 mpg light trucks in 2020) ^a
	→ “Pay-at-the-pump” automobile insurance ^b
	→ Intelligent traffic systems controls, including intelligent roadway signing, staggered freeway entry and electronic toll collection.
	→ Domestic carbon cap and trade system with assumed permit price of \$50/tC

^aA side analysis examines the potential reduction in vehicle miles of travel from policies that affect the evolution of land use patterns and investments in highway infrastructure.

^a These voluntary agreements, because they are met in the Advanced scenario, would have the same effect as a CAFE standard of the same level.

^b “Pay-at-the-pump” involves paying for a portion of automobile insurance by means of a tax on gasoline, thereby “variabilizing” the cost of insurance to reflect miles traveled.

For industry, the pathways create an array of 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, detailed in Table 1.2, include expansion of existing information programs, financial incentives, greater cost-shared R&D investments, and strengthening of energy efficiency standards on motors systems. Measures are taken to encourage the diffusion and improve the implementation of combined heat and power (CHP) in the industrial sector.

For transportation, the scenarios result from a combination of financial incentives for efficient automobiles (“golden carrots”), continued and strengthened R&D, several government programs, and voluntary energy efficiency targets for light-duty vehicles. A side analysis examines the potential reduction in vehicle miles of travel from policies that affect the evolution of land use patterns and investments in highway infrastructure.

For electricity, the policies include extending the production tax credit of 1.5¢/kWh over more years and additional renewable technologies, setting stricter particulate matter standards, enhancing RD&D, and facilitating the deployment of wind energy.

Table 1.4 Illustrative Electricity Sector Policies, by Scenario

Moderate Scenario	Advanced Scenario
→ Wind deployment facilitation (e.g., facilitate siting on Federal land, design operator protocols to accommodate wind intermittency)	→ Same
→ 1.5¢/kWh production tax credit (PTC) for the first 10 years of operation for wind and biomass power installed through 2004.	→ Same, for all non-hydro renewable electricity options
→ 1¢/kWh credit for biomass cofiring during the years 2000-2004	→ 1¢/kWh credit for biomass cofiring during the years 2000-2014
	→ Renewable portfolio standard—represented by 1.5¢/kWh PTC in 2005–2008 to signify cap in Clinton Administration proposal
→ Enhanced R&D – represented by the electric technology cost and performance of the AEO99 high renewables and high fossil cases	→ Limited additional technology advances beyond those of the Moderate scenario. Includes carbon sequestration option.
→ Up to 1% net metering.	→ Up to 5% net metering.
→ Full national restructuring of the electricity industry in 2008 resulting in marginal cost pricing, lower reserve margins, etc.	→ Same
	→ SO ₂ ceiling reduced in steps by 50% between 2010 and 2020 to represent tighter particulate matter standards
	→ Domestic carbon cap and trade system with assumed permit price of \$50/tC

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, wall, windows, and foundations in existing buildings). In other cases, policies included in the CEF study have less stringent goals than the policies modeled in other studies (e.g., Geller, Bernow, and Dougherty, 1999; Tellus Institute, 1999). 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 business-as-usual forecast already includes a vmt growth rate that is judged to be unrealistically low (see Appendix E-2). Finally, numerous policies examined in other studies are omitted because they were considered to exceed the levels of public commitment and cost that were used as guidelines to define the Moderate and Advanced scenarios. Examples include:

- **Buildings:** preserve or reinstate 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 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 cap 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 the nation’s energy and environmental goals. Thus, if the nation requires acceleration, these other studies should be consulted to identify stronger actions.

1.4 POLICY SCENARIO RESULTS

This section begins with a discussion of the BAU forecast, since it provides the baseline for assessing the impacts of alternative policy scenarios.

1.4.1 The Business-as-Usual Forecast

The BAU scenario was developed from EIA’s AEO99 Reference Case (EIA, 1998). Like the EIA reference case, it is based on federal, state, and local laws and regulations in effect on July 1, 1998, and does not reflect the potential impacts of pending or proposed legislation. However, it does incorporate the impacts of scheduled administrative actions, such as the issuance of scheduled standards which the EIA estimates do not. In addition, BAU is based on the assumption that federal funding of energy R&D continues at current levels. This ongoing investment, in combination with other private- and public-sector actions, is presumed to result in a steady pace of technological progress. For instance,

- New residential building shell efficiencies are assumed to improve by approximately 25% by 2020 relative to the 1993 average, due to advanced insulation methods and windows.
- In industry, total energy intensities are forecast to decrease by 1.1% annually, of which a reduction of 0.3% annually is through efficiency improvements.
- Switching to low rolling resistance tires is assumed to reduce fuel consumption by 1 trillion Btu in 2010, and purchases of alternative-fuel vehicles by State governments are assumed to increase to 75% of State fleet purchases in 2001 (EIA, 1998a, pp. 220-223).

The BAU scenario forecasts that U.S. energy consumption will increase 1.2% annually from 94 quads in 1997 to 110 quads in 2010 (Table 1.5). During the subsequent decade, the annual growth rate will drop to 0.8%, bringing total U.S. consumption to 119 quads in 2020. While there is necessarily great uncertainty associated with any specific forecast, all indications are that the United States is on a path toward increasing energy consumption well into the foreseeable future.

**Table 1.5 Primary Energy and Carbon Emissions, by Sector:
Reference Case vs. Business-as-Usual Forecasts**

	Primary Energy (quadrillion Btu)				Carbon Emissions (MtC)			
	2010		2020		2010		2020	
	AEO99 Reference Case	BAU Scenario	AEO99 Reference Case	BAU Scenario	AEO99 Reference Case	BAU Scenario	AEO99 Reference Case	BAU Scenario
Residential	21.1	21.2	22.9	23.1	333	330	375	363
Commercial	17.2	17.3	18.1	18.3	282	280	308	300
Industrial	39.4	38.7	42.1	41.1	549	534	595	563
Transportation	33.1	33.1	36.9	36.8	626	626	697	696
Total	110.8	110.2	119.9	119.4	1790	1769	1975	1922
Electric Generators*	39.2	39.2	42.1	41.9	655	645	746	718

Notes: BAU = Business-As-Usual scenario. Source for AEO99 Reference Case forecast: Table A2, EIA 1998a. *The primary energy consumed by electric generators, and their carbon emissions, are distributed across consumption sectors and therefore are fully included in the row labeled "Total."

The CEF study's BAU scenario varies only slightly from the EIA reference case. The differences reflect several changes. First, the BAU forecast assumes lower nuclear power relicensing costs than the reference case (these lower costs are believed to be more realistic). Second, the BAU forecast modified base year values as well as retirement rates in three industries—cement, iron and steel, and pulp and paper—based on detailed studies of these industries. Finally, it uses higher retirement rates for all industrial sectors and lower lifetimes of equipment to reflect actual lifetimes of installed equipment, based on detailed assessments of the same three industries. All of the input variations that distinguish these two cases are documented in Appendix A.

BAU forecasts that U.S. carbon emissions from fossil fuel consumption will increase 1.4% annually from 1,480 MtC in 1997 to 1,769 MtC in 2010 (Table 1.5). During the subsequent decade, the annual growth rate is forecast to be 0.6%, increasing emissions to 1,922 MtC in 2020. The carbon emissions forecasts of the BAU scenario and the EIA reference case vary somewhat more than their energy forecasts. This is because in addition to assuming slower growth in energy consumption, BAU extends the operation of some nuclear plant capacity assumed to be shut down in the reference case, resulting in a slower rate of growth in the CO₂ emitted per kWh. Carbon emissions in the BAU scenario are almost 1% less in 2010 and are 3% less in 2020 than in the reference case.

The latest information on energy consumption and greenhouse gas emissions in the U.S. (EIA, 1999a, Tables A2 and A19, EIA, 1999b) indicates that in 1998, the nation's energy consumption grew by only 0.5% and carbon emissions grew by only 0.4%, relative to 1997 levels. During the same year, the economy exhibited continuous growth, with approximately a 4% increase in GDP. Unlike buildings and transportation, the industrial sector's emissions actually dropped in 1998. This decline was likely affected by a warmer than normal winter season and structural shifts in U.S. manufacturing away from energy-intensive industries and toward information-intensive businesses. If this slowdown in energy demand and carbon emission growth rates reflects long-term structural shifts, then both the BAU and AEO00 forecasts for carbon and energy may be too high.

Notwithstanding these 1998 estimates, both BAU and the reference case anticipate that each sector (buildings, industry, transportation, and electric generators) will increase its carbon emissions over the next 20 years. Emissions from the transportation sector are expected to grow most quickly and emissions from industry, least quickly. Without strong policy intervention and/or significant energy price increases, it appears unlikely that carbon emissions in the United States will stabilize or decline.

Results of the two policy scenarios are described in the following sections, in terms of energy savings and carbon reductions, then key policies and technologies, and finally, costs and benefits. In each case, the policy scenarios are compared with the BAU forecast to assess the magnitude and nature of their impacts.

1.4.2 Energy Savings of the Policy Scenarios

Table 1.6 and Figure 1.1 present the energy use trajectories produced by the Moderate and Advanced policy scenarios and the BAU forecast. The presentation of values with three or more significant figures in this table and throughout the 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 our resources and the CEF-NEMS methodology described earlier.

Table 1.6 Primary Energy by Sector (quadrillion Btu)*

			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*	30.1	34.2	39.3	37.5 (-5%)	34.6 (-12%)	42.9	38.4 (-10%)	32.6 (-24%)

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 A2, p. 44. Source for other 1990 data and 1997 data: Energy Information Administration (1998a), Table B2, p. 141.

*A number of key technologies were not modeled within the CEF-NEMS framework and are therefore not reflected in these numbers. These omitted technologies include: combined heat and power (CHP) in industry, CHP-district energy systems in buildings, solar domestic hot water heaters, and fuel cells in buildings. The first two of these are modeled in off-line analyses and show considerable potential for further reductions in energy use.

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

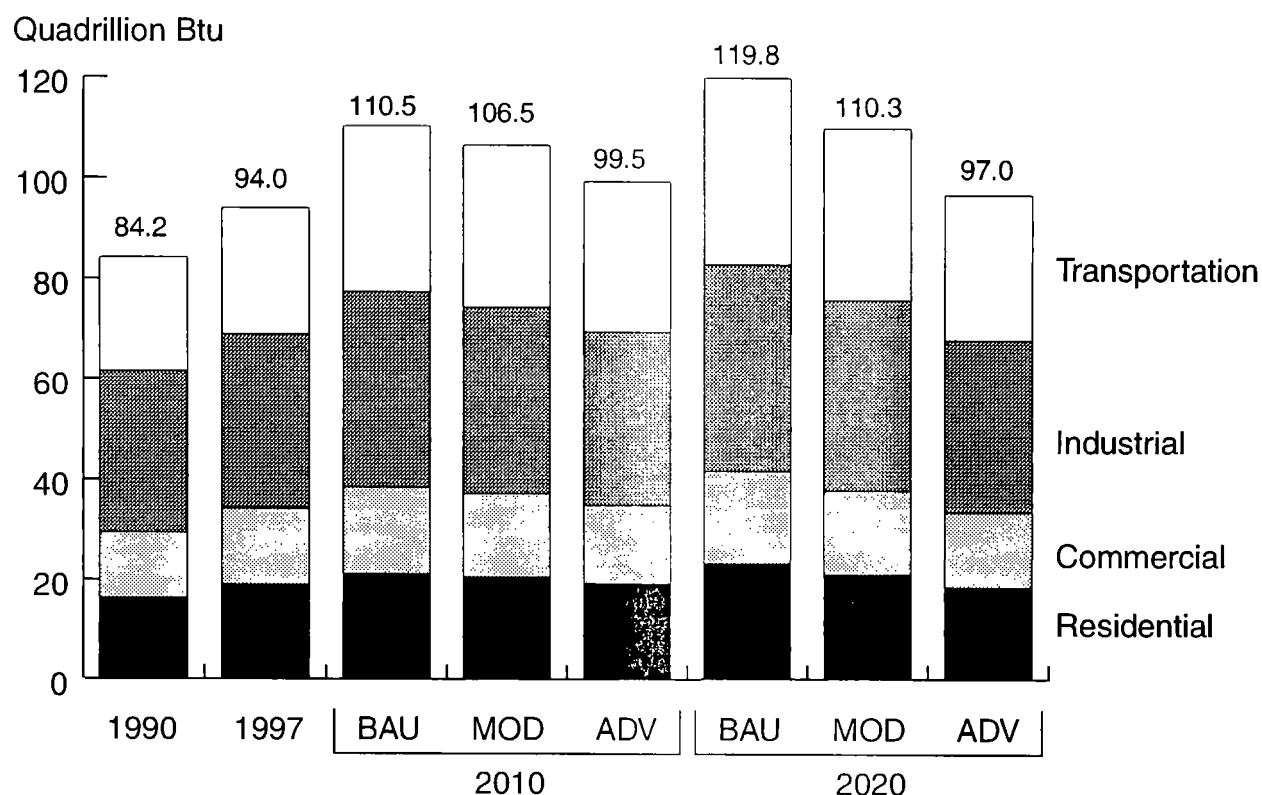
In the Moderate scenario, energy consumption grows at an annual rate of 1.0% between 1997 and 2010. Instead of reaching 110 quads in 2010, energy use increases to 107 quads. Overall, the Moderate scenario for 2010 shows an increase of 13% above the 94 quads consumed in 1997 (26% above the 84 quads used in 1990). During the second decade, energy consumption grows at an annual rate of 0.3%. Instead of reaching 120 quads in 2020, it increases to 110. The Moderate scenario for 2020 shows an increase of 17% above the 94 quads consumed in 1997 (31% above the 84 quads used in 1990). Transportation energy use grows considerably faster than energy use in the other sectors.

In the Advanced scenario, with its more aggressive policies, energy consumption grows at an annual rate of only 0.4% between 1997 and 2010, approximately half the growth rate of the Moderate scenario. In the second decade, the accelerated penetration of efficient technologies in each end-use sector reverses the growth trend. Energy use between 2010 and 2020 decreases at a rate of 0.3% annually. The Advanced

scenario projects an overall increase in energy use to 100 quads in 2010, just 6% higher than in 1997 and 19% higher than in 1990. Energy use in 2020 decreases to 97 quads, just 3% above 1997 levels and 15% above the 84 quads consumed in 1990.

Table 1.7 and Figure 1.2 show the energy consumption by fuel type for the BAU, Moderate, and Advanced scenarios. There are several notable observations from this table.

Figure 1.1 Primary Energy by Sector (quadrillion Btu)



Note: BAU = Business-As-Usual; MOD = Moderate Scenario; ADV = Advanced Scenario. See Table 1.6 for the values associated with this graph.

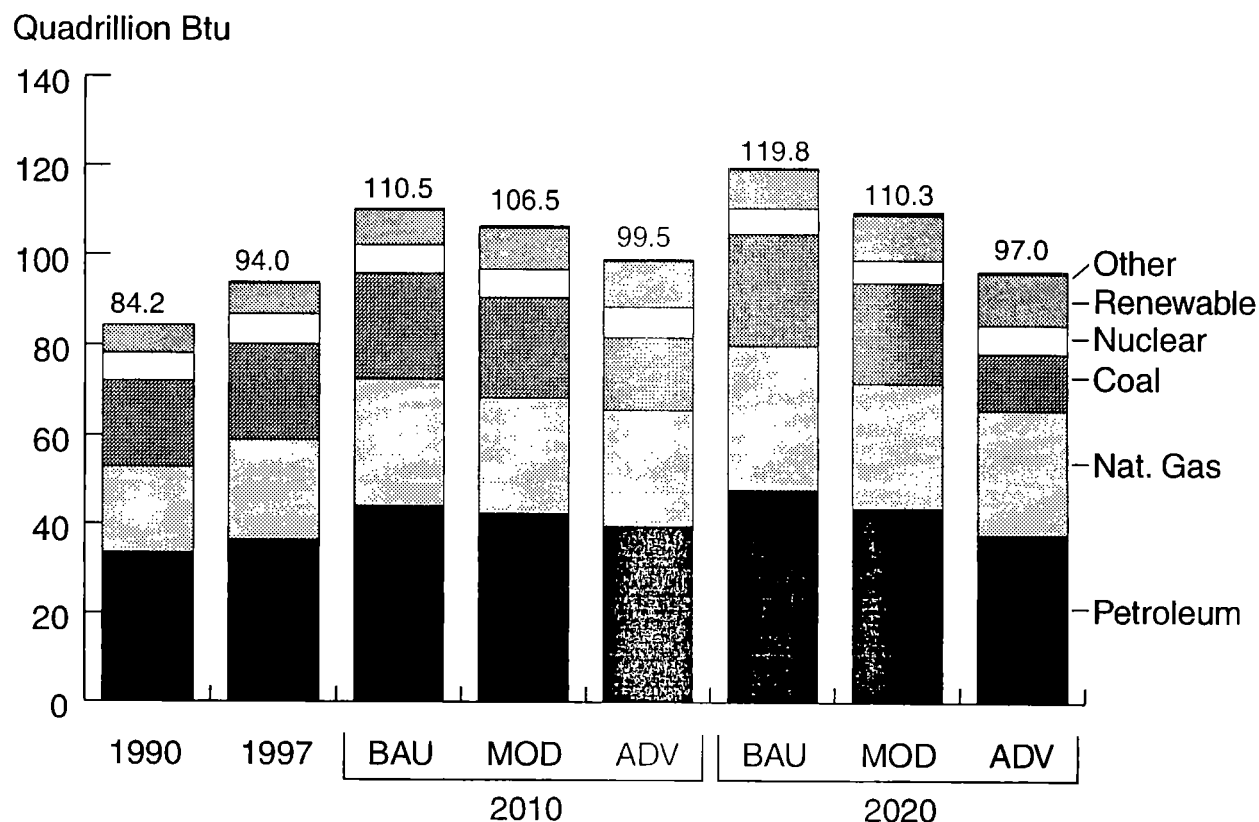
Table 1.7 Energy Consumption by Source (quadrillion Btu)

	1990	1997	2010			2020		
			BAU	Mod.	Adv.	BAU	Mod.	Adv.
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*	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	99.5	119.8	110.3	97.0

			(-4%)	(-10%)	(-8%)	(-19%)
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Note: BAU = Business-As-Usual; Mod. = Moderate; Adv.= Advanced. Numbers in parentheses represent the percentage change compared with BAU. *Other sources include methanol and liquid hydrogen.

Figure 1.2 Energy Consumption by Source (quadrillion Btu)



Note: BAU = Business-As-Usual; MOD = Moderate; ADV = Advanced. See Table 1.7 for the values associated with this graph.

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 increases from 1997 levels in both 2010 and 2020. Relative to BAU, coal consumption declines by about the same magnitude as natural gas and petroleum in both 2010 and 2020—on the order of 5 to 8% from 1997 levels. However, in the Advanced scenario with a \$50/tonne carbon charge, coal use declines to 77% of 1997 consumption in 2010 and 60% of 1997 consumption in 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 scenario. This is because the increased energy savings from efficiency investments, the increased use of renewable energy, and the maintained use of nuclear power in the Advanced scenario are greater in magnitude than the decline in coal use.

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 longer-

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% to 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).

1.4.3 Carbon Emissions Reductions of the Policy Scenarios

Table 1.8 and Figure 1.3 display the carbon emissions by sector for the three scenarios.

In the Moderate scenario, carbon reductions generally follow—but are somewhat greater than—the reductions in energy use for buildings, industry, and transportation. Between 1997 and 2010, carbon emissions grow at an annual rate of 1.0%. Instead of reaching 1,769 MtC in 2010 (BAU), they increase to 1,684 MtC. During the second decade, carbon emissions grow at an annual rate of only 0.3%, to 1,743 MtC instead of 1,922 MtC in 2020. Annual carbon emissions in 2010 are 85 MtC lower in the Moderate scenario than in BAU, and in 2020 they are 179 MtC lower. However, in both time frames, carbon emissions are considerably higher than in 1990 or 1997.

In contrast, the Advanced scenario—with its more aggressive demand- and supply-side policies—shows markedly greater percentage reductions in carbon emissions than in energy use. Between 1997 and 2010, carbon emissions do not grow at all; and during the second decade they decrease at an annual rate of 1.0%. Instead of growing to 1,922 MtC per year by 2020, carbon emissions are brought close to 1990 levels in 2020 (i.e., 1,357 MtC). Carbon emissions in 2010 are 302 MtC lower in the Advanced scenario than in BAU (a 17% reduction), and in 2020 they are 565 MtC lower than in the BAU scenario (a 29% reduction).

The most significant carbon emissions reductions in the end-use sectors occur in buildings and industry. These reductions result from two changes: increased energy efficiency and reduced carbon in the fuels used to generate electricity.

Table 1.8 Carbon Emissions from Fossil Energy Consumption, by Sector (MtC)*

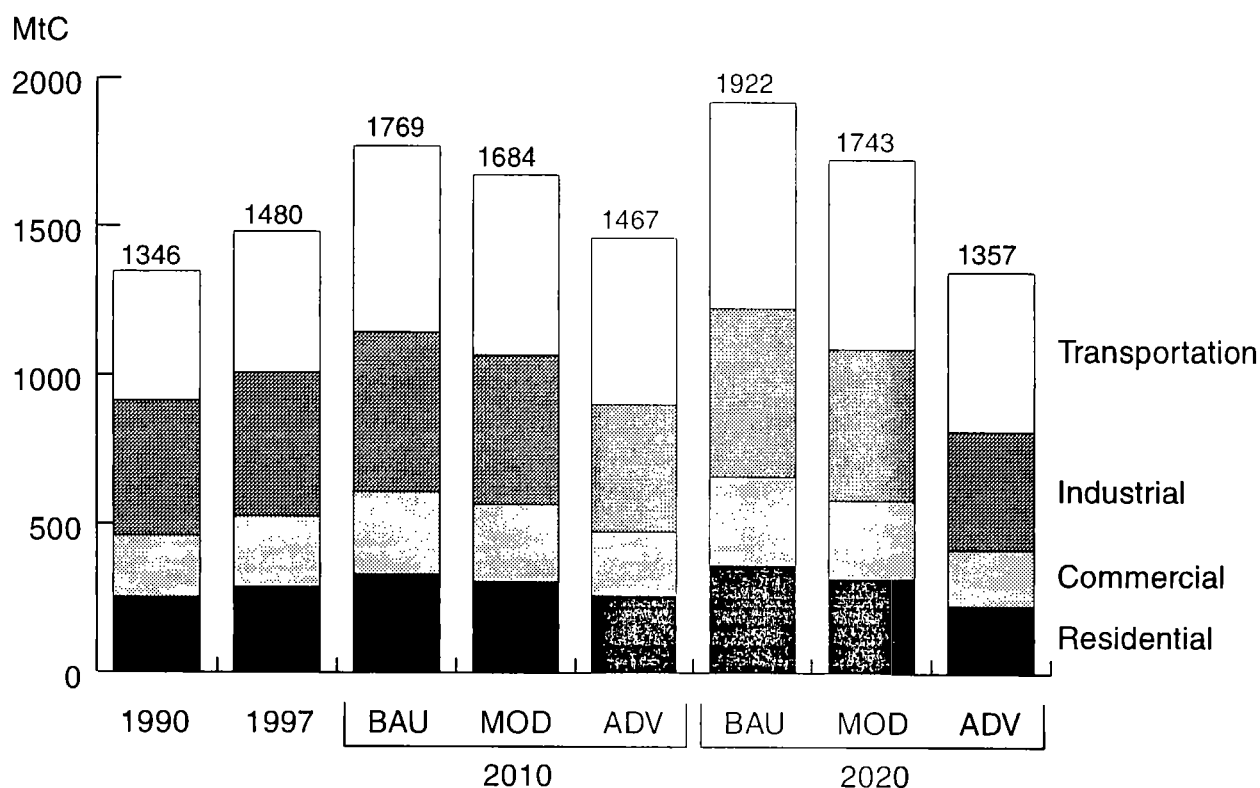
	1990	1997	2010			2020		
			BAU	Mod.	Adv.	BAU	Mod.	Adv.
Residential	253	287	330	311 (-6%)	260 (-21%)	363	323 (-11%)	230 (-37%)
Commercial	207	237	280	263 (-6%)	218 (-22%)	300	271 (-10%)	195 (-35%)
Industrial	454	483	534	505 (-5%)	429 (-20%)	563	511 (-9%)	399 (-29%)
Transportation	432	473	626	606 (-3%)	560 (-11%)	696	638 (-8%)	533 (-23%)
Total	1346	1480	1769	1684 (-5%)	1467 (-17%)	1922	1743 (-9%)	1357 (-29%)
Electric Generators ^a	477	532	645	597 (-7%)	460 (-29%)	709	623 (-12%)	382 (-46%)

Note: BAU = Business-As-Usual; Mod. = Moderate; Adv. = Advanced. Numbers in parentheses represent the percentage change compared with BAU. Source for 1990 and 1997 data: Energy Information Administration (1998b), Table 7, p. 21.

*A number of key technologies were not modeled within the CEF-NEMS framework and are therefore not reflected in these numbers. These omitted technologies include: combined heat and power (CHP) in industry, CHP-district energy systems in buildings, solar domestic hot water heaters, and fuel cells in buildings. The first two of these are modeled in off-line analyses and show considerable potential for further reductions in carbon emissions.

"The carbon emissions from electric generators are distributed across consumption sectors and therefore are fully included in the row labeled "Total."

Figure 1.3 Carbon Emissions by Sector (MtC)



Note: BAU = Business-As-Usual; MOD = Moderate; ADV= Advanced. See Table 1.8 for the values associated with this graph.

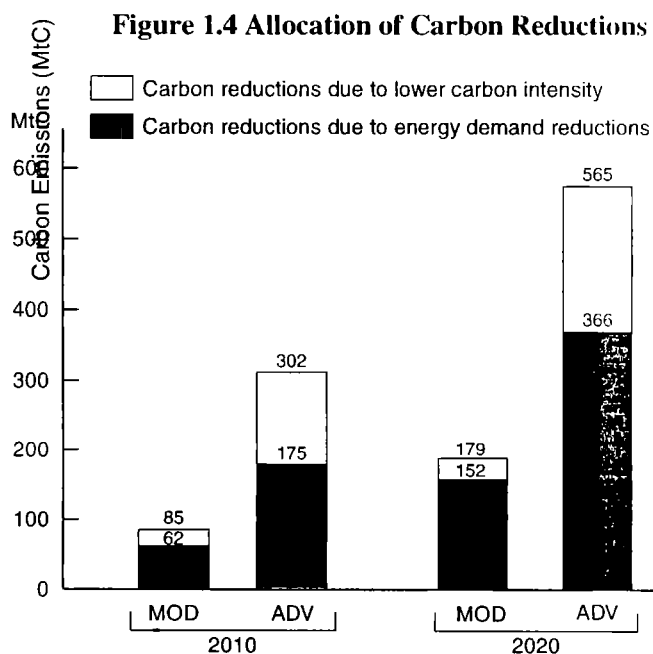
The carbon intensity of the U.S. energy system is forecast to remain unchanged in the BAU scenario. Measured in terms of million metric tons of carbon emissions per quadrillion Btu of energy, the economy continues to produce 16.0 MtC per quad of energy consumed (Table 1.9). The electricity sector is forecast to undergo a slight trend toward decarbonization, reducing its carbon emissions by 7% from 172 gC/kWh in 1997 to 160 gC/kWh in 2020.

Table 1.9 Changes in Carbon Intensity and Allocation of Carbon Reductions

	2010			2020		
	BAU	Mod.	Adv.	BAU	Mod.	Adv.
Carbon Intensity:						
Primary Energy: MtC/quad (Note: 1990=16.0; 1997=15.7)	16.0	15.8	14.7	16.0	15.8	14.0
		(-1%)	(-8%)		(-1%)	(-13%)
Electricity Only: gC/kWh* (Note: 1990=167; 1997=172)	164	159	131	160	161	109
		(-3%)	(-20%)		(1%)	(-32%)
Percent Reduction in Primary Energy Relative to BAU (A)		3.5	9.9		7.9	19.0
Percent Reduction in Carbon Emissions Relative to BAU (B)		4.8	17.1		9.5	29.4
Carbon Reductions due to End-Use Energy Reductions (in		62	175		152	366

MtC)**				
Carbon Reductions due to Lower Carbon Intensity (in MtC)	23	127	27	199
Total Carbon Reductions (in MtC)	85	302	179	565

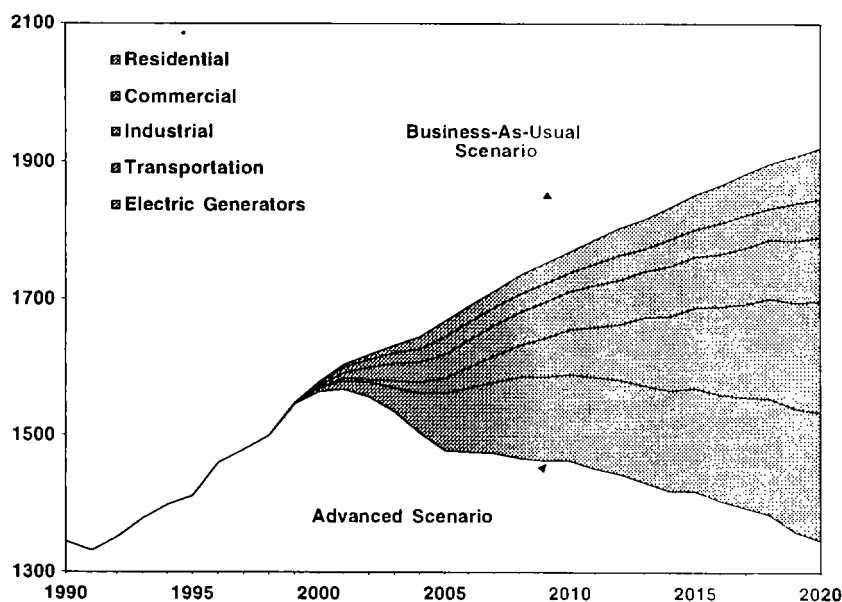
Note: BAU = Business-As-Usual; Mod. = Moderate; Adv. = Advanced. Numbers in parentheses represent the percentage change compared with BAU. *Excludes electricity cogeneration. **Calculated as (A)/(B) times total carbon reductions.



The carbon intensity of the U.S. energy system also changes very little (only 1%) as a result of the Moderate scenario's policies, decreasing by only 1% throughout the two decades. The electricity sector tracks the BAU scenario with a 7% decrease to 161 gC/kWh in 2020. As a result, most carbon reductions from the Moderate scenario, in both 2010 and 2020, are due to reductions in energy demand in the end-use sectors. Estimates of these demand-driven reductions are provided in Table 1.9 and Figure 1.4. The carbon reductions due to demand-driven reductions were estimated by:

- (1) dividing the percent reduction in energy by the percent reduction in carbon, and then
- (2) multiplying that fraction by the total carbon reductions.

Figure 1.5 Carbon Emission Reductions by Sector, in the Advanced Scenario



The carbon intensity of the U.S. energy system is reduced significantly by Advanced scenario policies, decreasing by 8% in the first decade and 13% in 2020 relative to essentially unchanged. The electricity sector undergoes even greater decarbonization in the Advanced scenario. It drops 20% in 2010 (from 164 gC/kWh in BAU to 131 gC/kWh in the Advanced scenario), and 32% in 2020 (from 160 gC/kWh in BAU to 109 gC/kWh in the Advanced

scenario). As a result, more than one-third of the carbon reductions from the Advanced scenario, in both 2010 and 2020, are due to the lower carbon intensity of the energy system (labeled "electric generators" in Figures 1.5).

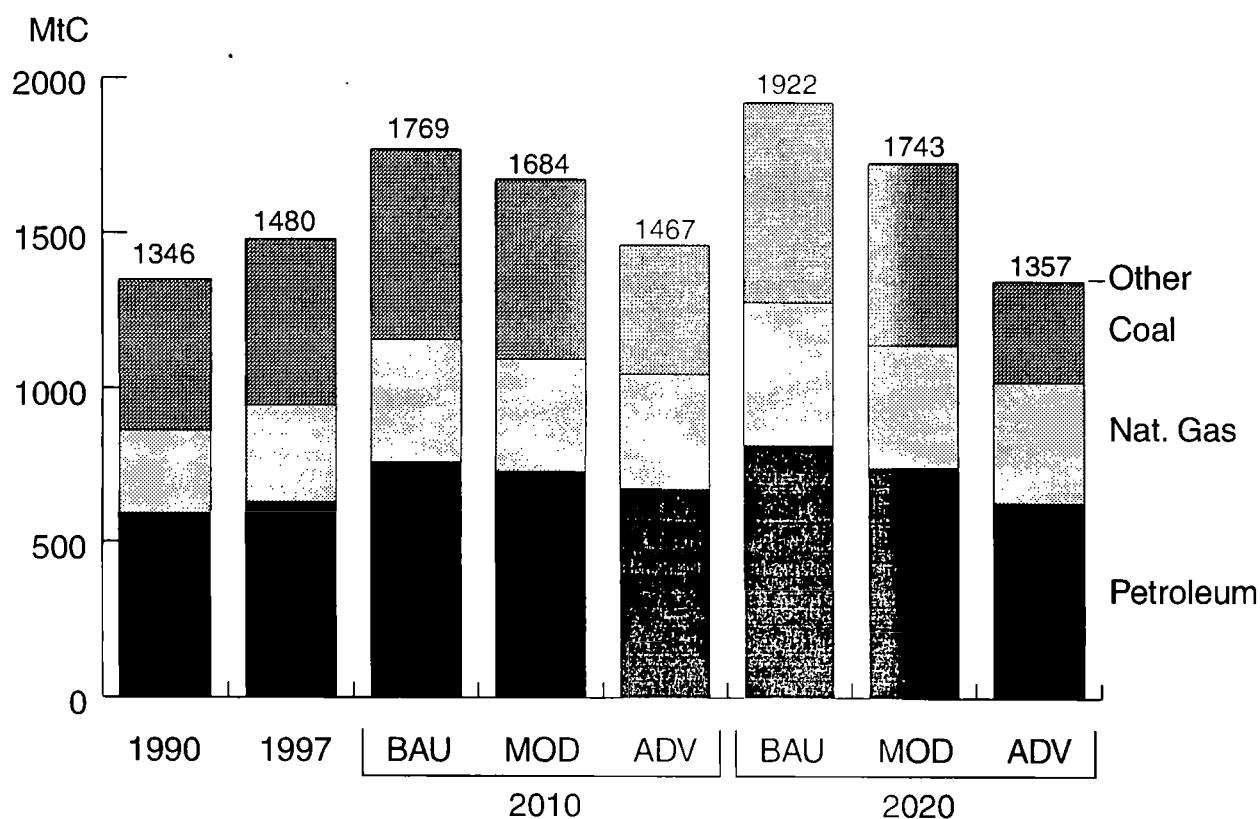
Much of the difference in carbon emissions between the two scenarios is caused by the policies in the Advanced scenario that increase the use of low-carbon fuels for electricity generation. These policies result in greater switching from coal to natural gas, increased use of renewable electricity, and extended nuclear power plant operation in the Advanced scenario, relative to the Moderate scenario (Table 1.10 and Figure 1.6).

Table 1.10 Carbon Emissions from Fossil Energy Consumption, by Source (MtC)

	1990	1997	2010			2020		
			BAU	Mod.	Adv.	BAU	Mod.	Adv.
Petroleum	591	628	755	727 (-4%)	673 (-11%)	818	742 (-9%)	627 (-23%)
Natural Gas	273	319	404	373 (-8%)	375 (-7%)	460	402 (-13%)	398 (-14%)
Coal	482	533	608	581 (-4%)	418 (-32%)	642	593 (-8%)	328 (-50%)
Other*	0	0	1	3 (200%)	2 (100%)	2	5 (150%)	3 (50%)
Total	1346	1480	1769	1684 (-5%)	1467 (-17%)	1922	1743 (-9%)	1357 (-30%)

Note: BAU = Business-As-Usual; Mod. = Moderate; Adv. = Advanced. Numbers in parentheses represent the percentage change compared with BAU. Source for 1990 and 1997 data: Energy Information Administration (1998b), Table 6, p. 21. *Other sources include methanol and liquid hydrogen.

Figure 1.6 Carbon Emissions by Source (MtC)



Note: BAU = Business-As-Usual; MOD = Moderate; ADV = Advanced. See Table 1.10 for the values associated with this graph.

1.4.4 Key Policies and Technologies

The success of different types of policies and programs varies by end-use sector, reflecting sector-specific market and organizational barriers and imperfections that inhibit the full implementation of cost-effective technologies. Two policies, however, are important to all of the sectors in the Advanced scenario: the domestic carbon cap and trade system and the doubling of federal RD&D appropriations. The importance of the cap and trade system is documented in the sensitivity analysis described in section 1.5. The importance of expanded R&D is illustrated in Table 1.11.

Due to modeling difficulties, a number of key technologies were not modeled within the CEF-NEMS framework and are therefore not reflected in the bottom-line numbers describing the Moderate and Advanced scenarios. These omitted technologies include: combined heat and power (CHP) in industry, CHP-district energy systems in buildings, solar domestic hot water heaters, and fuel cells in buildings. The first two of these are modeled in off-line analyses, which suggest that these technologies could grow significantly as the result of supporting policies and programs. This would reduce both energy use and carbon emissions because of the higher efficiencies of CHP systems.

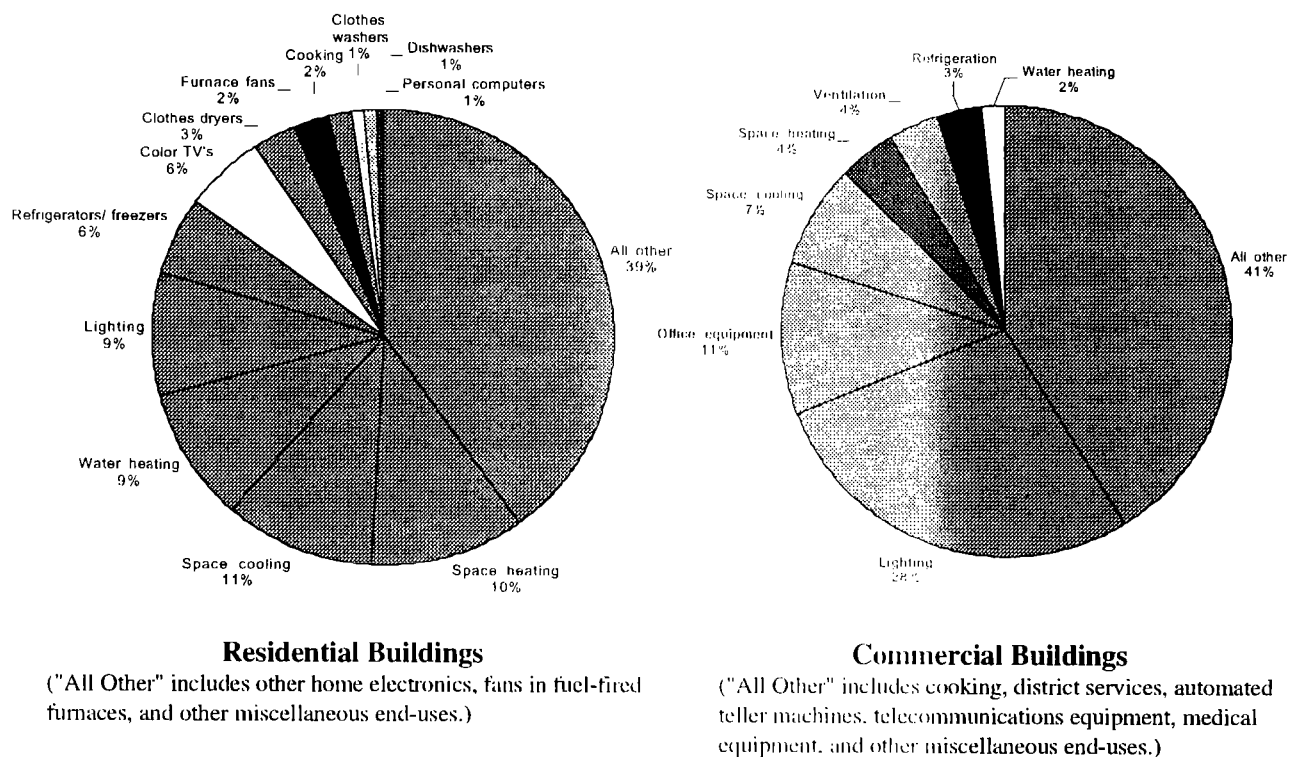
Buildings. Savings from “other electric” uses in residential and commercial buildings are extremely important, particularly savings from electronic end-uses. About 3 quads of primary electricity is saved in these electronic end-uses by 2020 in the Advanced Scenario. A large fraction of these savings comes from movement toward a “one-watt” standby loss goal by 2010, based on the switch-mode power supplies that are now widely used in the best new equipment.

Table 1.11. Illustrative R&D Advances in the Advanced Scenario

Buildings	Industry
Heat Pump Water Heaters (HPWHs): R&D reduces the cost of HPWHs by 50% in 2005, relative to the BAU. Small Metal Halide (Mini-HID) Lamps: R&D produces a 20-Watt mini-HID with an electronic ballast that has the same brightness as a 100-Watt incandescent lamp and an incremental cost of \$7.50, available in 2005.	Iron and Steel Technologies: Development of near net shape casting technologies will save up to 4 MBtu/ton steel and reduce production costs between \$20 and \$40/ton. Smelt reduction will start to replace blast furnaces at the end of the scenario period, reducing energy use by 20-30% in ironmaking as well as emissions from coke ovens and ore agglomeration. Pulp and Paper Technologies: R&D will produce an efficient black liquor gasifier integrated with a combined cycle making a kraft pulp mill a net electricity exporter. This results in primary energy savings of up to 5 MBtu/ton air-dried pulp. New drying processes (e.g. condebelt and impulse drying) in the paper machine will be successfully developed and commercialized resulting in energy savings of up to 1.4 MBtu/ton paper.
Transportation	Electric Generators
Direct Injection Diesel Engines: R&D enables direct injection diesel engines to meet EPA's proposed Tier 2 NOx standards in 2004. Hydrogen Fuel Cell Vehicles: R&D drives 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.	Natural Gas Combined Cycle: R&D reduces capital costs from the BAU forecast of \$375/kW to \$322/kW for the 5th of a kind plant; carbon sequestration adds \$4/MWh. Wind: R&D reduces capital costs from \$778/kW throughout the period to \$680/kW in 2000 down to \$611/kW in 2016; Fixed O&M costs decline from \$25.93/kW-yr throughout the period to \$21.1/kW-yr in 2000 down to \$16.4/kW-yr in 2020.

Commercial lighting is the second-largest single source of savings, contributing about 0.9 quads of primary energy by 2020 in the Advanced scenario. Residential equipment (water heating, cooling, heating, and lighting savings) also produce significant energy and carbon reductions (Fig. 1.7).

Figure 1.7 Carbon Emission Reductions in the Advanced Scenario in 2020, by Buildings End Use
(Reductions are Relative to the Business-as-Usual Forecast)



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.

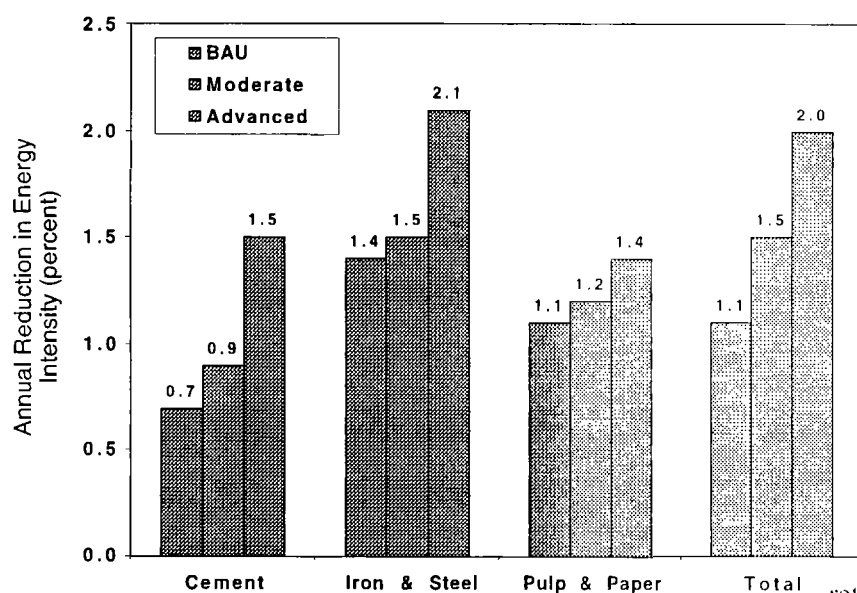
Industry. Energy is saved in all industrial subsectors under both the Moderate and Advanced scenarios. Continuing intra- and inter-sectoral shifts, as well as ongoing efforts to reduce environmental impacts and improve energy efficiency, contribute to the savings within the industrial sector. Decarbonization of the power sector contributes to savings, especially in electricity-intensive industrial subsectors (Fig. 1.8).

Voluntary agreements between government and industry are the key policy mechanism for achieving these savings. Also important are the numerous policies and programs that support the voluntary agreements. These include:

- 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.

Figure 1.8 Annual Reductions in Energy Intensity in the Industrial Sector



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, preventative maintenance, and motor and drive system improvements – 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 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.

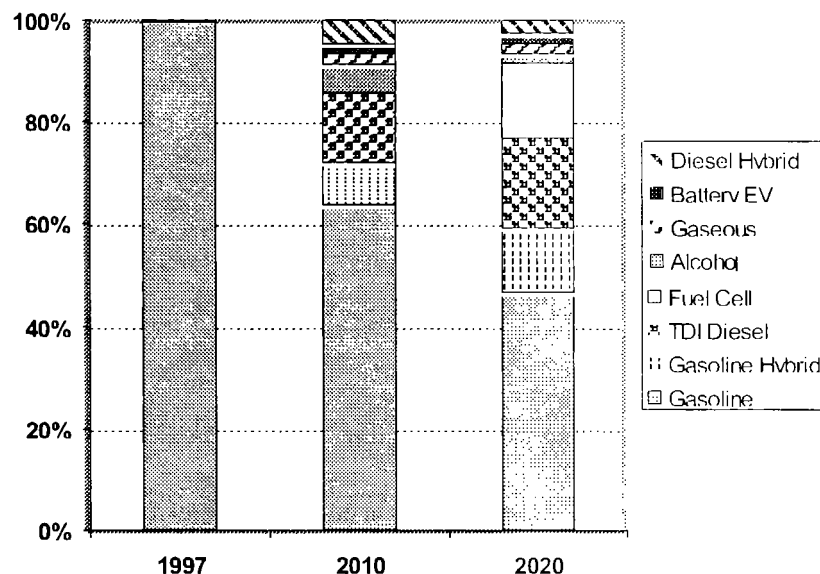
In the steel industry, new technologies like scrap preheating for electric arc furnaces are more efficient than the technologies used in existing plants, and new casting technologies reduce material and energy losses further. New advanced smelting reduction technologies lead to significant savings after 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. The development and implementation of these practices and technologies are accelerated in the CEF policy scenarios, due to increased policy activities and voluntary sector agreements. This will increase energy efficiency beyond that assumed in the BAU scenario.

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 or 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 \$4,000 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 non-highway modes of transport.

The key distinguishing features of the Advanced scenario are (1) the greater degree of technological success, attributed to a doubling of R&D investment; (2) 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 (3) significant fuel price signals for highway vehicles in the form of pay-at-the-pump insurance fees and a modest carbon tax. The combined effect of these measures is an array of impressive new technologies in large numbers (Fig. 1.9). 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, which according to our assumptions are cheaper and more energy efficient, are the most successful, accounting for 1.0 million of the 2.2 million total sales in 2020. In 2020, there are 3.9 million hydrogen fuel cell vehicles on the road consuming 0.1 quads of hydrogen annually. Advanced technologies also improve fuel economy significantly in non-highway transport.

Fig. 1.9 Advanced Scenario New Light-Duty Vehicle Sales



Energy efficiency is also improved by restraining the large forecasted growth in vehicle horsepower. In 1998, the average hp of new passenger cars sold in the United States was 155. In the BAU case, passenger car horsepower 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. However, vehicle weight decreases in the advanced scenario by about 12 percent for passenger cars, so that

vehicle acceleration performance would still be about 25 percent faster than today's cars.

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 cap and trade system in the Advanced scenario. The resulting carbon allowance does three things. First, it makes the building of any 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. Second, the carbon allowance directly impacts the variable cost of production, causing the remaining carbon-intensive technologies to lower their capacity. Third, it encourages extension of the life of existing nuclear plants and the 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 generation drops 2% between 2010 and 2020, generation capacity declines by 4%.

A 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 or 2008, it encourages the development of a strong capacity 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 allowance 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 charge, wind quadruples by the time the PTC expires (2005). 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 for the allowances. 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 have much impact on the overall carbon intensity of the production, but they are powerful in conjunction with the carbon charge. In the BAU scenario, the carbon intensity 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 charge, 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 carbon charge, there was only a 3% decline in carbon intensity from BAU. With the carbon charge, 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 alone.

1.4.5 Costs and Benefits of the Policy Scenarios

In this section, we estimate the first-order economic impacts of the CEF scenarios. Specifically, four “direct” cost and benefit components are examined:

- 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 charge revenues to the public.

In the CEF scenarios, these costs and benefits arise over time 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. The nation's energy bill reflects the changing energy prices and demands. The investments made in more efficient end-use technologies, on the other hand, are not reflected in this bill and must be accounted for separately. With the annual auction of carbon permits, the government accrues revenues. These revenues are then distributed back to the public.

Summary of Direct Costs and Benefits. In both the Moderate and Advanced scenarios and in both time frames (2010 and 2020), the annual energy bill savings and carbon charge revenues exceed the annualized direct costs. This finding is not surprising. It is consistent with many economic-engineering studies (see Section 1.6) and with the views of many economists (see Box 1.1). The gap is wider in 2020 than in 2010, reflecting the greater energy reductions as more cost-effective, clean energy technologies are developed and deployed. These net benefits do not reflect the macroeconomic impacts of the scenarios.

Two externality benefits are quantified but are not monetized. These include improved air quality and energy security. Amenity costs that may result from the CEF scenarios are also not monetized. One of these, however, is discussed: the lower horsepower of light-duty vehicles purchased by consumers in the CEF scenarios relative to the BAU forecast. Long-run macroeconomic costs are discussed primarily in terms of estimates from other published studies. In addition, we describe some industries and regions likely to experience significant economic impacts, at least in the short run, if the nation transitions to the type of clean energy future characterized in the two policy scenarios.

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.

Box 1.1
Economic Climate Change Consensus

"Economic studies have found that there are many potential policies to reduce greenhouse gas emissions for which the *total benefits outweigh the total costs*. For the United States in particular, sound economic analysis shows that there are policy options that would slow climate change without harming American living standards, and these measures may in fact *improve U.S. productivity in the longer run*."

— From a statement signed by ~2500 economists led by Nobel laureates Kenneth Arrow and Robert Solow, at a January 1997 meeting of the American Economics Association. *Italics added for emphasis*

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. (Details on these 12 cases are provided in Appendix E-1). 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 one 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 1.12). For the Advanced scenario, they range from \$9 to \$13 billion per year in 2010 and 2020.

Table 1.12 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

In addition to these administrative costs, other policy implementation costs must be considered.

- 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 1.12. 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 1.14.)
- 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 allowance 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 1.12.

Research, development, and demonstration (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 1.13). 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.

Table 1.13 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

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 on an annual basis, our incremental technology investment cost in a particular year is the annualized cost of the total investment made to that point in 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.

Between 2010 and 2020, these annual costs increase from \$11 billion to \$31 billion in the Moderate scenario, and from \$31 billion to \$66 billion in the Advanced scenario (Table 1.14). The transportation sector accounts for approximately half of these costs in both years.

**Table 1.14 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*	0	0	0	0
Total	11.4	30.5	29.6	65.9

*These investment costs are reflected in the price of electricity.

Changes in the Energy Bill. Scenarios can project energy cost increases (as in the case of more costly, but cleaner energy options) or decreases (as in the case of reduced energy use resulting from energy-efficient technologies). The total impact is a function of changes in energy prices, as well as changes in the amounts of energy and the types of energy used.

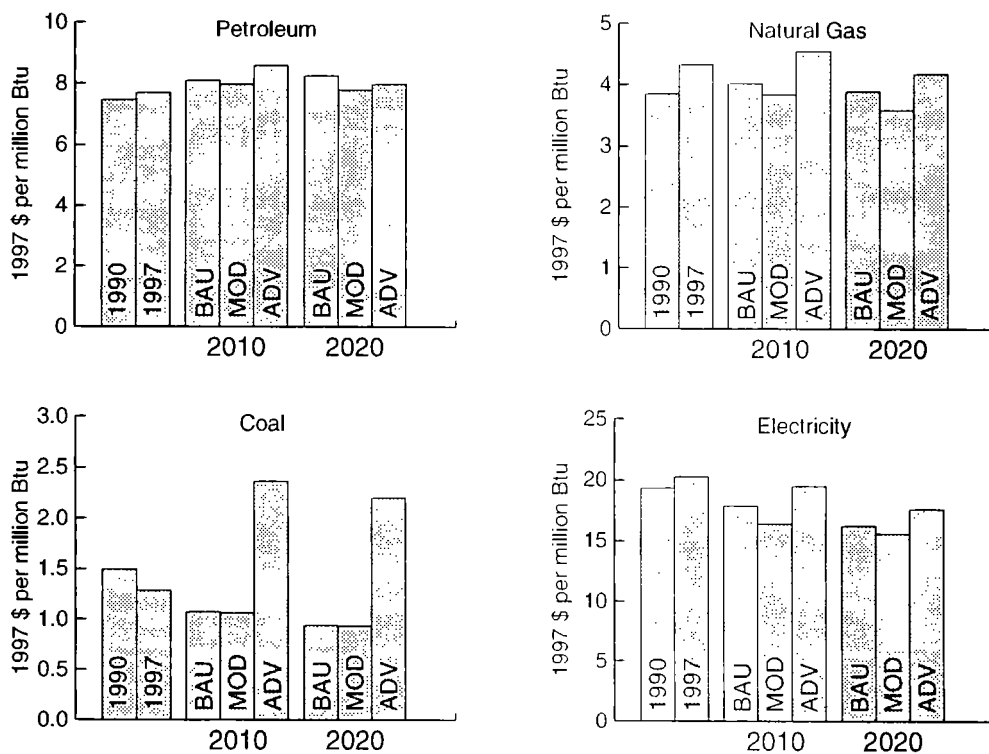
The energy bill is calculated as the sum over all fuels (including electricity) in all end-use sectors of the fuel price times the amount of fuel used. The average energy prices to all users are shown, by type of energy and by scenario, in Table 1.15 and Figure 1.10. The Advanced scenario prices include the \$50/tonne carbon permit charge that energy producers are assumed to add to energy prices as a result of the carbon cap and trade system. Overall, the carbon permit charge raises energy prices while lower demand exerts downward pressure on energy prices.

Table 1.15 Average Energy Prices to All Users

Average Energy Prices (1997 \$ per Million Btu)	1990	1997	2010			2020		
			BAU	Mod.	Adv.	BAU	Mod.	Adv.
Petroleum	7.46	7.69	8.12	7.96 (-2%)	8.58 (6%)	8.25	7.76 (-6%)	7.92 (-4%)
Natural Gas	3.85	4.32	4.02	3.80 (-5%)	4.55 (13%)	3.90	3.56 (-9%)	4.14 (6%)
Coal	1.49	1.28	1.07	1.06 (-1%)	2.35 (120%)	0.94	0.93 (-1%)	2.22 (136%)
Electricity	19.3	20.26	17.85	16.44 (-8%)	19.32 (8%)	16.15	15.51 (-4%)	17.92 (11%)
Energy Bill (billion 1997\$)	563*	552	651	595 (-9%)	634 (-3%)	694	594 (-14%)	572 (-18%)

Note: BAU = Business-As-Usual; Mod. = Moderate; Adv. = Advanced. Numbers in parentheses represent the percentage change compared with BAU. *Source: EIA (1998d), Tables 3.4 and E1.

Figure 1.10 Average Energy Prices to All Users (1997 \$ per Million Btu)



BAU = Business-As-Usual Scenario; Mod = Moderate Scenario; Adv = Advanced Scenario.

The BAU scenario assumes that electricity prices will be 12% lower than in 1997 by 2010, and will decline another 8% by 2020 due to electricity restructuring in parts of the U.S. [Note: Following the lead of EIA's Reference Case, the BAU assumes that five regions of the United States 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 time frames. This increase is due largely to the inclusion of the \$50/tC carbon permit price.

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, due largely 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 due primarily to the domestic carbon cap and trade 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.

Despite the projected growth in U.S. petroleum use in the BAU scenario, petroleum prices are forecast to grow only modestly (1.3% per year) over the next two decades. Petroleum prices grow even more slowly in the Moderate scenario because of dampened growth in demand. In contrast, the Advanced scenario results in petroleum prices that are 6% higher than in the BAU scenario in 2010, but they are 4% lower than the BAU in 2020 because of the strong performance of clean diesel and fuel cell vehicles in that time frame.

The combination of evolving prices and demand for energy results in energy bill trajectories that vary widely across the scenarios (Tables 1.15 and 1.16). Under BAU conditions, the U.S. energy bill is forecast to increase 26%, from \$552 billion in 1997 to \$694 billion in 2020 (in 1997\$). In both 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 in the end-use sectors. In the Moderate scenario, U.S. energy cost savings are \$56 billion in 2010 and increase to \$100 billion in 2020.

Efficiency increases in the end-use sectors are large enough to reduce the nation's energy bill even with an increase in energy price due to the \$50/tonne carbon permit value of the Advanced scenario. The energy bill savings are not as great over the first decade because of the energy price increases discussed earlier and the lag effect of stock turnover, which extends the time required for some energy-saving equipment to be installed. In this case, the energy bill savings are \$17 billion in 2010. The savings rise to nearly \$122 billion in 2020 as a result of even greater improvements in the energy efficiency of buildings, industry, and transportation. The transportation sector accounts for a large portion of the energy bill savings in both 2010 and 2020.

**Table 1.16 Net Energy Bill Savings in 2010 and 2020
(in Billions 1997\$ per Year)**

	Moderate Scenario		Advanced Scenario*	
	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

*The energy prices used to calculate the energy bill savings in the Advanced scenario include the cost of the carbon permit charges.

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

As a result, the domestic carbon cap and trade system imposes minimal first-order changes in the total income of "the public." There will be a change in the distribution of income, with some winners and losers, but little change in aggregate income. The value of the transfer payments is shown in Table 1.17.

**Table 1.17 Net Transfers to the Public of the Carbon Charge in 2010 and 2020
(in Billions 1997\$ per Year)**

	Moderate Scenario		Advanced Scenario	
	2010	2020	2010	2020
Total	0*	0*	72.9	67.4

*The domestic carbon cap and trade system only operates in the Advanced scenario.

As with a tax, the carbon allowance payments to the government do 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. There is a small portion (\$1.8B to \$2.5B per year) of lost consumer and producer surplus that is not captured in the energy bill calculation of the Advanced scenario. It is included as a separate entry in Table 1.18.

The method used to transfer carbon charge 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, 1998c):

- Returning collected revenues back 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. Preliminary analysis by the Environmental Protection Agency and Argonne National Laboratory has quantified this effect (Hanson and Laitner, 2000).

Net Direct Savings. Table 1.18 shows the "net direct savings" of the two policy scenarios. The total savings are the difference between the direct benefits shown in Tables 1.16 and 1.17 (i.e., net energy bill

savings and carbon charge transfers to the public) and the direct costs shown in Tables 1.12 through 1.14 (i.e., annualized program implementation and administration costs, RD&D costs, and annualized incremental technology investment costs). For completeness, the savings are also decreased by a comparatively small loss in consumer and producer surplus due to the carbon cap and trade system. [The link between these costs and macroeconomic costs are still being worked.]

In 2010, net energy bill savings and carbon charge transfer payments exceed direct costs by \$40 billion in the Moderate scenario and by \$46 billion in the Advanced scenario. By 2020, the gap has widened to an estimated \$62 billion of direct savings in the Moderate scenario and \$106 billion in the Advanced case.

**Table 1.18 Net Direct Savings of the Clean Energy Future Scenarios
in 2010 and 2020 (in Billions 1997\$ per Year)***

	Moderate Scenario		Advanced Scenario	
	2010	2020	2010	2020
Investment Costs:				
• Annualized policy implementation and administration costs	-2.6	-6.4	-8.8	-12.9
• 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	-15.7	-38.3	-41.2	-81.6
Net Energy Bill Savings:				
• Gross energy bill savings	55.3	100.3	89.2	189.3
• Carbon permit costs	0	0	-72.9	-67.4
Net Energy Bill Savings	55.3	100.3	16.4	121.9
Carbon Charge Transfers to the Public	0	0	72.9	67.4
Loss of Consumer/Producer Surplus	0	0	-2.5	-1.8
Total	39.6	62.0	45.6	105.9

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

More certain environmental externality benefits include cleaner air and water, which can produce significant public health benefits (Romm and Ervin, 1996). In both of the policy scenarios, emissions of local air pollutants are substantially reduced. These reductions are an added benefit of the cuts in fossil fuel combustion that occur largely as a result of policies directed at reducing carbon emissions. SO₂ emissions from the electric sector in the Moderate scenario remain at the cap in 2010, but the allowance price needed to keep emissions at that level drops by 27%. With lower demand and improved new technologies, it is easier to meet the limits, and the market price of allowances declines. NO_x and mercury emissions also decline (Table 1.19).

Table 1.19 Other Air Emissions in the Electric Sector

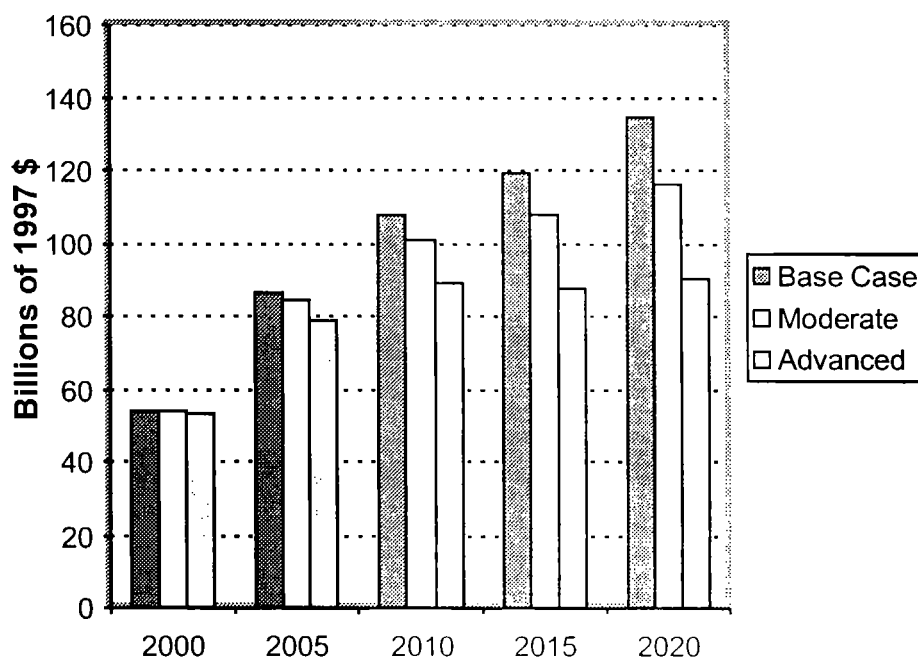
	2010					2020		
	1990	1997	BAU	Mod.	Adv.	BAU	Mod.	Adv.
SO ₂ Emissions (MtSO ₂)	15.6	11.6	8.4	8.3	8.5	8.2	8.2	4.1
SO ₂ Allowance Price (\$/ton)	—	77	224	210	98	114	96	161
NO _x Emission (MtNO _x)	7.5	5.3	3.7	3.5	2.7	3.8	3.5	2.2

Note: BAU = Business-as-Usual scenario; Mod. = Moderate scenario; Adv. = Advanced scenario.

In the Advanced scenario, SO₂ emissions are further restricted to reduce particulate formation. By 2020 they have declined to half the Phase II limits set by the Clean Air Act Amendments of 1990. As a result, costs of sulfur allowances rise to \$161/ton in 2020. Simultaneously, NO_x emissions by 2020 fall to about half of the current NO_x emission from the electric sector, and mercury emissions decline significantly.

The CEF policy scenarios also result in energy security externality effects. Oil security, for instance would be enhanced, while other aspects of energy security might be harmed. Policies and technologies implemented in the Moderate and Advanced scenarios significantly reduce U.S. petroleum consumption and, consequently, imports. Total U.S. oil consumption rises to 24.5 million barrels per day (mmbd) in the BAU scenario but falls to 19.4 mmbd in the Advanced scenario (Figure 1.10). In the BAU scenario, U.S. petroleum imports rise from 10.6 mmbd in 2000 to 15.9 in 2020. In the Advanced scenario, only 11.0 mmbd are imported in 2020. Under BAU, U.S. oil imports increase from 49% of U.S. demand today to 65% in 2020. In the Advanced scenario, the share of imports also increases, but only to 56%.

Figure 1.11 U.S. Expenditures on Imported Petroleum



The 1.9 mmbd reduction in imports in the Moderate scenario and 4.9 mmbd reduction in the Advanced scenario reduce the U.S. bill for imported oil in 2020 from \$135 billion to \$90 billion (in \$1997). Thus the change in annual balance of payments is \$45 billion in favor of the United States. The price of an imported barrel of oil in both the BAU and Advanced scenarios is \$22.73. Because the integrated runs do not estimate the impacts of reductions in U.S. oil demand on world oil prices, the benefits of reduced consumption in the form of lower prices for both imported and domestic oil are not available. If one assumes that world oil prices were about \$10 per barrel, then the annual transfer of wealth from U.S. oil consumers to world oil exporters would be \$74 billion in the BAU scenario and \$51 billion in the

Advanced scenario. This would produce a net annual savings of \$23 billion to U.S. consumers in avoided wealth transfer (Figure 1.11).

In contrast to the oil security benefits, it has been argued that a significant reduction in the use of domestic coal would compromise the nation's energy security. Such reductions could increase exposure to the risk of interruptions of natural gas and petroleum supplies. This is a conclusion of the Electric Power Research Institute's Energy-Environment Policy Integration and Coordination Study or E-EPIC.

There are also a variety of ancillary or collateral costs and benefits that would accompany the CEF policy scenarios. On the cost side are:

- amenity losses (e.g., from cars with lower horsepower) 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.

On the benefits side are:

- the productivity and product quality gains that have accompanied many investments in industrial efficiency improvements (Romm, 1994; 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. Results reported in Elliott et al. (1997) and Laitner (1999) indicate that the total benefits—including both energy and non-energy savings—that accrue from so-called “energy-saving” projects can be much greater than the energy savings alone. In fact, based on numerous case studies, the authors conclude 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.

Macroeconomic Considerations. A range of macroeconomic indicators associated with the two policy scenarios is provided in Table 1.20.

One of the macroeconomic indicators reflects the energy productivity of the U.S. economy: the energy/GDP ratio. An expanded portrayal of this indicator is provided in Figure 1.12 in terms of U.S. energy use in kBtu/GDP in 1997\$. This figure shows the historic reduction in energy intensity of the U.S. economy from 1973–74 (the OPEC oil embargo) through 1986 (when energy prices began a period of decline that has continued to today). The EIA AEO99 reference case calls for a continuing improvement in this indicator as the result of a GDP growth rate that outpaces the increase in energy use. The Advanced scenario projects even larger energy productivity gains, especially in the second decade of the twenty-first century. This is a result of the leveling off of U.S. energy consumption at 97 quads in 2020 in the Advanced scenario, compared with the reference case forecast of 119 quads in 2020.

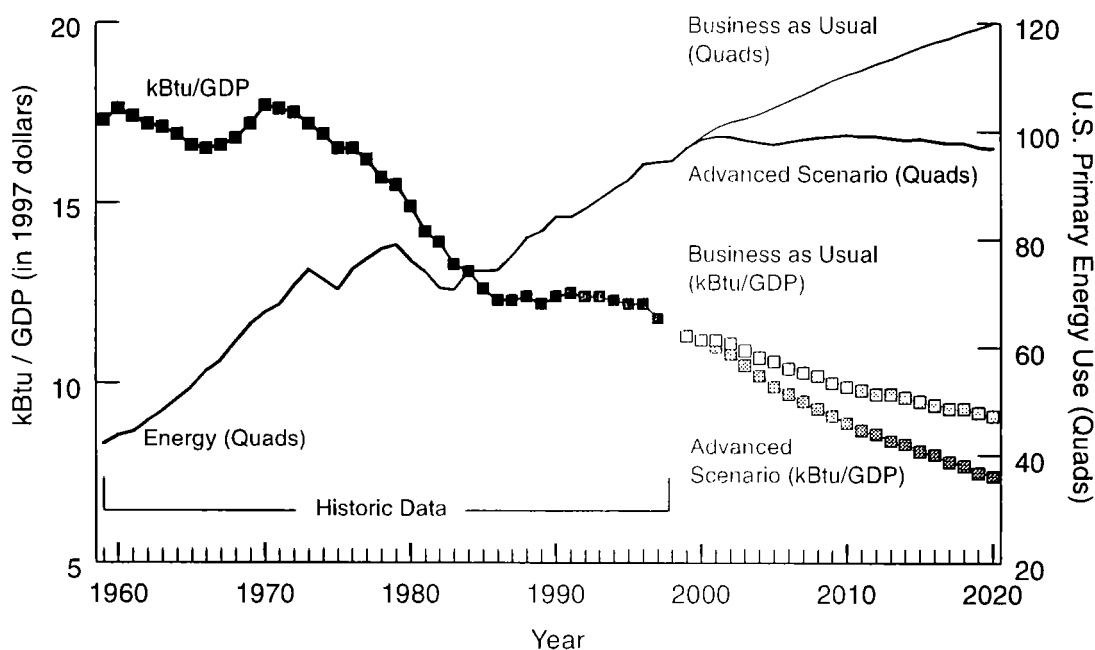
Table 1.20 Macroeconomic Indicators

	1990	1997	2010			2020		
			BAU	Mod.	Adv.	BAU	Mod.	Adv.
GDP (billion 1997\$)	6136 (1992\$)	8171	11,123	11,123 (0%)	11,123 (0%)	13,128	13,128 (0%)	13,128 (0%)
Energy/GDP Ratio (kBtu/1997\$)	13.7 (1992\$)	11.5	9.9	9.6 (-4%)	8.9 (-10%)	9.1	8.4 (-7%)	7.4 (-20%)

Carbon/GDP Ratio (gC/1997\$)	219 (1992\$)	181	159	151 (-6%)	132 (-17%)	147	133 (-10%)	103 (-29%)
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Note: BAU = Business-As-Usual; Mod. = Moderate; Adv. = Advanced. Numbers in parentheses represent the percentage change compared with BAU.

Figure 1.12 Energy/GDP Ratios



The CEF study does not model the macroeconomic effects of its two policy scenarios because of the difficulty of capturing second-order transition effects on costs and investments that total to less than 1% of national GDP. None of the existing macroeconomic models is suitable for this task. Instead, we commissioned the preparation of a short discussion paper, which appears in Appendix E-4. The purpose of this appendix is to review the issue of second-order or macroeconomic effects that might occur under the types of scenarios analyzed in the CEF study and to present bounds on the macroeconomic effects that might be associated with the Moderate and Advanced scenarios. The conclusions of this paper are summarized in the following paragraphs.

A key premise of the CEF study is that large-scale market and organizational failures, in addition to potentially substantial transaction costs, prevent consumers and firms from obtaining energy services at the least cost. The essential conclusion of the study's scenarios is that this problem can, to a considerable extent, be overcome through policies that correct the market failures, induce positive organizational change, and reduce the transaction cost barriers to the diffusion of energy-efficient technologies. This conclusion is supported by numerous past energy policy and program successes, as are described in Chapter 2 and elsewhere in this report. Examples of these successes include:

- the Energy Star Program's successful effort to introduce energy-saving features in computers and printers,
- five building technologies developed with significant DOE cost-sharing that produced annualized consumer cost savings of \$3 billion in 1996,
- EPA's Green Lights Program and DOE's Motor Challenge Program, which have overcome organizational impediments to energy-efficiency investments, and
- the introduction of national appliance efficiency standards.

Additional successes are described in EPA (1999b) and Brown et al. (1999).

Because the economy is not currently operating on its aggregate production-possibilities frontier with respect to energy-efficiency technologies, a Pareto improvement is available through intervening in markets for energy services and adopting other policy measures. Thus, whatever shifts or adjustments in markets occur as a result of policies that encourage efficiency investments, *the aggregate result is a gain in economic efficiency*. The primary policy included in this study that may not meet the Pareto improvement criterion is the carbon cap and trade policy.

Sectoral and Regional Impacts. A number of sectors of the economy and regions of the United States would likely experience negative economic impacts, at least in the short run, if the nation transitions to the type of clean energy future characterized in this study's two policy scenarios. For example, 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 SO₂ 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 CO₂, 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, 1998c).

Unequal regional impacts of CO₂ policies on the electricity industry are also anticipated because of regional differences in the resources used to generate electricity. In particular, interior states would 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 to 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 U.S. oil industry's ability to compete in world markets and to expand its production quickly in the event of oil supply shocks.

On the other hand, the growth of strong domestic wind and bioenergy industries could bring new employment opportunities to many regions and could lead to a revitalization of the economies of rural America. A wide range of other business opportunities would thrive under the Advanced scenario, including fuel cell manufacturing and energy services, and the viability of the nuclear energy industry would be strengthened.

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 U.S. companies in the vast global market for efficient and clean energy technologies. It could also enhance long-term markets for other U.S. 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).

1.5 SENSITIVITY ANALYSIS

This section analyzes a range of alternative policies to systematically assess the opportunities and consequences of a variety of futures other than the standard ones described in the rest of the report—the BAU, Moderate, and Advanced scenarios. These alternative scenarios are important for several reasons. First, they reflect the highly unpredictable nature of political and consumer views and they highlight the diversity of policy alternatives. Second, they characterize the impact of uncertainties in parameter values and model assumptions.

In this section we present the results of system-wide variations in policies—comparing and contrasting demand-side vs supply-side policies and examining cases that rely strictly on domestic carbon trading. The demand-side policies are those defined for the three end-use sectors in the Advanced scenario (excluding the domestic cap and trade system). The supply-side policies are those defined for the electricity sector in the Advanced scenario (excluding the domestic cap and trade system). Two values of the carbon charge were assessed: \$25/tC and \$50/tC. Twelve sensitivity cases were defined by combining various of these categories of policies, as shown in Table 1.21. The Advanced scenario is the combination of all three policy categories, with the \$50/tC carbon charge, and the BAU scenario is the absence of any of these policies. Results are summarized for both 2010 and 2020 in Table 1.21. Additional tables in Appendix D-5 provide more detailed results for each of these sensitivities.

1.5.1 Demand-Side Policies

Efforts to promote energy efficiency have been a cornerstone of U.S. energy policy ever since the OPEC oil embargo of 1973–74. These efforts have been viewed favorably by a majority of the public (Bonneville Power Administration, 1999; Sustainable Energy Coalition, 1999) and have produced positive impacts that are well documented (see Chapter 2). Thus it is plausible to imagine a future in which politicians and the public support a vigorous push to improve energy efficiency. This scenario could result, for instance from an increased awareness of the link between energy use and a range of negative environmental consequences. Or it could be precipitated by a rise in energy prices. Our analysis indicates that a push on energy efficiency, by itself, could produce significant reductions in energy use and proportionate cuts in carbon emissions.

When the demand-side policies from the Advanced scenario are modeled separately (i.e., without any supply-side policies and without a domestic carbon trading system), energy use in 2010 grows to only 103.1 quads, a 7% decrease relative to BAU. During the second decade of demand-side policies, accelerated strides in the performance and deployment of efficient technologies cause the historic energy use to “turn the bend” and decline, dropping to 102.2 quads by 2020. This is a 15% decrease from the BAU forecast and is 77% of the Advanced scenario’s energy reductions.

Table 1.21 Summary of Sensitivity Cases

	Carbon Charge	Moderate Demand and Supply-Side Policies	Advanced Demand-Side Policies*	Advanced Supply-Side Policies**	Advanced Demand and Supply-Side Policies
2010:					
No Carbon Trading	BAU Scenario:	Moderate Scenario:			
Primary Energy (Quads)	110.3	106.5	102.9	109.0	103.3
Carbon Emissions (MtC)	1769	1684	1634	1714	1619
Carbon Emissions (MtC) from Electric Generators	645	597	589	604	575

	Carbon Charge	Moderate Demand and Supply-Side Policies	Advanced Demand-Side Policies*	Advanced Supply-Side Policies**	Advanced Demand and Supply-Side Policies
\$25/tC					
Primary Energy (Quads)	109.1	104.9	100.7	107.5	101.0
Carbon Emissions (MtC)	1720	1625	1556	1652	1539
Carbon Emissions (MtC) from Electric Generators	608	555	534	557	515
					Advanced Scenario:
\$50/tC					
Primary Energy (Quads)	107.5	103.2	99.1	106.0	99.3
Carbon Emissions (MtC)	1663	1548	1504	1579	1463
Carbon Emissions (MtC) from Electric Generators	562	491	493	496	456
2020:					
No Carbon Trading	BAU Scenario:	Moderate Scenario:			
Primary Energy (Quads)	119.8	110.1	101.9	112.6	100.9
Carbon Emissions (MtC)	1922	1740	1602	1748	1568
Carbon Emissions (MtC) from Electric Generators	709	621	584	593	550
\$25/tC					
Primary Energy (Quads)	118.5	108.8	99.8	112.1	98.8
Carbon Emissions (MtC)	1842	1651	1490	1684	1472
Carbon Emissions (MtC) from Electric Generators	645	551	500	547	482
					Advanced Scenario:
\$50/tC					
Primary Energy (Quads)	116.5	107.6	98.3	110.8	96.8
Carbon Emissions (MtC)	1755	1546	1426	1562	1347
Carbon Emissions (MtC) from Electric Generators	571	461	443	440	374

*The advanced demand-side policies are those policies that are defined for the end-use sectors in the Advanced scenario (excluding the domestic cap and trade system).

**The advanced supply-side policies are those policies that are defined for the electricity sector in the Advanced scenario (excluding the domestic cap and trade system).

The drop in carbon emissions from the demand-side scenario is comparable to the drop in energy use. When demand-side policies are modeled separately, carbon emissions in 2010 grow to only 1641 MtC, 7% lower than the BAU forecast of 1771 MtC. During the second decade of demand-side policies, further efficiency investments cause carbon emissions to decline slightly (as with energy use), decreasing to 1609 MtC by 2020. This reduction is 16% of the BAU and is 55% of the Advanced scenario's carbon emission reductions.

Almost no further energy reductions—and only a modest decrease in carbon emissions—result from adding supply-side policies to the demand-side scenario, in either 2010 or 2020. This finding is not surprising since the supply-side policies focus on encouraging the production and use of clean energy options. Also, it highlights the fact that the success of demand-side policies can make it more difficult for low-carbon energy options to penetrate the market, partly because reduced demand restricts the need for new capacity.

In contrast, adding a carbon charge to the demand-side scenario significantly reduces both energy consumption and carbon emissions. In both 2010 and 2020, energy use decreases by an additional 2 quads with a \$25/t carbon charge and by an additional 4 quads with a \$50/t carbon charge. Coupling these two types of policies brings the energy and carbon reductions to within 90% of the reductions produced by the Advanced scenario.

1.5.2 Supply-Side Policies

One can imagine a future in which the United States implements an energy policy that focuses primarily on the production of cleaner energy through a variety of supply-side policies. This might result, for instance, from the rise in popularity of green power programs. Or it could result from a political preference for dealing with the smaller number of energy producers rather than expanding programs dealing with the large number of energy end-users.

To model this type of scenario, we look at the impacts of the Advanced scenario's supply-side policies in the absence of any demand-side interventions and without a domestic carbon trading system. When these supply-side policies are modeled, the impacts on energy use are minimal, ranging from a 1% decrease from BAU in 2010 to a 6% decrease in 2020. Carbon reductions are somewhat more significant, ranging from a 3% decrease from BAU in 2010 to a 9% decrease in 2020. Both of these impacts are much smaller than for the demand-side scenario.

Looking specifically at carbon emissions from electric generators, a more noteworthy carbon impact is indicated. A decrease of only 2% in electricity demand in 2010 relative to the BAU forecast—presumably due to slightly higher electricity prices, yields a 6% decrease in carbon emissions from electric generators. Similarly, electricity demand decreases by just 9% in 2020 relative to the BAU, but carbon emissions from electric generators decrease by 16%. Thus the reduced demand is not the principal driver; the more significant effect is from switching to low-carbon sources of electricity. Comparable decreases are achieved in the demand-side scenario, but the cause is the significant decline in electricity consumption.

Adding demand-side policies to the supply-side scenario produces a substantial drop in overall energy use and carbon emissions. The impact on carbon emissions from electric generators, however, is relatively small since the supply-side policies have already significantly reduced these by shifting electricity generation to cleaner fuels.

Adding a carbon charge to the supply-side scenario results in only a modest decrease in energy use, but it has a significant dampening impact on carbon emissions. The \$25/t carbon charge on its own cuts carbon emissions to 7% and 12% below the BAU forecast in 2010 and 2020, respectively. For electric generators, carbon emissions drop even more significantly, to 14% and 23% below the BAU in 2010 and 2020. At \$50/tC, the carbon charge has an even more dramatic effect on carbon emissions from electric generators, achieving 80% of the reduction in the electric sector in the Advanced scenario (without any additional demand-side policies).

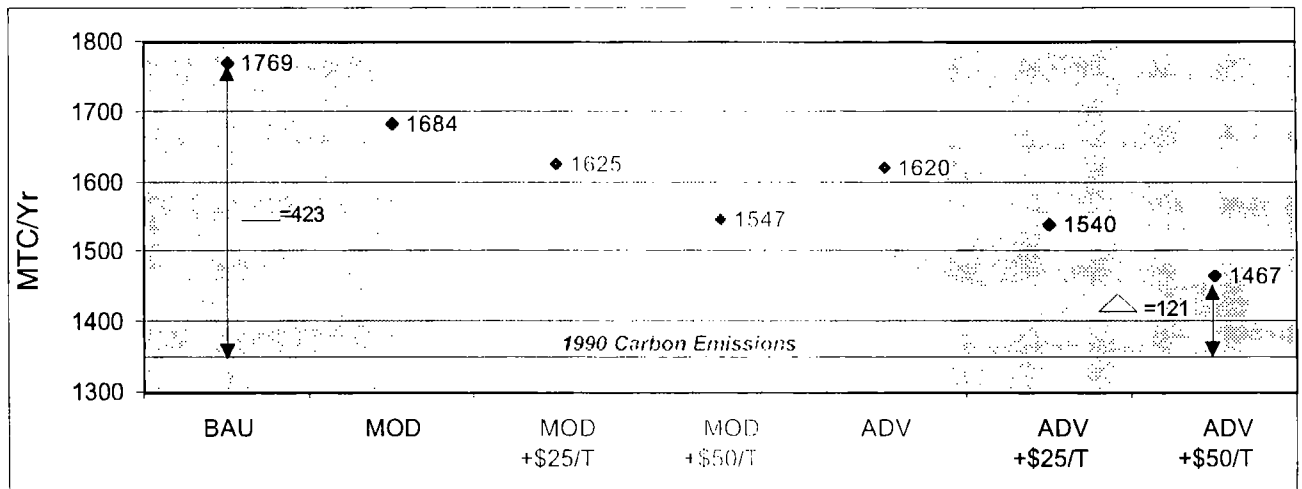
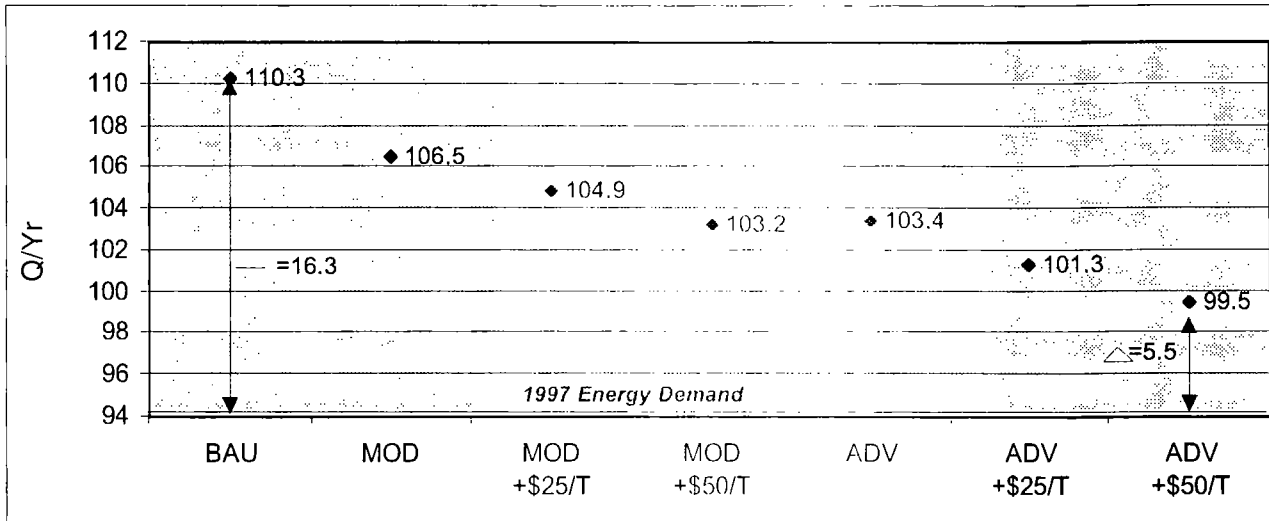
1.5.3 Carbon Trading Policy

Many analysts have argued for the merits of tackling the global climate change challenge by creating a domestic carbon trading program, as was done to reduce SO₂ emissions from electric generators. Trading programs could motivate innovative and low-cost actions to reduce CO₂ emissions. Thus it is plausible to imagine a future in which the nation implements a domestic carbon trading policy as its primary approach to carbon mitigation.

Compared with the demand- and supply-side cases, a trading case where carbon acquires a value of \$25/t has the least impact on energy use and carbon emissions. At a value of \$50/tC, the carbon trading case still reduces energy use and carbon emissions less than the demand-side scenario. Energy use drops by

only 2% in both 2010 and 2020 relative to BAU, and carbon emissions decrease by only 6% to 9% relative to BAU.

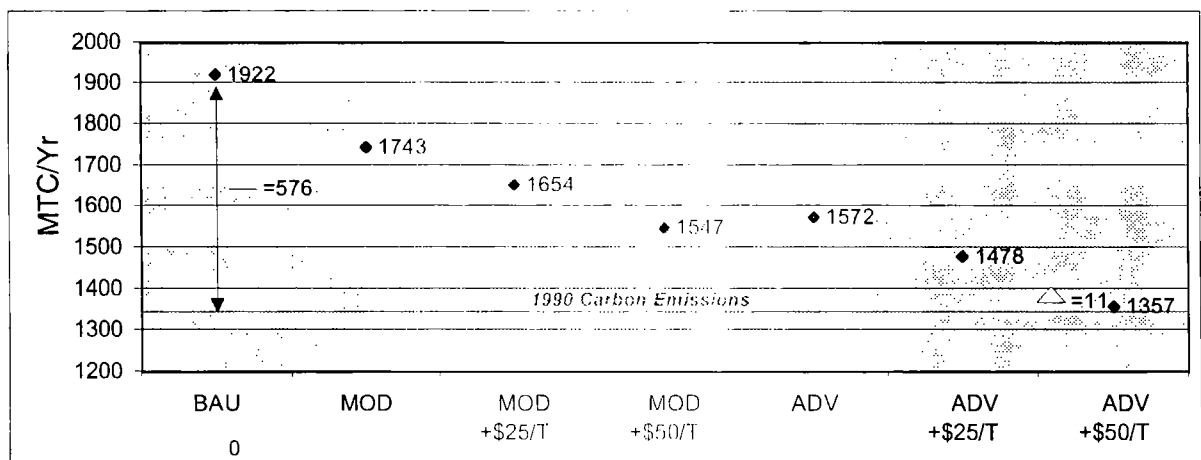
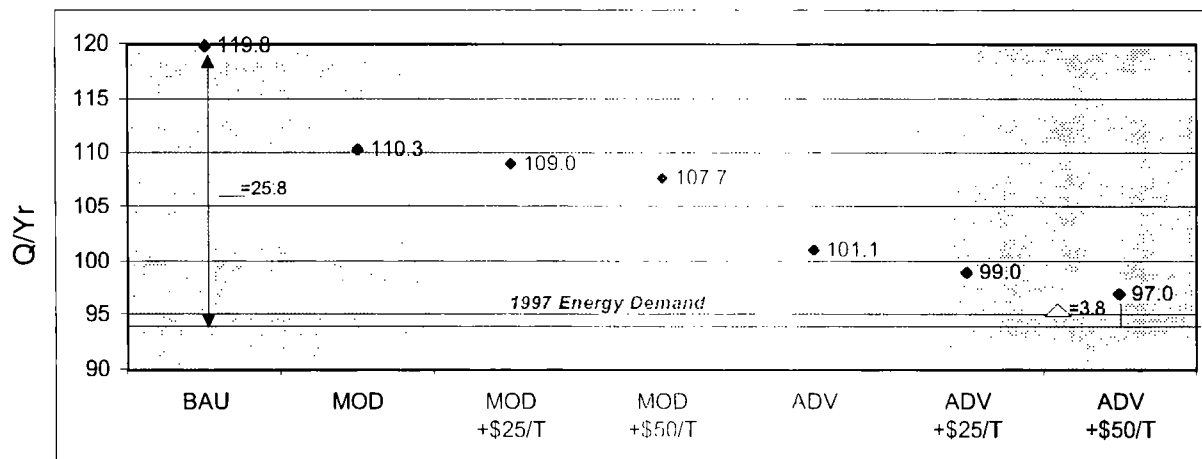
Figure 1.13 Sensitivity Cases for the Year 2010



Compared with the supply-side case, the carbon trading case with a value of \$50/tC is more effective at reducing energy use and carbon emissions in the first decade, but it is less effective in the second decade. The carbon trading system is assumed to be announced in 2002 and operational beginning in 2005. From then on, energy prices take on a proportionately higher value. The supply-side policies are more gradual. The RPS, for instance, is not fully in effect until 2010. Also, the restrictions on particulate emissions (modeled as an SO₂ ceiling) are not implemented until 2010 and then are enacted over the following decade in incremental steps.

The further reductions from adding demand-side policies to the carbon trading case are much greater than the incremental reductions from adding supply-side policies. In fact, of the various combinations shown in Table 1.19, coupling demand-side policies with carbon trading at \$50/tC comes the closest to achieving the energy and carbon reductions of the Advanced scenario.

Figure 1.14 Sensitivity Cases for the Year 2020



1.5.4 Summary

Among the three categories of policies, the demand-side policies produce the greatest energy and carbon reductions (Fig. 1.13 and 1.14). They dampen energy use and carbon emissions in approximately equal proportions. Supply-side policies and the carbon cap and trade policy, on the other hand, principally

reduce carbon emissions in the electricity sector. However, neither of these sets of policies is able to stabilize (or reduce) carbon emissions during the 20-year period. Adding a domestic cap and trade system to the demand-side policies gets to within 90% of the Advanced scenario's energy and carbon reductions. This is the most effective combination of two policy categories, bringing energy use and carbon emissions in 2020 down to below 1997 levels. In sum, the opportunities and consequences of each of these sets of policies varies considerably, and the value of each depends intimately upon the specific goals of the policy intervention—for example, short-term vs. long-term impacts and energy vs. carbon reductions.

Because our scenarios extend only to 2020, it is not possible to estimate the longer-term benefits of different policy clusters. For instance, what is the full cost of a policy scenario limited to demand-side options if it means delaying the development of environmentally attractive supply-side options? Would future U.S. export markets for supply-side technologies be diminished? Would the U.S. be less prepared to add clean power if, a compelling need were to unexpectedly emerge? Such longer-term considerations suggest that a diversified portfolio of demand- and supply-side policies is advantageous.

1.6 COMPARISONS ACROSS STUDIES

This section compares the results of the CEF analysis with those of other major carbon mitigation scenarios that employ engineering-economic (i.e., “bottoms up”) methodologies. The goal of these comparisons is to explain the divergence of modeling results by comparing the assumptions and methodologies of each study. The policy pathways that are modeled, the base and target years, and the baseline assumptions about economic growth and future energy prices can all affect results, including estimates of future energy consumption and carbon emission levels, rates of market penetration of key technologies, and the estimated costs associated with these scenarios.

Additional studies have used general equilibrium, “top-down” modeling to estimate the costs of achieving various levels of carbon reduction in the United States. These include studies by WEFA (1998), analyses using the Pacific Northwest National Laboratory's Second Generation Model (Edmonds et al., 1992), studies using MIT's Emissions Prediction and Policy Analysis Model (Jacoby et al., 1997), analysis by Manne and Richels (1997) sponsored by the Electric Power Research Institute, and analysis by Standard and Poors DRI (1998). Detailed comparisons are not provided with these studies because of the differences in basic methodology. However, the reader can find a lucid comparison of their projections and cost estimates for achieving the Kyoto Protocol goals in EIA's (1998c, chapter 7).

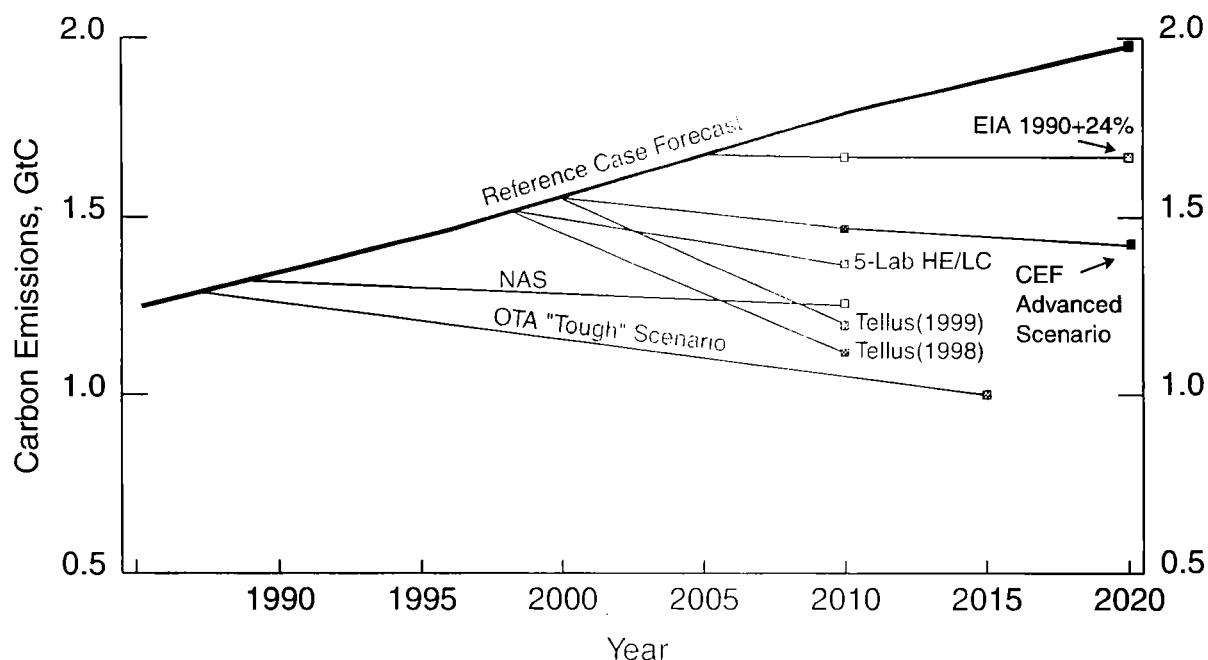
The following six engineering-economic studies are examined in the following pages:

- *Changing by Degrees: Steps to Reduce Greenhouse Gases*, by the Office of Technology Assessment (OTA, 1991);
- *Policy Implications of Greenhouse Warming: Mitigation, Adaptation, and the Science Base* by the National Academy of Sciences (NAS, 1992);
- Interlaboratory Working Group. *Scenarios of U.S. Carbon Reductions: Potential Impacts of Energy-Efficient and Low-Carbon Technologies by 2010 and Beyond*—also known as “The Five-Lab Study” (1997);
- *Policies and Measures to Reduce CO₂ Emissions in the United States: An Analysis of Options for 2005 and 2010* by Tellus Institute (1998);

- Bernow, S., et al. *America's Global Warming Solutions*. by Tellus Institute and Stockholm Environment Institute (1999);⁸ and
- *Impacts of the Kyoto Protocol on U.S. Energy Markets and Economic Activity*, by the Energy Information Administration (EIA, 1998c).

Each of these studies describes at least one “low-cost” carbon reduction scenario. To keep the comparisons manageable, only one scenario from each scenario is described. The scenario chosen in each case is the one that produces the largest carbon reductions while maintaining low costs (i.e., annual costs generally less than \$100 billion). These include the “tough” scenario from OTA (1991), the high-efficiency/low-carbon case from the Five-Lab study, the “climate protection” scenario from the 1998 and 1999 Tellus studies, and the EIA (1998) scenario that reduces carbon emissions to 24% above 1990 levels. The variation in carbon reduction levels across these scenarios is shown in Figure 1.15. To facilitate these cross-study comparisons, this figure portrays each scenario’s carbon reductions relative to EIA’s AEO99 Reference Case (EIA, 1999). Differences in the assumptions and methodologies used by these studies that help to explain variations across their findings are summarized study-by-study in the following paragraphs.

Figure 1.15 A Selection of Low-Cost Engineering-Economic Scenarios



The 1991 report by the Office of Technology Assessment (OTA) titled *Changing by Degrees* (U.S. Congress, 1991) analyzed the potential for energy efficiency to reduce carbon emissions by the year 2015, starting with the base year of 1987. Its “tough” scenario results in a 20% to 35% emissions reduction relative to 1987 levels, or emissions levels of 850 to 1000 MtC/year in 2015. The CEF study’s carbon reductions are considerably less than OTA’s “tough” case. However, the annual rate of decrease in carbon emissions is quite similar, as can be seen by the parallel positioning of their trajectories in Figure 1.15. The large difference between their endpoints is due partly to OTA’s 13-year “jumpstart.”

⁸ The Tellus Institute reports reflect an effort among leading non-governmental energy organizations that was begun with *America's Energy Choices* in 1991. The series of reports includes *Energy Innovations: A Prosperous Path to a Clean Environment* by five national environmental organizations (Alliance to Save Energy, et al., 1997).

The tough scenario achieved its reductions at an estimated net annual cost ranging from -\$20 billion to \$150 billion (in \$1987). Residential building efficiency improvements are seen as the least-cost options and are estimated to generate net savings in both the pessimistic and optimistic cases. Energy-efficient technologies for commercial buildings and for transportation are seen as saving or costing money, depending on the assumptions. Altogether, these three end-use efficiency “stair-steps” in the supply curve account for more than 450 MtC of reductions in the year 2015. The savings from the first three steps are offset by the net costs represented by the two remaining steps – industrial efficiency and electric generators. These two options are estimated to deliver more than 400 MtC of reductions. This study differs from the CEF Study in its view that industrial efficiency technologies have net costs, even under the most optimistic assumptions.

The **NAS scenario** (National Academy of Sciences, 1992) included energy conservation technologies that had either a positive economic return or that had a cost of less than \$2.50 (in \$1992) per tonne of carbon. Electric utility technology options play a negligible role. Altogether, NAS concluded that energy conservation technologies offered the potential to reduce carbon emissions by 463 MtC over a 20-year period, with more than half of these reductions arising from cost-effective investments in building energy efficiency. The CEF Advanced scenario describes bigger reductions overall (575 MtC over a 20-year period). However, only 369 MtC of these reductions come from energy efficiency improvements. A key reason that the NAS estimate is higher is that it did not use stock turnover periods to constrain the introduction of new technologies. Another reason is that it did not employ any type of “participation fraction” to limit the portion of purchases that actually buy optimum-efficiency equipment. Rather, the NAS study focused on the full technical potential of a suite of energy conservation technologies.

The NAS study estimated that it could realize this potential at a net benefit to the economy ranging from \$14 billion to \$116 billion per year (in \$1989). This net benefit results from adherence to the low-cost guidelines for including individual technologies. Power plant upgrades constitute the only supply-side technology option that does not exceed the NAS definition of a low-cost technology for reducing carbon emissions. These upgrades include 3% efficiency improvements to existing coal plants, 5% efficiency improvements to hydroelectric plants, and a 5% increase in the average capacity factor of existing nuclear power plants. In contrast, new electricity supply technologies that emit no carbon are estimated to require high implementation costs. They are therefore not part of the potential emission reduction estimated by the NAS Study, thereby keeping costs low.

The pace of carbon reductions in the Five-Lab study’s **“high-efficiency/low-carbon” scenario** is quite similar to the pace of reductions in the Advanced scenario. This is documented by the parallel carbon reduction trajectories shown in Figure 1.14. However, in 2010 both the carbon and energy reductions in the CEF study’s Advanced scenario are less than those of the Five-Lab study’s HE/LC case. This difference is largely due to the distinct time frames of each study. The Five-Lab study’s scenarios used a variation of the EIA AEO97 reference case as its baseline and assumed that a national focus on efficient and clean energy technologies would begin in 1998. In contrast, the CEF study uses a variation of the AEO99 reference case as its baseline and therefore is working against a 5% higher level of energy use and carbon emissions in 2010. In addition, it assumes that new policies begin in 2000, which allows only 10 years, instead of 12, to produce impacts by 2010. These two differences make it more difficult to devise low-cost strategies to bring future energy use and carbon emissions back down to historic levels, such as those described for the U.S. in the Kyoto Protocol.

Some sector-specific differences also exist in the energy savings modeled by the CEF and Five-Lab studies. Specifically, the CEF study shows lower savings for the transportation sector, and higher savings for both buildings and industry. In the Advanced scenario, 20 years are required for the transportation sector to deliver energy reductions comparable to those achieved in the other two sectors. The Five-Lab study showed less of a lag partly because it had two more years in which to generate results.

Carbon emissions from electricity production in the HE/LC Case are somewhat higher than in the Advanced scenario in 2010. This is due primarily to the greater use of wind energy and the relicensing of more nuclear plants in the Advanced scenario. These potential carbon reductions are somewhat offset by the Advanced scenario's smaller introduction of biomass cofiring, hydropower, and fossil plant efficiency improvements, compared with the HE/LC case. In contrast to the electricity sector, the end-use sectors in the HE/LC case generate greater carbon reductions than in the Advanced scenario. This is partly because the impacts of fuel cells in buildings and combined heat and power in industry are not included in the CEF bottom-line estimates, and ethanol displaces less gasoline in the Advanced scenario. In the Five-Lab study, the savings from lower energy bills exceed the incremental technology investment costs and the cost of administering the programs and policies required to motivate these investments. The same is true for the CEF study, if the recycled revenues from the cap and trade system are used to offset higher energy prices, as was implicitly assumed in the Five-Lab study.

The Tellus Institute's 1998 "**climate protection**" scenario modeled the carbon emission reductions from a vigorous set of RD&D and deployment policies. Compared to the policies modeled in the Advanced scenario, these policies are more aggressive. For instance they include stricter appliance and buildings standards, stronger CAFÉ standards, a carbon content standard for transportation fuels, incentives for more rapid investment in new manufacturing equipment in industry, and a 10% "unconstrained" renewable portfolio standard in the electric utility sector. The result is an estimated decrease in carbon emissions of 593 MtC in 2010. This is approximately the same level of reduction that is achieved by the CEF Advanced scenario in 2020. The reductions are particularly strong in the transportation sector due to the aggressive policies of the climate protection scenario. It foresees the potential to reduce petroleum use by 2.2% per year. In contrast, the CEF study estimates growth in petroleum use through 2010, and reductions during the second decade only after sufficient R&D-generated improvements have materialized.

The "**climate protection**" scenario produced by the Tellus Institute in 1999 models many of the same policies as in its 1998 climate protection scenario. Again, these are generally more aggressive than the policies modeled in the CEF study's Advanced scenario and include

- a cap and trade system to reduce the carbon intensity of the electric sector by 40% in 2010,
- incentives for biomass cofiring and district energy systems with cogeneration,
- stricter appliance and building standards,
- a carbon content standard for motor fuels to achieve a 10% reduction by 2010;
- a 10% unconstrained renewable portfolio standard, and
- facilitation of high speed intercity rail development and intermodal freight movement.

The result is a rapid decline in carbon emissions to 1,150 MtC in 2010.

The 1998 climate protection scenario estimates net annual benefits of \$87 per tonne of reduced carbon, for a total annual savings of \$52 billion (in \$1997). The net annualized savings of the 1999 climate protection scenario is estimated to be \$43 billion (in \$1996) in 2010. A substantial portion of this scenario's carbon reductions comes from a 28% decrease in petroleum use, relative to the business-as-usual scenario. This sizeable reduction reflects a set of policies to decrease vehicle miles traveled and to shift the nation toward more efficient transportation modes. Such policies are not considered in the Advanced scenario of the CEF study, although they are discussed in detail in Appendix E-2.

The EIA's **1990+24% scenario** is driven by a single policy instrument: a domestic cap and trade system that limits emissions in 2010 to 24% above 1990 levels. (EIA also models scenarios that reduce carbon emissions to +9%, -3%, and -7%. These are not described here because the costs of these scenarios are significantly higher.) It is assumed that this policy is implemented in 2005 and operates through 2010. At the 1990+24% cap (i.e., a carbon reduction of 123 MtC in 2010), carbon permits are estimated to trade at

\$67 per tonne (in \$1996). The annual macroeconomic costs to the economy are estimated to be \$56 to \$88 billion (\$1992) between 2008 and 2012. This range reflects two different revenue recycling schemes (either a social security tax rebate or a personal income tax rebate). The 1990 + 24% scenario produces only a 2% reduction in petroleum consumption. Thus the analysis suggests that a small increase in oil prices from the carbon cap and trade system would have a minimal impact on vehicle efficiencies.

The primary differences between the EIA analysis and that of the present study is that the 1990+24% scenario achieves all of its carbon reductions through a domestic carbon cap and trade system, that is modeled as a carbon tax. We have seen in our analysis that carbon charges are effective in producing fuel switching in the electric utility sector, from coal to natural gas, but have relatively little impact on energy demand. Because of the low demand elasticity in the end-use sectors, EIA has had to apply a high carbon tax to obtain demand reductions. In contrast, the CEF study (and most of the other studies examined here) has used policies – such as appliance standards and voluntary agreements – to achieve such demand reductions, and thus has not needed such high carbon charges. The EIA study did not increase RD&D programs, while the CEF study significantly increases RD&D investments, with resulting technology improvements (especially in the transportation sector).

1.7 STUDY LIMITATIONS AND REMAINING ANALYSIS NEEDS

The objective of this CEF study is to develop scenarios that show how energy efficiency and clean energy technologies can address U.S. energy and environmental challenges while enabling continued economic growth. To meet this objective within our resources, we have restricted the scope of the CEF study. These limitations, and the need for further analysis, are described in the following paragraphs.

Perhaps the most significant limitation of the study is its focus on domestic carbon emissions. This focus results from these facts:

- Although the United States faces many energy and environmental issues, global climate change could be the most challenging.
- Many of the policies and technologies that address carbon emissions have co-benefits such as improved air quality, security of energy supplies, and energy productivity.
- Carbon emissions from fossil fuel combustion represent 83% of U.S. emissions of greenhouse gases.
- While global climate change is an international issue, and international trading of carbon allowances may become a reality, the potential for domestic carbon emission reductions can be evaluated largely independently of the international trading opportunities and is relevant to the international debate.

This focus on carbon emissions means that while we have included some policies directed at other issues (e.g., electric sector restructuring), we have not examined many policies relevant to other greenhouse gas emissions, to carbon sink development, to local air pollution emissions, or to international carbon trading or export market opportunities.

In spite of the long-term nature of the global climate change problem, we elected to constrain the study's modeling to a near-term (2020) time frame to better represent specific policy opportunities and impacts. This time frame is also consistent with the use of NEMS, which extends only through 2020. One result of "truncating" our analysis at 2020 is that the modeling is not responsive to needs and conditions that emerge in subsequent years. This is not a limitation of the BAU forecast, but it is a limitation of the CEF scenarios. These scenarios could be improved if circumstances after 2020 could be foreseen (e.g., breakthrough technologies, more or less severe environmental conditions, export market developments, etc.) and factored into the design of policies and programs.

Because of the long lifetimes of power plants, refineries, and many other energy investments, decisions made over the next two decades will have far-reaching implications for subsequent decades and may not

be optimal for the long run. In addition, the RD&D investments of the next few decades will determine which long-term options become available after 2020 and which are foreclosed. The impact of short-term decisions over the longer term is illustrated vividly by the six global energy scenarios developed for the next century by Nakicenovic, Grubler, and McDonald (1998), which are discussed in Chapter 8.

Although we have examined the direct costs and benefits of the policies included in the different scenarios, we have not assessed the cost of no policies (i.e., the cost of inaction). The study also does not assess the cost of policies to promote low-cost adaptation to climate change (e.g., strengthening physical infrastructures, emergency preparedness programs, and improved air conditioning technologies). An entirely different study would be required to assess the costs of a changing global climate.

The study is also limited in terms of methodology. As discussed in Section 3.7, “Remaining Analysis Needs,” a major methodological weakness is our limited ability to analyze non-fiscal policies. These include information and technical assistance programs, demonstration projects, and voluntary agreements. There is a need for more detailed documentation of program impacts so that analyses such as the CEF study can be better grounded, and future policies and programs can benefit better from past experiences. Modeling the results of R&D programs also proved difficult. We cannot forecast with precision, we can only illustrate by example, the kinds of improvements in technologies over time that can be the determining factor in the acceptance of many clean energy technologies. Resource limitations also prevented this study from analyzing markets at the disaggregated level of detail required for some technologies to be accurately assessed, such as combined heat and power, building shell/equipment interactions, and distributed generation.

The CEF study is also methodologically limited in its assessment of the macroeconomic impacts of policies. This is particularly problematic for policies involving large transfer payments, such as domestic carbon cap and trade policy with its redistribution impacts, transition costs, and equity issues.

Given these limitations of scope and methodology, caution should be used when applying the CEF study results. First, the study consists of a set of scenarios, not forecasts. The scenarios are distinguished by a range of public perceptions of the severity of the global climate change problem. If the public does not perceive the problem as extremely serious, these scenarios will not materialize. Second, it is not possible in a study of this nature to conceive of all the mechanisms that energy markets will find to deal with the problem. In general, modeling is poorly suited to anticipating the market's capacity to innovate. In particular, studies by Porter and others strongly suggest that, given flexibility and policy signals that “steer” rather than “row” (precisely the kind that are difficult to model), markets will innovate without incurring substantial price penalties (Porter and van Linde, 1995). Thus it is likely that we overestimate the cost of reducing U.S. carbon emissions.

Similarly, not all policy opportunities have been identified. Inasmuch as better opportunities will emerge, the policies of this study should be taken more as well-documented possibilities than as recommendations. Finally, while we identify near-term technology and policy opportunities, these should not be pursued to the exclusion of technologies and policies that will help us address the longer term beyond 2020.

Many of the CEF study's limitation could be improved with a modest amount of further analysis. These analyses could include the following:

- modeling the impacts of non-fiscal policies;
- improved modeling of macroeconomic impacts of policies;
- improved modeling of distributed power generation, such as fuel cells in buildings and combined heat and power in industry;

- expansion of the modeling capabilities to include a fuller range of air pollutants, so that co-control policies (e.g., air quality and carbon reduction policies) can be more easily analyzed; and
- better characterization of the impacts of uncertainties.

The development of models with longer time frames, finer geographic disaggregation, and a broader array of international considerations would likely require a more significant amount of additional analysis.

1.8 CONCLUSIONS

This analysis documents the important role that policies can play in stimulating the development and market penetration of efficient and clean energy technologies. These technologies, in turn, could help the United States meet a wide array of challenges including global warming, energy supply vulnerabilities, air pollution, and economic competitiveness. Our assessment suggests that the incremental technology and policy costs required to implement these technologies would be less than the energy cost savings from the more efficient use of energy throughout the economy in combination with the carbon charge transfer payments.

This report has developed a variety of scenarios. None of them—including the BAU scenario—is a prediction of the future. They all attempt to characterize the results of different assumptions about the future on the energy system (demand, supply, and price) and, to a lesser degree, the economy.

It is reasonable to ask what we have learned from the exercise. There are many possible answers to this question, depending in part on the viewpoint and judgments of the reader, and in part on the logic of the analysis itself. All of the conclusions are, of necessity, tinged by the uncertainty that is inherent in any discussion of the future.

In the discussion that follows, we present our conclusions approximately in order of increasing uncertainty, as we describe what is needed to achieve reductions in carbon emissions and other pollutants in the 2010 to 2020 time frame.

It is clear that a baseline built on current approaches to energy policy in this nation will result in substantial increases in carbon and other pollutant emissions in 2010 and 2020. The BAU case shows increases in carbon emissions of 31% and 43% above 1990 levels in 2010 and 2020, respectively. Although many different futures based on a continuation of current economic and policy trends are possible, virtually all of them would show substantial increases in carbon emissions. Thus we conclude that, without major shifts in policy and/or in the economic environment, the United States will be much further from stabilizing its carbon emissions if today's trends continue.

The Moderate scenario shows what a considerable effort to increase efficiency could achieve. The authors believe that the scenario demonstrates a range of policies and technologies that are conceivable with a modest shift in the present political context. One view of the Moderate scenario, which shows an increase in energy demand of 27% and 31% above 1990 levels in 2010 and 2020, respectively (an energy reduction of 4% and 8% from BAU in those years), is that it is a modest effort to curb demand growth. Others, contemplating the policies and technologies that need to come into play to make this case happen, may view it as a more significant departure from current trends and policies. The authors view this case as one in which uncertainty about technologies and the likelihood of policies to bring them into the market is relatively modest. That is, in all end-use sectors, the technologies with favorable economics to achieve the demand reductions are available. The greatest uncertainty is the willingness of the nation to adopt policies to encourage them. The second-greatest uncertainty is the likely effectiveness of the policies and, therefore, the aggressiveness with which they would need to be pursued. In all of our analyses of this scenario, we observe a favorable direct economic impact.

Another type of measure to reduce carbon emissions is a direct cap on emissions, resulting in a carbon charge. We have analyzed \$25/tC and \$50/tC cases. We focus on the \$50/t case here. If we apply \$50/tC to the BAU case, carbon emissions are reduced by 24% and 30% in 2010 and 2020, respectively. There are two very different types of uncertainties relating to this reduction. First, there is the issue of whether and under what circumstances a policy that would lead to an increase in energy prices, through a carbon charge, would be adopted. Such a charge is difficult to imagine in the present political environment. It would require a substantial recognition of the importance to the nation of reducing carbon emissions and a willingness to commit resources and effort to do so. The second set of uncertainties relates to the modeling. For example, we have analyzed the economics of retirement of coal-fired plants and their replacement by natural gas-fired plants under different carbon charges. These studies are based on costs averaged across a large number of plants and do not necessarily reflect the real-world costs of individual plants. Future work could show greater or lesser replacement of coal-fired power plants at a \$50/tC charge. Our analysis suggests that the direct costs of this carbon charge on the economy would be small (defined as less than the net savings to the economy of the Moderate scenario).

The CEF-NEMS analysis estimates that the measures identified in the Moderate scenario combined with a cap on carbon that resulted in a \$50/tC charge would lead to an increase in carbon emissions above 1990 levels of 15% in both 2010 and 2020. We believe there is less uncertainty in the technology or the economics of this case compared with the political feasibility of implementing the policies (e.g., increasing federal budgets for energy efficiency programs and energy technology R&D; implementing selected energy efficiency policies and/or achieving voluntary agreements with industry; and establishing a carbon cap equivalent to a \$50/tC charge).

There is an important point to be made about natural gas supply in this case. While there is of necessity some uncertainty in domestic supply of natural gas and its cost, the moderate case with a \$50/tC charge has a lower natural gas demand than the BAU. Thus the uncertainty of gas availability at low prices is reduced in this case relative to BAU. This realization makes clear the importance of combining energy efficiency programs, which make more natural gas available, with supply policies that increase use of natural gas.

The Advanced scenario, by combining much more aggressive policies and pursuing advanced R&D goals much more actively, shows carbon emission reductions during the second decade of our analysis period. Are these scenarios achievable? What are the preconditions for success, or a degree of success, in achieving them? If they can be achieved, are they affordable?

There are no simple answers to these questions. All of the authors of the report view the cases as plausible—that is, nothing in them violates our knowledge of energy technologies or markets. However, there are considerable uncertainties. First and foremost is political feasibility. Even more than the Moderate scenario with a carbon charge, the Advanced scenario requires a dramatic change in political will. Very active market policies, with substantial federal funding, along with regulatory policies, commitment by industry on energy efficiency well beyond present practice, and greatly increased R&D are all prerequisites. There is little to suggest that such fundamental policy and budget changes are conceivable in the present political environment.

The issue here is not likelihood in the present political environment but feasibility in a different one. If for whatever reason—clear evidence of climate change, new scientific findings, international pressures—the nation did commit to a path of significant carbon reductions, then how plausible is a case such as our Advanced scenario and what are the major uncertainties and barriers to achieving the CEF-NEMS modeled results?

We first discuss three large areas of uncertainty. In many cases, technology is not presently available to achieve the Advanced Scenario results. The scenario requires substantial progress toward more efficient vehicles. A combination of advanced diesels with greatly lowered emissions, fuel cell hybrids, reduced-cost alcohol fuels, gasoline hybrids, and electric vehicles will need to be commercial and affordable

before 2010. Similarly, costs for key renewable energy sources such as wind and biomass co-firing must be significantly reduced over the same time period. Important improvements in energy-efficient technologies—either cost or performance—are needed for both buildings and industry as well; success in these sectors also depends strongly on program implementation. It is not certain that these technological improvements will occur in the time frame suggested. It is also possible that technology innovation in response to the combined set of policies described in the study plus similar or more aggressive policies enacted in other countries and not analyzed, could lead to greater technical progress than assumed. If the country—government and private sector—invests in the R&D substantially (we assume a doubling), the authors believe that the technology improvements required for the Advanced case are plausible.

The second area concerns the effectiveness of the policies. This is tied closely with the success in technology R&D. If the R&D is successful, and the technologies are available and cost-effective, then the policies need far less aggressive a push. For example, if advanced vehicle design makes 60 mpg cars (and even light duty vehicles) affordable without degrading performance, then achieving either a voluntary agreement or mandatory standards on fuel economy is far less difficult than under conditions of technological uncertainty. In a world in which the goal of reducing carbon emissions is widely accepted, the consumer is far more likely to trade acceleration for fuel economy, thus making fuel efficiency agreements or standards easier to adopt. Nonetheless, even in a world in which there is strong agreement among many parties in favor of reducing greenhouse gas emissions, there remain uncertainties about the efficacy of the policies. Particularly in buildings and in industry, it remains possible that market barriers to energy efficiency will be more stubborn than expected and/or that the real costs of implementing energy efficiency will be higher than we have estimated. Again, R&D interacts with policies: a successful R&D effort produces technologies that make policy easier to implement.

A related policy issue concerns the transition to an Advanced scenario. The biggest transition issue concerns the movement away from coal. There is no question that the coal industry would be dramatically affected by the policies and measures that bring about the Advanced scenario: coal production is down 50% from the BAU case in 2020 (down 10% from 1997 levels). This would dramatically and adversely affect the coal industry and its related transportation modes (rail and barge). Other industries – natural gas, renewables, and providers of energy efficiency – would clearly gain.

The final area concerns the cost of the Advanced scenario. The cost results are critical to the plausibility of the scenario. If the scenario saves consumers and society money, then the policies underlying it become much more plausible than if there is a substantial net cost to society. The results suggest that society would have benefits of tens of billions of dollars per year by 2020. This estimate depends in large measure on our estimates of the costs and performance of the technologies and, to a lesser extent, of the policies. The technologies could be more expensive than we expect, or the policies could be more costly. (They could also be less costly.) The large net benefit in the analysis is encouraging, in that it suggests some margin for error without causing adverse economic impacts. But it is worth repeating that these costs depend on advances in technology combined with smart and efficient policies; without these, the costs are necessarily much higher.

In summary, there are a variety of possible viewpoints on the Advanced scenario. The authors believe that it could only happen with dramatic changes in government policy and national will (affecting both consumers and industry). Even with these dramatic changes, there remain important uncertainties. Will the technology advance as much as now appears to us plausible? Will the advances take place in the time frame that we anticipate? Will the policies work as well as we expect? To some, the likelihood of “yes” is high, and the Advanced scenario is highly plausible given the transformation of the policy environment. Others who look in detail at the technologies and policies enumerated in the report may feel that a substantial portion of the reductions in energy use and emissions in going from the Moderate to the Advanced scenario is highly plausible – again assuming the technology R&D investment and the willingness to pursue policies. There will be those who are much more pessimistic about technology and policy and who believe that little if any of the results of the Advanced scenario are likely. The authors of this report have a range of views about these results, but in all cases find themselves in either the first or

second of these three groups: we believe that, with the sufficient commitment, the United States could achieve all or a substantial portion of the Advanced scenario and at a negligible cost (or benefit) to the economy.

Climate change is but one of the concerns that U.S. energy policy must address. This study identifies a set of policy pathways that could significantly accelerate the development and deployment of cost-effective energy technologies. By targeting clean energy technologies, these policies offer the potential for multiple benefits: greenhouse gas reductions, energy bill savings, balance-of-payment benefits, enhanced security through energy diversity, and improved air quality. These multiple benefits are produced by moving forward on many fronts – on policies to remove market and organizational barriers, on programs to facilitate deployment, and on technology development. These are all key ingredients of a clean energy future.

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