Scenarios for a
Clean Energy Future

Interlaboratory Working Group on
Energy-Efficient and Clean Energy Technologies

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Cover Photos

Malden Mills, the industry pictured, replaced its power plant in 1999 with the help of DOE after it had been destroyed by fire in 1995. DOE provided financial and technical support to develop a cogeneration plant that has one of the lowest emissions of any industrialized heat and electric combined facility in the United States.

Four Times Square—a 48-story skyscraper—is one of the most environmentally and technologically advanced buildings in the nation. Assistance with these advanced technologies was provided by New York State Energy Research and Development Authority (NYSERDA) and DOE's State Energy Program.

The car depicted represents the work of DOE's Partnership for a New Generation of Vehicles program. With the assistance of DOE, the Big Three automotive manufacturers in the U.S. (DaimlerChrysler, Ford, and General Motors) have each developed their own new concept vehicle designed to utilize hybrid electric propulsion to enable them to achieve fuel efficiency of up to 80 miles per gallon.

The wind turbine technology represented on the cover is located at Buffalo Ridge, MN. Its development was supported by the DOE Wind Power program implemented through NREL's National Wind Technology Center.

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SCENARIOS FOR A CLEAN ENERGY FUTURE

Prepared by the
Interlaboratory Working Group on
Energy-Efficient and Clean-Energy Technologies

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PREFACE

This report, *Scenarios for a Clean Energy Future,* was commissioned by the U.S. Department of Energy s Office of Energy Efficiency and Renewable Energy. It was produced by the Interlaboratory Working Group, composed of scientists from Argonne National Laboratory, Lawrence Berkeley National Laboratory, the National Renewable Energy Laboratory, Oak Ridge National Laboratory, and Pacific Northwest National Laboratory. The report seeks to develop a better understanding of the potential for R&D programs and public policies to foster clean energy technology solutions to the energy and environmental challenges facing the nation. These challenges include global climate change, air pollution, oil dependence, and inefficiencies in the production and use of energy.

The study uses a scenario-based approach to examine alternative portfolios of public policies and technologies. The policies were selected by the authors through a dialogue with numerous representatives from the private sector, non-profit organizations, universities, and government. These policies range from expansions of long-existing programs to new policies, some of which are clearly controversial.

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

This study identifies the potential for impressive advances in the development and deployment of clean energy technologies without significant net economic impacts. Widespread use of these technologies would do much to cut U.S. greenhouse gas emissions. In reviewing the study s results, however, it is important to remember the imprecision of policy analysis; uncertainties derive from such diverse issues as the likely pace of technology advancements and the response of consumers to market-based incentives.

We believe this study will make a substantial contribution to developing a deeper understanding of the potential for clean energy technologies and policies to meet future energy and environmental goals and challenges. This study provides a foundation of analysis that can help the nation identify smart, sustainable energy policies and technologies.

The contributions to this study by multiple national laboratories, and industry and university participants and reviewers, are another example of the effective partnerships that the Department of Energy is fostering to advance the nation s energy and environmental agenda.

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ACRONYMS

AEO	Annual Energy Outlook
AER	Annual Energy Review
AFV	alternative-fueled vehicle
AFVM	Alternative Fuel Vehicle Model
ANL	Argonne National Laboratory
ASHRAE	American Society of Heating, Refrigeration, and Air-conditioning Engineers
BAU	business as usual
BTS	Office of Building Technology, State and Community Programs
Btu	British thermal unit
CAFÉ	corporate average fuel economy
C	carbon
CC	combined cycle
CCTI	Climate Change Technology Initiative
CEF	Clean Energy Future
CHP	combined heat and power
CIDI	compression ignition (diesel) direct injection
CO_2	carbon dioxide
CRADA	cooperative research and development agreement
CT	combustion turbine
DOE	U.S. Department of Energy
DOT	U. S. Department of Transportation
EERE	Office of Energy Efficiency and Renewable Energy
EIA	Energy Information Administration
EPA	U.S. Environmental Protection Agency
EPACT	Energy Policy Act of 1992
ESCO	energy services company
ESPC	Energy Savings Performance Contract
FAA	Federal Aviation Administration
FEM	Fuel Economy Model
FEMP	Federal Energy Management Program
FY	fiscal year
GDI	gasoline direct injection
GDP	gross domestic product
GHG	greenhouse gas
g/mi	grams per mile
GW	gigawatt
GWP	global warming potential
HVAC	heating ventilation, and air-conditioning
ICE	internal combustion engine
IGCC	integrated gasification combined cycle
IOF	industries of the future
IPP	independent power producer
IPCC	International Panel on Climate Change
kWh	kilowatt-hour
LBNL	Lawrence Berkeley National Laboratory
LDV	light-duty vehicle
LEV	low emission vehicle
MBtu	million Btu

MEC	model energy code
mmbd	million barrels of oil per day
MtC	million metric tons of carbon
MW	megawatt
mpg	miles per gallon
mph	miles per hour
NAECA	National Appliance Energy Conservation Act of 1987
NEMS	National Energy Modeling System
NO_x	nitrogen oxides
NREL	National Renewable Energy Laboratory
OIT	Office of Industrial Technologies
OPEC	Organization of Petroleum Exporting Countries
OPT	Office of Power Technologies
ORNL	Oak Ridge National Laboratory
OTT	Office of Transportation Technologies
PATH	Partnership for Advanced Technology in Housing
PATP	"pay at the pump" auto insurance
PFC	perfluorocarbon
PM	particulate matter
PNGV	Partnership for a New Generation of Vehicles
PNNL	Pacific Northwest National Laboratory
ppm	parts per million
PTC	production tax credit
PV	photovoltaic
Quad	quadrillion Btu (10^15 Btu)
R&D	research and development
RD&D	research, development and demonstration
RPS	renewable portfolio standard
SEAB	Secretary’s Energy Advisory Board
SO_2	sulfur dioxide
SUV	sports utility vehicle
tBtu	trillion Btu
TDI	turbocharged direct injection
TPC	technology possibility curve
TWh	TerraWatt-hour
UEC	unit energy consumption
VMT	vehicle miles traveled
VOC	volatile organic compounds

GLOSSARY

Barrel (petroleum): A unit of volume equal to 42 U.S. gallons.

Biomass: Any organic matter available on a renewable or a recurrent basis, including agricultural crops and residues, wood and wood residues, urban and animal residues, and aquatic plants.

Bioenergy: Energy derived from biomass as electricity or heat, or combinations of heat and power; in the form of liquid or gaseous fuels, it is often referred to as biofuels.

British Thermal Unit (Btu): One British thermal unit, or BTU, is roughly equivalent to burning one kitchen match. It is the quantity of heat required to raise the temperature of one pound of water one degree Fahrenheit. (one Btu = 1055 Joules)

Carbon Dioxide (CO_2): A colorless, odorless, non-poisonous gas that is a normal part of the ambient air. Carbon dioxide is a product of fossil fuel combustion.

Climate Change: The change in weather patterns and surface temperatures that appears to be occurring as the result of large increases in greenhouse gas concentrations in the earth's atmosphere.

Cogeneration: The production of electrical energy and another form of useful energy (such as heat or steam) through the sequential use of energy.

Combined Cycle: An electric generating technology in which electricity is produced from otherwise lost waste heat exiting from one or more gas (combustion) turbines. The exiting heat is routed to a conventional boiler or to a heat recovery steam generator for utilization by a steam turbine in the production of electricity. Such designs increase the efficiency of the electric generating unit.

Criteria Pollutant: A pollutant determined to be hazardous to human health and regulated under the Environmental Protection Agency's (EPA) National Ambient Air Quality Standards. The 1970 amendments to the Clean Air Act require EPA to describe the health and welfare impacts of a pollutant as the "criteria" for inclusion in the regulatory regime.

Crude Oil: A mixture of hydrocarbons that exists in the liquid phase in natural underground reservoirs and remains liquid at atmospheric pressure after passing through surface separating facilities. Crude oil production is measured at the wellhead and includes lease condensate.

Discount Rate: The interest rate used to assess the value of future cost and revenue streams; an essential factor in assessing true returns from an investment in energy efficiency, as well as opportunity costs associated with not making that investment. In this report, we always use real discount rates that do not include inflation. To obtain the equivalent nominal discount rate including inflation, simply add the percentage annual inflation rate to the real discount rate

Distillate Fuel Oil: The lighter fuel oils distilled off during the refining process. Included are products known as ASTM grades numbers 1 and 2 heating oils, diesel fuels, and number 4 fuel oil. The major uses of distillate fuel oils include heating, fuel for on- and off-highway diesel engines, and railroad diesel fuel.

Electric Utility Restructuring: With some notable exceptions, the electric power industry historically has been composed primarily of investor-owned utilities. These utilities have been predominantly vertically integrated monopolies (combining electricity generation, transmission, and distribution), whose prices have been regulated by State and Federal government agencies. Restructuring the industry entails the introduction of competition into at least the generation phase of electricity production, with a corresponding decrease in regulatory control. Restructuring may also modify or eliminate other traditional aspects of investor-owned utilities, including their exclusive franchise to serve a given geographical area, assured rates of return, and vertical integration of the production process.

Energy: The capacity for doing work as measured by the capability of doing work (potential energy) or the conversion of this capability to motion (kinetic energy). Energy has several forms, some of which are easily convertible and can be changed to another form useful for work. Most of the world's convertible energy comes from fossil fuels that are burned to produce heat that is then used as a transfer medium to mechanical or other means in order to accomplish tasks. Electrical energy is usually measured in kilowatthours, while heat energy is usually measured in British thermal units.

Energy Services Company: A company which designs, procures, finances, installs, maintains, and guarantees the performance of energy conservation measures in an owner's facility or facilities.

Energy Saving Performance Contract: An agreement with a third party in which the overall performance of installed energy conservation measures is guaranteed by that party.

Ethanol: A denatured alcohol (C_2H_5OH) intended for motor gasoline blending.

Externalities: Benefits or costs, generated as a byproduct of an economic activity, that do not accrue to the parties involved in the activity.

Fluorescent Lamps: Fluorescent lamps produce light by passing electricity through a gas, causing it to glow. The gas produces ultraviolet light; a phosphor coating on the inside of the lamp absorbs the ultraviolet light and produces visible light. Fluorescent lamps produce much less heat than incandescent lamps and are more energy efficient. Linear fluorescent lamps are used in long narrow fixtures designed for such lamps. Compact fluorescent light bulbs have been designed to replace incandescent light bulbs in table lamps, floodlights, and other fixtures.

Fossil Fuel: Any naturally occurring organic fuel formed in the Earth's crust, such as petroleum, coal, and natural gas.

Fuel Cells: One or more cells capable of generating an electrical current by converting the chemical energy of a fuel directly into electrical energy. Fuel cells differ from conventional electrical cells in that the active materials such as fuel and oxygen are not contained within the cell but are supplied from outside.

Gas-Turbine Electric Power Plant: A plant in which the prime mover is a gas turbine. A gas turbine typically consists of an axial-flow air compressor and one or more combustion chambers which liquid or gaseous fuel is burned. The hot gases expand to drive the generator and then are used to run the compressor.

Global Warming: Global warming is the increase in global temperatures that the earth has been experiencing this century. Gases that are thought by many to contribute to global warming through the greenhouse effect include carbon dioxide, methane, nitrous oxides, chlorofluorocarbons (CFCs), and halocarbons (the replacements for CFCs). Carbon dioxide emissions are primarily caused by the use of fossil fuels for energy.

Greenhouse Gas: Any gas that absorbs infrared radiation in the atmosphere.

Heat Pump: A device that extracts available heat from one area (the heat source) and transfers it to another (the heat sink) to either heat or cool an interior space. Geothermal heat pumps can operate more efficiently than the standard air-source heat pumps, because during winter the ground does not get as cold as the outside air (and during the summer, it does not heat up as much).

Independent Power Producer: A wholesale electricity producer (other than a qualifying facility under the Public Utility Regulatory Policies Act of 1978), that is unaffiliated with franchised utilities. Unlike traditional utilities, IPPs do not possess transmission facilities that are essential to their customers and do not sell power in any retail service territory where they have a franchise.

Kerosene: A petroleum distillate that is used in space heaters, cook stoves, and water heaters; it is suitable for use as an illuminant when burned in wick lamps (see Watthour).

Kilowatt (kW): One thousand watts of electricity (see Watt).

Kilowatthour (kWh): One thousand watthours.

Light Truck: Two-axle, four-tire trucks with a gross vehicle weight less than 10,000 pounds.

Liquefied Natural Gas: Natural gas (primarily methane) that has been liquefied by reducing its temperature to -260°F at atmospheric pressure.

Liquefied Petroleum Gas: Ethane, ethylene, propane, propylene, normal butane, butylene, and isobutane produced at refineries or natural gas processing plants.

Megawatt (MW): One million watts of electricity (see Watt).

Methanol: A light volatile alcohol (CH_3OH) used for motor gasoline blending.

Natural Gas: A mixture of hydrocarbons (principally methane) and small quantities of various nonhydrocarbons existing in the gaseous phase or in solution with crude oil in underground reservoirs.

Nitrogen Oxides (NO_x): A product of combustion of fossil fuels whose production increases with the temperature of the process. It can become an air pollutant if concentrations are excessive.

Nuclear Electric Power: Electricity generated by an electric power plant whose turbines are driven by steam generated in a reactor by heat from the fissioning of nuclear fuel.

Oxygenates: Any substance which, when added to motor gasoline, increases the amount of oxygen in that motor gasoline blend.

Ozone: Three-atom oxygen compound (0_3) found in two layers of the Earth's atmosphere. One layer of beneficial ozone occurs at 7 to 18 miles above the surface and shields the Earth from ultraviolet light. Several holes in this protective layer have been documented by scientists. Ozone also concentrates at the surface as a result of reactions between byproducts of fossil fuel combustion and sunlight, having harmful health effects.

Particulates: Visible air pollutants consisting of particles appearing in smoke or mist.

Petroleum: A generic term applied to oil and oil products in all forms.

Photovoltaic Cell: An electronic device consisting of layers of semiconductor materials fabricated to convert incident light directly into electricity (direct current).

Photovoltaic Module: An integrated assembly of interconnected photovoltaic cells designed to deliver a selected level of working voltage and suited for incorporation in photovoltaic power systems.

Primary Energy: The energy that is embodied in resources as they exist in nature (e.g., coal, crude oil, natural gas, or sunlight). For the most part, primary energy is transformed into electricity or fuels such as gasoline or charcoal. These, in turn, are referred to as secondary or site energy.

Propane: A normally gaseous straight-chain hydrocarbon (C_3H_8). It is a colorless paraffinic gas that is extracted from natural gas or refinery gas streams.

Quadrillion Btu (Quad): Equivalent to 10 to the 15th power Btu (1 quad = 1.055 x 10e18 joules).

Renewable Energy: Energy obtained from sources that are essentially inexhaustible (unlike, for example, the fossil fuels, of which there is a finite supply). Renewable sources of energy include conventional hydroelectric power, wood, waste, geothermal, wind, photovoltaic, and solar thermal energy.

Standard Industrial Classification (SIC): A set of codes developed by the Office of Management and Budget which categorizes industries according to groups with similar economic activities.

Turbine: A machine for generating rotary mechanical power from the energy of a stream of fluid (such as water, steam, or hot gas). Turbines convert the kinetic energy of fluids to mechanical energy through the principles of impulse and reaction, or a mixture of the two.

Watt (Electric): The electrical unit of power. The rate of energy transfer equivalent to one ampere of electric current flowing under a pressure of one volt at unity power factor.

Watthour (Wh): The electrical energy unit of measure equal to 1 watt of power supplied to, or taken from, an electric circuit steadily for one hour.

Wind Energy: The kinetic energy of wind converted into mechanical energy by wind turbines (i.e., blades rotating from a hub) that drive generators to produce electricity.

AUTHORSHIP

Marilyn A. Brown (Oak Ridge National Laboratory, ORNL), Mark D. Levine (Lawrence Berkeley National Laboratory, LBNL), and Walter Short (National Renewable Energy Laboratory, NREL) provided the overall DOE National Laboratory leadership for the Clean Energy Future study. They authored the Executive Summary and Chapters 1 (Integrated Analysis and Conclusions), 2 (Introduction and Background), 3 (Study Methodology) and 8 (The Longer-Term and Global Context).

Chapter 4 (Buildings) was led by Jonathan Koomey (LBNL) and Andrew Nicholls (Pacific Northwest National Laboratory, PNL). Carrie A. Webber and Celina S. Atkinson (LBNL) conducted the detailed technical analysis across all end-uses and policies, and Brad Holloman (PNNL) contributed data and analysis for certain key technologies and policies.

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Most of the appendices were prepared by these same authors and collaborators. The ancillary studies (Appendix E) were written by: Amy Wolfe and Marilyn Brown (ORNL) E-1; Frank Southworth (ORNL) E-2; David South (Energy Resources International) E-3; Alan H. Sanstad (LBNL), Stephen J. DeCanio (University of California at Santa Barbara), and Gale A. Boyd (ANL) E-4; Paul Lemar (Resource Dynamics Corp.) E-5; Reid Harvey, Francisco de la Chesnaye, and Skip Laitner (U.S. Environmental Protection Agency) E-6; and David South (Energy Resources International) E7.

Etan Gumerman, Cooper Richey, and Jonathan Koomey (LBNL) produced the integrated CEF-NEMS computer runs that are described in the chapters and are documented in detailed tables in Appendix D. Additional contributors are listed in the endnotes to several chapters. Jonathan Koomey and Cooper Richey (LBNL) and Marilyn Brown and Stan Hadley (ORNL) produced the integrating cost calculations reported in Chapter 1.

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Other DOE staff members provided valuable input and feedback on individual chapters. These include:

- Mary Beth Zimmerman, Darrell Beschen, Dave Boomsma, Mike McCabe, Lou Divone, Ken Friedman, Phil Patterson, and Joe Galdo (DOE/EERE)
- Doug Carter and Jay Braitsch (DOE Office of Fossil Energy)
- John Stamos and Carolyn Heising (DOE Office of Nuclear Energy, which also provided funding for some supplemental analysis)
- Bob Marlay and Jeff Dowd (DOE Office of Policy).

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,
- assessment of energy savings and CO_2 reduction opportunities in the iron, steel, and paper industries,
- analysis of transportation technology supply curves, and
- assessment of non-CO_2 greenhouse gas opportunities.

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:

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"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.

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[1] Jeanne Briskin was the EPA manager for the steel and paper industries. Skip Laitner was the EPA manager for the remaining industrial sector analyses and was also an active participant in all aspects of the CEF Study.

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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.

Tonia Edwards (ORNL) coordinated production of this report and its appendices, working across numerous platforms and software applications. Other support staff at ORNL are also gratefully acknowledged, including Charlotte Franchuk, Ed Lapsa, and Erin Schwartz.

EXECUTIVE SUMMARY

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

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

The Study's Key Conclusions

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

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

Uncertainties in the CEF assessment are unlikely to alter the overall conclusions. The policy and technology opportunities identified in the CEF are so abundant that they compete with each other to reduce carbon emissions. We would expect enough of them to be successful to achieve the results we claim. Furthermore, a broad range of technology options, with sufficient research, could provide additional solutions in the long run.

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

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

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

CEF SCENARIOS

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

The structured development of energy scenarios allows a way to examine a range of public policies and to consider alternative possibilities. The CEF study develops three scenarios: Business-as-Usual (BAU), Moderate, and Advanced. The BAU scenario assumes a continuation of current energy policies and a steady, but modest pace of technological progress. In contrast, the Moderate and Advanced scenarios are defined by policies that are consistent with increasing levels of public commitment and political resolve to solving the nation's energy-related challenges. Some of the public policies and programs that define the scenarios are cross-cutting; others are designed individually for each sector (buildings, industry, transportation, and electric generation) and assessed for impacts to 2020.

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

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

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

Following a detailed assessment of market failures and institutional barriers to the market penetration of clean energy technologies, numerous policies were chosen for examination in the CEF study. These policies include fiscal incentives, voluntary programs, regulations, and research and development. Many of the policies were selected on the basis of their potential to reduce carbon dioxide emissions. Others were designed specifically for air quality (e.g., reducing SO_2 emissions in the electric sector), oil security (e.g., alternative fuels research), and economic efficiency (e.g., restructuring of the electric sector).

Regardless of the driving force behind them, almost all reduce carbon dioxide emissions and improve air quality. Policies are generally stronger in the Advanced than in the Moderate scenario, with larger expenditures on public-private RD&D partnerships, stricter standards, higher tax incentives, and greater government investment in programs that promote efficient and clean energy technologies. Some policies are assumed to begin in 2000; others are assumed to begin in subsequent years. Their impacts tend to be gradual, as stock turnover and other factors dampen initial responses. Delays in implementation would miss immediate capital replacement opportunities.

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

Table 1 Key Policies in the Advanced Scenario*

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

*The scenarios are defined by approximately 50 policies. The 10 in this table are the most important ones in the Advanced scenario. Each policy is specified in terms of magnitude and timing. For instance, “Efficiency standards for equipment” comprise 16 new equipment standards introduced in various years with specific levels of minimum efficiencies.

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

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

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

METHODOLOGY

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

We have used various assessment methods, analytic tools, and expert judgments to analyze the impacts of individual policies. The CEF-NEMS model – based on the Energy Information Administration's (EIA) National Energy Modeling System (NEMS) – is then employed to quantitatively integrate the impacts of each scenario's policies. The integration step of CEF-NEMS allows the estimated effects of changes in energy use in each sector to be considered in the resultant energy use patterns of the other sectors. The CEF-NEMS also assesses additional changes in energy demand where new policies or technologies affect energy prices. Macroeconomic impacts and feedback are separately assessed through an analysis of previous published modeling results.

The EIA's Reference case from the *Annual Energy Outlook 1999* is used as the starting point for the CEF BAU forecast (the most recent available from the EIA at the time of this analysis). Thus the EIA's Reference case assumptions on fossil fuel supplies, world oil prices, energy transport, end-use service demands, and macroeconomic growth underlie the three CEF scenarios[2].

The CEF BAU forecast and the EIA Reference case forecast differ only slightly. The BAU forecast uses different base year values and stock turnover rates for several industries, which result in a lower rate of growth of energy use. This is the principal cause of the CEF BAU forecast having ~0.5% lower total energy use in 2010 and 2020 than the EIA Reference case. Carbon emissions in the BAU forecast are almost 1% less in 2010 and are 3% less in 2020 than in the EIA Reference case, primarily because the BAU assumes lower nuclear power relicensing costs.

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

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

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

reflected in this study. Likewise, potential feedbacks from any technology or policy-induced shifts in sector output on energy use are not reflected in this analysis.

RESULTS

Key findings of this study are presented in Table 2 for the BAU forecast and for the Moderate and Advanced scenarios. Results are also shown for one of the numerous alternative policy sets that are examined – in this case, the Advanced scenario with a domestic carbon trading system that equilibrates at a carbon allowance price of $25/tC. Dozens of alternative policies were analyzed to reflect the unpredictable nature of political and consumer views and to highlight the diversity of policy options. The presentation of results with three or more significant figures here and throughout this report is not intended to imply high precision, but rather is designed to facilitate comparison among the scenarios and

Table 2 Selected Results for 2010 and 2020*

			2010 Scenarios			
	1990	**1997**	**BAU Forecast**	**Moderate**	**Advanced ($25/tC)[a]**	**Advanced ($50/tC)[b]**
U.S. Primary Energy Use in Quadrillion Btu (Percent Change from BAU)	84.2 –	94.0 –	110.4 –	106.2 - 106.5 (-4%)	101.0 (-9%)	98.2 - 99.3 (-11% to -10%)
U. S. Energy Bill in Billion 1997$ (Percent Change from BAU)	516 –	552 –	651 –	595 (-9%)	598 (-8%)	634[c] (-3%)
U.S. Carbon Emissions in Million Metric Tons (Percent Change from BAU)	1,346 –	1,480 –	1,769 –	1,679 - 1,684 (-5%)	1,539 (-13%)	1,437 - 1,463 (-19 to -17%)

			2020 Scenarios			
	1990	**1997**	**BAU Forecast**	**Moderate**	**Advanced ($25/tC)[a]**	**Advanced ($50/tC)[b]**
U.S. Primary Energy Use in Quadrillion Btu (Percent Change from BAU)	84.2 –	94.0 –	119.8 –	109.6 - 110.1 (-9% to -8%)	98.8 (-18%)	94.4 - 96.8 (-21% to -19%)
U. S. Energy Bill in Billion 1997$ (Percent Change from BAU)	516 –	552 –	694 –	594 (-14%)	541 (-22%)	572[c] (-18%)
U.S. Carbon Emissions in Million Metric Tons (Percent Change from BAU)	1,346 –	1,480 –	1,922 –	1,730 - 1,740 (-10% to -9%)	1,472 (-23%)	1,307 - 1,347 (-32% to -30%)

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

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

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

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

to allow the reader to better track the results. An uncertainty range for each value would be preferred to our single-point estimates, but the analysis required to prepare such ranges was not possible given the available resources and the process described above.

Energy Use. The Moderate and Advanced scenarios produce reductions in energy use as a result of the many CEF policies that are directed at the adoption of energy-efficient technologies. Efficiency standards play a major role in reducing energy demand in the buildings sector. Voluntary agreements with industries and voluntary labeling and deployment programs are also key to the substantial demand reductions of these scenarios. Such efficiency improvements are generally most economic when it is time to replace existing equipment; they therefore take time to materialize.

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

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

Energy use reductions in the Advanced scenario are more than twice those of the Moderate scenario because of two types of policy changes. First, the policies of the Moderate scenario have been strengthened in the Advanced scenario. For example, RD&D has been further expanded and performance standards in the buildings sector have been applied to more end uses. Secondly, additional policies are applied in the Advanced scenario, including domestic carbon trading, voluntary agreements to improve the fuel economy of light-duty vehicles, and pay-at-the-pump automobile insurance. An off-line analysis of combined heat and power in industry suggests that policies tackling barriers to this technology could increase energy savings by an additional quad in 2010 and by an additional 2.4 quads in 2020.

Carbon Emissions[3]. By 2020, carbon emissions in the Advanced scenario are 30 to 32% lower than in the BAU forecast. These emission reductions are nearly three times those of the Moderate scenario (Figures 1 and 2). This much stronger performance of the Advanced scenario results from the focus of many of its policies on the use of low-carbon energy resources.

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

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

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

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

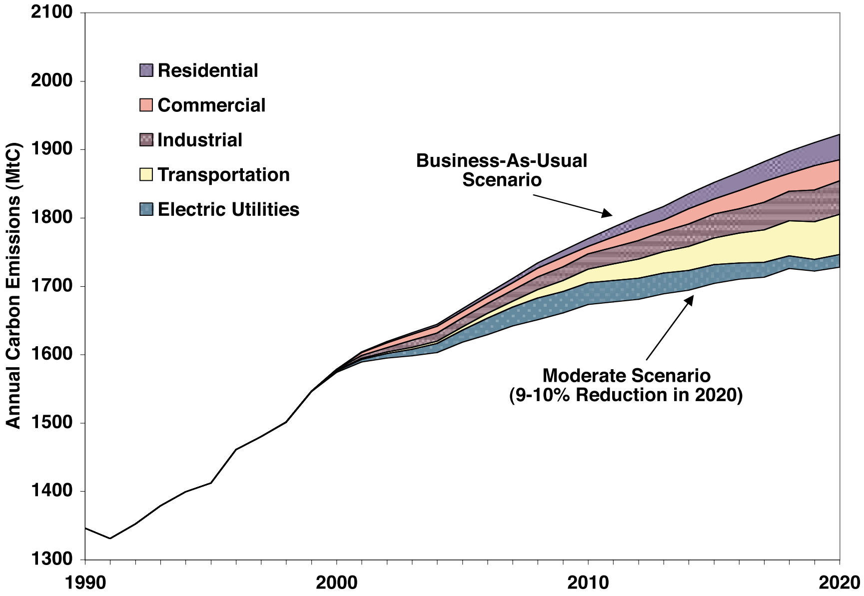
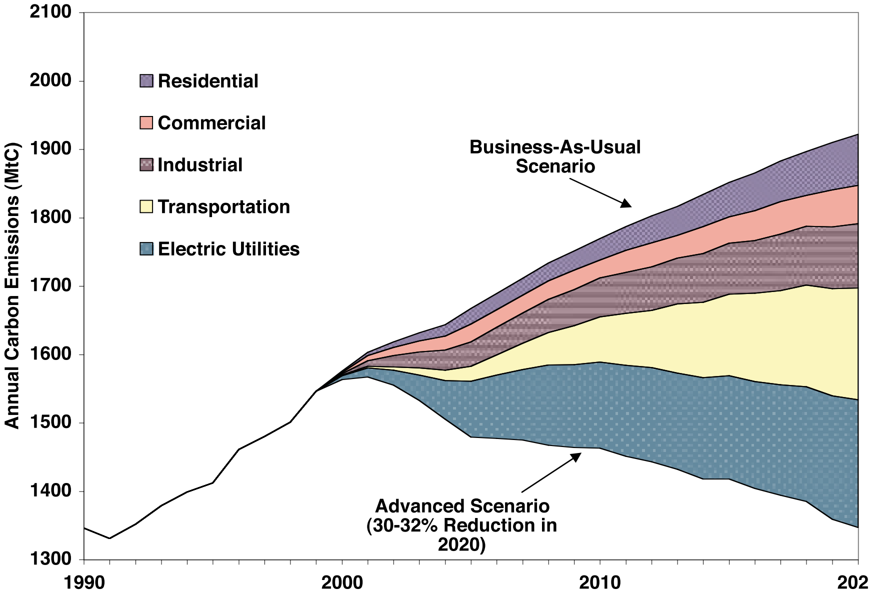


Fig. 2 Carbon Emission Reductions, by Sector, in the Advanced Scenario



Overall, the Moderate scenario brings CO_2 emissions 20% of the way back to 1990 levels by 2010; the Advanced scenario with a carbon permit value of \$25/tC brings them 54% of the way down; and the Advanced scenario at \$50/tC closes 72% of the gap. In the context of the U.S. Kyoto Protocol goal of reducing greenhouse gas emissions to 7% below 1990 levels by 2010, the CEF policies would need to be supplemented by other means such as international carbon trading, reductions in other greenhouse gases, and/or stronger domestic policies. In the Advanced scenario, carbon emissions drop fully to 1990 levels by the year 2020.

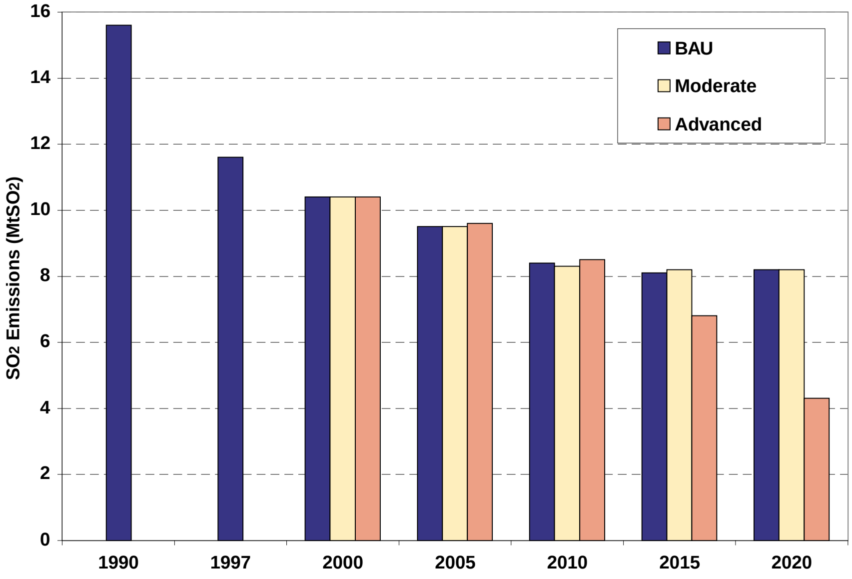
Costs and Benefits. In both the Moderate and Advanced scenarios and in both timeframes (2010 and 2020), the nation pays less for its energy than in the BAU forecast. This is largely due to the accelerated development and deployment of energy-efficient technologies that reduce primary energy use. In 2010,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

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

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

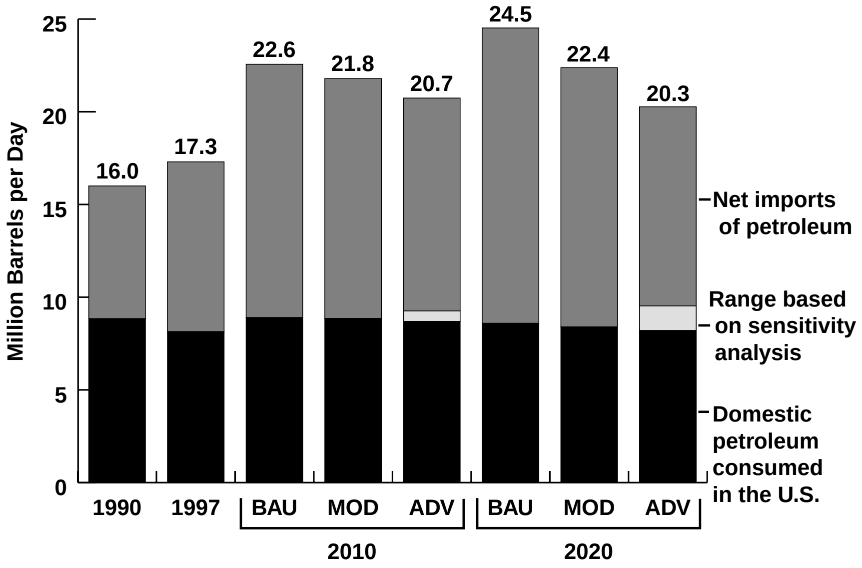
The impacts summarized above do not reflect several important other benefits: reduced vulnerability to oil supply disruptions, cleaner air, and improved balance of payments. For example, in the Advanced scenario, in 2020:

Fig. 3 SO_2 Emission Reductions in the Electric Sector



- SO_2 emissions from the electric sector decline from 8.2 million metric tons in the BAU forecast to 4.1 million metric tons in the Advanced scenario, resulting in substantial environmental and health benefits (see Fig. 3).

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



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

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

As is true of any study that estimates future impacts of technology and policy, these scenarios have many uncertainties. The first concerns RD&D. On one hand, the Advanced scenario depends on technologies not currently available or cost-effective. For instance, substantial progress toward more efficient vehicles is assumed, as well as important evolutionary improvements in renewable and fossil-fueled electricity technologies. The degree of success for RD&D is inherently uncertain, however, and it is not possible to be sure that the results would turn out as estimated. On the other hand, the broad portfolio of technologies adds to the robustness of the results and, conceivably, the Advanced policies could lead to greater technical progress than assumed. The second major uncertainty is in the effectiveness, benefits, and costs of policies. This is closely tied to the success of RD&D. If efficient and clean energy technologies become increasingly cost-effective, then the policies driving them to market in the Advanced scenario are much easier to pursue and much more likely to generate net economic gains.

LONG-TERM AND GLOBAL CONTEXT

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

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

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

SUMMARY

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

Chapter 1

INTEGRATED ANALYSIS AND CONCLUSIONS[1]

This report presents results of a study of the potential for efficient and clean energy technologies to address a number of energy-related challenges facing the United States. These challenges include global climate change, air pollution, oil supply vulnerability, energy price volatility, and inefficiencies in energy production and 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 of the nation's energy system, while decreasing its carbon and pollution content. Conducted by researchers from five U.S. Department of Energy national laboratories[2], this study makes a strong case for the value of energy technology research, development, demonstration, and deployment as an effective public response. The study identifies specific public policies and government efforts that could foster solutions with positive economic impact.

1.1 STUDY OBJECTIVES

The principal goal of this study is to produce well-documented scenarios 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;
- the vulnerability of U.S. oil supply and price volatility associated with the continued concentration of oil supplies in politically unstable parts of the world; and
- the existence of inefficiencies in energy production and end-use systems[3].

While cognizant of all of the above challenges, *Scenarios for a Clean Energy Future* (aka, the CEF study) concentrates primarily upon the challenge of global climate change – 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, heating, refrigeration, mobility, and industrial processes). Using the framework of the 11-Lab study (DOE National Laboratory Directors, 1998), these technologies include:

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[1] Authors: Marilyn A. Brown, Oak Ridge National Laboratory (ORNL), Mark D. Levine, Lawrence Berkeley National Laboratory (LBNL), and Walter Short, National Renewable Energy Laboratory (NREL). Jonathan Koomey and Cooper Richey (LBNL) and Marilyn Brown and Stan Hadley (ORNL) produced the integrating cost calculations reported in this chapter.

[2] The five national laboratories 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, natural gas, and more efficient fossil-fueled electricity plants), and
- measures that integrate carbon sequestration into the energy production and delivery system (e.g., integrated gasification combined cycle plants with carbon separation and storage).

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

Overview of the Report

Chapter 2 provides introductory and background material, including an overview of recent energy and CO_2 emission trends, an explanation of the energy efficiency paradox, an explanation for the government role, and an overview of several past energy policy and program successes. Chapter 3 describes the analysis methodology employed in this study.

Chapters 4 through 7 address each of the major energy sectors: buildings (Chapter 4), industry (Chapter 5), transportation (Chapter 6), and electricity (Chapter 7). The following topics are covered in each of these chapters:

- the sector's current energy technology and fuel characteristics;
- the business-as-usual forecast for the years 2010 and 2020, including the amounts and types of forecast energy requirements and production;
- barriers to accelerated use of clean energy systems;
- public policies and programs that could address these barriers;
- the methodology employed to analyze these policies;
- the analysis results, including a description of key technologies, policies, end-uses, and energy resources; and
- remaining analysis needs.

Chapter 8 looks beyond 2020 at the longer-term, global context. This broader scope ensures that our near- to mid-term scenarios are responsive to anticipated, long-term energy needs, technology developments, and market opportunities, while also reflecting the increase in uncertainty that characterizes 50-year planning.

Additional details on the study can be found in the appendices. Appendix A itemizes the alterations made to the Energy Information Administration's National Energy Modeling System (NEMS) to create the CEF-NEMS. Appendix B provides details on the policy implementation pathways, including timing and magnitudes, how the policy was modeled, an explanation of key assumptions, and citations to key references justifying the assumptions, modeling approach, and inputs. Appendix C presents key technology assumptions used in the modeling, and Appendix D presents detailed results. Appendix E describes several ancillary analyses. These appendices are available at:
http://www.ornl.gov/ORNL/Energy_Eff/CEF.htm

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 one potential path for energy-efficient and low-carbon technologies to reduce carbon emissions in the United States to their 1990 levels by the year 2010. Key sectors of the economy were examined independently: buildings, transportation, industry, and electric generators. Specifically, the report identified one 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 this technology set, the resulting reduction in energy costs would be roughly equal to or exceed the direct costs of implementing the technologies[4].

Unlike the Five-Lab study, the current study identifies specific policies and programs needed to motivate consumers and businesses to purchase the technologies that make up its scenario. 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 cleaner 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 (Koomey, 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 grows, natural gas prices would rise, and some switching to other fuels would result. Through the integration process, such interactions are 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 quantitatively to 2020 and qualitatively to 2050 – and they address an array of multiple challenges, not just global climate change. By documenting the benefits that efficient and clean energy technologies can deliver in the short term and by characterizing the potential of emerging technologies, the CEF report informs a broad range of readers about policy-driven, technology-based approaches to reducing greenhouse gas emissions and addressing other energy-related challenges.

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

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[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] Koomey, 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.

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 policies that address energy-related challenges. Scenarios are stories of how the future might unfold; they are not predictions. They are useful for organizing scientific insight, gauging emerging trends, and considering alternative possibilities. A range of assessment methods, analytic tools, and expert judgement is used to analyze the impacts of individual policies. The CEF-NEMS model is then employed to integrate the impacts of each scenario's set of policies. Macroeconomic impacts and feedback are assessed through 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 are defined by policies that are consistent with increasing levels of public commitment and political resolve to solving the nation's energy-related challenges. Some of the public policies and programs that define the scenarios are cross-cutting; others are designed individually for each sector (buildings, industry, transportation, and electric generators) and assessed for impacts out to 2020. Numerous policies are examined, including fiscal incentives, voluntary programs, regulations, and research and development.

The CEF scenarios are quantitatively assessed as a package in terms of both benefits and costs projected out to 2020. The benefits include lower greenhouse gas emissions, reduced local air pollution, reduced oil imports, and energy savings from more efficient energy production and use. The costs include the necessary private-sector investment in efficiency and low-carbon technologies, the cost of implementing federal programs designed to encourage such technologies, and 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. This 20-year domestic focus 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, an array of additional technology options are qualitatively described. With successful research, these options could provide additional pathways to address global energy-related challenges through 2050. These include carbon sequestration, novel nuclear reactor designs, advanced gas and chemical separation technologies, fuel cell/turbine hybrids, and a host of efficient and renewable energy technologies. 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 and in the near-term.

1.2.2 Treatment of Uncertainties

The use of scenarios in this study addresses one key uncertainty – the public response to the nation's energy-related challenges. However, additional uncertainties are associated with any study that estimates future impacts of technology and policy. Principal among these is the assumed cost and performance of technologies that are under development. Uncertainties also arise from 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 portray 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 revolutionary technology- and market-driven developments, the CEF characterization of policy impacts over the next 20 years may be off target. However, given the time required for breakthrough technologies to penetrate the market – partly due to the longevity of equipment and infrastructure already in place – it is unlikely that yet-to-be-discovered technologies could have a major impact on the U.S. energy system during the 20-year modeling period.

All scenario-building exercises run the risk of unanticipated breakthroughs. History has experienced numerous transformations that were unanticipated by qualified planners. For instance, energy analysts in the 1970s failed to predict America's massive shift to sports utility vehicles in the 1990s – a shift that interrupted the post-oil embargo’s decade of steady gains in automobile efficiency. Similarly, electricity analysts in the 1970s 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 – a shift that transformed the electricity industry.

We may also have failed to fully reflect transformational trends that are already under way. 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. On the one hand, Romm (1999, p. 9) argues that e-commerce could lead to significant reductions in the demand for energy services: “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.” Others argue that the explosion of Internet usage and e-commerce could increase demand for energy services.

Despite such potential omissions, the CEF study undertakes 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 or petroleum prices rise substantially 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 preferences: e.g., what if the only acceptable new policy is a domestic carbon trading system?

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 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.

One 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, methods, results, and 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, in our opinions, to the conclusions drawn. While the authors of this report have a range of views about the results, they believe that with sufficient commitment, the United States could achieve a substantial portion of the future portrayed by the Advanced Scenario.

1.3 POLICY IMPLEMENTATION PATHWAYS

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

As noted, the analysis focuses on three scenarios: BAU, 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 the Energy Information Administration (EIA) and published in the *Annual Energy Outlook 1999* (EIA, 1998a). 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.

Many of the policies were selected on the basis of their potential to reduce carbon emissions. Others were designed specifically for air quality (e.g., reducing SO_2 emissions in the electric sector), oil security (e.g., alternative fuels R&D), and economic efficiency (e.g., restructuring of the electric sector). 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. Two key differences for all of the sectors is the addition of a domestic carbon trading system to the Advanced scenario and increased R&D resources in both the Moderate and Advanced scenarios.

- **Domestic carbon trading system.** Emissions trading programs work by allocating allowances that permit the release of limited quantities of emissions during a specified period (e.g., annually). They allow sources to comply with the cap by reducing emissions or purchasing permits from other sources that can reduce emissions at lower cost. A firm's response will depend on its costs of control compared with the market price of carbon permits.

We assume that the domestic carbon trading program is announced in 2002 and is implemented in 2005[7]. 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[8]. (A $25/tC case is also analyzed.) The federal government collects the carbon permit revenues and transfers them back to the public. The idea of the carbon permit rebate is to leave people's "incomes" intact while changing the relative price of carbon-based fuels.

- **Increased R&D resources.** The Moderate scenario assumes a 50% increase in federal government appropriations for cost-shared research, development, and demonstration (RD&D) in efficient and clean-energy technologies. The increase is based on an assumed baseline of $1.4 billion in current federal energy R&D. This baseline, and the assumed increase includes research on energy-efficient end-use technologies as well as power generation technologies using renewable resources, natural gas, coal, and nuclear energy[9]. Since these resources are spent in public/private RD&D partnerships, they are matched by private-sector funds. The increase is assumed to be implemented gradually between 2000 and 2005, and to continue through 2020.

  The Advanced scenario assumes that the federal government doubles its appropriations for cost-shared RD&D, resulting in an increase of $2.8 billion per year (half as federal appropriations and half as private-sector cost share). Both scenarios assume a careful targeting of funds to critical research areas and a gradual, 5-year ramp-up of funds to allow for careful planning, assembly of research teams, and expansion of existing teams and facilities.

A set of guidelines was developed for selecting policies for each sector and scenario. These are described in Chapter 3. More than 50 policies are modeled; therefore, it is not possible to estimate the impacts of each policy in isolation. As a result, we focus on scenarios that involve collections of policies, tailored to meet the needs of each sector.

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; and expanded R&D. They also include tax credits consistent with the Clinton Administration's 1999 Climate Change Technology Initiative (CCTI); continuation of market transformation programs such as Rebuild America and Energy Star labeling; and related public benefits programs financed by electricity line charges.

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

[8] $50 per tonne of carbon corresponds to 12.5 cents per gallon of gasoline or 0.5 cents per kWh for electricity produced from natural gas at 53% efficiency (or 1.3 cents per kWh for coal at 34% efficiency). $25/tC corresponds to half these incremental costs.

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

Table 1.1 Illustrative Buildings Sector Policies, By Scenario

Moderate Scenario	Advanced Scenario
➢ Expand voluntary labeling and deployment programs such as Energy Star, Building America, and Rebuild America to increase the penetration of efficient technologies in the market	➢ Enhanced programs, more end-uses covered, and more penetration
➢ Implement new efficiency standards for equipment, beyond those already planned	➢ More end-uses covered by standards; another round of standards for some products
➢ 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
➢ 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[a]	➢ 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 trading system with assumed permit price of $50 per metric ton of carbon, announced in 2002 and implemented in 2005

[a] Unlike other policies enumerated here, we do not explicitly model government procurement policy in this analysis. However, we recognize it here as an important and strategic enabling policy that is essential for the voluntary programs to achieve their estimated penetration levels.

For industry, the pathways include voluntary agreements with industry groups to achieve defined energy efficiency and emissions goals, combined with a variety of government programs that strongly support such agreements. These programs, 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.

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 BAU scenario	➢ Build upon existing voluntary sector agreements with associations and companies to achieve an energy efficiency improvement of 1.0% per year over the BAU 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 1,600 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 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 trading system with assumed permit price of $50 per metric ton of carbon, announced in 2002 and implemented in 2005.

For transportation, the scenarios result from a combination of financial incentives for efficient automobiles (“golden carrots”), strengthened R&D, several government programs, and voluntary energy efficiency targets for light-duty vehicles. The pay-at-the-pump automobile insurance program involves paying for a portion of automobile insurance by means of an added fee to gasoline, thereby “variabilizing” the cost of insurance to reflect miles traveled. Thus, the increase in the price of gasoline is somewhat offset by lower insurance premiums (depending on how much one travels).

Table 1.3 Illustrative Transportation Sector Policies, by Scenario*

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 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 (paid for by adding 34¢ per gallon of gasoline in 2010 and 51¢ per gallon in 2020)
	➢ Intelligent traffic systems controls, including intelligent roadway signing, staggered freeway entry and electronic toll collection
	➢ Domestic carbon trading system with assumed permit price of $50 per metric ton of carbon, announced in 2002 and implemented in 2005

*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.

[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.

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

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 trading system with assumed permit price of $50 per metric ton of carbon, announced in 2002 and implemented in 2005

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 are less stringent than the policies modeled in other studies (e.g., Geller, Bernow, and Dougherty, 1999; Tellus Institute, 1998). Examples include the higher levels of efficiency for appliances and the larger annual reductions in energy intensity for industrial plants specified by Geller, et al. (1999). Policies aimed at reducing vehicle miles of travel (vmt) were not included, because the BAU forecast already includes a vmt growth rate that our reviews indicated are unrealistically low (Appendix E-2). Finally, numerous policies examined in other studies are omitted, because they were considered to exceed the levels of action or cost that were used as guidelines to define the Moderate and Advanced scenarios. Examples of policies **not** included are:

- **Buildings:** mandate the demand-side management programs run by electric utility companies in the 1980s and first half of the 1990s, which were responsible for a substantial fraction of the energy efficiency improvements already realized in the buildings sector.

- **Industry:** establish tax incentives for new capital investments in energy equipment to accelerate the rate at which technological innovation diffuses into industries, thereby more quickly retiring outmoded and inefficient production equipment and facilities.
- **Transportation:** enact greenhouse gas standards for motor fuels that would be specified as a limit on the average greenhouse gas emissions factor of all motor fuels.
- **Electricity:** require all coal-fired power plants to meet the same emissions standards as new plants under the Clean Air Act, thereby removing the "grandfathering" clause that has allowed higher polluting, older coal-fired plants to continue to operate unabated.

Clearly, inclusion of such policies would result in accelerated progress toward meeting the nation's energy and environmental goals. Thus, if the nation requires acceleration, these other studies could 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, 1998a). 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, the BAU forecast 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 (or 125,000 gallons of gasoline) 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, without change, 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[a]	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.

[a]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 three changes. First, the BAU forecast assumes lower nuclear power relicensing costs than the EIA 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. 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 AEO99 Reference case, resulting in a slower rate of growth in the CO_2 emitted per kWh. Carbon emissions in the BAU scenario are almost 1% less in 2010 and are 3% less in 2020 than in the EIA 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 Gross Domestic Product (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, carbon reductions, key policies and technologies, and 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 Fig. 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.

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 two quads saved in this scenario in the residential sector in 2020 is enough to meet the current annual home energy needs of 11 million households. The 2.7 quads of energy saved in the transportation sector in 2020 is equivalent to the energy needed to fuel 44 million of today's cars for a year.

Despite these energy savings, 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. Energy use in 2020 decreases to 97 quads, just 3% above 1997 levels and 15% above the 84 quads consumed in 1990. This energy savings of 23 quads in 2020 is enough to meet the current energy needs of all the citizens, businesses, and industries located in the top three energy consuming states (Texas, California, and Ohio) or the combined current energy needs of the 30 lowest consuming states.

An off-line analysis of combined heat and power in industry suggests that policies tackling barriers to this technology could increase energy savings by an additional 5 to 10%. Specifically, energy consumption is estimated to decrease by a further 0.3 quads in the Moderate scenario in 2010 and by an additional 0.5 quads in 2020. In the Advanced case, the potential additional reduction from CHP policies is estimated to be considerably larger: 1.1 quads in 2010 and 2.4 quads in 2020.

Table 1.6 Primary Energy by Sector (quadrillion Btu)*

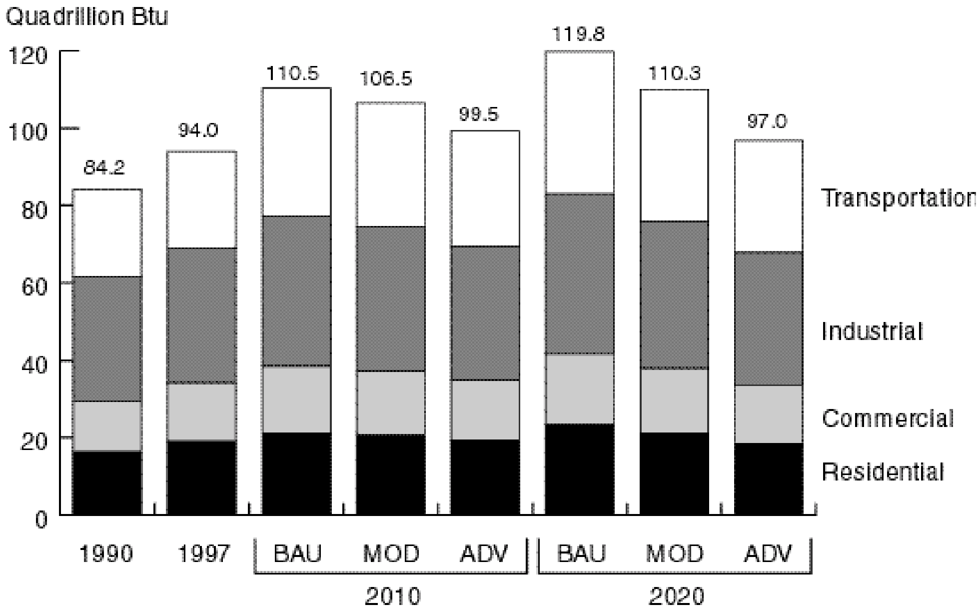
			2010			2020		
	1990	1997	BAU	Mod.	Adv.	BAU	Mod.	Adv.
Residential	16.3	19.0	21.2	20.4 (-4%)	19.3 (-9%)	23.2	21.1 (-9%)	18.3 (-20%)
Commercial	13.1	15.2	17.3	16.7 (-3%)	15.9 (-9%)	18.5	17.0 (-9%)	15.4 (-18%)
Industrial	32.2	34.8	38.8	37.2 (-4%)	34.7 (-11%)	41.2	38.0 (-8%)	34.3 (-17%)
Transportation	22.6	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[a]	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, including combined heat and power (CHP), solar domestic hot water heaters, and fossil fueled on-site generation in buildings. An off-line analysis suggests that policies tackling barriers to CHP in industry could reduce energy consumption by an additional 0.3 quads in the Moderate scenario in 2010 and by an additional 0.5 quads in 2020. The energy saved by new CHP systems in the Advanced case are estimated to be considerably larger: 1.1 quads in 2010 and 2.4 quads in 2020.

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

Fig. 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 and Fig. 1.2 show the energy consumption by fuel type for the BAU, Moderate, and Advanced scenarios. This table includes several notable observations.

Table 1.7 Energy Consumption by Source (quadrillion Btu)*

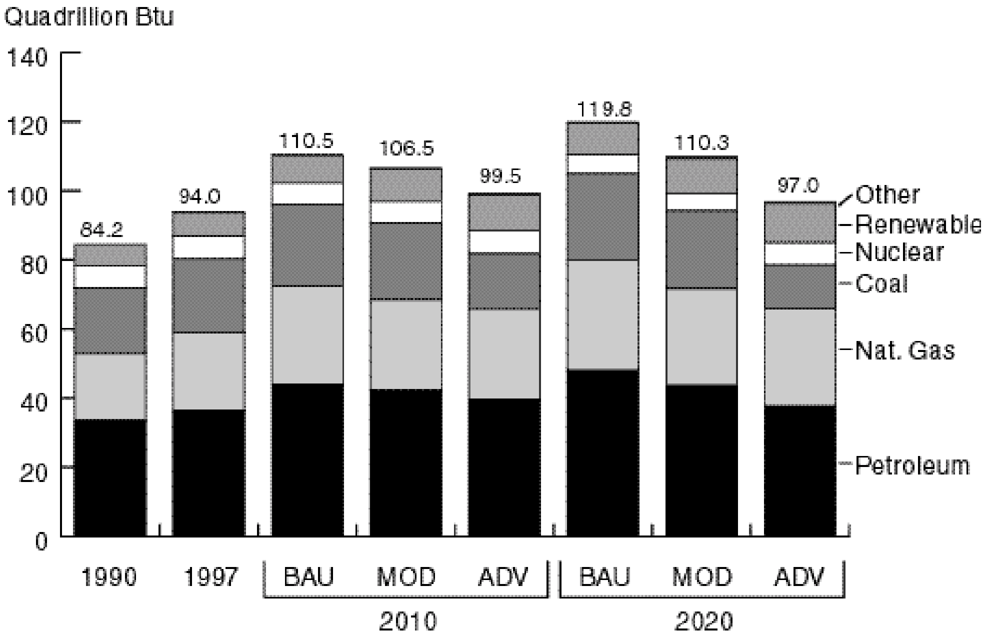
			2010			2020		
	1990	1997	BAU	Mod.	Adv.	BAU	Mod.	Adv.
Petroleum	33.6	36.5	44.1	42.5 (-4%)	39.7 (-10%)	47.9	43.7 (-9%)	37.8 (-21%)
Natural Gas	19.3	22.6	28.3	26.1 (-8%)	26.2 (-7%)	32.1	28.1 (-12%)	28.2 (-12%)
Coal	19.1	21.1	23.7	22.6 (-5%)	16.3 (-31%)	25.0	23.0 (-8%)	12.7 (-49%)
Nuclear Power	6.2	6.7	6.2	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[a]	0.3	0.3	0.4	0.5 (25%)	0.4 (0%)	0.4	0.6 (50%)	0.6 (50%)
Total	84.1	94.0	110.5	106.5 (-4%)	99.5 (-10%)	119.8	110.3 (-8%)	97.0 (-19%)

Note: BAU = Business-As-Usual; Mod. = Moderate; Adv.= Advanced. Numbers in parentheses represent the percentage change compared with BAU.

*The off-line analysis of CHP policies suggests that increased CHP in industry would result in the following adjustments to the above Moderate and Advanced scenario results, both in 2010 and 2020. It would increase natural gas consumption, decrease petroleum-based industrial boiler fuels, decrease coal in both the electricity and industrial sectors, and slow the growth of wind and biopower, especially in the Advanced Scenario in 2020.

[a] Other sources include methanol and liquid hydrogen.

Fig. 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 and for explanatory footnotes

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 permit price, 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, increased use of renewable energy, and 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).

The off-line analysis of CHP policies suggests that increased CHP in industry would result in the following adjustments to the scenario results, both in 2010 and 2020. It would increase natural gas consumption, decrease petroleum-based industrial boiler fuels, decrease coal in both the electricity and industrial sectors, and slow the growth of wind and biopower, especially in the Advanced Scenario in 2020.

1.4.3 Carbon Emissions Reductions of the Policy Scenarios

Table 1.8 and Fig. 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 timeframes, carbon emissions are considerably higher than in 1990 or 1997.

In contrast, the Advanced scenario – with its more aggressive demand- and supply-side policies, and with a domestic carbon trading system – 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. An off-line analysis of combined heat and power in industry suggests that policies tackling barriers to this technology could reduce carbon dioxide emissions by an additional 5 to 8%. In the Moderate scenario they would reduce emissions by an additional 5 MtC in 2010 and 10 MtC in 2020; in the Advanced scenario they would reduce emissions by an additional 26 MtC in 2010 and 40 MtC in 2020.

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

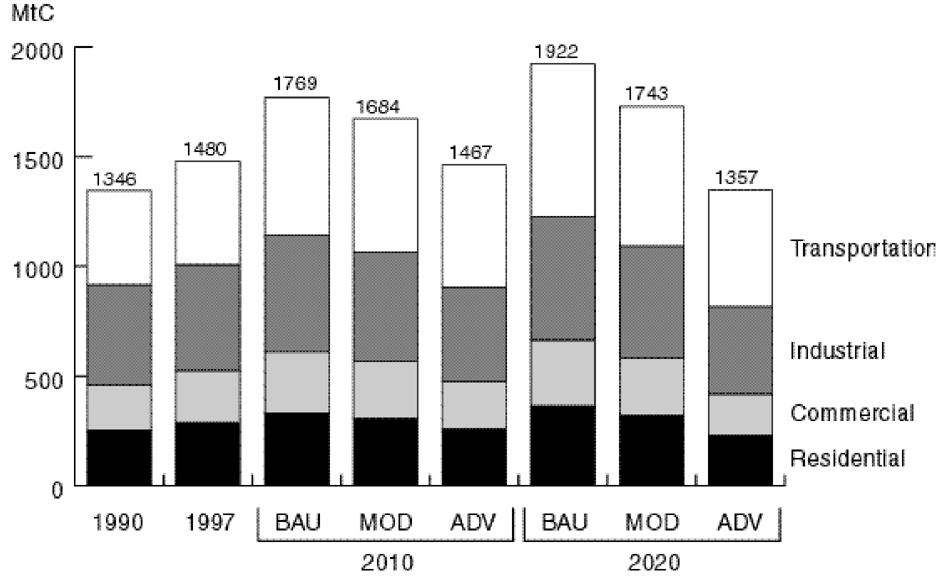
			2010			**2020**		
	1990	1997	BAU	Mod.	Adv.	BAU	Mod.	Adv.
Residential	253	287	330	311 (-6%)	260 (-21%)	363	323 (-11%)	230 (-37%)
Commercial	207	237	280	263 (-6%)	218 (-22%)	300	271 (-10%)	195 (-35%)
Industrial	454	483	534	505 (-5%)	429 (-20%)	563	511 (-9%)	399 (-29%)
Transportation	432	473	626	606 (-3%)	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.

*An off-line analysis of CHP in industry suggests that policies tackling barriers to this technology could decrease carbon emissions by an additional 6 to 9%.

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

Fig. 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 (-1%)	14.7 (-8%)	16.0	15.8 (-1%)	14.0 (-13%)
Electricity Only: gC/kWh[a] (Note: 1990=167; 1997=172)	164	159 (-3%)	131 (-20%)	160	161 (1%)	109 (-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 MtC)[b]		62	175		152	366
Carbon Reductions due to Lower Carbon Intensity (in MtC)		23	127		27	199
Total Carbon Reductions (in MtC)		85	302		179	565

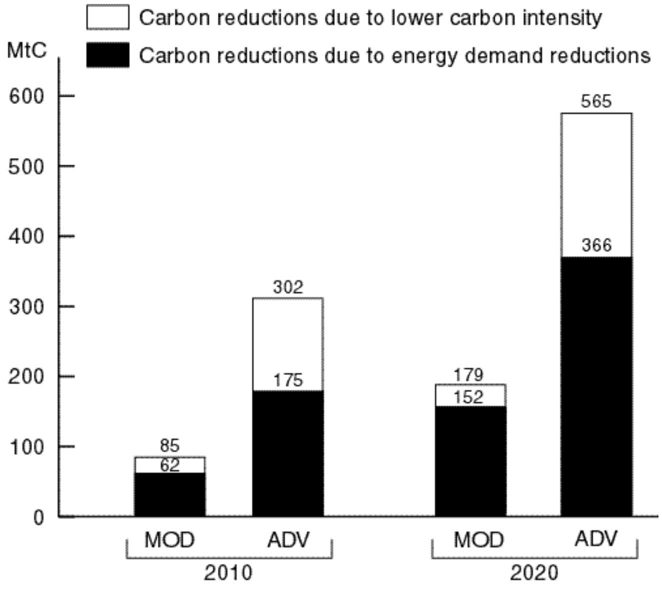
Note: BAU = Business-As-Usual; Mod. = Moderate; Adv. = Advanced. Numbers in parentheses represent the percentage change compared with BAU.

*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), solar domestic hot water heaters, and fossil fueled on-site generation in buildings. An off-line analysis of CHP in industry suggests that policies tackling barriers to this technology would decrease carbon emissions in both scenarios. In the Moderate scenario they would reduce emissions by an additional 5 MtC in 2010 and 10 MtC in 2020, and in the Advanced scenario by an additional 26 MtC in 2010 and 40 MtCin 2020.

[a] Excludes electricity cogeneration.

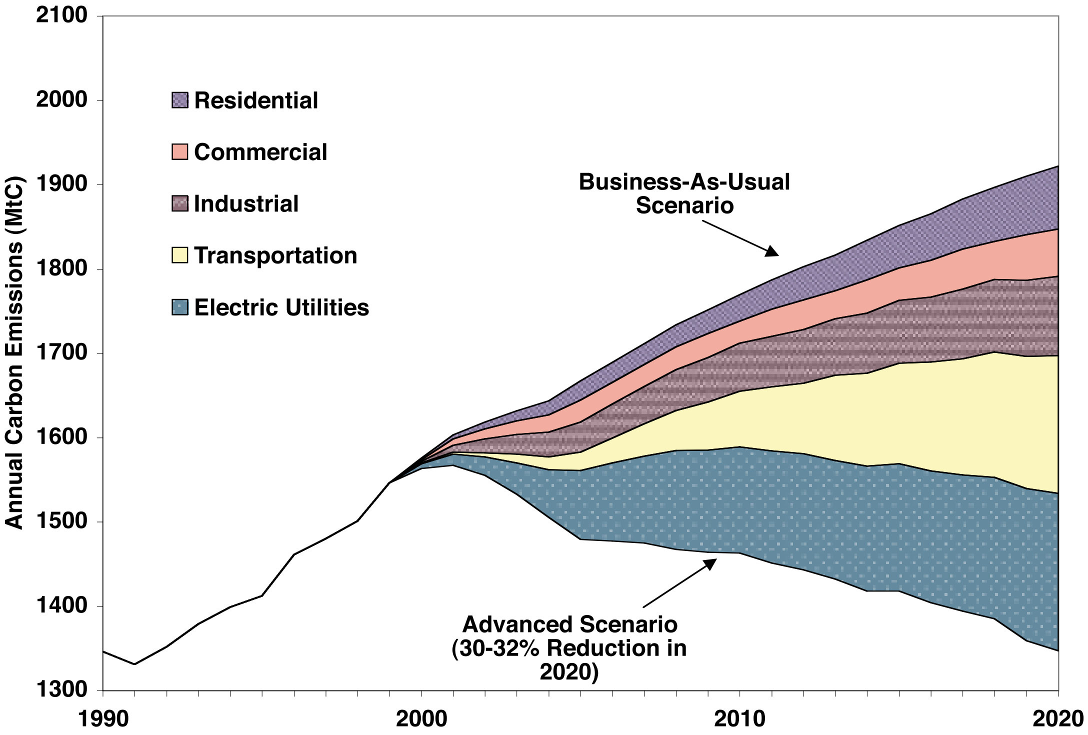
[b] Calculated as (A)/(B) times total carbon reductions.

Fig. 1.4 Allocation of 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 from 1997 intensities 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 Fig. 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.

Fig. 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 Fig. 1.5).

Much of the difference in carbon emissions between the two scenarios is caused by the policies in the Advanced scenario, including carbon trading, 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 Fig. 1.6).

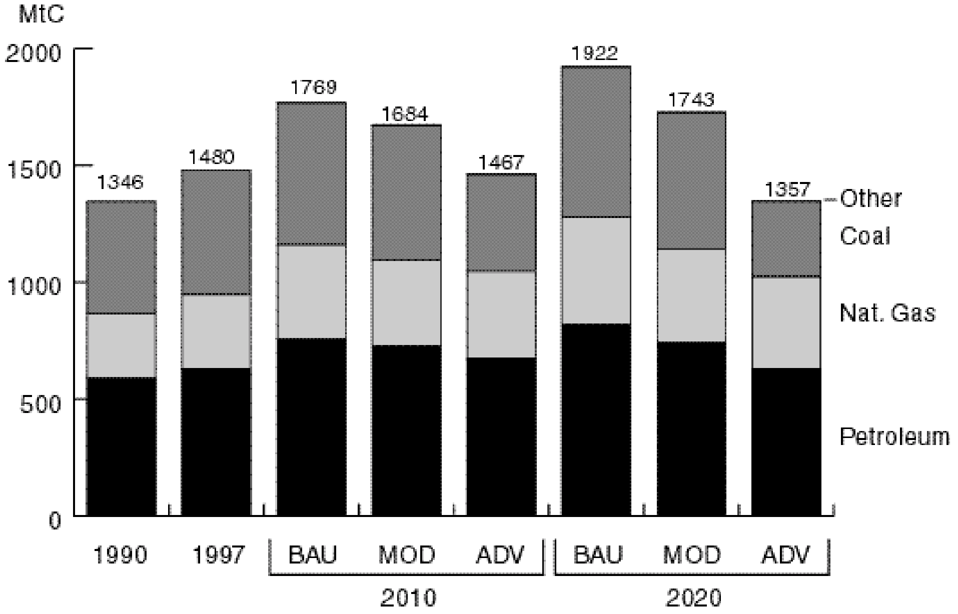
Table 1.10 Carbon Emissions from Fossil Energy Consumption, by Source (MtC)

			2010			2020		
	1990	1997	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[a]	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.

[a] Other sources include methanol and liquid hydrogen.

Fig. 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 trading system and the doubling of federal RD&D appropriations. The importance of the carbon trading system is documented in the sensitivity analysis described in Section 1.5. The importance of expanded R&D is illustrated in Table 1.11.

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	**Iron and Steel Technologies:** Development of near net shape casting technologies saves up to 4 MBtu/ton steel and reduces production costs between \$20 and \$40/ton Smelt reduction starts 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
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	**Pulp and Paper Technologies:** R&D produces 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 is 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 NO_x standards in 2004	**Natural Gas Combined Cycle:** R&D reduces capital costs from the BAU forecast of \$405/kW to \$348/kW for the 5th of a kind plant; carbon sequestration adds \$4/MWh
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	**Wind:** R&D reduces capital costs from \$778/kW throughout the period in the BAU down to \$611/kW in 2016; fixed O&M costs decline from \$25.9/kW-yr throughout the period in the BAU down to \$16.4/kW-yr in 2020

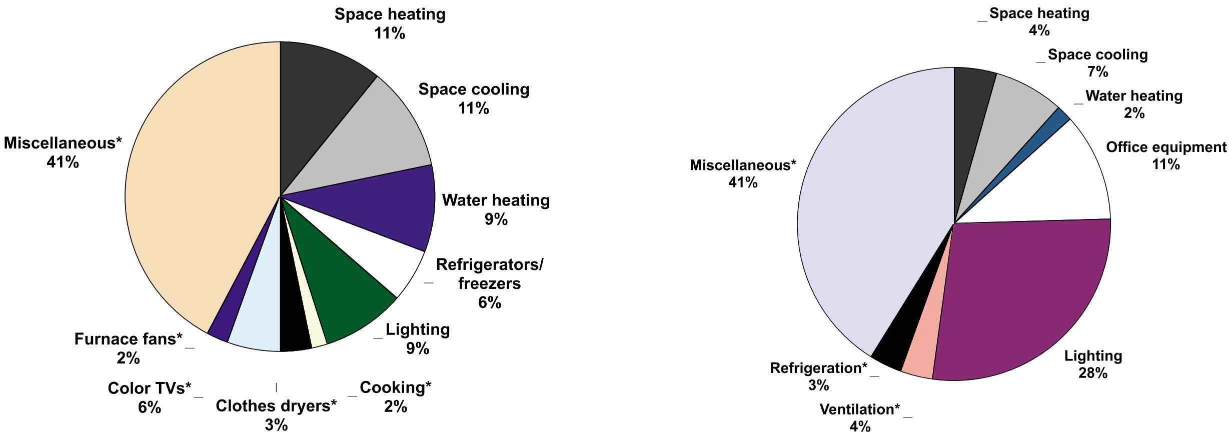
Buildings. The largest energy and carbon savings in residential buildings occur in the category "all other" uses (including cooking, clothes dryers, clothes washers, dishwashers, color TVs, and personal computers – see Fig. 1.7). A large fraction of these savings comes from movement toward a "one-watt" standby loss goal by 2010, based on the switch-mode power supplies that are now widely used in the best new equipment. Next in rank order are space cooling, space heating, water heating, and lighting.

In commercial buildings, lighting and "all other" end-uses dominate the energy and carbon savings. "All other" in the commercial sector includes a collection of small end-uses that are explicitly represented in CEF-NEMS, including ventilation, cooking, and refrigeration, as well as other unidentified uses.

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.

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



Residential Buildings

Constituents of the “All other” category shown in Tables 4.8 and 4.9 are marked with asterisks above. “Miscellaneous uses” include clothes washers, dishwashers, other home electronics, ceiling fans, pool pumps, and other unidentified end-uses.

Commercial Buildings

Constituents of the “All other” category shown in Tables 4.8 and 4.9 are marked with asterisks above. “Miscellaneous uses” include transformers, traffic lights, exit signs, cooking, district services, automated teller machines, telecommunications equipment, medical equipment, and other unidentified end-uses.

Note: Carbon savings from electrical end-uses include both demand-side efficiency and supply-side effects.

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).

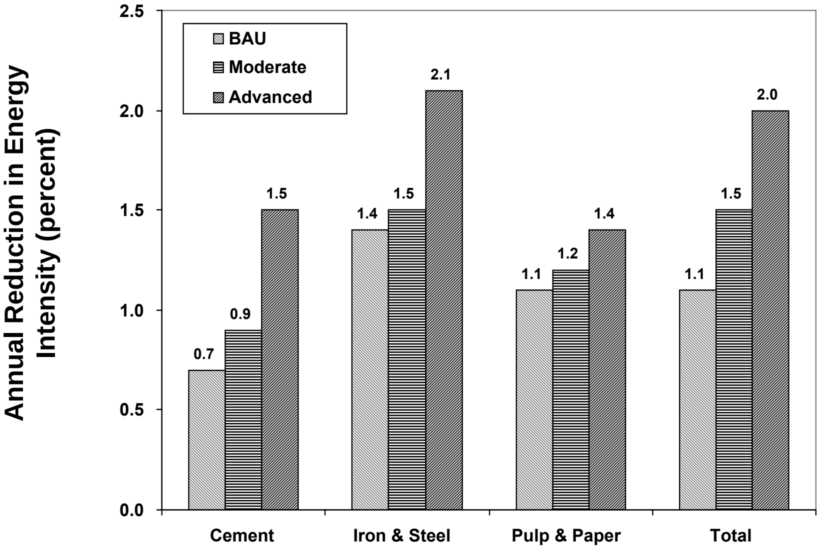
Voluntary agreements between government and industry are the key policy mechanism for achieving these savings. The following policies and programs support the voluntary agreements:

- information programs,
- technology demonstrations,
- energy efficiency audit programs,
- financial incentives, and
- funding for R&D.

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

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

Fig. 1.8 Annual Reductions in Energy Intensity in the Industrial Sector



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

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

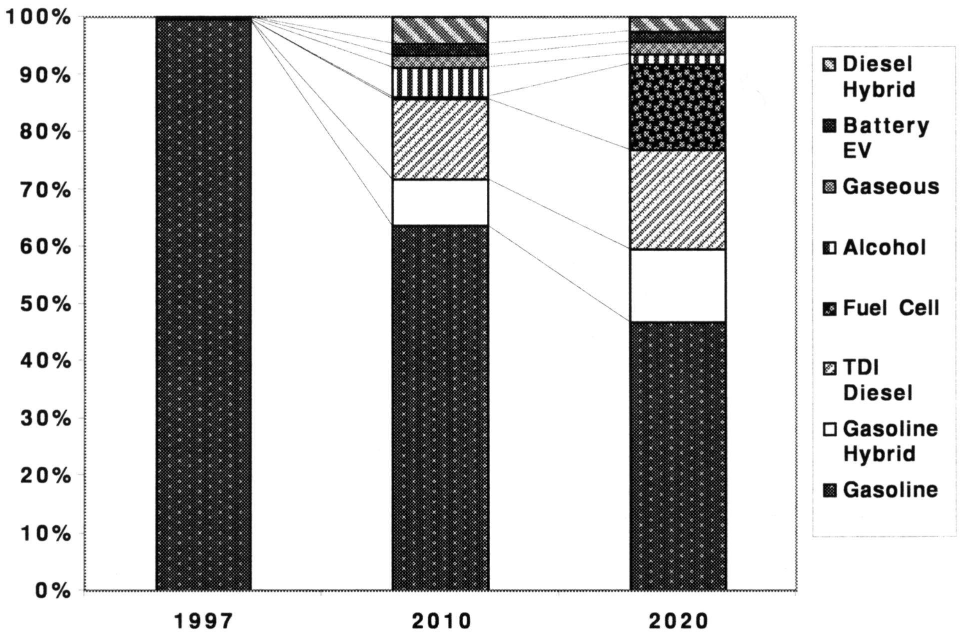
In the Moderate scenario, a combination of several conventional technologies and the turbo-charged direct injection (TDI) diesel have the greatest impact on passenger car and light-truck fuel economy. Even with incentives of up to $4,000 per vehicle, advanced alternative technologies appear to be unable 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:

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

The combined effect of these measures is an array of impressive new technologies in large numbers (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, 3.9 million hydrogen fuel cell vehicles are on the road consuming 0.1 quads of hydrogen annually. Advanced technologies also improve fuel economy significantly in non-highway transport.

Fig. 1.9 Advanced Scenario New Light-Duty Vehicle Sales



Energy efficiency is also improved by restraining the large forecasted growth in vehicle horsepower (hp). In 1998, the average hp of new passenger cars sold in the United States was 155. In the BAU case, passenger car hp increases to 251 by 2020. Light truck horsepower increases even more, from 189 in 1998 to 293 in 2020. The Advanced scenario foresees much more modest increases, to 174 hp for cars and 199 hp for light trucks. 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 trading system in the Advanced scenario. The resulting carbon permit price:

- makes the building of new coal plants cost-ineffective and increases the retirement of coal and other fossil steam plants between 1997 and 2020 – from 66 GW in the BAU scenario to 187 GW in the Advanced scenario,
- impacts the variable cost of production, causing the remaining carbon-intensive technologies to lower their capacity, and
- encourages extension of the life of existing nuclear plants and development of non-hydro renewables, especially wind and biomass.

Restructuring also plays a significant role. By removing incentives for regulated utilities to retain capital investments that are no longer cost-effective, deregulation encourages the retirement of inefficient plants when new plants represent a more cost-effective option. A somewhat contrary impact is that restructuring promotes real-time pricing and customer shifts in peak load requirements. This lowers the need for additional capacity as existing plants operate more fully, which in turn reduces the need to build new, cleaner plants that displace older plants. In the Advanced scenario, while 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 permit penalty on other technologies and advances in technology. This 18-fold increase would require an unprecedented growth in production capacity of suppliers of wind generation equipment. In the Moderate scenario, with its shorter schedule for the PTC and no RPS or carbon permit price, wind quadruples by the time the PTC 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 permits. Without technology improvements, low- and non-carbon supplies are more expensive and less likely to displace current inefficient and carbon-intensive sources. Technology advances alone are generally insufficient to impact the overall carbon intensity of the production, but they are powerful in conjunction with the carbon permit price. In the BAU scenario, the carbon intensity by 2020 is 160 gC/kWh. The Moderate scenario, with only modest improvements in fossil technology efficiencies and lower demand growth, actually has 2.3% higher carbon intensity; lower demand means fewer opportunities to build low-carbon systems. Also, with no carbon permit price, there is little incentive to reduce carbon emissions. The Advanced scenario has higher fossil efficiencies but lower demand still. When the Advanced scenario was modeled without a $50/tC permit price, carbon intensity declined by 3% from BAU. With the carbon permit price, the intensity dropped 32% to 109 g/kWh.

Advances in non-hydro renewable technologies help increase the penetration of new technologies into the market and help make them a viable long-term supply. Production of non-hydro renewable energy in the

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

Cross-Cutting Technologies. Several technologies apply to multiple sectors. These include combined heat and power systems, bioenergy, and fuel cells. The use of CEF-NEMS as an integrating model, which considers all sectors simultaneously, simplifies the evaluation of these technologies. Special considerations in their treatment are discussed in Chapter 3. The following box shows where the reader can find information on these technologies.

Where Did the Cross-Cutting Technologies Go?

Several technologies apply to multiple sectors and are therefore discussed in more than one of the chapters in this report. The following “wiring diagram” shows where the reader can find information on three of these cross-cutting technologies.

Cross-Cutting Technology:	Where to Find Them:
Bioenergy	Biomass Gasification (Industry--Chapter 5) Biofuels (Transportation--Chapter 6) Biopower (Power--Chapter 7)
Combined Heat & Power	District Energy Systems (Buildings--Chapter 4) Biomass Gasification (Industry--Chapter 5) Electricity Production (Electricity--Chapter 7)
Fuel Cells	Stationary Applications in Buildings (Buildings--Chapter 4) Transportation (Transportation--Chapter 6) Ternary Cycle in Natural Gas Combined Cycle & Integrated Gasification Combined Cycle (Electricity--Chapter 7)

1.4.5 Costs and Benefits of the Policy Scenarios

In this section, we report our estimates of the first-order economic impacts of the CEF scenarios. Specifically, five “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 permit 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.

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.*

Summary of Direct Costs and Benefits. In both the Moderate and Advanced scenarios and in both timeframes (2010 and 2020), the estimated annual energy bill savings exceed the sum of the annualized policy implementation costs and the incremental technology investments. This finding is consistent with many economic-engineering studies (Section 1.6) and with the views of many economists (see box). 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: 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 reported in 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.

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 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.

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 and benefits on an annual basis, we emphasize the annualized incremental technology costs for each year. The annualized cost for a particular year is the annualized cost of the total investment made to that time. We approximate the annualized cost by calculating an investment cost per unit of energy conserved and multiplying this cost of conserved energy (in $/kWh or $/MBtu) by the energy savings in that year.

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

Between 2010 and 2020, the annual incremental technology investment costs – totaled across all technologies and sectors – increase from $11 billion to $30 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[a]	0	0	0	0
Total	11.4	30.5	29.6	65.9

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

It is also useful to estimate the incremental capital outlays required each year to purchase the energy efficiency and clean energy technologies that are promoted by the CEF scenarios. These costs reflect the actual incremental expenditures needed for each scenario in each year. They can be calculated from the year-by-year annualized costs of these investments shown in summary in Table 1.14. The annualized cost calculations involve spreading the cost of capital across the operating lifetimes of new investments, while calculating the capital outlays requires removing that annualization and determining the change in actual capital investments from one year to the next. The actual capital outlays allow us to examine how the nation's investment capital would be affected by the CEF policies.

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

The incremental capital outlays vary year-to-year in both the Moderate and Advanced scenarios. In the Moderate scenario they increase from several billion in 2000 to $17 billion in 2015, after which they decline gradually. In the Advanced scenario, incremental technology investments increase more rapidly from $4 billion in 2000 to $30 billion in 2005; after that they decrease to $17 billion in 2020. These energy-efficiency capital outlays are small relative to gross private domestic investments made in the United States on an annual basis, which totaled $1.7 trillion in 1999 (Bureau of Economic Analysis, 2000). By comparison, the AEO99 reference case projects Real Investment at annual rates of $2,011 billion in 2010 and $2,508 billion in 2020 (in 1997$).[10] Thus, the CEF capital outlays are no more than 2% of total capital investments in any year between 2000 and 2020.

Changes in the Energy Bill. The total change in energy bill is a function of changes in energy prices, as well as changes in amounts and types of energy used. Generally, both factors are at work and are described below. The energy bill is calculated as the sum over all fuels (including electricity) in all end-use sectors of the fuel price times the amount of fuel used minus the pay-at-the-pump fee[11]. Average energy prices to all users are shown, by type of energy and by scenario, in Table 1.15 and Fig. 1.10. Prices for fuels are shown in 1997$ per million Btu. Energy prices are given in more common units (e.g., gallons of gasoline and thousand cubic feet of natural gas) in Table 1.16. 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 domestic carbon trading system. Scenarios can project energy price increases (as when carbon permit costs are added or 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 BAU scenario assumes that electricity prices will be 12% lower by 2010 than in 1997 and will decline another 8% by 2020 due to electricity restructuring in parts of the 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

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[10] The 1992 dollars of the AEO99 reference case are converted to 1997 dollars using the 1997 chain-type price index for Fixed Gross Private Domestic Investment (AEO99, Table 20; Council of Economic Advisers 1999, Table B-7).

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

Table 1.15 Average Energy Prices to All Users

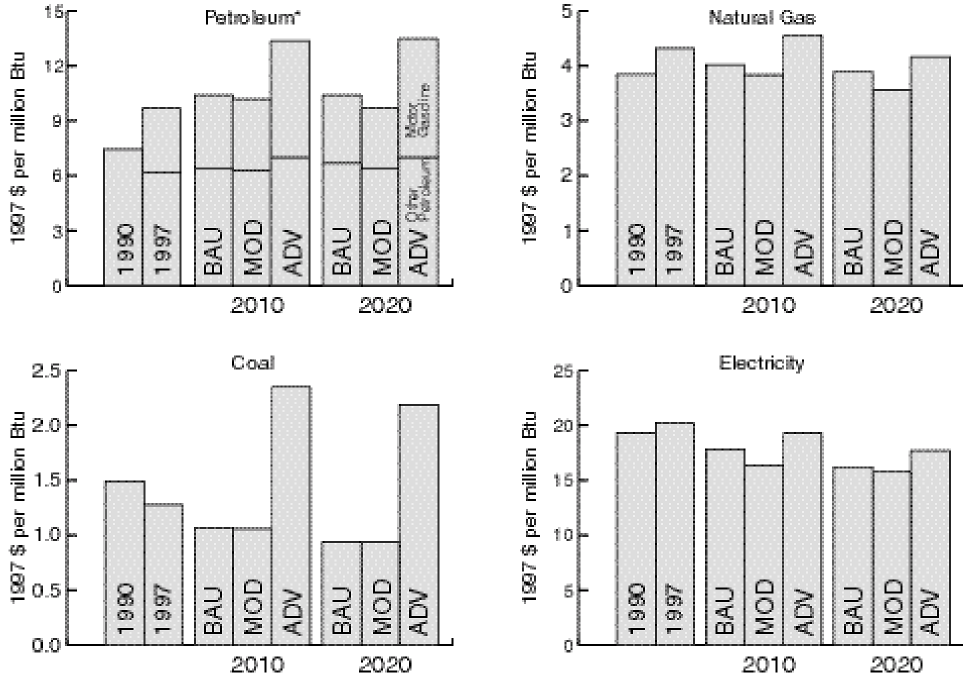
			2010			2020		
Average Energy Prices (1997$ per Million Btu)	1990[a]	1997	BAU	Mod.	Adv.[b]	BAU	Mod.	Adv.[b]
Motor Gasoline	9.96	9.70	10.40	10.16 (-2%)	13.41 (29%)	10.41	9.74 (-6%)	13.54 (30%)
Other Petroleum	6.72	6.17	6.38	6.27 (-2%)	7.09 (11%)	6.65	6.36 (-4%)	7.01 (5%)
Natural Gas	4.20	4.32	4.02	3.80 (-5%)	4.55 (13%)	3.90	3.56 (-9%)	4.14 (6%)
Coal	1.63	1.28	1.07	1.06 (-1%)	2.35 (120%)	0.94	0.93 (-1%)	2.22 (136%)
Electricity	21.08	20.26	17.85	16.44 (-8%)	19.32 (8%)	16.15	15.51 (-4%)	17.92 (11%)
Energy Bill (billion 1997$)	516	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.

[a] Source: EIA (1998d), Tables 3.3 and 3.4, inflated to 1997$ using consumer price indexes for energy from Table B-58, Council of Economic Advisers (2000).

[b] The Advanced scenario prices include the $50/tonne carbon permit cost that energy producers are assumed to add to energy prices as a result of the domestic carbon trading system. Motor gasoline prices also include the pay-at-the-pump insurance charge of $2.72 per MBtu in 2010 and $4.08 per MBtu in 2020. The pay-at-the-pump insurance charge is not included in the energy bill shown in the last row of this table.

Fig. 1.10 Average Energy Prices to All Users
(1997 $ per Million Btu)



*For petroleum, the top bars designate the price of motor gasoline including the pay-at-the pump insurance charge, while the lower bars designate the price of other petroleum products.

Table 1.16 Average Energy Prices in Common Units

		2010			2020		
Average Energy Prices (1997 $ per Million Btu)	1997	BAU	Mod.	Adv. [a]	BAU	Mod.	Adv. [a]
Motor Gasoline (1997 $ per gallon)	1.21	1.30	1.27 (-2%)	1.68 (29%)	1.30	1.22 (-6%)	1.69 (30%)
Natural Gas (1997 $ per Mcf)	4.44	4.13	3.90 (-6%)	4.67 (13%)	4.01	3.66 (-9%)	4.25 (6%)
Coal (1997 $ per ton)	27.26	22.79	22.57 (-1%)	50.04 (120%)	20.02	19.80 (-1%)	47.27 (136%)
Electricity (1997 cents per kWh)	6.91	6.09	5.61 (-8%)	6.59 (8%)	5.51	5.29 (-4%)	6.11 (11%)

Note: Mcf = thousand cubic feet; BAU = Business-As-Usual; Mod. = Moderate; Adv. = Advanced. Numbers in parentheses represent the percentage change compared with BAU.

[a] The Advanced scenario prices include the $50/tonne carbon permit cost that energy producers are assumed to add to energy prices as a result of the domestic carbon trading system. The gasoline prices also include the pay-at-the-pump insurance charge of 34¢ per gallon in 2010 and 51¢ per gallon in 2020.

efficiency. The Advanced scenario, on the other hand, produces electricity prices that are 9% higher than BAU in the two timeframes. This increase is due largely to the inclusion of the $50/tC carbon permit price[12]. It also is affected by the greater use of renewable resources in power production.

The end-use price trajectories for natural gas are similar to those for electricity. In the BAU scenario, end-use prices are forecast to decline by 7% between 1997 and 2010 and by another 3% over the subsequent decade. The Moderate scenario results in even lower natural gas end-use prices in both 2010 and 2020, 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 trading system. Improved energy-efficiency reduces demand for natural gas in industry and buildings, which prevents price escalation as the result of rising natural gas demand in the power sector.

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

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

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

forecast, both in 2010 and 2020. Prices for other petroleum products in the Advanced scenario are 11% higher than the BAU forecast in 2010 and 5% higher than the BAU in 2020.

The magnitude of change in motor gasoline prices is perhaps best understood in terms of 1997$ per gallon of gasoline. In the Advanced scenario, a gallon of gasoline costs $1.68 in 2010 and $1.69 in 2020, compared to $1.30 in the BAU forecast for both time periods and lower prices in the Moderate scenario. In the Advanced scenario, 12¢ of the increase is a result of the carbon permit cost. The pay-at-the-pump increment is 34¢ in 2010 and 51¢ in 2020. The price of gasoline does not rise in full by the sum of these increments because the reduction in demand exerts downward pressure on prices.

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

The combination of evolving prices and demand for energy results in energy bill trajectories that vary widely across the scenarios (Table 1.17). 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 and decreased energy use in the end-use sectors. In the Moderate scenario, U.S. energy cost savings are $55 billion in 2010 and increase to $100 billion in 2020.

In the Advanced scenario, efficiency increases in the end-use sectors are large enough to reduce the nation's energy bill even with increased energy prices. The energy bill savings in 2010 are $16 billion, which is much smaller than in the Moderate scenario because of the energy price increases and the time required to turn over the existing stock of equipment. The savings rise to nearly $122 billion in 2020 as a result of improvements in the performance of energy-efficient technologies and their greater penetration in buildings, industry, and transportation. The transportation sector accounts for a large portion of the energy bill savings in both 2010 and 2020.

Table 1.17 Net Energy Bill Savings in 2010 and 2020
(in Billions 1997$ per Year)

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

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

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

As a result, the domestic carbon trading system imposes minimal first-order changes in the total income of "the public." Distribution of income will change, with some winners and losers, but aggregate income will change very little. This is a fairly gross system, but more refined rebate and allocation options are emerging (Bovenberg and Goulder, 2000; Center for Clean Air Policy, 1999; Weyant and Hill, 1999; Fischer, Kerr, and Toman, 1998a, b). The value of the transfer payments is shown in Table 1.18.

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

Table 1.18 Net Transfers to the Public of the Carbon Permit Revenues in 2010 and 2020 (in Billions 1997$ per Year)

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

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

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

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

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

Net Direct Savings. Table 1.19 shows the "net direct savings" of the two policy scenarios. The total savings are the difference between the direct benefits shown in Tables 1.17 and 1.18 (i.e., net energy bill savings and carbon permit revenue 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). The direct costs for both scenarios rise over time at a nearly linear pace. The energy bill savings of the Moderate scenario also rise at an essentially linear rate, as does the sum of the net energy bill savings (which includes the cost of carbon permits) and the carbon permit revenue transfers in the Advanced scenario. The net energy bill savings are negative in 2005, but by 2010 and in subsequent years, consumers experience positive net energy bill savings.

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

Figures 1.11 and 1.12 compare the annual gross energy savings with the two measures of incremental technology investment costs: the annualized costs and the annual capital outlays. These figures show that the investments spurred by the CEF policies quickly pay back in terms of reduced energy costs. This is true in both the Moderate and Advanced scenario.

Table 1.19 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**
Policy Implementation and Investment Costs:				
• Annualized policy implementation and administration costs	-3.2	-6.7	-9.1	-13.0
• RD&D costs	-1.4	-1.4	-2.8	-2.8
• Annualized incremental technology investments	-11.4	-30.5	-29.6	-65.9
Total Investment Costs	**-16.0**	**-38.6**	**-41.5**	**-81.7**
Net Energy Bill Savings:				
• Gross energy bill savings	55.3	100.3	89.2[a]	189.3[a]
• Carbon permit costs	0	0	-72.9	-67.4
Net Energy Bill Savings	**55.3**	**100.3**	**16.4**	**121.9**
Carbon Permit Revenue Transfers to the Public	**0**	**0**	**72.9**	**67.4**
Total	**39.3**	**61.7**	**47.7**	**107.6**

*These net direct savings do not account for the macroeconomic impacts of the scenarios. For example, the savings in the Advanced scenario are decreased by a small loss in consumer and producer surplus due to the domestic carbon trading system. These are estimated to be $2.5 billion in 2010 and $1.8 billion in 2020. Other macroeconomic costs are discussed later in this chapter and in Appendix E-4.

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

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). The "clean air story" is described in the following box. The CEF policy scenarios also result in energy security externality effects. Oil security, for instance would be enhanced. (This is one of the aspects of the "oil story.")

A variety of ancillary or collateral costs and benefits 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, but could be considerable. On the benefits side are:

- the productivity and product quality gains that have accompanied many investments in industrial efficiency improvements (Romm, 1994; Romm, 1999) and
- the growth in export markets for energy technologies.

Fig. 1.11 Annual Gross Energy Bill Savings and Incremental Technology Investments of the Moderate Scenario: 2000 through 2020

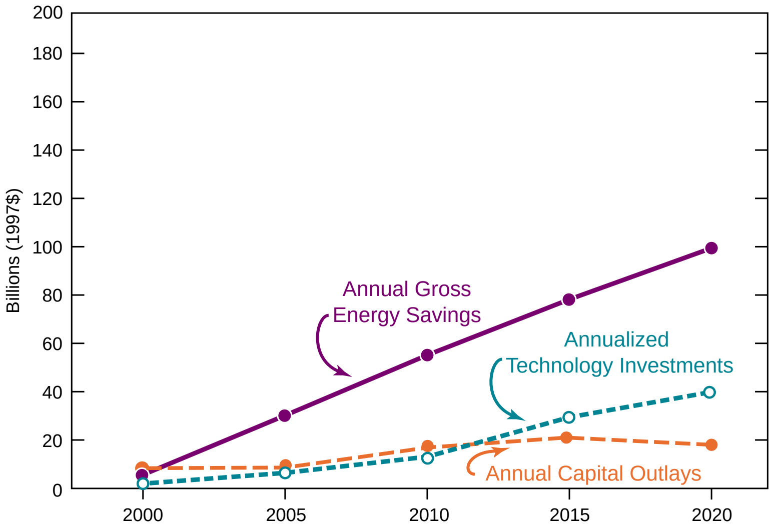
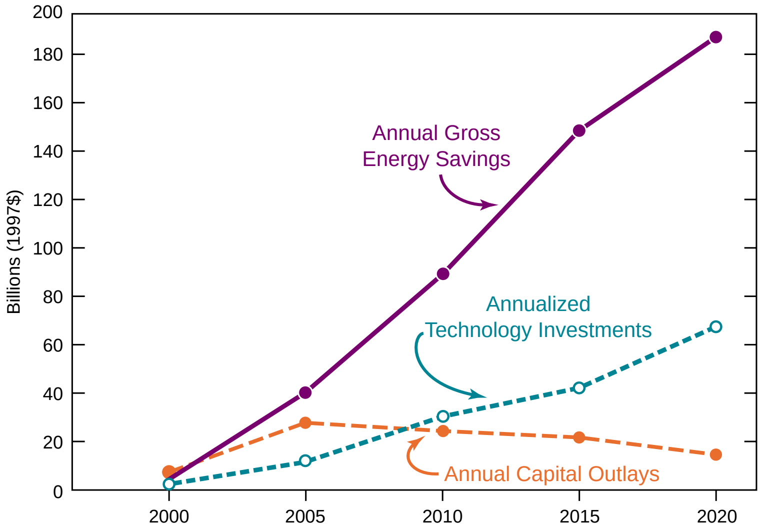


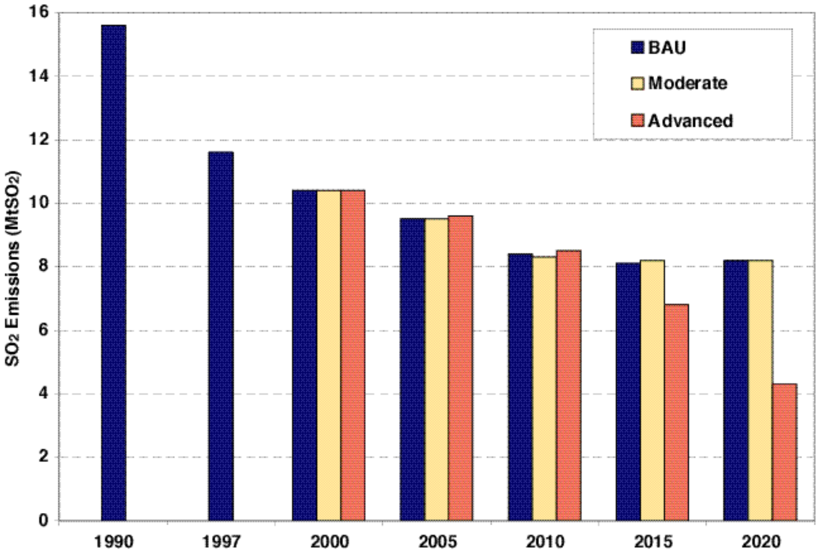
Fig. 1.12 Annual Gross Energy Bill Savings and Incremental Technology Investments of the Advanced Scenario: 2000 through 2020



The Clean Air Story

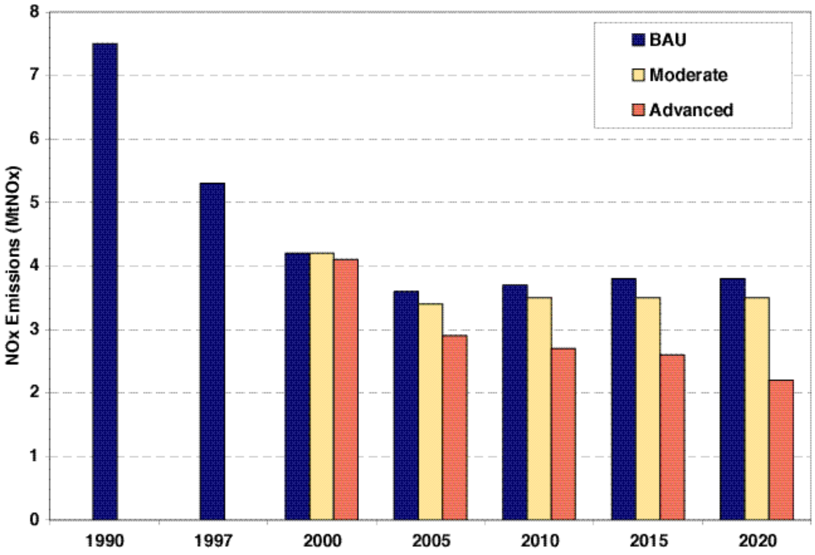
In both the Moderate and Advanced scenarios, emissions of local air pollutants are substantially reduced. These reductions are an added benefit of the cuts in fossil fuel combustion that occur largely as a result of policies directed at increasing energy efficiency and reducing carbon emissions.

SO_2 Emission Reductions in the Electric Sector



In the Moderate scenario, SO_2 emissions from the electric sector in 2010 remain at the limits set by the Clean Air Act Amendments of 1990. However, the allowance price needed for SO_2 to keep emissions at that level drops to \$96/ton in 2020 (a 16% decrease relative to the BAU forecasted allowance price of \$114/ton). With lower demand and improved new technologies, it is easier to meet the limits. NO_x and mercury emissions also decline in the Moderate scenario.

NO_x Emission Reductions in the Electric Sector



In the Advanced scenario, a policy is modeled that calls for SO_2 emissions to be reduced in steps between 2010 and 2020, so that by 2020 they have declined to half the Phase II limits set by the Clean Air Act Amendments of 1990. This policy is designed to represent tighter particulate matter standards. As a result, the cost of sulfur allowances in the Advanced scenario in 2020 rises to \$161/ton in 2020. Simultaneously, NO_x emissions by 2020 fall to less than half of the current NO_x emissions from the electric sector, and mercury emissions decline significantly.

While the monetary value associated with clean air is difficult to estimate, the benefits of the Clean Energy Future scenarios are clearly positive in terms of improved human and ecological health.

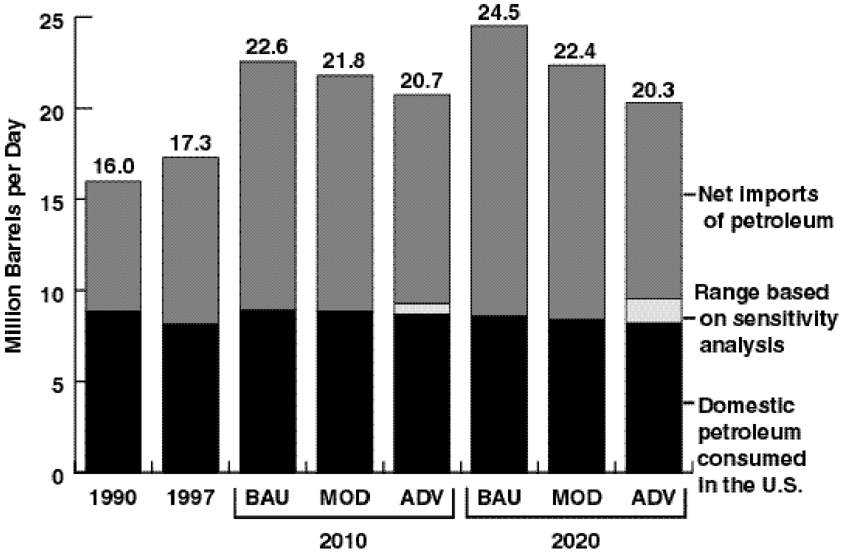
The Oil Story

What is the possible fate of oil in twenty-first century America? The Advanced scenario shows that it is possible for the United States to significantly decrease its use of oil in the coming decades, while growing the economy. It illustrates a future in which oil is a smaller percentage of the fuels used to run the economy, which translates into a more secure energy future.

In 1997 the U.S. consumed approximately 17 million barrels per day (mmbd) of crude oil and petroleum products.[13] Consumption of these fuels is forecast to rise to approximately 23 mmbd by 2020. The aggressive policies in the Advanced scenario bring petroleum consumption in 2020 down to 1997 levels, resulting in a savings of approximately 5 mmbd in 2020, when compared to the BAU forecast[14]. Over the same two decades, the population is expected to grow by 20%. Thus, the oil-to-GDP ratio in the Advanced scenario is much lower in the Advanced scenario in 2020 than the ratio today.

The Advanced scenario also brings about a reduction in the nationÕs expected reliance on imported oil. This translates into a significant improvement in the nationÕs balance of payments.

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



The reduced oil consumption is brought about by the improved performance and deployment of energy-efficient technologies in cars, trucks, and home heating equipment, motivated by an array of policy changes. Technology such as the turbo-charged diesel injection engine, cellulosic ethanol, hydrogen fuel cell vehicles, and lightweight materials will enable the transportation sector, the main consumer of oil, to use petroleum more efficiently and to increase its reliance on alternative fuels.

While gasoline prices are higher in the Advanced scenario than in the BAU forecast, the cost of fuel per mile of travel is essentially unchanged because of fuel efficiency gains. In 1997, gasoline prices averaged $1.21 per gallon and the average light-duty vehicle got 20.5 miles to the gallon Ðresulting in a fuel cost of 5.90¢ per mile. In the Advanced scenario, gasoline prices increase to $1.69 in 2020, and fuel efficiency of the existing fleet of light-duty vehicles increases to 28.3 mpg. This results in a fuel cost of 5.98¢ per mile. Thus, consumers pay essentially the same per mile of travel in the Advanced scenario in 2020 as they do today, while also paying for a portion of their insurance premiums through the cost of their fuel.

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[13] One million barrels per day of petroleum use is equivalent to an annual energy consumption of 2.1 quadrillion Btu.

[14] The numbers given here assume the same world oil prices in both scenarios. As a result, they overestimate the reduction of oil imports and underestimate the economic benefits resulting from lower oil prices A sensitivity analysis testing alternative assumptions about OPEC behavior and world oil prices is described Chapter 6 (Section 6.5.5.)

Neither of these benefits is included in the analysis of direct costs and benefits, yet they could be considerable. Results reported in Elliott et al. (1997) and Laitner (1999) 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 Effects. The CEF study does not model the macroeconomic impacts of its two policy scenarios because of the difficulty of estimating transition and long-term macroeconomic effects on costs and investments that average less than 1% of national GDP over the study period. Instead, 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 as a result of the energy price changes that could result from the permit trading option included in the Advanced scenario. The conclusions of this paper are summarized here.

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 these market failures 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 described in Chapter 2.

The authors conclude, based on information presented in Chapter 2, that the economy is not currently operating in an optimal fashion with respect to the provision of energy services (i.e., it is not operating on its aggregate production-possibilities frontier). As a consequence, Pareto improvements are available through policy interventions. Thus, whatever shifts or adjustments in markets occur as a result of such policies*, the aggregate result is a gain in economic efficiency*. In the case of the domestic carbon trading policy, however, the question arises of the possibility of substitution between GDP and carbon reductions. That possibility motivated the analysis of the $50/tonne carbon permit price in Appendix E-4.

Appendix E-4 assesses the macroeconomic costs of a $50/tonne carbon permit price by examining the Energy Modeling Forum's recent compilation of results from simulations using seven of the leading energy/economic models (Weyant and Hill, 1999). These seven models provide alternative estimates of what it might cost to achieve carbon emissions at 1990 levels from energy use and generation. The scenarios varied according to how much (and among which countries) international trading was allowed to occur. Four trading scenarios were run: (1) no trading of international emissions rights; (2) full Annex I (or Annex B)[15] trading of emissions rights; (3) the "double bubble," which considers separate European Union and "rest of Annex I" trading blocs; and (4) full global trading of emissions rights.

To estimate the GDP loss associated with a $50/tonne carbon permit price, the authors of Appendix E-4 calculated a "GDP response curve" for each model indicating the expected response of GDP to various carbon permit prices. Each curve was determined by a quadratic extrapolation using the Annex I trading and global trading scenarios as reported by the Energy Modeling Forum (EMF-16), in Weyant and Hill (1999). (These are the scenarios with carbon permit prices that bracket or are close to the $50/tonne level.) For each model, the origin and the two estimates of implicit carbon permit price and GDP loss determine a unique quadratic response curve.

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[15] The Annex I (of the 1992 Framework Convention on Climate Change) countries include the U.S., OECD-Europe, Japan, CANZ (Canada/Australia/New Zealand), and the EEFSU (East Europe and Former Soviet Union) countries. The Annex B (of the Kyoto Protocol) list varies slightly from the Annex I list (Weyant and Hill, 1999).

The estimated 2010 GDP losses (in 1997$) associated with $50/tonne carbon permit price range from $4 billion for the MERGE3 model to $66 billion for the CETA model. These are the same order of magnitude as the $48 billion in net direct benefits estimated for the Advanced scenario in 2010.

Appendix E-4 also explores the transitional macroeconomic adjustment costs of the carbon permit price caused by the economy's reacting to higher energy prices in the CEF scenarios. This is accomplished by examining two EIA analyses that use the DRI model to examine the effects of introducing carbon permit prices into the U.S. economy (EIA, 1998c and 1999c). When carbon trading is phased in beginning in 2000 (EIA, 1999c), achieving the CEF Advanced scenario levels of reduction requires a $63/tonne carbon permit price, which results in a GDP loss (including both transitional and long-term macroeconomic costs) of $39 billion. This is equal to the median of the range predicted by the seven models described in EMF-16 (Weyant and Hill, 1999). Based on the EIA study (1998c) that models carbon trading beginning in 2005, the CEF Advanced scenario levels of reduction would require a $66/tonne carbon permit price. This results in a GDP loss (including both transitional and long-term macroeconomic costs) ranging from $47 billion to $74 billion (in 1997$). The lower estimate occurs when revenues are recycled using payroll tax reductions, and the higher estimate occurs with revenue recycling through personal tax rebates, which do not correct pre-existing distortions in taxes.

As with the long-term macroeconomic costs described in the previous paragraphs, these findings show that even in the transition period, potential GDP losses can be mitigated – and indeed potential GDP gains may result – when revenue recycling is used to stimulate investment. In 2010, the net direct savings are of the same order of magnitude as the macroeconomic (transitional plus long-term) costs. Over the following decade, the net direct savings grow as energy-efficient technologies gain market shares, while the long-term macroeconomic impacts remain steady and the transitional costs decline.

Macroeconomic Indicators. A range of macroeconomic indicators associated with the two policy scenarios is provided in Table 1.20. For simplicity, these assume that GDP grows in the Moderate and Advanced scenarios at the same pace as in the BAU forecast.

Table 1.20 Macroeconomic Indicators

			2010			2020		
	1990	1997	BAU	Mod.	Adv.	BAU	Mod.	Adv.
GDP (billion 1997$)	6136 (1992$)	8171	11,123	11,123 (0%)	11,123 [a] (0%)	13,128	13,128 (0%)	13,128 [a] (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%)

Note: BAU = Business-As-Usual; Mod. = Moderate; Adv. = Advanced. Numbers in parentheses represent the percentage change compared with BAU.

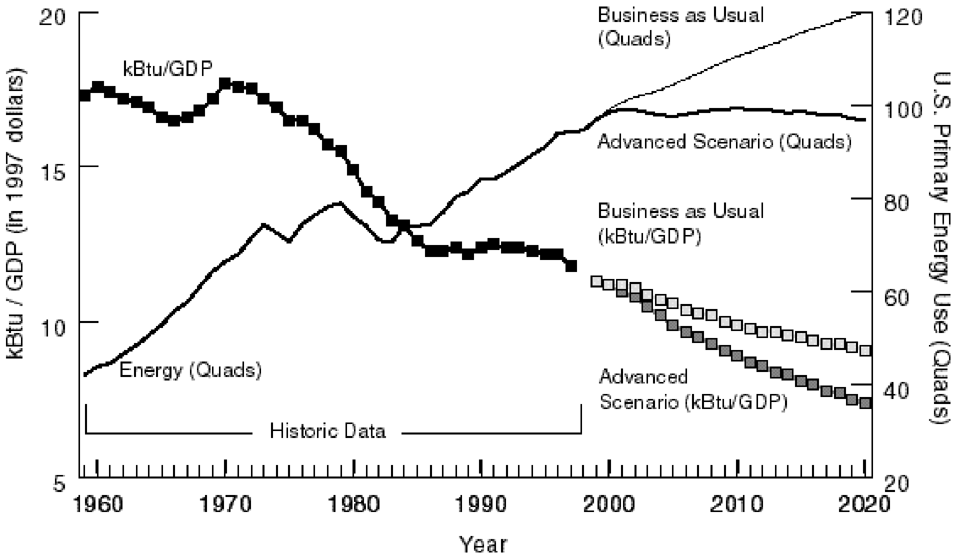
[a] As noted in the section on "Macroeconomic Effects," there is great uncertainty regarding the GDP levels that would result from Advanced scenario policies (ranging from an increase of $14 billion to a decrease of $44 billion, relative to the BAU). For the purposes of this table, we have assumed the same GDP levels as in the BAU forecast.

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 Fig. 1.13 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.

Sectoral and Regional Impacts. Many sectors of the economy and regions of the United States would benefit from a transition to the type of clean energy future characterized in this studyÕs two policy scenarios. For example, 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. Specific sectors likely to see positive impacts on output include:

- energy service companies, contractors, and consultants,
- light-weight materials and fuel cell manufacturing,
- nuclear energy services industry,
- wind turbine manufacturers and biomass producers and processors, and
- electronic sensors and controls and advanced battery manufacturers.

Fig. 1.13 Energy/GDP Ratios



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

The enhanced energy-technology innovation envisioned from the doubling of RD&D budgets in the Advanced scenario could lead to a stronger domestic economy through international cooperation. The development of advanced energy technologies could help expand the market share of 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).

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

Unequal regional impacts of CO_2 policies on the electricity industry are also anticipated because of regional differences in the resources used to generate electricity. In particular, interior states 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.

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

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 BAU, Moderate, and Advanced scenarios described in the rest of the report. 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.

Many types of uncertainties influence the CEF scenarios. Some of these uncertainties can be captured through quantitative sensitivity analyses, in which one or more key input assumptions are varied and the results studied. Other uncertainties are more difficult to capture – e.g., uncertainties in the specification of basic data and underlying assumptions, in the realism of the models and related forecasting approaches, and in the assessment of impacts of policies. Recognizing that sensitivity analysis captures only a portion of the uncertainty, we have carried out a range of sensitivities on a number of important variables. These are described in detail in subsequent chapters. To illustrate the approach, the following box summarizes a selection of sensitivity cases, including (1) higher natural gas prices, (2) shorter duration of the renewable

Results of Selected Sensitivity Cases

High Natural Gas Prices

By assuming limited technological progress in gas drilling, exploration, and recovery, natural gas prices in the electric sector were increased by 12% above the BAU scenario for 2020. The major impact is a reduction in natural gas consumption for electricity generation of about 12%. About three-quarters of the natural gas is replaced by coal in both the BAU and Advanced scenarios. The result is an increase in carbon emissions by between 6 and 10 MtC in the two cases, respectively. By also assuming that demand reduction policies were not implemented, natural gas prices were increased further to 26% over the BAU forecast for 2020. Coal increases make up two-thirds of the gas reduction. Biomass, geothermal, and wind make up 8%, 5%, and 4% of the lost gas generation, respectively.

High Natural Gas and Petroleum Prices

The EIA's "High World Oil Prices" (EIA, 1998a) were added to the high natural gas price sensitivity (described above) to model a future in which both natural gas and petroleum prices rise significantly. In this sensitivity, world oil prices increase from $19 per barrel in 1997 to $27 in 2010 and $29 in 2020. When this energy price trajectory is added to the standard Advanced scenario, light-duty vehicle miles of travel drop by 2% (by 2005) and the efficiency of the light-duty fleet increases by 2 to 3% compared to the standard Advanced scenario. The result is a significant decrease in carbon emissions from transportation. This is offset slightly by an increase in carbon emissions in the electric sector caused by a shift from natural gas to coal generation resulting from the higher natural gas prices and fuel switching from oil to electricity in buildings and industry.

Renewable Energy Policy and Cost Sensitivities

In this sensitivity, the renewable portfolio standard (RPS) was terminated in the Advanced scenario in 2004, four years ahead of schedule. This causes wind generation in the Advanced scenario to fall from 159 to 97 TWh in 2020. (It is 9 TWh in the BAU in 2020.) This results in an increase in carbon emissions in the Advanced scenario of 20 MtC in 2020. An increase in the projected capital costs for wind and biomass of 20 to 25% in 2020 has the same effect as early termination of the RPS.

No Diesel Penetration in Light-Duty Vehicles

The Advanced scenario has a penetration of 2.2 million high-efficiency diesels in 2010 and 3.1 million in 2020. We simulated a case in which there is no diesel penetration in light-duty vehicles. The effect was to reduce fuel economy for new light-duty vehicles from 41.9 to 40.5 mpg in the Advanced case in 2020. (This compares with a projected fuel economy of 30.5 mpg in the BAU in 2020.) The net effect is an increase in energy use of 0.5 quads in the Advanced scenario in 2020, or about 10 MtC. The absence of diesels has such a small effect on energy and carbon emissions because other efficient technologies (e.g., fuel cells) are assumed to be available to replace the diesels.

Higher Cost of Advanced Fossil Fuel Technology

Sensitivity analyses were conducted to examine a less optimistic future for the cost and performance of natural gas and integrated gasification combined cycle plants. (For example, capital costs for natural gas combined cycle plants were assumed to be 17 to 30% higher, depending on the scenario.) The results show a decline in carbon emissions (6 MtC for the Moderate and 3 MtC for the Advanced scenarios), resulting from replacement of the fossil energy generation by renewable and nuclear power. With higher cost advanced technologies, the market price for SO_2 credits increases slightly, as do electricity prices (by 1 to 2 mills per kWh). Because of the availability of advanced technologies for renewables and combustion turbines and the continued availability of relicensed nuclear plants as backstops, less R&D success for combined cycle technologies does not have a major impact on the overall results.

Table 1.21 Summary of Sensitivity Cases

	Domestic Carbon Trading System	**Moderate Demand and Supply-Side Policies**	**Advanced Demand-Side Policies[a]**	**Advanced Supply-Side Policies[b]**	**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
$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
$50/tC					**Advanced Scenario:**
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	623	584	593	550
$25/tC	118.5	108.8	99.8	112.1	98.8
Primary Energy (Quads)	1842	1651	1490	1684	1472
Carbon Emissions (MtC)	645	551	500	547	482
Carbon Emissions (MtC) from Electric Generators					
$50/tC					**Advanced Scenario:**
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

[a] 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).

[b] 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).

portfolio standard or higher cost of renewable energy technology, (3) no penetration of light-duty diesel engines, and (4) higher cost of advanced fossil fuel technologies.

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

In the following section, the results of system-wide variations in policies are presented – comparing and contrasting demand-side versus 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 carbon trading system). The supply-side policies are those defined for the electricity sector in the Advanced scenario (excluding the domestic carbon trading system). Two values of the carbon permit price 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 categories of policies, with the $50/tC carbon permit price, 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 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 well-documented, positive impacts (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 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.

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 1,771 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 how 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 carbon trading 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 permit price and by an additional 4 quads with a $50/t carbon permit price. 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 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 domestic carbon trading 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 permit price 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 permit price 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 SO_2 emissions from electric generators. Trading programs could motivate innovative and low-cost actions to reduce CO_2 emissions, as well as the emissions of other greenhouse gases such as CH_4, N_2O, HFC, PFC, and SF_6. 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 alone 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 (to 107.5 and 116.5 quads in 2020 compared with BAU forecasts of 110.3 and 119.8 quads). Carbon emissions decrease by only 6% to 9% relative to BAU (to 1663 and 1755 MtC in 2020 compared with BAU forecasts of 1769 and 1022 MtC).

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, restrictions on particulate emissions (modeled as an SO_2 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 1.21, coupling demand-side policies with carbon trading at \$50/tC comes the closest to achieving the energy and carbon reductions of the Advanced scenario.

1.5.4 Summary

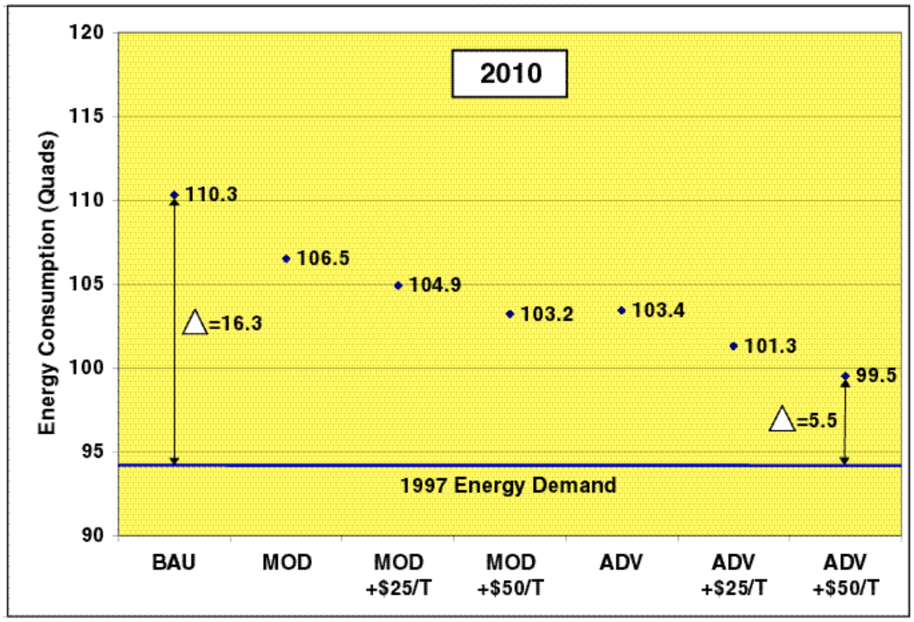
Among the three categories of policies, the demand-side policies produce the greatest energy and carbon reductions (Fig. 1.14 and 1.15). They dampen energy use and carbon emissions in approximately equal proportions. Supply-side policies and the domestic carbon trading policy, on the other hand, principally 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 carbon trading 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.

Fig. 1.14 Sensitivity Cases for the Year 2010



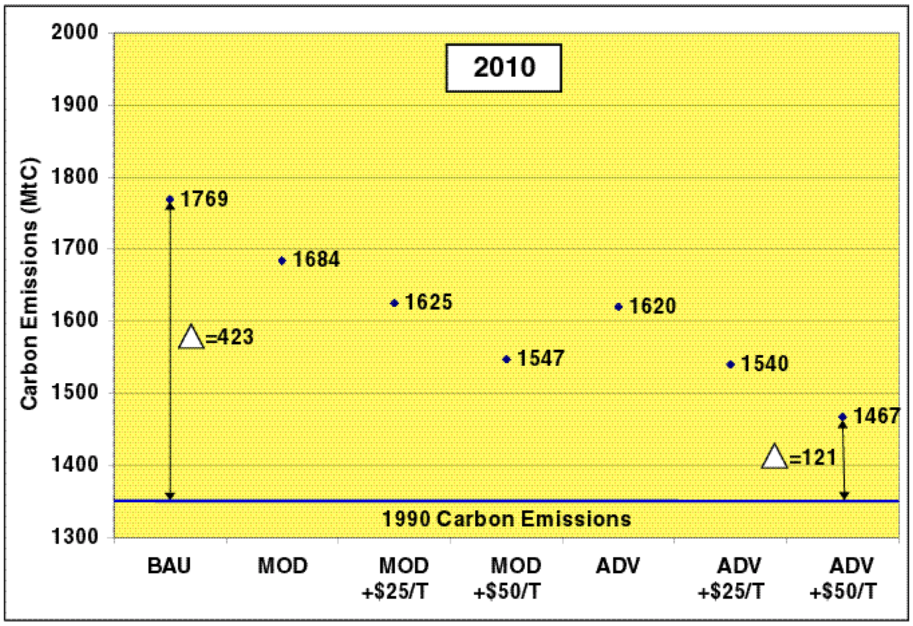
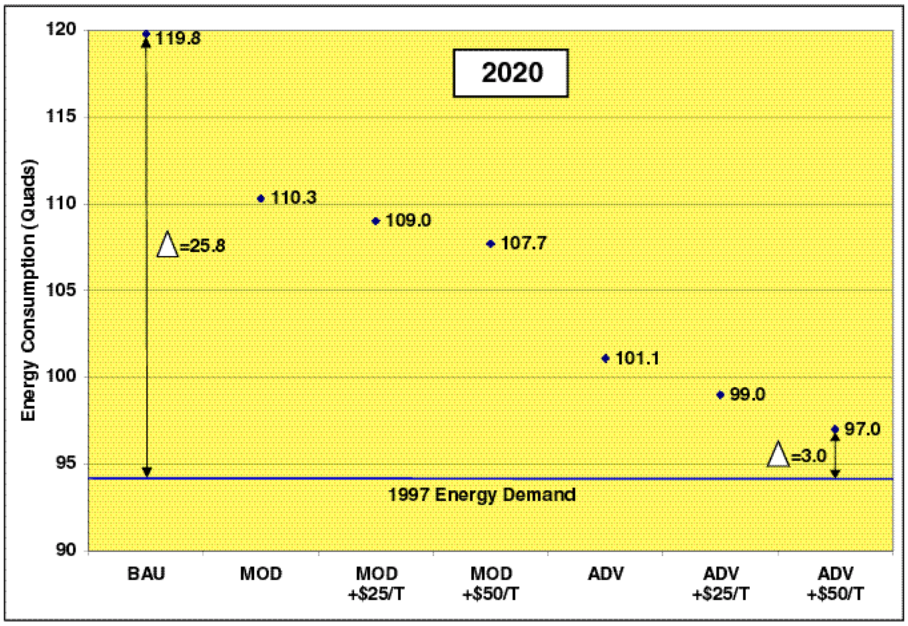
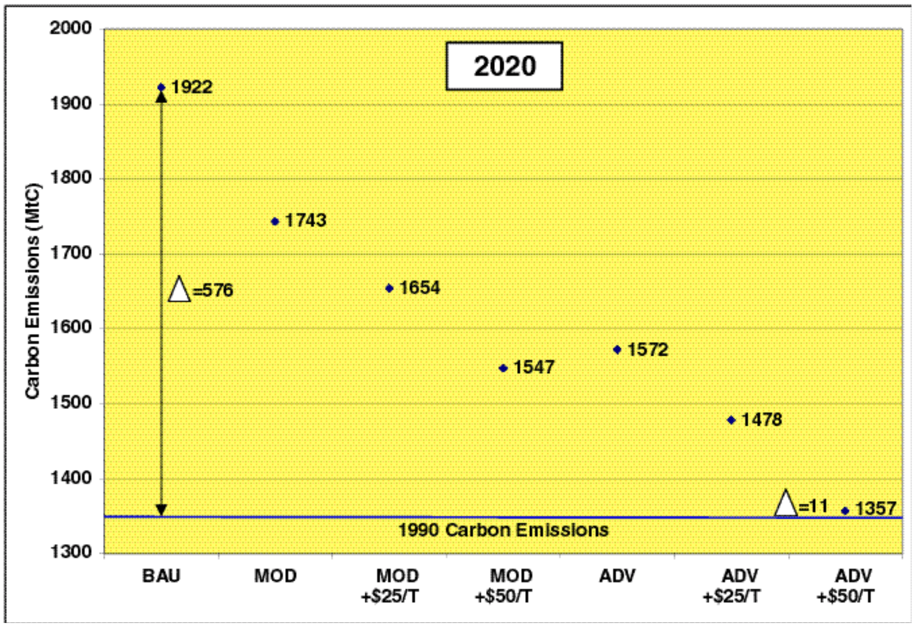


Fig. 1.15 Sensitivity Cases for the Year 2020





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 *Impacts of the Kyoto Protocol on U.S. Energy Markets and Economic Activit*y (1998c, chapter 7).

The following 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 CO_2 Emissions in the United States: An Analysis of Options for 2005 and 2010* by Tellus Institute (1998);
- Bernow, S., et al. (1999) *America's Global Warming Solutions*, by Tellus Institute and Stockholm Environment Institute[16];
- *Impacts of the Kyoto Protocol on U.S. Energy Markets and Economic Activity*, by the Energy Information Administration (EIA, 1998c); and
- *Analysis of the Impacts of an Early Start for Compliance with the Kyoto Protocol,* by the Energy Information Administration (EIA, 1999c).

Each of these studies describes at least one "low-cost" carbon reduction scenario. To keep the comparisons manageable, only one scenario from each study 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 (1998c and 1999c) scenarios that reduce carbon emissions to 24% above 1990 levels. The variation in carbon reduction levels across these scenarios is shown in Fig. 1.16. To facilitate these cross-study comparisons, this figure portrays each scenario's carbon reductions relative to EIA's AEO99 Reference case (EIA, 1999a). 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. For a more detailed, parameter-by-parameter comparison of many of these studies, see Brown et al. (1998).

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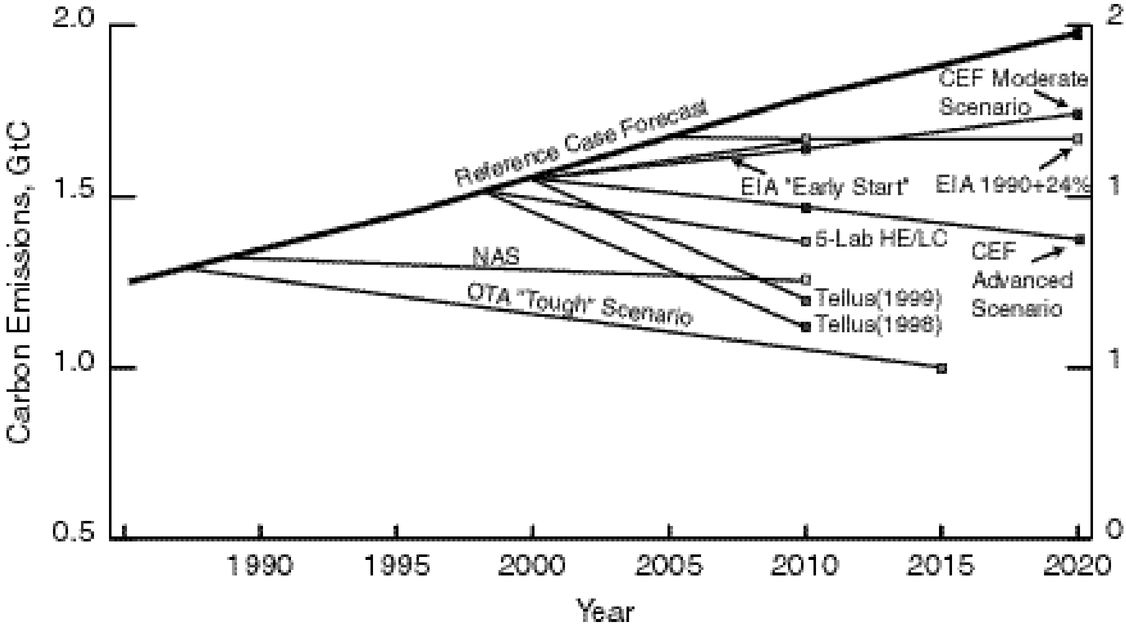
[16] The Tellus Institute reports reflect an effort among leading non-governmental energy organizations that was begun with *America's Energy Choices* in 1991. The series of reports includes *Energy Innovations: A Prosperous Path to a Clean Environment* by five national environmental organizations (Alliance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

Fig. 1.16 A Selection of Low-Cost Engineering-Economic Scenarios



The 1991 report by the Office of Technology Assessment (OTA) titled *Changing by Degrees* (Office of Technology Assessment, 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 **ÒtoughÓscenario** results in a 20% to 35% emissions reduction relative to 1987 levels, or emissions levels of 850 to 1,000 MtC/year in 2015. The CEF studyÕs carbon reductions are considerably less than OTAÕs ÒtoughÓcase. However, the annual rate of decrease in carbon emissions is similar, as can be seen by the parallel positioning of their trajectories in Fig. 1.16. The large difference between their endpoints is due partly to OTAÕs 13-year Òjumpstart.Ó

The tough scenario achieved its reductions at an estimated net annual cost ranging from -$28 billion to $212 billion (in 1997$). 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 Òstair-stepsÓin 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 Ð 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 $2.85 (in 1997$) 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 Òparticipation fractionÓ 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 studyÕs **Òhigh-efficiency/low-carbonÓ scenario** is similar to the pace of reductions in the Advanced scenario, as documented by the parallel carbon reduction trajectories shown in Fig. 1.15. However, in 2010 both the carbon and energy reductions in the CEF studyÕs Advanced scenario are less than those of the Five-Lab studyÕs HE/LC case. This difference is largely due to the distinct timeframes of each study. The Five-Lab studyÕs 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 down future energy use and carbon emissions to historic levels.

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 scenarioÕs 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, 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 domestic carbon trading system are used to offset higher energy prices, as was implicitly assumed in the Five-Lab study.

The Tellus InstituteÕs 1998 **Òclimate protectionÓ 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, increased CAFE standards, a carbon content standard for transportation fuels, incentives for more rapid investment in new manufacturing equipment in industry, and a 10% ÒunconstrainedÓ 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 **Òclimate protectionÓ 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 studyÕs 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 scenarioÕs carbon reductions comes from a 28% decrease in petroleum use, relative to the BAU 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 **1990+24% scenario** described in *Impacts of the Kyoto Protocol on U.S. Energy Markets and Economic Activity* (EIA, 1998c), is driven by a single policy instrument: a domestic carbon trading system. In this scenario, emissions in 2010 are limited by a cap defined as 24% above 1990 levels. (EIA also models scenarios that reduce carbon emissions to +9%, -3%, and Ð7%. These other cases are not described here because their costs are significantly higher.) It is assumed that the domestic carbon trading system is phased in beginning in 2005. 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) in 2010. 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 introduction of carbon prices in 2005 in the 1990+24% scenario lowers the demand for energy services due to both the direct effect of higher energy prices on energy markets and the indirect effect of higher energy prices on the economy. There is also greater adoption of more efficient equipment and increased use of low-carbon fuels. U.S. coal consumption is significantly lower, while petroleum consumption decreases by a modest 2%. Thus, the analysis suggests that a small increase in oil prices from the domestic carbon trading system would have a minimal impact on vehicle efficiencies.

Consumption of natural gas, nuclear power, and renewable energy is higher, primarily for electricity generation.

In EIAÕs **ÒEarly StartÓscenario** (EIA, 1999c), it is assumed that a domestic carbon trading program is phased in beginning in 2000. This earlier start date smooths the transition of the economy to carbon reduction targets in 2008-2012. Other assumptions of the analysis are the same as in the EIA study described above (EIA, 1998c). The earlier start date reduces the carbon prices in 2010 from $67 (1996$) to $62 per MtC in the 1990+24% case. With the early start, actual GDP begins to rebound back toward its level in the Reference case sooner, and the recovery is smoother than in the case with a 2005 start date. Thus, the early start case involves a tradeoff. Its peak impacts are less severe, but they occur earlier than with the 2005 start. Net present value calculations show that the cumulative discounted impacts are larger in the early start cases.

The primary differences between these two EIA analyses and the present study are that the 1990+24% scenarios achieve their carbon reductions through a domestic carbon trading system, that is modeled as a carbon tax. We have seen in our analysis that carbon permits 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 Ð such as appliance standards and voluntary agreements Ð to achieve demand reductions, and thus has not needed such high carbon permit prices. The EIA study also did not assume increased RD&D programs, while the CEF study assumes significantly increased RD&D resources, with resulting technology improvements in all sectors of the economy, especially in the transportation.

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 dioxide emissions. This focus results from these facts:

- Although the United States faces many energy and environmental issues, 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 dioxide 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 permits 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 non-CO_2 greenhouse gas emissions, carbon sink development, local air pollution emissions, or 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 studyÕs modeling to a near-term (2020) timeframe to better represent specific policy opportunities and impacts. This timeframe is also consistent with the use of NEMS, which extends only through 2020. One result of ÒtruncatingÓ 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, ÒRemaining Analysis Needs,Ó 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. More detailed documentation of program impacts is needed 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 trading 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 marketÕs capacity to innovate. In particular, studies by Porter and others strongly suggest that, given flexibility and policy signals that ÒsteerÓ rather than ÒrowÓ (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 studyÕs 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 timeframes, 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 climate change, 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 permit transfer payments.

This report has developed a variety of scenarios. None of them Ð including the BAU scenario Ð 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.

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 timeframe. All of the conclusions are, of necessity, tinged by the uncertainty that is inherent in any discussion of the future.

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 todayÕs 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 emerge 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 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 permit value. We have analyzed $25/tC and $50/tC cases and 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. Two very different types of uncertainties relating to this reduction. First is the issue of whether and under what circumstances a policy leading to an increase in energy prices, through a domestic carbon trading system, 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 gasÐfired plants under different carbon permit prices. 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 domestic carbon trading system 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).

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?

These questions have no simple answers. The authors of the report view the cases as plausible Ðthat is, nothing in them violates our knowledge of energy technologies or markets. Of the considerable uncertainties, first and foremost is political feasibility. Even more than the Moderate scenario with a carbon permit price, 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 Ðclear evidence of climate change, new scientific findings, international pressures Ðthe 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 Ðeither cost or performance Ðare 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 timeframe 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 Ðgovernment and private sector Ðinvests 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 agree to reduce 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 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. 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 40% from 1997 levels). This would dramatically and adversely affect the coal industry and its related transportation modes (rail and barge). Other industries Ð natural gas, renewables, and providers of energy efficiency Ðwould 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 more plausible than if there is a substantial net cost to society. The results suggest that society might 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.) It is also 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, a variety of viewpoints are possible in the Advanced scenario. The authors believe that it could happen only 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 plausible? Will the advances take place in the timeframe that we anticipate? Will the policies work as well as we expect? To some, the likelihood of ÒyesÓ 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 Ð 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 Ð on policies to remove market and organizational barriers, programs to facilitate deployment, and technology development. These are all key ingredients of a clean energy future.

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Chapter 2

INTRODUCTION AND BACKGROUND[1]

This chapter begins by providing background on climate change. It then describes recent energy and CO_2 emission trends in the United States (Section 2.2), so that the "clean energy future" scenarios can be placed into an historical context. Section 2.3 characterizes and explains the nation's energy efficiency gap: the existence of numerous untapped opportunities for cost-effective energy-efficiency investments. This section includes an overview of the market imperfections and institutional barriers that cause this gap. The government role and the rationale for public policies and programs are described in Section 2.4. The chapter ends by highlighting a number of past energy policy and program successes.

2.1 BACKGROUND ON CLIMATE CHANGE

According to the second assessment report of the Intergovernmental Panel on Climate Change (IPCC), the earth's surface temperature has increased about 0.2º C per decade since 1975. Further, recognizing a number of uncertainties, "the balance of evidence suggests that there is a discernible human influence on global climate" as the result of activities that contribute to the production of greenhouse gases (IPCC, 1996, p.5; see the following box). By preventing heat radiated from the sun-warmed earth from escaping into space, the increased concentration of greenhouse gases in the atmosphere contributes to climate change.

The gases that produce the "greenhouse" effect are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and a host of engineered chemicals such as hydrofluorocarbons (HFCs) and perflorocarbons (PFCs). About 90% of U. S. greenhouse gas emissions from anthropogenic sources come from energy production and use, and most (82%) of these emissions are a byproduct of the combustion of fossil fuels (EIA, 1998b, Table ES2, p. x) (Fig. 2.1).

2.1.1 The Role of Carbon Dioxide

CO_2 accounts for a majority of recent increases in the heat-trapping capacity of the atmosphere, with worldwide atmospheric concentrations of CO_2 increasing at about 0.5% annually. Anthropogenic CO_2 has resulted in atmospheric CO_2 concentrations that exceed preindustrial levels by 30%. Energy-efficient, renewable-energy, and other low-carbon technologies reduce CO_2 emissions by reducing the need for fossil fuel combustion.

The Balance of Evidence on Climate Change

"Our ability to quantify the human influence on global climate change is currently limited because the expected signal is still emerging from the noise of natural variability, and because there are uncertainties in key factors. These include the magnitude and patterns of long term natural variability and time-evolving patterns of forcing by, and response to, changes in concentrations of greenhouse gases and aerosols, and land surface changes. Nevertheless, *the balance of evidence suggests that there is a discernible human influence on global climate."*

— From the Intergovernmental Panel on Climate Change (IPCC, 1996, p. 5). *Italics added for emphasis.*

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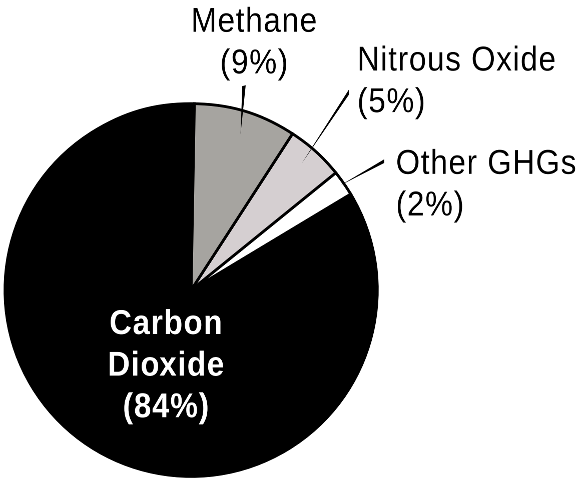
[1] Author: Marilyn A. Brown, Oak Ridge National Laboratory (ORNL).

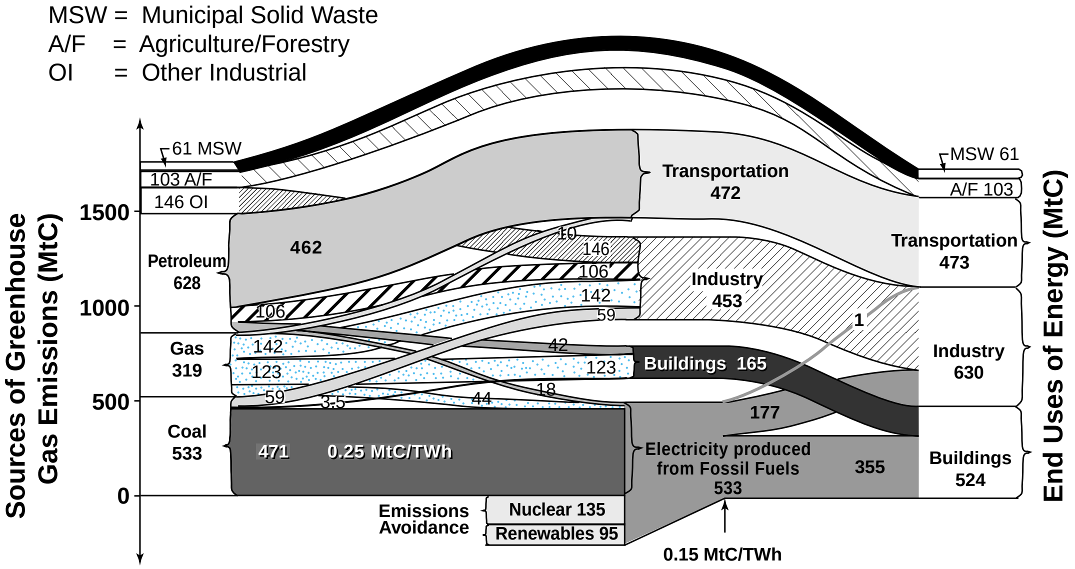
This report describes the greenhouse gas reduction benefits of its scenarios principally in terms of carbon emission reductions. Carbon dioxide units are converted into carbon units (i.e., million tonnes of carbon – MtC) by dividing by 44/12 or 3.67. This ratio is the molecular weight of carbon dioxide divided by the molecular weight of carbon[2].

Fig. 2.1 Greenhouse Gas Emissions in the United States in 1997
(Source: EIA, 1998b, Table ES2, p. x)



In 1997, human activities in the United States resulted in CO_2 emissions totaling about 1480 MtC. Emissions of other greenhouse gases in that year were equivalent to another 290 MtC, bringing total emissions in 1997 to approximately 1770 MtC. The relationships between sources of emissions and end uses of energy in the United States are portrayed schematically in Fig. 2.2. This figure illustrates the key role of energy production and use (primarily the combustion of fossil fuels) as a source of U.S. greenhouse gas emissions. Fig. 2.2 makes it clear that significant reductions in greenhouse gas emissions can be accomplished only through an assemblage of actions ranging from more effective production, distribution, and use of energy to a reliance on lower-carbon fuels.

Fig. 2.2 Sources of Greenhouse Gas Emissions and End Uses of Energy in the United States in 1997 (Source: Derived from data published in EIA, 1998a, b)



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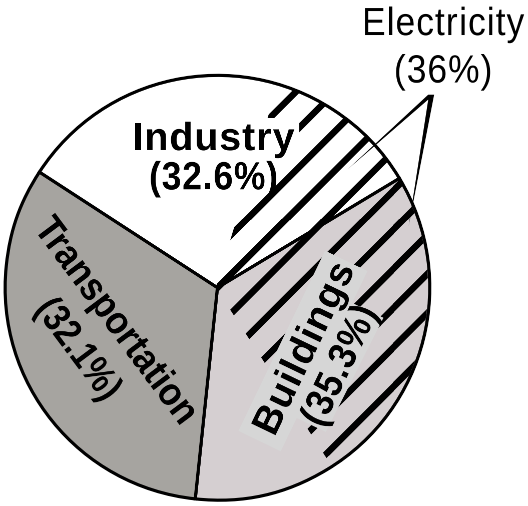
[2] This approach has been adopted for two reasons. First, carbon dioxide is most commonly measured in carbon units in the scientific community, in part because it is argued that not all carbon from combustion is, in fact, emitted in the form of carbon dioxide. Second, carbon units are more convenient for comparisons with data on fuel consumption and carbon sequestration (EIA, 1998b). Note that, in the U.S., a "ton" (sometimes referred to as a "short ton") equals 2,000 pounds; a metric ton, or "tonne," equals 1000 kilograms (approximately 2,204 pounds).

Given the magnitude of carbon emission reductions needed to stabilize atmospheric CO_2 concentrations, multiple approaches to carbon management will be needed. Such changes have the potential to transform the nation's buildings, industries, vehicles, and electricity production (Fig. 2.3).

Each of the three energy end-use sectors (buildings, industry, and transportation) account for approximately one-third of CO_2 emissions in the United States. Electricity production, which is used primarily to heat, cool, and light buildings and to power motors and other equipment in industry, produces 37% of the nation's CO_2. This diversity of sources and uses of fossil energy means that no single technological "fix" exists for reducing carbon dioxide emissions.

Fig. 2.3 CO_2 Emissions in the United States, by Source, in 1997
(Source: EIA, 1998b)



Using the framework of the 11-Lab study (DOE National Laboratory Directors, 1998), there are three options for reducing atmospheric carbon (see the following box). First, **energy efficiency** can decrease the "energy intensity" of the U.S. economy, thereby reducing carbon emissions. Energy-efficient technologies and products such as more efficient cars, trucks, and household appliances provide the same energy services using less fuel or electrical power and thereby emitting less carbon. Similarly, energy requirements can be reduced through efficient system designs, such as co-locating facilities that produce both electrical power and heat with facilities that need them. A broad array of energy-efficiency options exists.

Second, the use of **low-carbon technologies** can decrease the "carbon intensity" of the nation's energy economy, thereby reducing carbon emissions. These technologies either increase the efficiency of energy production or use fuels that emit less carbon such as renewable energy resources and nuclear power. Electricity generation from natural gas is also a low-carbon technology when compared to current coal-fired power plants; natural gas emits 13 MtC per quad of energy used compared with 25 MtC per quad for coal (EIA, 1999b, Tables A2 and A19). Biomass feedstocks offer an array of low-carbon options, including ethanol fuels, chemicals, materials, and electricity. The carbon emissions from biomass combustion are largely offset by CO_2 absorption during plant growth.

Options for Reducing Atmospheric Carbon

- Energy efficiency
- Low-carbon technologies
- Carbon sequestration
  - Sequestration of atmospheric carbon
  - Sequestration of separated carbon (pre- or post-combustion)

Third, **carbon sequestration** technologies offer another suite of approaches to reducing atmospheric concentrations of CO_2. Carbon sequestration can include various ways of (1) removing CO_2 from the atmosphere and storing it or (2) keeping anthropogenic carbon emissions from reaching the atmosphere by capturing and diverting them to secure storage (U.S. Department of Energy, Office of Science and Office of Fossil Energy, 1999). Most approaches to "carbon sequestration" will require considerable additional research to ensure their successful development and acceptance. However, in the long-term, they could play significant roles. We describe carbon sequestration options in more detail in the discussion of future energy R&D in Chapter 8. Because of the longer-term time frame of most carbon sequestration approaches, energy efficiency improvements and the use of low-carbon technologies are the principal approaches assessed in this report.

In addition to analyzing methods for reducing atmospheric concentrations of carbon dioxide in order to mitigate global climate change, strategies to adapt to climate change are also being explored by scientists (Smith and Lenhart, 1996). Adaptation refers to adjustments in practices, processes, or systems to projected or actual changes in climate. A range of these is listed in the box below. As with most approaches to carbon sequestration, adaptation approaches would require significant R&D. In addition, many of these approaches could require fundamental changes to manmade and natural systems. Adaptation to climate change as a whole has been understudied. Where it is addressed, it is often by analogy, arguing that current adaptations to droughts, floods, pests, and other natural hazards provide a pattern of adaptive response for future climate change (Wilbanks and Kates, 1999). Further evaluation of adaptation options is needed but is well beyond the scope of this study.

Adaptation Strategies

Adaptation refers to adjustments in practices, processes, or systems to projected or actual changes in climate. Adaptation can be spontaneous or planned, and can be carried out in response to or in anticipation of changes in conditions. Some of the adaptation pathways that have been discussed to date include:

- strengthening physical infrastructures (e.g., hardening seacoast structures against sea-level rise),
- strengthening information infrastructures (e.g., early warnings of potential disruptive changes),
- strengthening institutional infrastructures (e.g., emergency preparedness),
- geoengineering to mitigate climate change impacts (e.g., accelerating the adaptation of natural biosystems, genetic engineering of crops and forests, long-distance water transfers), and
- geoengineering to reduce climate change without reducing emissions (e.g., orbiting reflecting panels, changing the path of the Gulf Stream).

2.1.2 Other Greenhouse Gas Emissions

In order to compare the effect of different greenhouse gases, scientists have invented the Global Warming Potential (GWP) scale. The GWP is an attempt to provide a simple measure of the relative radiative effects of the emissions of various greenhouse gases. Using the GWP, all greenhouse gases are compared to the effect of one molecule of CO_2. While any time period can be selected, 100-year GWPs are used by the IPCC and the United States, and are therefore used here[3]. The GWP of CO_2 is one.

Although non-CO_2 emissions of greenhouse gases are small by weight, they have 100-year GWPs that range from 21 for methane to 23,900 for sulfur hexafluoride (SF_6). Fig. 2.4 shows the relative contribution of these other gases in MtC equivalent units. The largest non-CO_2 greenhouse gas contribution is from methane, which was responsible for the equivalent of 180 MtC in 1997. Next is nitrous oxide (N_2O), which was responsible for 109 MtC equivalent and has a GWP of 310. Various halocarbons and other engineered chemicals (i.e., HFCs, PFCs, and SF_6) contributed 37 MtC equivalent

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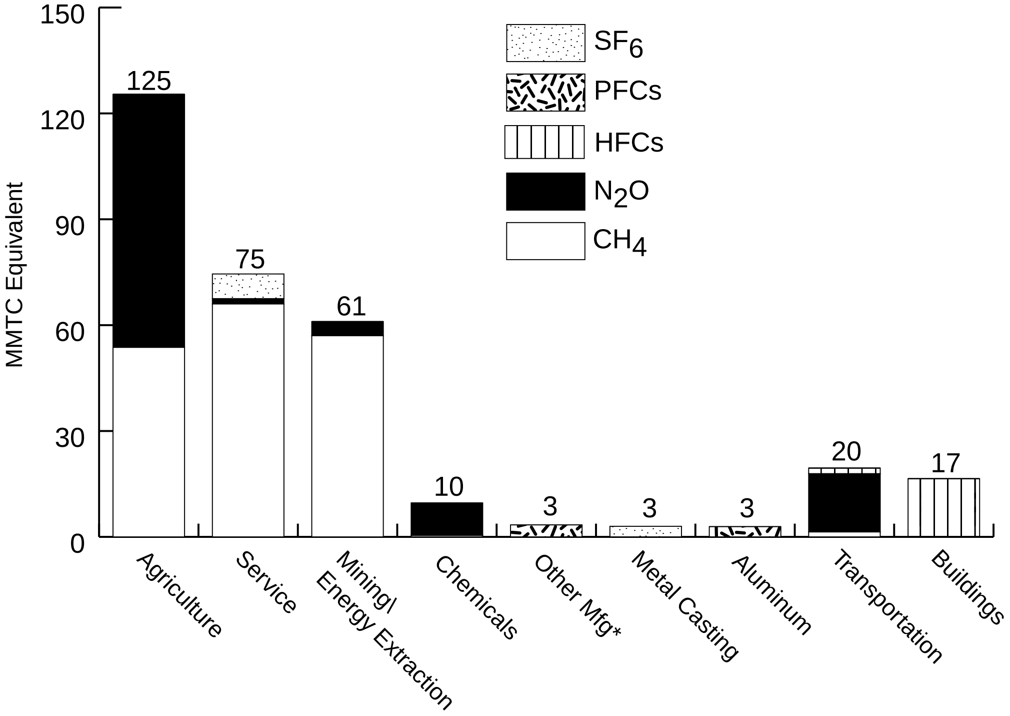
[3] Specifically, the GWP of a greenhouse gas is the ratio of global warming, or radiative forcing (both direct and indirect), from one unit mass of a greenhouse gas to that of one unit mass of carbon dioxide over 100 years.

in 1997. The rapidly growing emissions of these engineered chemicals is a source of concern; in 1990 their emissions were estimated to be only 22 MtC (EPA, 1999a, Tables ES-9 to ES-11). Many of these engineered chemicals are emitted not only in energy-intensive industries but also in "high-tech" and service industries, which are expanding rapidly.

Fig. 2.4 Emissions of Non-CO_2 Greenhouse Gases by End-Use Sector and Industry

[(Sources: EIA (1998b) Tables 15, 25, and 30, and pp. 54-56, and EPA (1999a) Table ES-11)]



*Mainly semiconductors

This report does not conduct original research on the potential for reducing non-CO_2 greenhouse gases. However, a brief review of the literature is provided in Appendix E-6 in an effort to characterize what is known about cost-effective reduction opportunities that could complement the carbon-reduction potential of energy-efficient and low-carbon energy technologies. Specifically, Appendix E-6 provides a perspective on the current and projected emissions of these gases, outlines the potential methods for achieving emissions reductions for various sources, and summarizes a number of recent studies on the costs of reductions for both the U.S. and other countries. This review suggests that a reduction in non-CO_2 emissions of approximately 128 MtC equivalent can be achieved at $50/tonCE in 2010 (excluding carbon sinks). Further, it shows that including the full basket of gases could lower overall greenhouse reduction costs compared to a scenario that is limited only to carbon dioxide. Reilly, et al. (1999) support this finding, concluding that "inclusion of sinks and abatement opportunities from gases other than CO_2 could reduce the cost of meeting the Kyoto Protocol by 60%." Hayhoe, et al. (1999) come to a similar conclusion.

2.1.3 The United Nations Framework Convention on Climate Change and the Kyoto Protocol

The United States has entered into a global effort to stabilize atmospheric concentrations of greenhouse gases, the long-term objective of the U.N. Framework Convention on Climate Change. Predictions of global energy use in the next century suggest a continued increase in carbon emissions and rising concentrations of carbon dioxide in the atmosphere unless major changes are made in the way we produce and use energy. For example, the Intergovernmental Panel on Climate Change (IPCC, 1992) predicted in its "IS92a" scenario that future global emissions of CO_2 to the atmosphere will increase from approximately 7 billion tonnes of carbon (GtC) per year in 1990 to about 21 GtC/year by 2100. This same scenario also projects a doubling of atmospheric CO_2 concentration by 2050, with accelerating rates of increase beyond that. Although the effects of increased CO_2 levels on global climate are uncertain, many scientists agree that a doubling of atmospheric CO_2 concentrations could have a variety of serious environmental consequences.

In December 1997 in Kyoto, Japan, 160 nations reached agreement on an historic step to control greenhouse gas emissions. The Kyoto Protocol set differentiated GHG-reduction targets for key industrial powers ranging from 10% above (Iceland) to 8% below (European Union) baseline levels (1990 and 1995, depending on the gas and aggregated using GWPs). The time frame for meeting the agreement's goals was set at 2008-2012. The United States agreed to a 7% reduction from its baseline levels, a goal that must be ratified by the U.S. Senate prior to implementation. When various accounting rules for the set of six gases are factored in, and when offsets for activities that absorb carbon dioxide are considered, the level of effort required of the U.S. has been estimated to be a 3% real reduction below 1990 levels by 2008-2012 (Eizenstat, 1998).

Some of this goal could be met through the international trading of carbon permits, which is provided for in the Kyoto Protocol. Discussion of international options is beyond the scope of this study, which focuses strictly on domestic opportunities for carbon dioxide reductions. This study does not model the international trading of emission permits, nor does it assess the link between any U.S. carbon price and the international market-clearing price of carbon permits. However, extensive literature indicates that international trading opportunities lower the cost of meeting reduction targets compared to domestic-only approaches (Council of Economic Advisers, 1998; Edmonds, et al., 1999; Weyant and Hill, 1999).

2.2 HISTORICAL ENERGY AND CO_2 *EMISSION TRENDS*

2.2.1 National Trends

In the era of low energy prices preceding the early 1970s, the energy efficiency of many household, transportation, and industrial technologies in the United States improved very little. As a result, the nation's energy demand and gross domestic product (GDP) grew in lock step: a 3% annual increase in GDP meant a 3% annual increase in energy demand. There was a widespread view in the United States that this linkage was unchangeable, that energy was essential for economic growth. There was little recognition that energy efficiency could break that link without sacrificing economic vitality. By 1973, the nation's energy budget had grown to 74 quadrillion Btu.

The inextricable connection between energy and economic growth came to an abrupt end with the oil embargo of 1973-74. From 1973 to 1986, GDP grew 35% in real terms. During this same period the nation's consumption of primary energy rose and fell twice in response to energy price signals, policy changes, and other fluctuations, but averaged about 74 quads[4]. Relative to previous decades, it was an

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[4] Primary energy is the energy recovered or gathered directly from nature. It includes mined coal, produced crude oil and natural gas, collected biomass, harnessed hydropower, solar energy absorbed by collectors, and heat produced in nuclear reactors. For the most part, primary energy is transformed into electricity or fuels such as gasoline, jet fuel, heating oil, and charcoal. These are called secondary energy resources. The end-use sectors of the energy system provide energy services such as illumination, air conditioning, refrigerated storage, transportation and consumer goods using both primary and secondary energy.

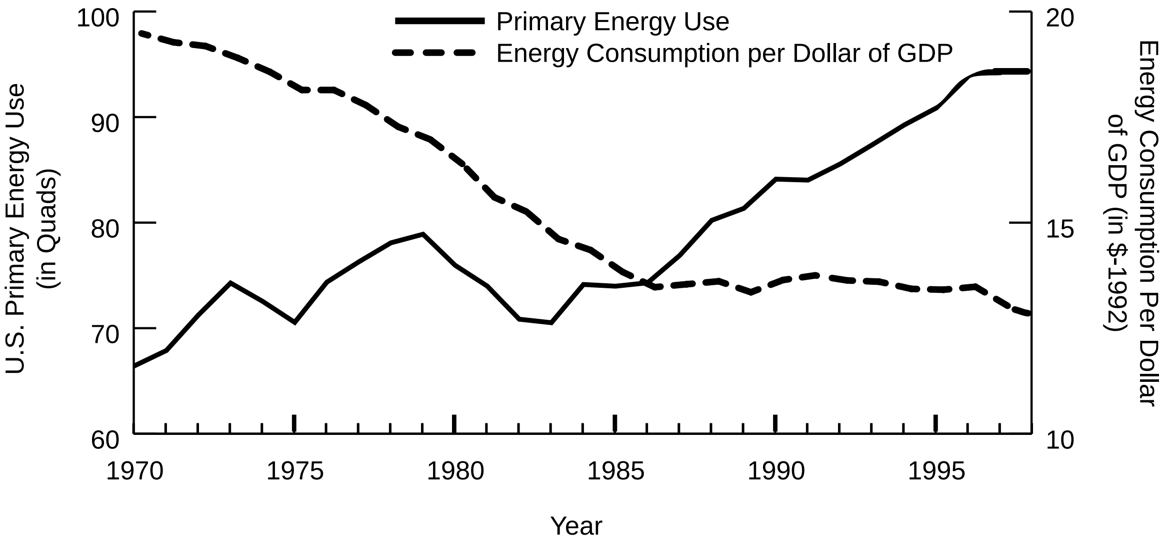
energy-conscientious period. Americans purchased more fuel-efficient cars and appliances, insulated and caulked their homes, and adjusted thermostats. Businesses retrofitted their buildings with more efficient heating and cooling equipment and installed energy management and control systems. Factories adopted more efficient manufacturing processes and purchased more efficient motors for conveyors, pumps, fans, and compressors. Rapid technological advances enabled many of these improvements. These investments were motivated partly by higher energy prices, but they were also encouraged by federal and state policies that were enacted and implemented to promote energy efficiency and to reduce oil dependency.

Two factors enabled the avoidance of energy increases during this period: energy efficiency and structural economic changes including declines in energy-intensive industry and increases in the service sector. An analysis by DOE (1995) concluded that energy efficiency contributed approximately twice as much to this trend as did structural changes. The energy efficiency improvements were caused by higher energy prices, government policies and programs, the availability of more efficient technologies, and other factors such as behavioral changes resulting from concerns about an energy crisis. It has been estimated – but with a very high degree of uncertainty – that through 1981 higher prices might have been responsible for about two-thirds of the efficiency-induced energy savings (Hirst, Marlay, Greene, and Barnes, 1983).

The gains in energy productivity achieved by the United States during this period represent one of the great economic success stories of this century (Fig. 2.5). The extent that the U.S. economy improved its energy productivity can be quantified by examining the relationship between total energy consumption and GDP. In 1970, nearly 20 thousand Btu of energy were consumed for each (1992) dollar of GDP. By 1986, the energy intensity of the economy had dropped to 14 thousand Btu of energy per (1992) dollar of GDP (EIA, 1999a, p. 13).

This information shows unambiguously that improved energy efficiency played a dominant role (along with important contributions from changes in the structure of the economy) in achieving zero energy growth over this 13-year period. Looking ahead, an actual decrease in U.S. energy consumption over the next ten years would be required if the United States were to meet its Kyoto Protocol goals through domestic reductions alone (i.e., without international trading). Yet the inducement of high real energy prices does not exist (with the exception of periodic oil price fluctuations), and government energy RD&D has been scaled back.

Fig. 2.5 Energy Consumption Per Dollar of Gross Domestic Product: 1973-1995 (Source: EIA, 1999a, Table 1.5)



Starting in 1986, the nation has benefited from declining real energy prices – a trend that has largely continued to the present. Some of this price decline may have resulted from the deregulation of some energy markets. It may also have resulted to some unquantifiable extent from public- and private-sector R&D, which has led to steady improvements in energy exploration and production technologies. Finally, energy efficiency gains have helped dampen the demand for energy, placing downward pressures on prices.

Government investments in energy R&D and deployment programs grew rapidly following the oil embargo until 1980 when they experienced dramatic decreases. To illustrate, consider the timeline of funding for DOE's Office of Energy Efficiency and Renewable Energy (EE/RE). In 1980, the EERE appropriations reached a peak of approximately \$2.8 billion (in \$1995); this was followed by a ten-year decline in EERE appropriations. By 1989 the EERE budget had decreased to \$700 million (in \$1995). Throughout the 1990s the EERE appropriations have averaged approximately \$800 million per year (in \$1995), growing to their current level of \$1.068 billion (in \$2000).

Declining energy prices and energy efficiency R&D expenditures have contributed to a renewal of the relationship between growth of the economy and growth in energy use, which has increased from 74 quads in 1986 to 94 quads in 1997. As a result, the energy intensity of the economy has remained steady at about 13 thousand Btu per (1992) dollar of GDP. If the forecasted strong increases in GDP through 2010 are realized, and if this is combined with decreases in electricity prices and only slight increases in oil and natural gas prices (as forecasted at the time of this analysis), energy demand is predicted to reach 111 quads in 2010 (EIA, 1999b, p. 148, Table B2). While this represents a decrease in the energy intensity of the economy [to 11 thousand Btu of energy per (1992) dollar of GDP], it represents an increase in energy consumption and carbon emissions. The challenge is to curb the increase in energy demand and reduce the carbon content of the fuels used, while enabling the economy to continue to grow.

2.2.2 Sectoral Trends

The past quarter century has seen significant differences in energy consumption trends in buildings, industry, and transportation (Tables 2.1 and 2.2). For instance, during the 1973-86 period when the country's primary energy use was steady at 74 quads, energy use in buildings and transportation increased by 2.7 quads and 2.2 quads respectively. Over the same period, industry experienced a compensating decline of 4.9 quads, partly due to intersectoral shifts toward less energy-intensive service industries, a slowdown in manufacturing output, and investments in energy conservation.

Table 2.1 Primary Energy Use and Carbon Emissions from Fossil Energy Consumption: 1973-1997

	1973	1986	1990	1995	1997
Energy Use (in Quads):					
Buildings	24.1	26.9	29.5	32.3	33.6
Industry	31.5	26.6	32.1	34.5	35.8
Transportation	18.6	20.8	22.5	24.1	24.9
Total	74.3	74.3	84.1	90.9	94.4
Total carbon emissions from energy (in MtC)	**1260**	1240	1346	1412	1480

Sources: Energy use estimates are from EIA (1999a, Table 2.1, p. 37). Carbon emissions estimates for 1990, 1995, and 1997 are from EIA (1998b, p. 21). Carbon emission estimates for 1973 and 1986 were derived using factors for carbon emissions from combustion of oil, natural gas, and coal for 1990.

Over the entire period from 1973 to 1997, energy use increased in buildings from 24.1 to 33.7 quads (40%); in industry, from 31.5 to 35.7 quads (13%); and in transportation, from 18.6 to 24.8 quads (33%). As shown in Table 2.3, the rate of growth in energy use in buildings and transportation was relatively steady from 1973 to 1997, compared with the industrial sector. The growth rates for these two sectors were less than 1% per year from 1973 to 1986, and between 1.3% and 2.5% per year from 1986 to 1997. These increases reflect population growth as well as larger residential square footage and more vehicle miles traveled per capita. Growth in energy demand in industry, in contrast, has been much more volatile. Industry experienced substantial declines in energy use from 1973 through 1986 when energy prices were rising. It then experienced an increase of 4.8% per year from 1986 to 1990 and relatively small annual increases since then, reflecting flat or falling prices.

Table 2.2 Change in Energy Use and Carbon Emissions: 1973-1997

	Change from 1973 to 1997:		**Change from 1990 to 1997:**	
Energy Use:	**Change in Quads**	**Percentage Change**	**Change in Quads**	**Percentage Change**
Buildings	9.6	39.8	4.2	14.2
Industry	4.2	13.3	3.6	11.2
Transportation	6.2	33.3	2.3	10.2
Total	19.9	26.8	10.1	12.0
Carbon emissions:	**MtC**	**Percentage**	**MtC**	**Percentage**
Total	220	17.5	134	10.0

Table 2.3 Historical Growth Rates: 1973-1997

Energy Use:	**AAGR 1973-97**	**AAGR 1973-86**	**AAGR 1986-90**	**AAGR 1990-95**	**AAGR 1995-97**
Buildings	1.41%	0.85%	2.25%	1.77%	2.46%
Industry	0.14%	-1.31%	4.81%	1.45%	1.72%
Transportation	1.32%	0.86%	2.10%	1.29%	1.44%
Total	0.89%	0.0%	3.18%	1.48%	1.97%
Carbon emissions	0.67%	–0.12%	2.03%	1.16%	1.95%

AAGR = Average Annual Growth Rate

The growth of carbon emissions during the period roughly follows that of energy demand growth. Table 2.1 shows estimated carbon emissions from 1973 to 1997. Like energy, carbon emissions were flat between 1973 and 1986. The increase in the fraction of coal in the final mix from 17.5% in 1973 to 23.2% in 1986 was offset by the increasing fraction of primary energy from nuclear power, from 0.1% in 1973 to 6.0% in 1986. From 1986 to 1997, carbon emissions grew more slowly than energy consumption. This was a result of an increase in the share of natural gas from 22.5% in 1987 to 25.4% in 1997 and the continued growth of nuclear power. Over the same period there was a small decrease in the consumption of coal (23.3% to 22.5%) and a larger decrease in petroleum use (43.3% to 39.7%).

2.3 THE ENERGY EFFICIENCY GAP

The discussion of national energy trends following the 1973-74 oil embargo highlighted the great strides in energy efficiency that have made the U.S. economy much less energy intensive today than it was in

1970. Nevertheless, numerous engineering-economic studies have identified many potential investments in energy efficiency that appear to be cost-effective, but which remain unexploited (Interlaboratory Working Group, 1997; Office of Technology Assessment, 1991; National Academy of Sciences, 1992; Tellus Institute, 1997). This would not be surprising if a relatively small number of such investments were identified, or if only a small portion of future energy growth were to be prevented by making these investments. However, a large number of so-called "bottom-up" analyses[5] indicate the continued existence of a sizeable untapped reservoir of highly cost-effective investments that could have a significant impact on U.S. energy efficiency.

If energy-efficient technology is cost-effective, why doesn't more of it just happen? If individuals or businesses can make money from energy efficiency, why don't they all just do so? Assuming the empirical data show that a significant proportion of truly cost-effective and efficient technologies are not adopted, why does their cost-effectiveness fail to propel them to commercial success? Conversely, if consumers and businesses are not taking actions to bring about energy efficiency, then perhaps these reports of widespread untapped energy efficiency opportunities are exaggerated? Is it possible that these opportunities carry liabilities (e.g., different labor skill requirements) and costs (e.g., greater maintenance or program administration costs) that are simply hidden or are difficult to quantify? Are other characteristics (other than cost) more important?

The following sections provide evidence that sizeable cost-effective opportunities for energy efficiency improvements exist in the economy. First we look at individual technology case studies that present compelling evidence of an efficiency gap. Next we describe a range of market failures and institutional barriers that explain the existence of this gap. Then we characterize sector differences in market failures and barriers. This lays the groundwork for discussing the government's role and the rationale for public policies and programs.

2.3.1 Case Studies of Individual Technologies

Many different case studies could be cited showing that consumers and businesses often choose not to purchase highly cost-effective energy technology. The technologies in these examples were clearly superior to the technologies being replaced and no significant "hidden costs" to the consumer could be identified.

Electronic ballasts for fluorescent lighting have been commercially available since 1976. They were a well-tested technology, with performance characteristics equal to or better than standard ballasts by the early 1980s, if not earlier. By 1987, five states—including California and New York—had prohibited the sale of standard ballasts. But the remaining three-quarters of the population chose standard ballasts over efficient ballasts by a ratio of 10-to-1, even though the efficient electronic ballast paid back its investment in less than two years for virtually all commercial buildings (Koomey, Sanstad, and Shown, 1996). The time required to establish retail distribution service networks and to gain consumer confidence are typical causes of slow innovation diffusions such as this. (Since 1990, federal standards have prohibited the sale of the standard ballast.)

Meier and Whittier (1983) studied a case in which consumers were given a choice in stores throughout the United States of two **refrigerators** that were identical in all respects except two: energy efficiency and price. The energy-efficient model (which saved 410 kilowatt hours per year, more than 25% of

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[5] Previous assessments of the potential for U.S. carbon reductions use either top-down or bottom-up models. Top-down studies are based on aggregate economic analysis which places energy supply and demand in the context of the entire economy. Bottom-up studies have been based on engineering analysis of specific energy efficiency or renewable energy technology options (Jaccard and Montgomery, 1996).

energy usage) cost $60 more than the standard model. The energy-efficient model was highly cost-effective in almost all locations of the country. In most regions, it provided an annual return on investment of about 50%. In spite of these favorable economics, which were easily observed by the purchaser, more than half of all purchasers chose the inefficient model because first cost mattered more than life-cycle cost.

Using data from EPA's Green Lights Program, DeCanio (1998) has shown that there is a large potential for profitable energy-saving investments in **lighting** that is not being realized because of impediments that are internal to private and public-sector organizations. While economic forces play a role, economics alone cannot explain either the level of or the variation in returns to energy-efficient lighting investments. Impediments include capital rationing and lack of organizational rewards for energy managers who reduce utility bills.

Industrial motor systems represent the largest single end use of electricity in the American economy—23% of U.S. electricity consumption—and they present a very substantial energy-efficiency potential. The results of a recent market assessment involving on-site surveys of 265 industrial facilities document that technologies offering a simple payback of 3 years or less can typically save businesses 11% to 18% of the energy used to drive motors (Xenergy, Inc., 1998). DOE's Motor Challenge program conducts audits, demonstrations and technical assistance to encourage the use of proven, cost-effective technologies to improve industrial motor systems. Monitoring and validation of energy use data from these activities confirm the profitability of these investments, underscoring the large gap between current practice and potentially economically smart investments. Limited information, expertise, and capital all contribute to the existence of this gap.

2.3.2 What Accounts for the Energy Efficiency Gap?

The existence of a range of market failures and institutional barriers helps to explain the efficiency gap. "Market failures" occur when there is a flaw in the way markets operate. Such failures include (1) where there are misplaced incentives; (2) where distortionary fiscal and regulatory policies exist; and (3) where there are unpriced effects (so-called externalities – see the side box) such as air pollution (Jaffe and Stavins, 1994; IPCC, 1996).

"Market barriers" refer to obstacles that are not based on market failures but which nonetheless contribute to the slow diffusion and adoption of energy-efficient innovations (Jaffe and Stavins, 1994, Hirst and Brown, 1990, Levine et al., 1995, and U.S. Department of Energy, Office of Policy and International Affairs, 1996b). To the extent that it is in society's best interest to use its energy more efficiently and to reduce

Externalities and Public Goods

Externalities are goods or services that people consume as byproducts of other people's activities. They are called externalities because they are "external" to market transactions and are therefore unpriced. When the externalities are "positive," people benefit from their consumption without having to pay. As a result, positive externalities tend to be under-produced. When the externalities are negative, the individual's well-being is compromised and, from a societal perspective, too much is produced.

A public good is some good or service that has two principal characteristics. First, one person's consumption of it does not reduce the amount of it available for other people to consume. This characteristic is called "inexhaustibility." Second, once such a good is provided, it is difficult to exclude other people from consuming it, a characteristic called "nonexcludability."

emissions from fossil fuel combustion, it is important to understand the full range of obstacles to clean energy technologies. The following generic barriers are discussed below: (1) insufficient and incorrect information, (2) low priority of energy issues, (3) capital market imperfections, and (4) incomplete markets for energy-efficient features and products.

Many of these failures and barriers, along with other sector-specific barriers, are discussed in subsequent chapters with respect to specific technologies and markets. Such failures and barriers also occur in other parts of the economy, impeding the market entry and uptake of numerous new technologies. We do not cover the literature documenting the other types of "technology gaps" that result. Instead, we provide a short summary of each of the market failures and barriers, listed above, that produce the energy efficiency gap.

Market Failures. Misplaced incentives inhibit energy-efficient investments in each of the sectors. Homeowners and apartment dwellers often must use the energy technologies selected by architects, engineers, and builders who seek to minimize first costs. Industrial buyers choose the technologies that are used in the production process and are mainly concerned with availability and the known dependability of standard equipment. Specialists write product specifications for military purchases that limit access to alternatives. Fleet managers select the vehicles to be used by others. The involvement of intermediaries in the purchase of energy technologies limits the ultimate consumer's role in decision making and leads to an under-emphasis on life-cycle costs (DOE, 1996b). For example, if a landlord buys the energy-using equipment while the tenants pay the energy bills, the landlord is not incentivized to invest in efficient equipment unless the tenants are aware of and express their self-interest. Thus, the circumstance that favors the efficient use of equipment (when the tenants pay the utility bills) leads to a disincentive for the purchase of energy-efficient equipment. The case that favors the purchase of efficient equipment (when the landlord pays the utility bills) leads to a disincentive for the tenants to use energy efficiently.

Distortionary fiscal and regulatory policies can also restrain the use of efficient and clean energy technologies. A range of these market imperfections was recently identified in an analysis of 65 projects aimed at installing distributed generation (Alderfer, Eldridge, and Starrs, 2000). Distributed power is modular electric generation located close to the point of use. It includes environmentally-friendly renewable energy technologies such as wind turbines and photovoltaics, as well as highly efficient fossil-fuel technologies such as gas turbines and fuels cells. Regulatory barriers identified in this survey include prohibitions against uses of distributed energy resources other than emergency backup when disconnected from the grid and state-to-state variations in environmental permiting requirments that result in significant burdens to project developers. Tariff barriers include buyback rates that do not provide credit for on-peak production and backup and standby charges that can be excessive.

Unpriced effects are usually thought of in terms of negative impacts from the production, distribution, and use of energy. Because energy prices do not include the full cost of environmental externalities, they understate the societal cost of energy. Likewise, because public goods are unpriced, markets tend to under produce them. Economists have long noted that private-sector investments in R&D are insufficient from a public perspective because they do not reflect societal benefits. There is little disagreement about these statements in principle; at the same time, there is considerable disagreement about the magnitude of external costs and whether or how they should be incorporated into energy markets.

Market Barriers. Suboptimal investments in energy efficiency often occur as the result of **insufficient and incorrect information**. Market efficiency assumes free and perfect information, although in reality information can be expensive and difficult to obtain – in the energy sectors as elsewhere. The time and cost of collecting information is part of the transaction costs faced by consumers. Where the consumer is not knowledgeable about the energy features of products and their economics (for any of a large number of reasons, including technical difficulties and high costs of obtaining information) investments in energy efficiency are unlikely. For example, residential consumers get a monthly electricity bill that provides no breakdown of individual end-uses. Similarly, the price paid for different levels of vehicle fuel economy is buried in base prices or in the price of complete subsystems such as engines. Further, efficiency differences are coupled with substantive differences in other critical consumer attributes such as acceleration performance, level of luxury, and vehicle handling. This is analogous to shopping in a supermarket that has no product prices; if you get only a total bill at the checkout counter, you have no idea what individual items cost. Supermarkets, of course, have copious price labeling; household utility bills, in contrast, do not.

Decision-making complexities are another source of imperfect information that can confound consumers and inhibit “rational” decision-making. Even while recognizing the importance of life-cycle calculations, consumers often fall back to simpler first-cost rules of thumb. While some energy-efficient products can compete on a first-cost basis, many of them cannot. Properly trading off energy savings versus higher purchase prices involves comparing the time-discounted value of the energy savings with the present cost of the equipment – a calculation that can be difficult for purchasers to understand and compute. This is one of the reasons builders generally minimize first costs, believing (probably correctly) that the higher cost of more efficient equipment will not be capitalized in the price of the building. The complexities of decision making is one form of transaction cost.

Energy efficiency is not a major concern for most consumers because energy costs are not high relative to the cost of many other goods and services. In addition, the negative externalities associated with the exploration, conversion, distribution, and consumption of many forms of energy are not well understood by the public. The result is that the public places a **low priority on energy issues** and energy efficiency opportunities. In turn, this reduces producer interest in providing energy-efficient products.

Capital market barriers can inhibit efficiency purchases. Different energy producers and consumers have varying access to financial capital, and at different rates of interest. In general, energy suppliers can obtain capital at lower interest rates than can energy consumers – resulting in an “interest rate gap.” Differences in these borrowing rates may reflect differences in the knowledge base of lenders about the likely performance of investments as well as the financial risk of the potential borrower. At one extreme, electric and gas utilities are able to borrow money at low interest rates. At the other extreme, low-income households may have essentially no ability to borrow funds, resulting in an essentially infinite discount rate for valuing improvements in energy efficiency. The broader market for energy efficiency (including residential, commercial, and industrial consumers) faces interest rates available for efficiency purchases that are also much higher than the utility cost of capital (Hausman, 1979; Ruderman et al, 1987; Ross, 1990). Information gaps, institutional barriers, short time horizons, and non-separability of energy equipment all contribute to this gap, and each is amenable to policy interventions that could move the rates down towards auto-loan, mortgage, and opportunity costs.

Incomplete markets for energy efficiency are often a serious obstacle. Energy efficiency is generally purchased as an attribute of a product intended to provide some other service. Fuel economy in automobiles, for example, is one of a large number of features that come in a package for each make and model. If higher fuel economy were treated as an optional item, available at a higher price, then consumers would have a choice of efficiency levels. But such a separate choice does not presently exist. Circumstances often constrain choices of efficiency. For example, the complexity of design, construction, and operation of commercial buildings provide powerful disincentives to producing an efficient building (Lovins, 1992).

As a result of this host of market failures and barriers, the discount rate that consumers appear to use in making many energy efficiency decisions is higher than the interest rate at which consumers could borrow money. This discount rate gap has been widely observed in the literature and is reflected in some key energy models such as the National Energy Modeling System.

2.3.3 Sectoral Differences in Market Failures and Barriers

Each end-use sector functions differently in the U.S. energy marketplace. One of the reasons for this variation is the distinct market structure for delivering new technologies and products in each sector. Residential and commercial building technology is shaped by thousands of building contractors and architectural and engineering firms, whereas the automotive industry is dominated by a few manufacturers. As a result, the principal causes of energy inefficiencies in manufacturing and transportation are not the same as the causes of inefficiencies in homes and office buildings, although there are some similarities (Hirst and Brown, 1990.)

For example, in the manufacturing sector, investing in cost-effective, energy-efficiency measures (which cut operating costs and therefore increase profits) is hampered by a common preference to invest resources to increase output and market share as a preferred route to expanding profits (Ross, 1990 and Sassone and Martucci, 1984). In the building sector, information gaps prevent the energy-efficient features of buildings from being capitalized into real estate prices. This is partly due to the lack of widely adopted building energy rating systems (Brown, 1997). These information gaps are less characteristic of the transportation sector, where fuel economy is well understood in terms of miles per gallon. Of course, filling an information gap does not necessarily change purchase behavior.

The end-use sectors also differ in terms of their ability to respond to changing energy prices. This is partly due to the varying longevity of the equipment that they used. For example, cars, lighting, and equipment turn over more quickly than industrial boilers. There are also differences in fuel flexibility. The U.S. transportation system today is relatively fuel-inflexible, being primarily dependent on petroleum, while portions of the buildings and industrial sectors have multiple fuel choices.

The vast differences in the R&D capability of the sectors also influence their ability to respond quickly to changing energy prices and market signals. The private sector as a whole spends more than $110 billion per year on R&D, dwarfing the government expenditure on all non-defense technology R&D (National Science Foundation, 1997). Of the private-sector R&D expenditure, the automobile manufacturers stand out – Ford alone spends more than $8 billion per year in R&D. Next comes the rest of the industrial sector. Here manufacturers account for a majority of R&D expenditures. In the buildings sector, the construction industry has virtually no indigenous R&D. The Council on Competitiveness in 1992 estimated that the construction industry spends less than 0.2 percent of its sales on R&D, far less than the 3.5% that other industries spend on average.

Finally, each of the sectors is distinct in terms of the primary societal benefits from improved energy efficiencies. Fuel economy in transportation is essential to improving air quality and protecting against oil price volatility. Energy productivity in the industrial sector is essential to economic competitiveness and pollution prevention. Energy efficiency in the buildings sector makes housing more affordable on a life-cycle basis, and is critical to reducing SO_2, NOx, and particulate matter since most of the energy consumed in buildings is fossil-generated electricity. This is yet one more reason why the Clean Energy Future's public policies and programs are customized specifically to meet the needs of each sector.

2.4 THE GOVERNMENT ROLE

The existence of market failures and barriers that inhibit socially optimal levels of investment in energy efficiency is the primary reason for considering public policy interventions. In many instances, feasible, low-cost policies can be implemented that either eliminate or compensate for market imperfections and barriers, enabling markets to operate more efficiently to the benefit of society. In other instances, policies may not be feasible; they may not fully eliminate the targeted barrier or imperfection; or they may do so at costs that exceed the benefits.

To foster energy efficiency, reducing transaction costs is particularly important. For clean energy supply technologies, addressing public externalities and public goods is especially critical. Each of the four sector chapters describes the market imperfections and barriers that prevent efficient and clean energy technologies, and links these to sector-specific public policies and programs. Some of these linkages are illustrated below.

2.4.1 Transaction Costs

Several of the problems we have discussed, particularly those related to information, can be viewed as transaction costs associated with energy decision making. Examples include the costs of gathering and processing information, making decisions, and designing and enforcing contracts relating to the purchase and installation of energy-using technology. These costs are real, in the sense that they must be borne by the consumer and should be included in the cost of the energy efficiency measure. A key question is whether there are institutional interventions that can reduce these costs for individual consumers. For example, the time and effort required to find a refrigerator that has a cost-effective level of energy efficiency can be significant.

Information programs (e.g., product ratings and labeling) and technical assistance (e.g., industrial energy assessments) can help make up for incomplete information by reducing the consumer’s cost of acquiring and using needed information. They can also simplify decision making and can help consumers focus on energy issues which may seem small to an individual consumer but which can be large from a national perspective.

Weatherization assistance directly addresses the lack of access of low-income households to capital. Programs that support financing through energy services companies and utilities also address this barrier. More indirectly, but just as important, technology demonstrations provide financial markets with evidence of performance in the field, which is critical to reducing the cost of capital. For instance, electric utility companies in many regions have demonstrated the value of advanced lighting technologies through various incentive programs that have subsequently led to the widespread acceptance of these products (Levine and Sonnenblick, 1994) and the increased availability of financing through mechanisms such as energy-saving performance contracts.

2.4.2 Externalities and Public Goods

Many of the nation’s energy and environmental challenges are related to the existence of externalities and public goods. These market imperfections can be addressed through public policies and programs that bring market choices more fully in line with full costs and benefits.

The consumption of fossil energy using today’s conversion technologies produces a variety of negative externalities including greenhouse gas emissions; air, water, and land pollution associated with the discovery, extraction, processing, and distribution of fuels and power; and oil supply vulnerabilities associated with the need to import oil and the uneven geographic distribution of petroleum resources within the United States. As a result, more negative byproducts of energy use are produced than is socially optimal. If these market imperfections are to be corrected, public intervention is required.

Domestic carbon trading is one example of such a policy. The idea of the carbon trading system is to create fossil fuel prices that better reflect the full cost of fossil fuel consumption, causing consumers to make decisions that take into account the full cost of the resource. These higher prices should cause consumers to use less fossil fuel. At the same time, the government-collected carbon permit revenues can be recycled to consumers, as modeled in this study.

The public goods nature of research is an important rationale for government support of R&D on efficient and clean energy alternatives. R&D often results in benefits that cannot be captured by private entities. Although benefits might accrue to society at large, individual firms cannot realize the full economic benefits of their R&D investments. Further, companies that absorb the market risk of introducing new technologies are generally unable to reap the full benefits of their trailblazing. (Sometimes referred to as “early adopter” public benefits.) The benefits of advances in energy-efficient and clean energy technologies are not only experienced by the sponsoring company, but also flow to the public, to the company’s competitors, and to other parts of the economy. The risk of innovation leakage and exploitation by competing firms puts pressure on firms to invest for quick returns (Mansfield, 1994). Technology innovation is typically a longer-term investment fraught with risks to the investor. The result is an under-investment in R&D from the standpoint of overall benefits to society.

A report by the Council of Economic Advisers (CEA, 1995) estimated that the private returns from RD&D are 20 to 30%, while social returns (including energy security and environmental benefits) are 50% or higher. This gap limits the extent to which the private sector can supplant a government role in maintaining nationally beneficial RD&D. Generally the uncaptured social returns are greatest in fragmented industries such as construction. With the development of international markets, fragmentation is growing and industry’s priorities are shifting further away from basic and applied research and toward near-term product development and process enhancements. Business spending on applied research has dropped to 15% of overall company R&D spending, while basic research has dropped to just 2%. In addition, corporate investments in energy RD&D, in particular, are down significantly (DOE, 1996a, p. 2).

Great potential exists for public-private RD&D partnerships to produce scientific breakthroughs and incremental technology enhancements that will produce new and improved products for the marketplace. U.S. industry spends approximately $180 billion per year on all types of RD&D. These expenditures are much larger than the $24 billion spent by the federal government on industrial R&D (NSF, 2000) and they dwarf the U.S. government’s energy-related RD&D appropriations. If public policies reorient even a tiny fraction of this private-sector expenditure and capability to address the nation’s energy-related challenges, it could have an enormous impact. One way to reorient private-sector investments is through industry-government RD&D alliances that involve joint technology roadmapping, collaborative priorities for the development of advanced energy-efficient and low-carbon technologies, and cost sharing. These elements are all envisioned in the Clean Energy Future study’s policy scenarios.

2.5 PAST ENERGY POLICY AND PROGRAM SUCCESSES

Many different types of policies and programs comprise the policy implementation pathways that are analyzed in this report. They include:

- public-private RD&D partnerships;
- voluntary, information and technical assistance programs;
- regulatory policies; and
- financing, investment enabling, and fiscal policies.

Some indication of the potential cost-effectiveness of these policies can be gleaned from experiences to date.

From fiscal years 1978 through 1994, DOE spent less than $10 billion on energy-efficiency RD&D and related deployment programs. Estimates of the benefits of several dozen projects supported by this funding were published in DOE/SEAB (1995). In response to a detailed review of these estimates by the General Accounting Office in 1995/96, DOE concluded that five technologies developed with the support of DOE funding produced cumulative energy savings of $28 billion (in 1996$) from installations through 1996. Annualized consumer cost savings were estimated to be $3 billion in 1996[6], and annual greenhouse gas emissions reductions to be 16 MtC equivalent (Table 2.4).

Recent case studies of **public-private RD&D partnerships** are documented in DOE/EE (2000), Geller and Thorne (1999), and Geller and McGaraghan (1996). For example, DOE/EE (2000) describes 11 public-private RD&D partnerships that are estimated to have saved 5,050 trillion Btu of energy to date, or about $30 billion (1998$) in energy costs. These savings are approximately enough to meet the energy needs of all of the citizens, businesses, and industries located in the states of New York, Connecticut, and New Mexico for one year. Examples of technologies that have benefited from these partnerships are ozone-safe refrigerants, compact-fluorescent torchieres, lightweight automotive materials, diesel engine technologies, and geothermal heat pumps. It is important to note that DOE does not take full credit for the entire stream of benefits produced by these technologies. Most of these accomplishments have involved partnerships with many stakeholders contributing in important ways. However, the success stories are numerous and diverse, and they suggest that the potential for future accomplishments is great.

Table 2.4 Cumulative Net Savings and Carbon Reductions from Five Energy-Efficient Technologies Developed with DOE Funding

Energy-Efficient Technology	Net Present Value of Savings[a] (billions of 1996$)	Annualized Consumer Cost Savings in 1996 (billions of 1996$)	Annual Carbon Reductions in 1996 (MtC equivalent)
Building Design Software	11.0	0.5	8
Refrigerator Compressor	6.0	0.7	3
Electronic Ballast	3.7	1.4	1
Flame Retention Head Oil Burner	5.0	0.5	3
Low-Emissivity Windows	3.0	0.3	1
Totals	28	3.4	16

[a] Savings for the refrigerator compressor and flame retention head oil burner are through 1996 only; the remainder are savings from products in place by the end of 1996 and include estimated energy savings from the product's years in operation beyond 1996.

Government-run **voluntary and technical assistance programs** have strongly stimulated the adoption of cost-effective, energy-efficient technology, thereby narrowing the efficiency gap. The voluntary programs of the Environmental Protection Agency have amassed strong evaluation data documenting the investments in energy efficiency that their programs have stimulated (EPA, 1999b). Levine et al. (1995) cite examples of energy-saving features in computers and for standby power for television sets that are highly cost-effective but were not adopted by manufacturers until the U.S. Environmental Protection Agency (EPA) launched the Energy Star Program. (This program is now operated jointly with the U.S. Department of Energy.) In 1992, manufacturers producing almost all computers and laser printers agreed

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[6] Annualized consumer cost savings are the energy bill savings in 1996 minus the annualized cost premiums for better equipment.

to manufacture products with low standby losses. In January 1998, as a result of new efforts of the Energy Star Program, manufacturers agreed to reduce standby losses in TVs and VCRs.

There are also examples of successful **regulatory policies**. For instance, the promulgation of national appliance efficiency standards in the late 1980s provides a clear example of efficiency gains stimulated by regulation. Standards enforce the elimination of the worst practices and products in the market, and, given a continuous modification related to technical progress, they can provide dynamic innovation incentives. An in-depth analysis of the effects of appliance standards, as compared to a case in which market forces alone determined the energy efficiency of consumer products, showed a net benefit of standards enacted through 1994 of about $45 billion evaluated at a 6% real discount rate (Levine et al., 1995). Estimates of the costs of the standards, completed prior to their being promulgated, showed them to be highly cost-effective. Another retrospective study found the price of appliances to be unaffected by the issuance of new standards (Greening et al., 1997).

Many of the programs operated by Bonneville Power Administration and California's investor-owned utilities in the late 1980's and early 1990's provide compelling examples of effective **financing and investment-enabling policies** (Brown, 1993; Brown and Mihlmester, 1995a and b). Information outreach in combination with rebates and low-interest loans proved successful in many utility-operated demand-side management (DSM) programs (Parfomak and Lave, 1997). Additional examples of successful DSM programs can be found in the proceedings of the biennial National Energy Program Evaluation Conference (1999).

The policies and programs used here to illustrate past successes have been described primarily in terms of their energy 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 those from 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. Similarly, Romm and Ervin (1996) describe some of the public health benefits that have resulted from advances in energy-efficient technologies, such as clean air and water. Other collateral benefits include 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. Because many non-energy impacts are difficult to monetize they are often excluded from cost/benefit calculations.

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Chapter 3

STUDY METHODOLOGY[1]

3.1 OVERVIEW OF 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 faced by the United States. This objective requires that the methodology be:

- flexible to examine policies that affect not only financial decisions, but also policies directed at information dissemination, behavior, and regulation,
- scenario-based to allow examination of a range of uncertainties,
- dynamic with an extended time period to capture impacts over the longer term,
- consistent across sectors to ensure balance and fairness,
- integrated across sectors to capture inter-sectoral dependencies, and
- broad in assessing not only direct energy impacts, but also macro-economic impacts and costs.

The methodology developed here largely meets these requirements by employing a combination of tools and analytical approaches. A scenario-based approach is used to examine sets of public policies that are consistent with varying levels of public commitment to solving the nation's energy-related challenges. The scenarios allow us to examine the substantial synergisms between policies that are not evident when policies are viewed one at a time.

While scenarios assist in capturing a range of policy responses to climate change and other energy issues, there remains a very large number of uncertainties with respect to the outcome for each scenario. Within the limits of our resources, we partially address these uncertainties through sensitivity analyses. While we do present a number of sensitivities, we are forced to present our principal results as point estimates for each scenario. Consequently, individual elements of the results should not be construed as precise estimates, but rather as representative of a range of possible outcomes.

The two principal methodological enhancements that distinguish this study from the Five-Lab Study (Interlaboratory Working Group, 1997) are the analysis of policy impacts and the use of the CEF-NEMS model to integrate across market sectors. Policies included in the scenarios were selected based on the need to overcome specific market failures or barriers to attaining national energy and environmental objectives. As mentioned in Chapter 1, policies range from tax incentives to voluntary agreements to domestic carbon trading. The evaluation of such diverse policies required a variety of analytical tools and a range of expertise. The central integrating energy model, the CEF-NEMS model, was used to pull these diverse analyses together to evaluate each scenario's overall policy set. Technology and end-use-specific models were built and used to analyze some policies and sectors and their results integrated back into CEF-NEMS. Other portions of the analysis were completed outside of the CEF-NEMS model. These include:

- the assessment of policies to promote combined heat and power systems (see Appendix E-5);

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- the estimation of administrative costs of public policies and programs (see Appendix E-1); and
- the analysis of macro-economic impacts.

Many methodological improvements and technology updates to the individual sector analyses were also made. For buildings, we updated the existing cost and performance data for new and existing technologies and gathered additional information about the nature of miscellaneous energy uses. For industry, a new data gathering effort is used to enhance the analysis of three key industrial subsectors (cement, steel, and forest products). Considerable attention is also given to assessing the market potential of combined heat and power and energy-efficient motors and drives. For transportation, more attention is devoted to the economics of advanced technologies for light-duty vehicles and heavy trucks. In the electricity sector, improvements are made to the analytical treatment of renewable energy resources, plant retirements, and life extension of nuclear power. Finally, by using CEF-NEMS we are able to take advantage of the fossil fuel supply models of the NEMS which provide a price response to demand levels that was absent in the Five-Lab Study.

3.2 SCENARIOS

The purpose of scenario analysis, as explained by Peter Schwartz in his now classic book*, The Art of the Long View*, is to explore several possible futures in a systematic way (Schwartz 1996). Scenarios are tools "for ordering one's perceptions about alternative future environments." They help analysts think through both the opportunities and the consequences of a given future. The end result is not an accurate picture of tomorrow, but better decisions about the future.

3.2.1 Policy Implementation Pathways of the Scenarios

The CEF scenarios are defined by policies that are consistent with increasing levels of public commitment to solving the nation's energy-related challenges. The definition of these scenarios and the policy implementation pathways that they include were the subject of two workshops held in December 1998. One focused on energy efficiency and the other on renewable energy policies. Workshop participants included representatives of energy and environmental nongovernmental organizations (NGOs), gas and electric utilities and their associations, industry, State Energy Offices, the Association of State Energy Research and Technology Transfer Institutions, DOE and other federal agencies, and the study's National Laboratory team. These workshops led to the following scenario definitions.

Business-As-Usual Scenario (BAU). The BAU Scenario is the baseline forecast against which the other two scenarios are compared. The BAU Scenario is developed from the Reference Case published in the Energy Information Administration's *Annual Energy Outlook 1999* (AEO99)[2]. We start from the AEO99 Reference Case because it is widely available, frequently referenced, and a well-documented projection. We view the AEO99 Reference case as only a starting point for our analysis, not necessarily the most likely outcome even in a BAU world.

The BAU results vary only slightly from those of the AEO99 Reference Case. The differences are due primarily to changes in inputs for nuclear power relicensing and a few industrial process input parameters. The input variations are documented in detail in Appendix A. These slight input variations decrease U.S. primary energy consumption in the BAU 2010 and 2020 Scenarios by 0.5 quads relative to the EIA's Reference Case. Carbon emissions in the BAU Scenario are almost 1% less in 2010 and are 2% less in 2020 than the AEO99 Reference Case. Additional details on these changes can be found in Chapter 1 and in the sector results in the chapters that follow. In general, the BAU case assumes that no further

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[2] The AEO99 was the most recent available *Annual Energy Outlook* at the time the analysis was conducted.

legislative action is taken, but that scheduled administrative actions – such as the issuance of scheduled standards – will take place. Further, it assumes that the federal government's funding of energy R&D continues at approximately its current level. This ongoing investment, in combination with other private- and public-sector actions (some spurred by Federal collaboration), results in a steady pace of moderate technological progress.

The other two scenarios examined in this study reflect greater levels of enhanced national commitment to increasing the nation's energy productivity, reducing oil dependence, improving air quality, and addressing the threat of global warming. These alternative scenarios are labeled "Moderate" and "Advanced."

Moderate Scenario. The Moderate scenario is defined by a set of policies that the authors felt to be consistent with a national commitment to address these energy and environmental goals, if costs can be kept low. Thus, a modest shift in political will and public opinion is assumed. This shift enables the implementation of supporting policies and programs that would be difficult to implement in today's political environment. The shift also results in a greater willingness for individuals and businesses to purchase more energy-efficient and low-carbon technologies, a change that would reduce the costs and increase the effectiveness of complementary policy actions.

The policy implementation pathways that are employed in the Moderate scenario to increase investments in energy-efficient and low-carbon technologies fit the following criteria:

- are not highly controversial today
- generally have no increased net direct cost to the customer
- would not impose significant direct costs on any single region or sizable group
- correct one or more market imperfections
- involve a maximum increase of 50% in mature federal deployment program budgets
- involve a maximum increase of 50% in federal R&D budgets over the study period
- would not involve new fiscal policies that tax energy, either directly or indirectly.

The Moderate scenario is defined by combinations of policies such as information outreach efforts, enhanced R&D, government procurement programs, voluntary industry agreements, technical assistance, stricter codes and standards, feebates, rebates, and tax credits. The specific policies examined in both the Moderate and Advanced scenarios are listed in each of the sector chapters (4 through 7), and are illustrated in Tables 1.1 through 1.4.

Advanced Scenario. The Advanced scenario is defined by a set of policies that the authors felt to be consistent with a nationwide sense of urgency at meeting significant goals relative to energy productivity, oil supply vulnerability, air quality, and greenhouse gas mitigation. Thus, a substantial change in public opinion and political will is assumed. This change enables the implementation of supporting policies and programs that the authors felt would not be politically feasible in the Moderate scenario.

Policies in the Advanced scenario fit the following criteria:

- include all the Moderate scenario policies or more stringent versions of same
- may be highly controversial today
- may have net direct costs up to approximately $50/tonne

- may impose significant costs on one or more regions or sizeable groups
- correct one or more market imperfections
- involve a maximum increase of 100% in mature federal deployment program budgets
- involve a maximum increase of 100% in federal R&D budgets over the study period
- include a domestic carbon trading system

One key policy assumed in the Advanced scenario is the establishment of a system for the trading of carbon permits within the United States. This domestic trading system is applied to all fuels and all sectors of the economy; it is assumed to be announced in the year 2002 and fully implemented by the year 2005.

Carbon permits can be distributed in a number of different ways. They may be auctioned by the Federal government with the resulting revenues used or distributed back to taxpayers, or they may be allocated to existing carbon emitters. In the Advanced scenario, we assume the allowances are auctioned annually by the Federal government. Energy prices are based on marginal costs and therefore include the full carbon permit value, regardless of the allocation process[3]. However, the impact on the economy can vary significantly among different permit allocation schemes. Such macroeconomic impacts are discussed in more detail in Chapter 1, Section 3.5.2, and Appendix E-4 (qualitative analysis).

The level of the cap on domestic carbon emissions is not tied to any assumption regarding the ability of the United States to purchase allowances on the international markets, nor in the capability of the United States to reduce other greenhouse gases. The level of the cap was selected to keep the value of a carbon-trading permit to a level of about $50/tonne of carbon in the year 2010. This value was thought by the study participants and reviewers to represent a level consistent with the Advanced scenarioÕs assumption of a Ònationwide sense of urgency.Ó Should the price of permits under an international permit trading system be lower than $50/ton of carbon, then one would expect to see lower carbon permit prices in the United States as well, and fewer domestic carbon emission reductions than shown in this Advanced scenario. Conversely, higher international carbon allowance trading prices may yield more domestic reductions.

The policy pathways that define the Advanced scenario also include significant tax incentive programs, more stringent non-fiscal policies such as stricter fuel-economy or carbon-emission standards, accelerated R&D, and enhanced voluntary programs with outreach and incentive features that exceed those in the Moderate scenario.

3.2.2 Macroeconomic Inputs

All of the scenarios described in this report use the AEO99 forecasts of national economic output as measured by gross domestic product (GDP), which is projected to increase by 2.1% per year through 2020. Similarly, the buildings sector uses the AEO99 forecast of annual growth in residential buildings (1.1%) and commercial floorspace (0.8%). The industrial sector uses the AEO99 assumption of a 2.0% annual growth rate for manufacturing production; and the transportation sector uses the AEO99 forecast of a 1.6% annual increase in vehicle miles traveled and a 3.8% annual increase in air travel (EIA, 1998a).

All of the scenarios use the AEO99 world oil price forecast wherein world oil prices are assumed to rise from $18.55 per barrel in 1997 to $22.73 per barrel (in 1997$) in 2020. The Business-As-Usual scenario

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[3] Distribution schemes can be devised that would impact the energy results. For example, an output-based distribution in which all current generators are allocated permits based on their generation level, not their emission levels, would provide an economic advantage to nuclear, renewables, and other technologies that emit little or no carbon dioxide.

utilizes AEO99 assumptions for coal and natural gas as well. Coal and natural gas prices vary with the policy-based scenarios because they are determined endogenously within CEF-NEMS as a function of domestic supply and demand. The pricing models for these fossil fuels are taken directly from the AEO99 version of NEMS without alteration.

3.2.3 Time Frames

To capture the longer-term impacts of policies, we have extended the period of analysis from 2010 in the 5-Lab study to 2020 in this study. This extended period also allows the benefits of many technologies just now being introduced to the market to be more fully evaluated. While the CEF-NEMS model develops results on one-year time intervals, they are reported here for the principal years of interest: 1990, 1997, 2010 and 2020. The year 1990 is included because it is a reference point for the Kyoto accords on greenhouse gas emissions. The year 1997 is included as the last year of historical data in the AEO99 (although the latest 1998 data have become available during the course of our analysis and are discussed in several chapters).

Results for additional intermediate years are reported in the appendices. Finally, Chapter 8 provides a look beyond 2020.

3.2.4 Carbon Measurement

Throughout the report, the potential climate benefits of energy-efficient and low-carbon technologies are quantified in terms of reductions in millions of metric tons of carbon (MtC) emitted. Carbon dioxide is measured in carbon units, defined as the weight of the carbon content of carbon dioxide. Carbon dioxide units at full molecular weight (typically, MtC) can be converted into carbon units by dividing by 44/12, or 3.67. This approach has been adopted for two reasons. First, carbon dioxide is most commonly measured in carbon units in the scientific community, in part because it is argued that not all carbon from combustion is, in fact, emitted in the form of carbon dioxide. Second, carbon units are more convenient for comparisons with data on fuel consumption and carbon sequestration (EIA, 1998b). Note that, in the U.S., a "ton" (sometimes referred to as a "short ton") equals 2000 pounds; a metric ton, or "tonne," equals 1000 kilograms (approximately 2204 pounds).

Carbon dioxide emissions reductions are estimated by using factors to convert the energy impacts into million tonnes of carbon (MtC). The conversion factors come from EIAÕs *Emissions of Greenhouse Gases in the United States* (1998, Table B1, p. 106) and are shown in Table 3.1.

Table 3.1 Factors for Converting Fossil Energy Savings into Carbon Emission Reductions

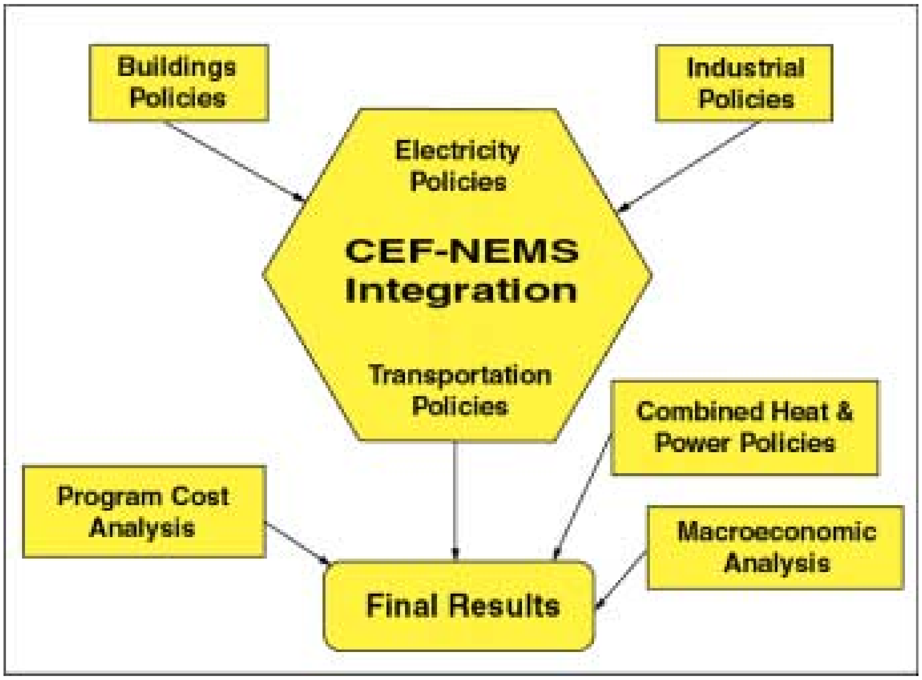
	Conversion Factors (MtC/TBtu)
Natural Gas	0.0145
Petroleum Fuels:	
Distillate Fuel	0.0200
LPG	0.0170
Petrochemical Feedstock	0.0194
Residual Fuel	0.0215
Other Petroleum	0.0168
Coal:	
Metallurgical Coal	0.0255
Steam Coal	0.0257

3.3 ANALYSIS METHODS

A variety of analytical tools were used in assessing the above scenarios and their policy impacts on the multiple energy and environmental challenges faced by the United States. As shown by Fig. 3.1, sector-specific analyses and models were used extensively in the buildings and industrial sectors. In particular, the buildings sector used a variety of spreadsheet analyses and models to estimate and integrate the simultaneous impact of policies ranging from R&D improvements to voluntary programs. The synergies between policies impacting the industrial sector were assessed at the subsector level using technology possibilities, international experience, and empirical observations of past energy intensity changes. These sectors' results are translated into inputs to the energy integrating CEF-NEMS model, which is described below. For the transportation and electric sectors, inputs to CEF-NEMS were developed by starting from the inputs to the AEO99 Reference case (EIA 1998a) and modifying them to represent the policies of our two policy scenarios.

In general the above approach reasonably captured the energy markets of the different scenarios. However, as shown in Fig. 3.1, there were three principal areas that could not be well integrated within CEF-NEMS. Clearly the cost of implementing Federal policies and programs is not addressed in an integrating energy market model like CEF-NEMS. Also as shown in Fig. 3.1, industrial combined heat and power (CHP) systems are not captured by CEF-NEMS. Finally, we have assessed macroeconomic impacts of our scenarios outside of CEF-NEMS relying heavily on economic arguments and past analyses found in the literature.

Fig. 3.1 Analysis Methodology



3.3.1 Sector Approaches

To capture the significant interactions among technologies and policies, the buildings and industrial sectors required detailed accounting and judgment, not available in CEF-NEMS. For both these sectors, the general process was to use spreadsheets to first estimate the economic potential of the technology using the cost of capital for the discount rate. This economic potential implicitly assumes all market barriers and transaction costs have been removed. For those technologies with significant economic potential under these extremely optimistic assumptions, the next step was to estimate market penetration by considering the contribution that individual policies can make in removing the actual market barriers. In other words, rather than the standard practice of rolling all the barrier implications into a single discount rate or "hurdle rate," barriers were considered individually along with the policies designed to address them. This second step also considered careful stock accounting, retirement rates, scheduled maintenance practices, etc. With these considerations, estimates were made of the rate of market penetration of specific technologies under the different CEF policy scenarios. In the buildings sector, penetration rates were developed in correspondence with individual policies, taking into account interactions amongst the policies. In the industrial sectors, policies were considered at a more aggregated level but for a more diverse set of end uses.

For example, for the three energy-intensive industrial subsectors – paper, steel, cement – detailed evaluations were conducted at the process level. To identify retrofit opportunities, over one hundred commercially available technologies were characterized with respect to economic potential. For those policies that directly impact economic potential, multiple estimates of potential were developed. For those policies that impact market barriers and the response of the market, the policies were considered in aggregate and estimates were made of market penetration changes due to the policies. Policy-driven changes in energy use in the remaining industrial subsectors (glass, aluminum, agriculture, mining, construction, food, chemicals, metals-based durables, and other manufacturing) were assessed at a more aggregate level considering both historic trends and efficiency potentials identified in recent U.S. and international literature. Combined heat and power opportunities and improvements to motor and drive systems across all industrial subsectors were examined with separate models to estimate economic potential.

The results of these off-line buildings and industrial sector analyses were reinserted into CEF-NEMS using the parameters available in CEF-NEMS that most closely approximate the impact of the policies. In the buildings sector, this was accomplished through the discount rate, buildings and appliance standards, costs and other parameters in CEF-NEMS' buildings modules. In the industrial sector, these included the discount rates, energy intensity, and stock turnover rates. For example, after estimating the impact of an expanded lighting program under the Energy Star Buildings using spreadsheet models based on recent Green Lights experience, the discount rates and lighting standards employed in the CEF-NEMS building sector end-use models were adjusted to yield the same results. While this is something of an art, there is a strong rationale for the adjustment of discount rates in that they are set in the EIA's NEMS model to reflect historical records of consumers' energy purchases (as opposed to being set to the cost of capital to consumers). A policy like Energy Star Buildings alters consumers' purchases by removing market barriers and providing information and is therefore most accurately captured by changes to the implicit discount rates found in NEMS. In fact, in the AEO99 Reference case, the EIA does include an adjustment to discount rates to reflect their interpretation of the existing Green Lights program (EIA 1999). Details on these analyses outside of NEMS can be found in the individual sector chapters of the report and the appendices.

The electricity and transportation sector used CEF-NEMS for all market penetration estimates. Changes to NEMS in the electric sector varied from simple production tax credits for renewables to reduced SO_2 ceilings to represent tighter particulate matter standards, to competitive pricing in all regions to capture deregulation of the sector. For the most part, CEF-NEMS includes distinct parameters capable of representing such policies. For example, the duration of a tax credit is set by an input on the year of expiration. Similarly, a simple parameter for each region dictates the fraction of the electricity generated in the region that is priced competitively in that region (at the margin, as opposed to an average regulated electricity price). In the transportation sector, changes to NEMS included, among other things, a tax credit for high efficiency vehicles represented by changes in the capital cost of the vehicle, accelerated RD&D-driven reductions in the cost of ethanol, higher average miles per gallon reflecting voluntary agreements with vehicle manufacturers regarding fuel economy, and pay-at-the-pump insurance policies effected in NEMS through fuel price increases.

One particularly important policy for all sectors is the increase in R&D funding assumed for both the Moderate and Advanced scenarios. No reliable model exists that can take a policy that increases Federal R&D spending and translate it to future technology cost and performance improvements. A more realistic approach is to use expert judgment, peer-reviewed literature, and sensitivity analysis. The approach used in this study varied between sectors to reflect the differences in sectors. For example, in the electric sector we assumed the initial R&D funding increases would be focused on generating technologies that don't emit significant carbon, while the greater R&D funding of the Advanced scenario would include more improvements to fossil-fired generators. Actual values for future costs, heat rates, etc. were taken from published estimates of possible improvements, as well as from discussions with experts and reviewers and inserted into CEF-NEMS. On the other hand, in the industrial sector with its wide range of technologies, estimates of efficiency improvements were made in consultation with industry for over 100 specific processes in three major energy consuming industries (paper, cement and steel). Much broader assumptions were made for all the less-energy-intensive industries based on the general literature. More sector-specific detail can be found in the individual sector chapters and appendices.

3.3.2 CEF-NEMS

The integrating energy model employed for this study is the CEF-NEMS. The CEF-NEMS model is derived from the version of the National Energy Modeling System (NEMS) developed by the Energy Information Administration (EIA) for the analysis behind its 1999 Annual Energy Outlook (EIA, 1998a). This NEMS model has been developed over the last decade with significant peer review both directly and through the analyses it has been used to produce. The NEMS model is documented both in hardcopy (EIA, 1999 a, b, c) and on the worldwide web at:

http://www.eia.doe.gov/bookshelf/docs.html

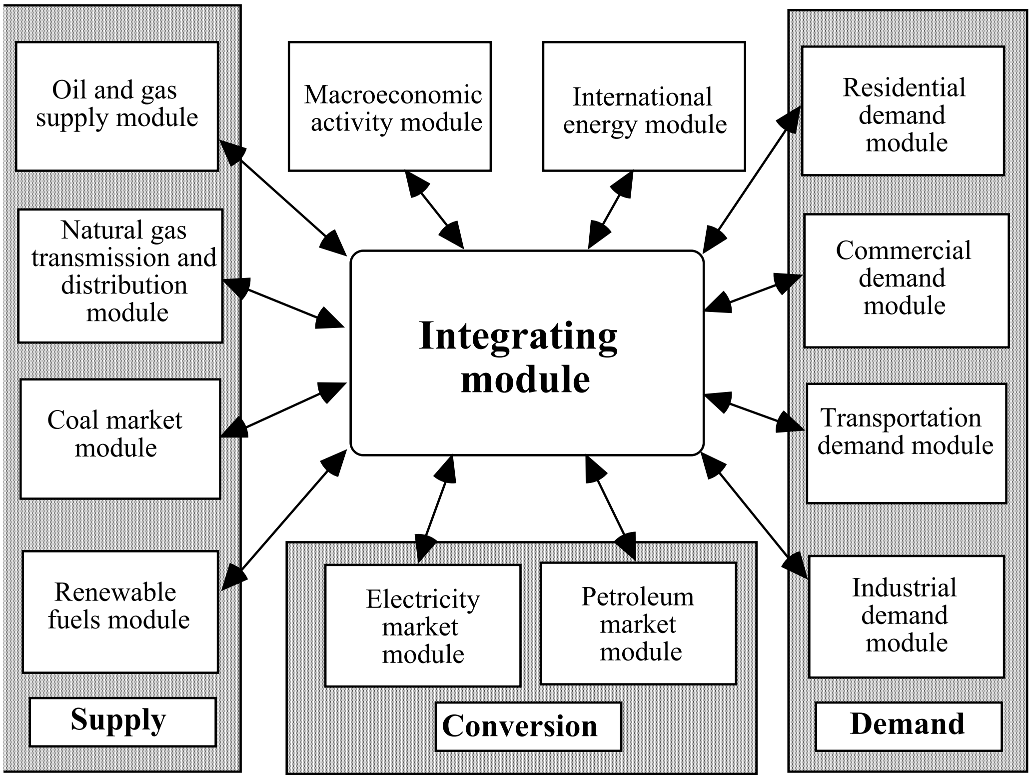
At the EIA's request, we have appended the acronym CEF (Clean Energy Future) to the front of the name, CEF-NEMS, to call attention to the fact that we have modified many of the inputs to the model in assessing our scenarios. We have not modified the basic structure of the model. Thus much of the description that follows is taken directly from EIA's description of NEMS (EIA, 1998a).

CEF-NEMS simulates the behavior of U.S. energy markets and their interactions with the U.S. economy. The model achieves a supply/demand balance in the end-use energy demand regions, defined as the nine Census divisions, 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 system reflects market economics, industry structure, and energy policies and regulations that influence market behavior.

CEF-NEMS represents domestic energy markets by explicitly representing the economic decision making involved in the production, conversion, and consumption of energy products. For example, the penetration of a new or advanced technology for electricity generation is projected only if the technology is deemed to be economic when considering the cost-minimizing mix of fuels.

As shown in Fig. 3.2, CEF-NEMS consists of one module that provides the mechanism to achieve a general market equilibrium among all the other modules; four supply modules (oil and gas, natural gas transmission and distribution, coal, and renewable fuels); two conversion modules (electricity and petroleum refineries); four end-use demand modules (residential commercial, transportation, and industrial); one module to simulate energy/economy interactions (macroeconomic activity); and one module to simulate world oil market (international energy activity). To assess the country's ability to reduce carbon while still achieving the economic growth of the Reference scenario under the same world oil prices, the macroeconomic and international energy modules were prevented from modifying world oil prices, and economic growth projections in the policy scenarios. Since this analysis focuses on policies and technologies in the electric sector and the end-use sectors, we provide below a brief introduction to how those CEF-NEMS modules work.

Fig. 3.2 Schematic Representation of the CEF-NEMS



Source: Adapted from EIA, 1998b.

Residential Demand Module. The residential sector encompasses residential housing units classified as single-family, multifamily, and mobile homes. Energy consumed in residential buildings is the sum of energy required to provide specific energy services that use selected technologies according to energy efficiency levels of building structures. The Residential Sector Demand Module projects energy demand following a sequence of five steps. The first step is to forecast housing stock. The second step is to simulate the behavior of residential consumers based on the relative importance of life-cycle costs, capital cost, and operating costs of competing technologies. The third step is to forecast appliance stocks using a piecewise linear decay function to retire equipment based on minimum and maximum life expectancies. The fourth step is to forecast changes in shell integrity for existing and new buildings. The fifth step uses price elasticities to capture consumer responses to fuel price changes in estimating the energy consumed by the equipment chosen to meet the demand for energy services (EIA, 1998c).

Commercial Demand Module. The Commercial Sector Demand Module uses economic and engineering relationships to model commercial sector energy demands at the nine Census division level for eleven distinct categories of commercial buildings. Commercial equipment selections are performed for the major fuels of electricity, natural gas, and distillate fuel, for the major services of space heating, space cooling, water heating, ventilation, cooking, refrigeration, and lighting. The market is modeled using a constrained life-cycle cost minimization algorithm that considers commercial sector consumer behavior and time preference premiums. Numerous specialized considerations are incorporated, including the effects of changing building shell efficiencies, the relationship between non-utility generation of electricity and the relative price of fuels, and consumption to provide district services (EIA, 1998d).

Industrial Demand Module. The Industrial Demand Module estimates energy consumption by energy source for 9 manufacturing and 6 non-manufacturing industries. The manufacturing industries are further subdivided into the energy-intensive manufacturing industries and non-energy-intensive manufacturing industries. The energy-intensive manufacturing industries are modeled through the use of a detailed process flow accounting procedure, whereas for the non-energy intensive manufacturing industries unit energy consumption is held constant in the absence of price changes. The model forecasts energy consumption at the four Census region levels and apportions the forecast to the Census division level based on SEDS data (EIA, 1999a).

Transportation Demand Module. The NEMS Transportation Model comprises a series of semi-independent models, which address different aspects of the transportation sector. The primary purpose of this model is to provide mid-term forecasts of transportation energy demand by fuel type including, but not limited to, motor gasoline, distillate, jet fuel, and alternative fuels not commonly associated with transportation. Forecasts are generated through the separate consideration of energy consumption within the various modes of transport, including: private and fleet light-duty vehicles; aircraft; marine, rail, and truck freight; and various modes with minor overall impacts, such as mass transit and recreational boating. This approach is useful in assessing the impacts of policy initiatives, legislative mandates which affect individual modes of travel, and technological developments.

The model also provides forecasts of selected intermediate values, which are generated in order to determine energy consumption. These elements include estimates of passenger travel demand by automobile, air, or mass transit; estimates of the efficiency with which that demand is met; projections of vehicle stocks and the penetration of new technologies; and estimates of the demand for freight transport which are linked to forecasts of industrial output. (EIA, 1999c).

Electric Market Module (EMM). The EMM represents the capacity planning, generation, transmission, and pricing of electricity in the 13 NERC regions, subject to: delivered prices for coal, petroleum products and natural gas, the cost of centralized generation facilities, the cost of capital, and electric load shapes and demand. The submodules consist of load and demand-side management, capacity planning, fuel dispatching, and finance and pricing.

The solution sequence through the submodules for each time period can be viewed as follows (EIA, 1999b):

1. The load and demand-side management submodule processes electricity demand to construct load curves.
2. Given the load curves and fuel and system costs, the electricity capacity planning submodule uses a linear program optimization to project the construction of new plants.
3. Given the load curves, fuel costs, and plants; the electricity fuel dispatch submodule dispatches the available generating units, both utility and non-utility.
4. The electricity finance and pricing submodule calculates total revenue requirements for each utility operation and computes average and marginal-cost based electricity prices.

3.4 ANALYSIS OF CROSS-CUTTING TECHNOLOGIES

There are several technologies that apply to multiple sectors. These include combined heat and power or cogeneration systems, bioenergy, and fuel cells. The use of CEF-NEMS as an integrating model, which considers all sectors simultaneously, simplifies the evaluation of these technologies. However special considerations in their treatment are discussed briefly below.

3.4.1 Bioenergy

There are two principal forms of bioenergy considered by CEF-NEMS. These are biomass power and ethanol from biomass. Biomass power is further disaggregated in CEF-NEMS to include cofiring of coal plants with biomass and biogasification power plants. There is considerable overlap between these different bioenergy forms in terms of the biomass resources they require as feedstock. CEF-NEMS keeps track of all the demands on the biomass resources from these different conversion processes within different sectors (electricity and transportation) and prices the biomass resources accordingly. No additional modifications are required to handle this intersectoral dependency. Biomass gasification is also considered as a source of combined heat and power in industry. This is treated as an off-line analysis (see below) and is not integrated into CEF-NEMS.

3.4.2 Combined Heat and Power

The buildings and industrial end use sectors are currently taking advantage of opportunities to produce electricity and heat on site. These combined heat and power plants are expected to multiply over the next decade as turbine and fuel cell technologies improve. CEF-NEMS has a simplistic representation of the potential for these cogeneration technologies in the industrial sector, as it allows cogeneration to be used only to meet a fixed portion of new steam demand (depending on fuel and electricity costs), additional to demand in the baseyear, as industrial boilers are not retired in the model. Thus for this analysis combined heat and power opportunities in the industrial sector have been assessed using Resource Dynamics Corporation's DISPERSE model[4] (see Appendix A-2).

DISPERSE estimates the achievable economic potential for CHP applications by comparing on-site generation economics with competing grid prices. The model not only determines whether on-site generation is more cost effective, but also which technology and size appears to be the most economic. By permitting retirement of existing boilers (CEF-NEMS does not allow industrial boiler retirements) where economically feasible, the model estimates cogeneration potential for both traditional (where all unit output is used on-site) and non-traditional (where sales of electricity to the grid is permitted) applications of CHP. For each scenario, Resource Dynamics Corporation used the DISPERSE model results for economic potential in estimating industrial CHP production of electricity and steam, as well as the fuel consumption associated with that production.

The DISPERSE results have not been fully integrated into the CEF-NEMS model due to difficulties associated with replicating the results at the industrial subsector and regional level in CEF-NEMS. Instead, an off-line analysis of CHP in industry was conducted in order to estimate the overall impact of expanded CHP capacity on primary energy consumption and carbon dioxide emissions. This analysis was partially integrated with the Moderate and Advanced scenarios in that it uses the resulting estimates of industrial demand for steam and it displaces grid electricity resources that are the marginal resources in each scenario.

The off-line analysis of increased CHP examines three factors to assess impacts on primary energy consumption and carbon dioxide emissions:

- The fuel displaced at electric utilities at the margin,
- The boiler fuel displaced in the industrial sector, and

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[4] Distributed Power Economic Rationale Selection (DISPERSE) model.

- The fuel used by the CHP units.

3.4.3 Fuel Cells

Fuel cells are a technology that cut across sectors both because they can serve as a combined heat and power system as described above and because they can be used either to meet general electric loads or to propel a vehicle. Some of the improvements to stationary fuel cells can also be applied to mobile applications in vehicles, and vice versa. However these different applications of fuel cells require different performance characteristics. For example, a fuel cell as a stationary central power source might be built largely on site, as one stage in a ternary cycle operating at full load for 20 – 30 years with minimal maintenance requirements and substantial power conditioning equipment. On the other hand, a vehicular application would ultimately be mass produced by the millions to operate as a single stage at low (safer) temperatures on a highly cyclical schedule for less than the number of hours in a single year, but with regular maintenance. These differences in operating environments favor different fuel cell technologies in different applications with different costs and performance capabilities. Thus it is extremely difficult to compare the fuel cell costs and performance assumptions used in the electric, transportation, and other end use sectors. For this analysis, the type of fuel cell and its cost and performance were derived by consulting with experts on each individual application.

3.5 *ASSESSMENT OF BENEFITS AND COSTS*

Benefits and costs of the Moderate and Advanced scenarios are measured relative to the BAU Scenario. The different forms of benefits and costs are described below along with a brief statement as to how each has been assessed.

3.5.1 Benefits

Five types of benefits are quantified in this report.

Energy Bill Savings. The reductions in energy use that result from the policies evaluated are captured directly by the CEF-NEMS and sectoral modeling and analysis described above. The reductions in fossil fuel demands exerts a dampening influence on fossil fuel prices[5]. The combination of reduced demands and reduced prices significantly reduces the nation’s energy bill. Such energy bill savings are considered in our calculation of net direct savings below.

Local Air Pollution Benefits. For the electric sector these are estimated in CEF-NEMS. Emissions from the end-use sectors are not estimated by CEF-NEMS and therefore are not included in this report. However, shortly after publication of this report, the EPA is expected to release a study containing an independent analysis of all emissions associated with these scenarios.

Greenhouse Gas Emission Benefits. As stated earlier, the only greenhouse gas emissions analyzed are carbon emissions from fossil fuel use. However a qualitative assessment of the potential to reduce other greenhouse gases is provided in Appendix E-6.

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[5] In the Advanced scenario with its carbon trading system, the price of energy to the consumer will increase due to the carbon value paid by producers to the government for carbon allowances. Inasmuch as the government returns these allowance dollars to the private sector, they can be treated as a transfer payment that does not impact direct benefits or costs (but will most likely have indirect costs as discussed in the following section on “Macroeconomic Costs.”)

National Energy Security and Secure Oil Supplies. Alternative fuels and efficiency improvements, especially in the transportation sector, reduce the demand for oil. Through the integrating mechanism of the CEF-NEMS model we are able to calculate the total U.S. oil demand, domestic supply, and the residual imports required.

Macroeconomic Benefits. Inasmuch as there are large-scale market and organizational failures that prevent consumers and firms from obtaining energy services at least cost, the economy is not on its aggregate production-possibilities frontier. Thus at the aggregate level, a Pareto improvement is available in the economic efficiency of the economy. On the other hand, policies that change relative prices can create at least short-term reductions in measured GDP. See the section below on macroeconomic costs for a more complete discussion on the assessment of macroeconomic impacts.

3.5.2 Costs

There are three distinct forms of costs that we consider in evaluating the scenarios and their policies – incremental technology investment costs, policy implementation and administration costs, and macroeconomic costs.

Incremental Technology Investment Costs. Incremental technology costs refer to the additional technology investment required by consumers and businesses to purchase the more efficient equipment or energy service. 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. Since CEF-NEMS does not explicitly track such investment costs in the end-use sectors, we approximate them by calculating an investment cost per unit energy conserved and multiplying this cost of conserved energy (CCE, in \$/kWh or \$/MBtu) by the annual energy savings in that year.

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

Calculating the CCE requires a real discount rate and an equipment lifetime. For both the Moderate and Advanced scenarios, we used sector-specific, real discount rates to calculate the CCEs. These discount rates are: 7% for buildings, 15% for industry, and 10% for transportation. For these discount rates, we use the real cost of capital in these sectors because we are trying to measure the actual costs to the investor. As such, these CCE discount rates are lower than the "hurdle rates" that can be implicitly derived from actual investor decisions in these sectors (Meier, 1983, and Train, 1985). Such hurdle rates typically include market barriers and consumer preferences[6]. With these discount rates, efficiency technology CCEs are on the order of 1-5 1997\$/MBtu for fuels and 6-10 1997\$/MBtu for site electricity depending on the sector and energy end-use. (These CCEs are also used to estimate the economic potential of a technology, but not the market penetration of the technology. Market penetration is projected by reducing the economic potential to account for market barriers, less the impact of the CEF policies on those barriers.)

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[6] Hurdle rates may also include transaction costs. Insofar as transaction costs are actual monetary costs, they could also be included in a CCE calculation.

Policy Implementation and Administrative Costs. Policy implementation costs include the costs of administering the public policies and programs that are modeled in each scenario and the incremental R&D costs. For the purposes of this project, ***administrative costs*** include the following:

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

Preliminary cost increments were developed by estimating the administrative costs and energy savings associated with a range of policies and programs that have been in operation over the past decade or two. Estimates have been compiled to date for 12 policies and programs (see Table 3.2 and Appendix E-1 for details on these individual estimates). These policies and programs span a broad spectrum of interventions including building codes and standards, technical assistance to manufacturers, information on gas mileages, utility-operated demand-side management programs, weatherization assistance, and grants to small businesses for R&D.

The administrative costs associated with these 12 policies and programs show considerable variability. The smallest administrative cost estimates are for DOE's Building Standards and Guidelines Program ($0.052 per MBtu saved), and the largest estimates are for Southern California Edison’s market transformation programs in the residential market ($2.486 per MBtu).

Because of the small sample size, it is not possible to explain the differences across programs. However, it is likely the administrative costs will be greater in the early years of a program and that they might be less for regulatory policies such as codes and standards than for programs that provide a great deal of technical assistance and information outreach.

The average administrative cost for these 12 policies and programs is $0.54 per Mbtu of primary energy saved. This cost was rounded to $0.6/Mbtu and is used as the cost of policy implementation and administration within this CEF study. For end-use sector fuel savings, it is added directly to the incremental technology costs. For electricity savings in the end-use sectors, it is first multiplied by 2.9 to account for the difference between primary energy and delivered electricity.

These estimates of administrative costs are quite consistent with the independent findings of Berry (1991 and 1989). Berry reviewed the expenses incurred by utilities to administer demand-side management programs in the 1980s. Her work appears to provide the only published overview of administrative costs relevant to energy efficiency programs. She estimated that administrative costs are approximately 20% of the incremental technology costs per MBtu of energy saved. Similar proportions result when the administrative cost estimate of $0.54 per MBtu of primary energy saved is used in the Clean Energy Future Study – both in 2010 and 2020, and for both the Moderate and Advanced scenarios.

Net Direct Savings. Net Direct Savings are computed as the energy bill savings minus the sum of the direct costs (annualized incremental technology investment cost plus the program implementation and administration costs). These calculations are explained in detail in Chapter 1.

Macroeconomic Costs: The issue of macroeconomic costs and benefits devolves to almost a philosophical debate as to whether or not there is an "energy efficiency gap" that can be at least partially closed through energy policies i.e., are there cost-effective opportunities to reduce current energy use that are not being pursued because of market failures that can be removed through policy. If one believes that such a gap exists and can be reduced by policy, then the economy is not at its aggregate production-possibilities frontier, and such policies can yield a net benefit to the economy, not a net cost.

It is also true that while an efficiency gap may exist, not all policies examined in this study are directed solely at closing that gap. In particular, the carbon trading policy included in our Advanced scenario through a $50/tonne value on carbon emissions, may close the efficiency gap somewhat, but also has impacts – both short and long term – that do not necessarily move the economy closer to the production possibilities frontier. While we have not modeled these impacts directly, we have reviewed the literature (see Appendix E-4) and found a range of estimates for the GDP impacts of a carbon charge.

We present a host of evidence in Chapter 2 and the end-use sector chapters of this report to buttress our claim that an efficiency gap does exist that can be closed at least in part through policy. However even if one does not accept this evidence, it can be argued that the annualized incremental investment cost driven by the policies of this study (other than the carbon trading system) are overwhelmed by the aggregate total investment in the U.S. economy ($1,364 billion in 1998). Thus even assuming the economy is currently on its production-possibilities frontier, any attempt to estimate the size of the macroeconomic costs associated with these policies must be able to capture changes in second order impacts due to changes in a relatively small portion of the U.S. investment portfolio. Short-term transition costs associated with these second-order effects are even more difficult to model, especially given that most models:

1. capture only energy consumption, not changes in energy services;
2. extrapolate from past trends, missing opportunities for markets and the Federal government to react differently in the future;
3. can not model the substitution of information for energy that many of these policies effect.

Given the above modeling problems, we have estimated macroeconomic costs for only the domestic carbon trading policy, and that is done based largely on the literature. We have also estimated the direct economic impacts of the carbon trading policies on energy consumers and producers. Faced with higher energy prices due to a carbon value, consumers demand less energy. The higher price and reduction in consumption produce a loss in consumer surplus. Similarly, producers sell less and receive (after the carbon value is paid to the government auction) less for their energy, i.e. there is a loss in producer surplus.

Table 3.2 A Review of Administrative Costs for Energy-Efficiency Programs

Policy/Program	Type of Policy/Program
Residential Appliance and Commercial Equipment Program	Regulatory policies—Codes and Standards
Building Standards and Guidelines Program	Regulatory policies—Codes and Standards
Demand-Side Management Programs of the Bonneville Power Administration: Residential	Financing and investment enabling
Demand-Side Management Programs of the Bonneville Power Administration: Commercial	Financing and investment enabling
Weatherization Assistance Program	Financing and investment enabling
Market Transformation Programs of the Southern California Edison: Residential	Financing and investment enabling
Energy Star Programs: buildings and industry	Voluntary, information and technical assistance
Market Transformation Programs of the Southern California Edison: Non-Residential	Financing and investment enabling
Industrial Assessment Centers	Voluntary, information and technical assistance
Demand-Side Management Programs of the Bonneville Power Administration: Industrial	Financing and investment enabling
Energy-Related Inventions Program	Public-private RD&D partnerships
Fuel Economy Guide	Voluntary, information and technical assistance

3.6 REMAINING ANALYSIS NEEDS

As with any study of this magnitude, there are many areas where the analysis could be improved. The sector chapters (chapters 4 – 7) provide recommendations for improved analysis for individual sectors. The discussion that follows focuses on analysis issues that impact all the sectors.

Probably the largest single issue is a more complete treatment and presentation of the uncertainties inherent in any future scenarios. Secondly, the evaluation of the impact of policies that are non-fiscal in nature such as information programs, labeling, and voluntary agreements needs extensive detailed primary data collection and analysis. Other major analysis needs that cut across the sectors of the economy include the need to refine our estimates of the macroeconomic impacts of policies, the need to address non-energy-related greenhouse gas emissions and GHG reduction opportunities, and the need for an expanded time frame with finer geographic disaggregation of the analysis.

3.6.1 Analysis of the Impact of Non-Fiscal Policies

Most of the non-fiscal policies we examined are designed to change a decision-maker's response to the energy situation confronting him or her. Models like NEMS generally have a built in response function that simulates the decision-maker's response under a business-as-usual scenario. Thus the common approach to simulating a policy that impacts the decision-maker's response is to change the parameters of the model's response function. For example, one might lower the consumer discount rate to reflect increased knowledge of the options available due to an information program. The difficulty in this approach lies in determining how much to change the response function parameters.

We have chosen a less arbitrary, more detailed way of performing the analysis. Instead of changing model parameters, we have surveyed analyses and estimates of the performance of the different types of programs in impacting the decisions of consumers, overcoming market barriers, and thus causing increased penetration of more efficiency systems and technologies. We have applied our judgment to these estimates, and have attempted to be conservative in ascribing results to specific programs[7]. While perhaps more insightful than the simple model parameter change approach, this approach is also uncertain. However, there are ways that the estimates could be improved.

One method is to improve the empirical foundation for linking policies and programs with impacts. Many energy program evaluations have been undertaken – see, for example, the proceedings of the biennial National Energy Program Evaluation Conferences (1999). However, these program evaluations often do not have sufficient rigor for forecasting future impacts. Thus, filling key program evaluation gaps with strong assessments would be very helpful. A second method is to use the collective judgment of a group of knowledgeable individuals, experts in the fields of energy policy and program evaluation. The goal would be to estimate program costs and effectiveness under the assumption of much-expanded programs. Such estimates should represent a range of possible outcomes, reflecting uncertainties inherent in forecasting and modeling These could be derived through workshops or a structured delphi approach.

In assessing the potential effectiveness of expanding existing programs, one needs to consider a variety of influencing factors, most of which evolve over time, confounding the process of developing scenarios and forecasts. These factors include diminishing returns and free riders that would tend to reduce effectiveness over time. They also include learning, free drivers and spillovers, and economies of scale and scope that would all tend to increase effectiveness. These factors need to be better characterized and understood.

There are also difficulties with evaluating the impact of several policies all of which impact the same decision maker. For many of the policies proposed, there is little empirical data on past policies of a similar nature and certainly a lack of data on packages of policies. Such data and analysis of it are needed to better evaluate many of the policies suggested here. At a minimum, a more detailed assessment could reduce any remaining possible overcounting of impacts where multiple programs affect the same consumers.

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[7] In the building sector, CEF-NEMS was run to calculate the behavioral parameters that yielded the results of the independent analyses of the programs. This was done for analytic convenience (i.e., to permit the model to be used for sensitivity studies in the different scenarios). It was, however, not the basis for the estimate of the impacts of policies.

3.6.2 Expanded Technology Representations

Due to time and resource limitations, a number of technologies have not been explicitly considered in this analysis. In the buildings sector, we have not had an opportunity to include all shell measures, fuel cells, district heating and cooling, integrated space and water heating, advanced cooking technologies, nor photovoltaics in commercial buildings. In the transportation sector, we have included only the more promising alternative fuel vehicles. In the electric sector, we have not yet included all distributed generation options, nor new small, gas-cooled nuclear reactors, nor coal-fired generator refurbishments for improved efficiency.

The inclusion of these technologies presents formidable modeling issues in many cases. Our efforts to treat combined heat and power presents a good example of an important research need. The strategy was to perform a highly disaggregate model of combined heat and power (CHP) separate from NEMS and then to incorporate these results into NEMS. Because the assumptions and calculational procedures in NEMS for CHP were so different from those used in the independent analysis, it was impossible to achieve this integration (of a disaggregate analysis with the more aggregate analysis of NEMS). A serious analysis of the differences in the approaches in the two models, combined with an independent analysis of parameters to best characterize CHP, could go a long way toward reducing uncertainty in the role of CHP in different scenarios including the BAU scenario.

Similar modeling efforts are needed for characterizing possible roles of distributed electricity systems. Such modeling is much earlier in development, and will require considerable data and analysis before meaningful linkages can be achieved between disaggregate analyses and the more aggregate analysis in NEMS.

Many of the issues relating to retirement of coal plants and replacement by natural gas at different coal/gas price differentials have been resolved by improvements in the NEMS electricity module. There will likely continue to be important issues in this area that need attention.

In addition to modeling issues, there continues to be a need for improved characterization of technologies on both the demand and supply side for inclusion in the models. While technology analysis is needed in all sectors, the industrial sector needs the most attention. This study is one of the few efforts to evaluate segments of the industrial sector from the "bottom" up (i.e., by assessing energy efficiency technologies for the most energy-intensive sectors. We are encouraged that such analysis does improve the understanding of opportunities for industrial energy analysis at the sectoral level. Nonetheless, this work is in early stages and needs considerably more effort.

3.6.3 Transition Costs and Macroeconomic Impacts of Policies

While we have made the qualitative argument that there are macroeconomic benefits associated with moving closer to the production possibility frontier by closing the "energy efficiency gap," our quantification of those benefits is limited to the calculation of lower electricity and fuel bills. Similarly our treatment of policies not specifically directed at closing the energy gap is limited to the adoption of costs from the literature for the carbon trading system assumed in the Advanced scenario. Future efforts might include the refinement and use of macroeconomic models in conjunction with NEMS, or similar technology-rich models, to capture these impacts as well as to address equity issues, foreign trade implications, and regional employment implications. Foreign trade implications may require a general broadening of the analysis to an international framework.

3.6.4 Air Pollutants

While it has been our intent to direct this study towards a range of energy and environmental issues, we have not adequately addressed local air pollutant emissions. At this point, we have made estimates of only SO_x and NO_x emissions from the electric sector. Emission estimates for the end-use sectors require substantial technology detail not currently available in CEF-NEMS. It is our understanding that the EIA is modifying NEMS to estimate NO_x emissions in the transportation sector. Still other tools could be used in the future to develop better end-use sector estimates.

3.6.5 Non-Energy Emissions and GHG Reduction Opportunities

This study focuses on reductions in carbon dioxide emissions from the use of energy in the United States. However, 16% of the global warming potential of the gases emitted in 1997 by the United States can be attributed to greenhouse gases other than carbon dioxide. These include methane (9%), nitrous oxide (5%) and halocarbons and other gases (2%). While some of these non-carbon GHG emissions are also associated with energy use, most are emitted by agriculture and industrial processes (see Fig. 2.2). Analysis of these sectors and processes will require a different set of models and expertise. A review of the literature is provided in Appendix E-3.

Additional opportunities for reducing the impact of greenhouse gases include non-energy related carbon sequestration and management, aerosols and other light scattering mechanisms, and others. Reforestation and ocean fertilization to encourage planktonic growth are examples of non-energy-related carbon sequestration. Such opportunities are not included in this study. They need to be further researched and compared with the energy-related options discussed in this report. An assessment of carbon sequestration strategies can be found in a recent report sponsored by DOE's Offices of Science and Fossil Energy (1999).

3.6.6 Time Frame and Geographic Disaggregation

The climate change problem is a long-term problem. It will require continuing attention throughout this new century and beyond. The time frame of this study has been limited to 2020 to focus on near-term policy options to address not only climate change, but also other major energy and environmental issues. Unfortunately such a time frame does not capture the full potential of many of the opportunities identified in this report involving energy efficiency and advanced non-carbon-emitting technologies such as renewable energy. The promise of these technologies will be accentuated in a study that explores impacts beyond the 2020 time frame.

The performance and value of both clean energy and energy efficiency technologies can be highly dependent on the local climate, environment, and economic conditions. Recognition of these local variations is extremely important in assessing the potential of advanced technologies that need these niche market opportunities to develop further. Thus a valuable next step might be to conduct analyses at a finer geographic scale to produce national estimates that reflect such local variations.

3.6.7 Robustness of the Study's Conclusions

The various analysis needs and limitations described in this section do not invalidate the two key conclusions of this study:

- Smart public policies can contribute significantly to meeting the energy-related challenges facing the United States

- The direct economic benefits of these policies can outweigh their costs.

These conclusions are based on results which show overlapping opportunities between technologies competing with each to reduce carbon emissions at least cost. Certainly other opportunities will also arise beyond those which we have considered here. Consequently, the study's conclusions are unlikely to change materially even with improved modeling capability such as the ability to simulate non-fiscal policies, expanded technology representations, and greater geographic disaggregation. The expansive set of sensitivity runs, in conjunction with the substantial body of supporting literature, gives added confidence in the robustness of the conclusions reached by the study.

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Chapter 4

BUILDINGS SECTOR[1]

4.1 INTRODUCTION AND BACKGROUND

This chapter describes our detailed assessment of the achievable potential for reducing building sector carbon dioxide emissions in 2010 and 2020. We calculate dollar, energy, and carbon savings associated with adoption of more energy-efficient technologies, and explicitly define a set of policies and programs that would lead to this outcome. This chapter also assesses the potential role of research and development (R&D) in providing advanced building technologies and practices that will enable continued reduction in energy use and greenhouse gas emissions.

4.1.1 Overview of Sector

Energy is used in buildings to provide a variety of services such as space heating, space cooling, water heating, lighting, refrigeration, and electricity for electronics and other equipment. In the U.S., building energy consumption accounts for a little more than one-third of total primary energy consumption and related greenhouse gas emissions. The cost of delivering all energy services in buildings (such as cold food, lighted offices, and warm houses) was about $240 billion in 1997 (US DOE, 1999).

About two-thirds of building sector primary energy use is electricity, and this sector uses about two-thirds of all electricity generated nationally. Natural gas accounts for about one quarter of total primary energy in this sector, and electricity and natural gas account together for about 90% of building sector primary energy use. Oil consumption is only 4% of the total, although it is a significant heating fuel in the Northeast.

4.1.2 Buildings Sector Primary Energy Use in 1997

Fig. 4.1 shows the percentage breakdown of primary energy use by end-use in residential and commercial buildings. The breakdown of carbon emissions by end-use tracks the primary energy breakdown closely. Space heating is by far the largest identified end-use in the residential sector, accounting for just over one-third of the primary energy. Water heating is next, followed by refrigerator/freezers space cooling, and lighting. The “miscellaneous uses” category contains a variety of smaller end-uses, including clothes washers, dishwashers, home electronics, and all the other unidentified energy end-uses[2].

In the commercial sector, lighting accounts for about one quarter of total primary energy use, and is far and away the largest identified end-use in this sector. Space heating is next, followed by office equipment, cooling, and water heating. The “miscellaneous uses” category contains cooking, transformers, traffic lights, exit signs, district services, automated teller machines, telecommunications equipment, medical equipment, and other unidentified end-uses. It also includes an adjustment term to ensure that the total commercial sector energy use adds up to the totals reported in EIA’s State Energy Data Report.

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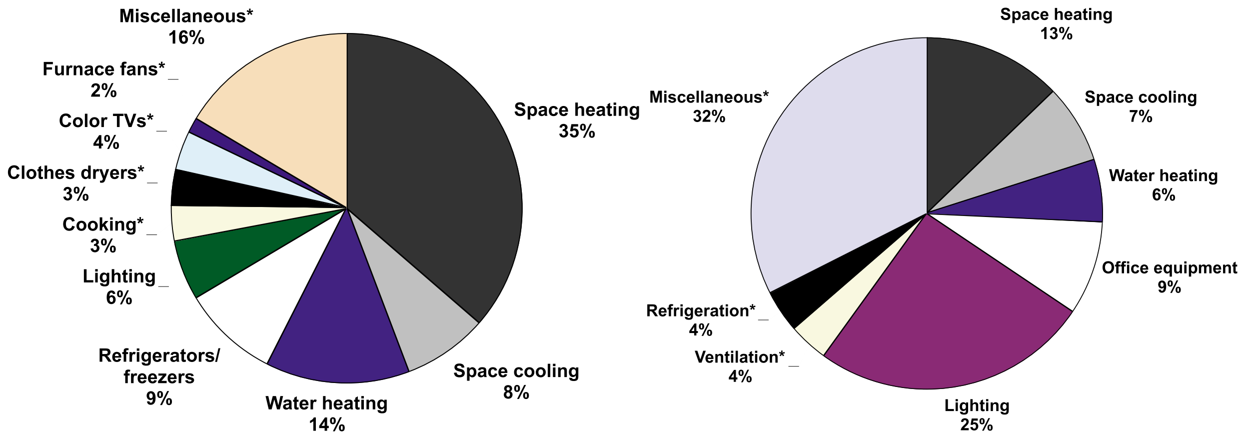
[2] More details on the constituents of the “all other” category (as used in Tables 4.8 and 4.9) and “miscellaneous uses” category can be gleaned from tables in Appendices B-1, C-1, and D-1.

Fig. 4.1 Primary Energy Consumption in the Buildings Sector by End Use, in 1997



Residential Buildings
Total Primary Energy Use in 1997 = 19.0 quads

Commercial Buildings
Total Primary Energy Use in 1997 = 15.2 quads

Constituents of the "All other" category shown in Tables 4.8 and 4.9 are marked with asterisks above. “Miscellaneous uses” include clothes washers, dishwashers, other home electronics, ceiling fans, pool pumps, and other unidentified end-uses.

Constituents of the "All other” category shown in Tables 4.8 and 4.9 are marked with asterisks above. "Miscellaneous uses " include transformers, traffic lights, exit signs, cooking, district services, automated teller machines, telecommunications equipment, medical equipment, and other unidentified end-uses.

This energy portrait in 1997 will of course not remain static in the next two decades, and that has important implications for energy policy design. EIA projects in its Reference Case Forecast, for example, that demand for personal computing and office equipment services in the commercial sector will result in energy increases of over 2% per year. By contrast, EIA also projects sharp *decreases* in home energy use for refrigeration and freezers, due to implementation of standards and technological improvements. These projected shifts mean that by 2020 energy demand for refrigeration will have fallen to 4% of total use (versus 9% now), while energy use for commercial office equipment will increase its share from 9 to 12% of that sector by 2020.

4.1.3 Technology Opportunity Examples

The fundamental insight driving the analysis in this report is that people don’t demand energy, per se. Instead, they demand warm rooms, cold beer, clean dishes, and hot food. It is widely known that technology can vastly decrease energy use, while still delivering these same services (or even better services) and saving consumers money. More recently, it has become clear that that systematic implementation of programs and policies (like ENERGY STAR® programs, Green Lights, Building America, Rebuild America, government procurement, and minimum efficiency standards) can help cost-effective efficiency technologies to be purchased when they would not have been implemented otherwise (ACEEE, 1998; Koomey et al., 1996 Koomey et al., 1998a; Webber and Brown, 1998).

4.2 BUSINESS-AS-USUAL CASE

The building sector uses the AEO99 reference case (US DOE, 1998a) as our business-as-usual (BAU) case, which is summarized in Tables 4.6 and 4.7 below. By 2020 in the BAU case, primary energy use in buildings grows by 37% and carbon emissions grow by 48% over 1990 levels. Compared to 1997 levels, primary energy use grows by 20%, and carbon emissions grow by 31%. The greater growth in carbon emissions is caused by a shift towards more carbon intensive electricity end-uses by the end of the forecast.

The AEO99 reference case contains assumptions about the effect of current policies. Minimum efficiency standards now on the books are included in the reference case, but no additional standards beyond those already enacted are assumed. The standards in the AEO99 case include the refrigerator, freezer, and room air conditioner (RAC) standards for which DOE has enacted final rules. Their date of implementation is October 1, 2000 (for RAC) or July 1, 2001 (for refrigerators and freezers), although in the AEO99 forecast they are modeled for convenience as being effective on January 1, 2001 and 2002, respectively.

The residential sector forecast includes significant increases in the thermal integrity of new homes caused by improvements in building codes and technology. This assumption is one that EIA is revisiting for the AEO2000 forecast.

The AEO99 case also includes EIA's estimates of the effects of the Clinton Administration's Climate Change Action Plan and the 1992 Energy Policy Act (EPACT). These two policies are projected to promote building code adoption, consumer labeling of efficient products, efficiency standards for equipment, energy-efficient mortgages, restructuring of the electric utility industry (which affects electricity prices for buildings), and voluntary programs that promote energy efficiency.

4.3 POLICY IMPLEMENTATION PATHWAYS

Students of end-use markets have long been puzzled by the lack of adoption of ostensibly cost-effective energy efficiency technologies. A rich literature has developed around this question, and analyses of various barriers to adoption of efficiency technologies are widespread (DeCanio, 1993; DeCanio, 1998; Fisher and Rothkopf, 1989; Golove and Eto, 1996; Hirst and Brown, 1990; Howarth and Andersson, 1993; Jaffe and Stavins, 1994; Koomey, 1990; Koomey et al., 1996; Lovins, 1992; NPPC, 1989; Oster and Quigley, 1977; Sanstad and Howarth, 1994; Sanstad et al., 1993). Various policies have been implemented over the past twenty years to ameliorate or sidestep these barriers, and we develop our policy pathways based on that program experience supplemented by professional judgment. We develop both moderate and advanced pathways, as discussed below.

4.3.1 Barriers to Adoption of Cost-Effective Efficiency Technologies

The barriers that inhibit adoption of cost-effective technologies can be broken down into those faced by users, and those faced by manufacturers, builders, designers and suppliers of efficient products.

4.3.1.1 Barriers faced by energy users

Organizations and individuals face a variety of complex barriers to choosing the most cost-effective efficiency option, which vary by user, technology, and end-use[3]. The list below is not comprehensive but illustrative of the kinds of constraints that users face. Each particular transaction is affected by different barriers, and this complexity has made it difficult for researchers to assess the effect of these barriers in a comprehensive way.

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[3] For a review of many of these reasons, see Stephen DeCanio, "Why do profitable energy-saving investment projects languish?" *Journal of General Management*, Vol. 20, No. 1 (Autumn 1994):62-71, and "Barriers within firms to energy-efficient investments," *Energy Policy* (September 1993): 906-914 .

Not knowing. It is impossible for a utility customer, even one who carefully reads her bills, to determine the contribution of various appliances to the total bill (the bills do not separate the cost for lighting from that for refrigeration or cooking). Attaching individual electricity meters to particular appliances is extremely rare, so that the consumer finds herself in a "supermarket without prices:" the user collects all the purchases in their shopping cart and gets one lump-sum bill to pay at the end of the month, with no separate accounting. No consumer can optimize when she doesn't know the price of purchasing a service.

Universal metering by appliance is unlikely to come about any time soon, but the ENERGY STAR label and wide distribution of energy information can help ameliorate this problem. Efficiency standards also mitigate this problem to some degree. As information and metering technologies become more widespread, this problem will become less important, but it will be many years before these technologies will have a significant effect on ameliorating this barrier.

Not caring. In most cases, energy is a small part of the cost of owning and operating a device or building, so the potential energy savings will not "make or break" the firm or make a family rich[4]. For example, before the advent of the ENERGY STAR television (TV) program, typical TVs with remote controls used 5 to 7 watts when turned off because a small amount of standby power is necessary to turn the TV on. TVs that qualify for ENERGY STAR must achieve standby power of three watts or less, a savings of roughly 50%. About ten major manufacturers now offer such TVs. When Sony examined their TV models, the company was able to reduce their standby power from 7-8 watts to about 0.6 watts. While a large savings in percentage terms, even this 90+% reduction will only save about $5 per year per TV. If implemented for all TVs across the U.S., the total savings would be hundreds of millions of dollars per year, but the cost per TV is so low that it would be hard to imagine consumers lobbying TV manufacturers to reduce the standby power of their units.

Since energy costs are typically small on an individual basis, it is easy (and rational) for consumers to ignore them in the face of information gathering and transaction costs. However, the potential energy, dollar, and emissions savings can be important when summed across all consumers, which is why government agencies like EPA and DOE work directly with manufacturers to improve the efficiency of their products. A little work to influence the source of mass-produced products can pay off in significant efficiency improvements and emissions reduction that rapidly propagate through the economy due to mass production and distribution. These programs eliminate the information and transaction costs that impede adoption of efficiency technologies without the program.

Unable to find out. Wise purchases are based on reliable and easily accessible information. Determining which energy efficient products are cost-effective and reliable is not a trivial task. Consumers and managers have limited time and attention, and they are not generally energy experts, so it's difficult for them to separate the winners from the losers. While these costs are a normal part of markets, they can be reduced or eliminated by centralized information collection and dissemination by a credible source (such as EPA, DOE, non-profit organizations, state energy offices, *Consumer Reports*, or electric utilities).

Can't raise the money. Many consumers and industries face capital constraints in pursuing those energy efficiency improvements that require additional incremental investment. These constraints surface as short payback time requirements for investments (2-3 years), or an inability to even consider investing due to lack of money. Creating attractive financing options that improve the consumer's monthly cash flow is one strategy that has proven successful in promoting the EPA's ENERGY STAR new homes program to builders and consumers.

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[4] Of course, for low-income families, the cost of energy can be a very significant part of their income. In this case capital constraints and information are more important barriers to promoting energy efficiency than "not caring".

Split incentives. Whenever the purchaser or operator of an appliance is not the same person who pays for the electricity, the incentive for considering efficiency can be diluted or eliminated. Landlords who pay the energy bills have no control over their tenants' energy use. Alternatively, if tenants pay the bills, then landlords will likely invest in improving energy efficiency only if it will improve tenant retention, justify higher rents, or increase the value of the property upon resale. For these latter conditions to hold there needs to be an objective way to measure the energy efficiency of a building, a situation that only exists in the few jurisdictions where home energy ratings are commonplace, and is rarer still in commercial buildings. Split incentives are particularly difficult to ameliorate, but minimum efficiency standards have been effective in counteracting them.

In residential buildings, about one-third of all households rent. About 90% of all multifamily households rent, which makes this barrier particularly important in this segment of the market.

4.3.1.2 Barriers faced by manufacturers, builders, designers, and suppliers

Energy-aware consumers may never even be offered energy-efficient products if manufacturers choose not to produce them, so it's important to understand the barriers manufacturers face in producing such goods. By the same token, a lack of consumer demand can also inhibit manufacturers from incorporating more efficiency into their products (If the customers don't ask for it, why deliver it?). This lack of demand can be a direct result of the long list of consumer barriers reviewed above. This "chicken and egg" problem is one that can be influenced by policies.

Reluctance to change. An important barrier is inertia. If a TV's power supply has worked well for ten or twenty years, why "rock the boat" with a new design, especially when the public is not clamoring for change? The introduction of ENERGY STAR, however, created a different dynamic. The marketing advantage of having a "green" product is brought to the attention of the marketing branch of the corporation, and these marketers become the advocates within that company for design changes that will make their jobs easier. As long as the new technology is at least as reliable and capable as that it replaces (and there's no reason why it shouldn't be) then the ENERGY STAR method for removing barriers can work well. In fact, reexamining time-honored choices about product design usually leads to increased product functionality and cost savings as well.

Inability to capture all benefits of research and development. If a company spends money on research and development (R&D) to create new products, they can reap some, but not all of the benefits from such innovation. As soon as the company creates a new product, competitors can copy those designs, without having to spend their own money on R&D. This situation leads to under-investment in R&D from society's perspective, which is the main justification for government sponsored R&D. This problem afflicts all sectors of the economy, and it is widely recognized by economists and public policy analysts around the world.

The problem is especially pronounced when an industry is as fragmented as the design and construction industries (Brambley et al. 1988). Oster and Quigley (1977), discussing R&D in the residential construction industry, state that

> "Small scale may be particularly problematic if many of the potential innovations in the industry are in organization, systems design, and in the integration of housing components. Here the minimum efficient scale for R&D activity is presumably rather large, and, more importantly, the returns to R&D are not easily captured by a single firm."

Fragmentation of the industry is also a problem in the commercial buildings sector, with the design and engineering of buildings split between many small design firms.

In addition, there is a longer-term public-purpose aspect to R&D. Certain kinds of long-term basic and applied research is unlikely to be funded by industry, because the payoff will be so far into the future. Government R&D can and does focus on many technologies that will not be cost effective for years, yet may be strategically important decades hence. Historical support for fuel cells and photovoltaics falls into this category.

Design and production cycles. Product design cycles can also slow the pace of innovation. Until a product has "run its course" and repaid the initial investment, most manufacturers are justifiably reluctant to modify production lines. These cycles have become shorter and shorter in recent years due to the growing impact of information technology, but they can be important in particular instances. By working with manufacturers to accommodate their design cycles, EPA has successfully encouraged dozens of them to incorporate efficiency into their next product cycle, while minimizing any transition costs for altering products.

Perverse fee structures. Lovins (1992) describes how typical fee structures for engineers and architects penalize efficiency. Lovins interviewed more than fifty design professionals and analysts of the design process, and documented a market rife with inefficiency and "perverse" incentives. These inefficiencies are driven mainly by the difficulty of creating optimized, custom-built buildings systems in the face of persistent institutional failures.

Lovins analyzes the prevailing fee structures of building design engineers, which are explicitly or implicitly based on a percentage of the capital cost of the project. The reason why fee structures like this one are pernicious is because good design for heating, ventilation, and air-conditioning (HVAC) systems will allow substantial reductions in capital costs *and* operating costs. Such design requires additional expenditures beyond the typical "rule-of-thumb" equipment sizing that most engineers do, which results in a net penalty for designers of efficient systems:

> "Designers who do extra work to design and size innovative HVAC systems exactly right, thereby cutting their client's capital and operating costs, are directly penalized by lower fees and profits as a result, in two different ways: they are getting the same percentage of a smaller cost, and they are doing more work for that smaller fee, hence incurring higher costs and retaining less profit (Lovins, 1992)."

The innovation stifling effects of such fee structures are reinforced by the obligations of professionals, as codified in law. Burnette (1979a, 1979b) points out that the judgement of a particular professional "need not be infallible, just reasonable within the norms established by the judgements and practices of other qualified professionals." Such a standard (and associated litigation) "leads to defensive design and institutionalized conformity" (Lovins, 1992). Use of inaccurate rules of thumb regarding equipment sizing[5], as well as those related to setting fees, are both expressions of that conformity.

Lovins shows how, even though this type of fee structure has been strongly discouraged in the U.S. since the early 1970s (through the threat of anti-trust action against the professional associations), the practice has been eliminated in name only: "both the designer and procurer of design services still generally base their fee *negotiation* on percentage-of-cost curves, just as if nothing had changed. In low-rise office

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[5] Since HVAC systems are typically oversized by factors of two and three, these rules of thumb (coincidentally or not) increase the designers profits because of fee structures based on the capital costs of the project.

projects, for example, 70% of U.S. designers estimate their fees as a percentage of project cost, even though only 15% bid them in that form; for low-rise hotels, 100% vs. 50%; for apartments, 50% vs. 5%."

4.3.2 Policies to Remove Barriers

Policies to remove barriers and reduce energy costs, energy use, and carbon emissions in buildings fall into nine general categories: voluntary programs, building efficiency standards, equipment efficiency standards, state market transformation programs, financing, government procurement, tax credits, accelerated R&D, and carbon trading systems. Each policy may affect residential buildings, commercial buildings or both, and each ameliorates specific market barriers that inhibit the adoption of cost-effective efficiency improvements. Tables 4.1 and 4.2 (below) summarize which barriers and end-uses (respectively) can be affected by each policy. The specific policies we consider are described in detail in Appendix B-1. Not all policies discussed here are used in our scenarios.

Table 4.1 Carbon Mitigation Policies and Which Barriers They Can Affect

Barrier	Policy Type								
	Voluntary Programs	Building Codes	Equipment Standards	State Market Transformation Programs	Financing	Government Procurement	Tax Credits	Accelerated R&D	Domestic Carbon Trading
SCENARIO	B	B	B	B	B	B	B	B	A
Barriers faced by users									
Not knowing	X	X	X	X			X		
Not caring	X	X	X	X					
Unable to find out	X	X	X	X			X		
Can't raise the money				X	X		X		
Split incentives		X	X						
Barriers faced by manufacturers, builders, designers, & product suppliers									
Reluctance to change	X	X	X			X			X
Inability to capture all benefits of R&D								X	
Design and production cycles	X							X	
Perverse fee structures					X		X		

(1) "B" under scenario signifies "both," "M" signifies Moderate Scenario only, "A" signifies Advanced Scenario only.

Voluntary Programs. Major voluntary buildings-sector programs in the U.S. include the ENERGY STAR programs operated by EPA and DOE, and the Building America and Rebuild America programs run by DOE. Programs exist for both residential and commercial products and buildings. The ENERGY STAR product programs are structured as labeling programs. Identifying high efficiency products for consumers is only one aspect of the program, however. The programs has also been effective in working with manufacturers to convince them to promote existing and develop new energy-efficient products.

Table 4.2 Carbon Mitigation Policies and Which End-Uses and Technologies They Can Affect

End-Use/Technology	Policy Type								
	Voluntary Programs	Building Codes	Equipment Standards	State Market Transformation Programs	Financing	Government Procurement	Tax Credits	Accelerated R&D	Domestic Carbon Trading
SCENARIO	B	B	B	B	B	B	B	B	A
Thermal Shell-Res. Retrofits	X	X		X	X	X	X	X	X
Thermal Shell-Res. New	X	X		X	X		X	X	X
Thermal Shell-Comml Retrofits	X	X			X		X	X	X
Thermal Shell-Comml New	X	X			X		X	X	X
Residential HVAC equipment	X		X	X	X		X	X	X
Commercial HVAC equipment	X	X	X	X	X	X	X	X	X
Residential Ducts				X	X		X	X	X
Commercial Ducts					X		X	X	X
Residential Water Heating	X		X	X	X		X	X	X
Commercial Water Heating	X	X	X		X	X	X	X	X
Residential Refrigeration	X		X	X				X	X
Commercial Refrigeration	X	X		X		X		X	X
Cooking Equipment			X					X	X
Laundry	X		X	X				X	X
Dishwashers	X		X					X	X
Residential Lighting	X			X				X	X
Commercial Lighting	X	X	X	X		X		X	X
Televisions	X								X
PCs	X					X			X
Office Equipment (not PCs)	X					X			X
Motors	X	X	X	X		X		X	X
Transformers	X		X					X	X
Water Conservation Measures		X	X				X		X
Residential Miscellaneous	X			X				X	X
Commercial Miscellaneous	X		X	X		X		X	X
District Energy Systems with Combined Heat and Power				X		X	X	X	X
Fuel cells				X		X	X	X	X

(1) "B" under scenario signifies "both", "M" signifies Moderate Scenario only, "A" signifies Advanced Scenario only.

(2) Fuel cells, district energy systems, shell retrofits, and state market transformation programs for new residential shells are not included in current scenarios.

ENERGY STAR's residential programs are all structured as labeling programs, even the ENERGY STAR new homes program for residential buildings. In this program, EPA works with builders to increase the construction of high efficiency homes, which can then be marketed using the ENERGY STAR label. Residential products covered by ENERGY STAR programs include residential HVAC equipment, insulation, windows, residential lighting fixtures, clothes washers, dishwashers, room air conditioners, refrigerators, televisions, VCRs, home audio equipment, and home computers. Future product programs may include other consumer electronics and water heaters. Also in development is a program aimed at existing homes.

Commercial products covered by the ENERGY STAR labeling programs include PCs, monitors, copiers, printers, fax machines, multi-function devices, exit signs and transformers.

Some commercial sector ENERGY STAR programs operate differently from equipment labeling programs, relying on high level corporate commitments and public recognition of participating corporations to promote cost-effective efficiency investments. The commitment of the chief executive of a company to these programs allows program champions within the organization to beat back institutional inertia and cut through red tape to make these investments happen. ENERGY STAR's commercial buildings programs are the ENERGY STAR Building program and the ENERGY STAR Small Business program, which focus on improving the energy efficiency of existing buildings by working with and educating building managers and business owners.

The DOE's Building America program is a private/public partnership that applies a systems-engineering approach to the design and construction of production housing. The goals of the partnership include producing homes on a community scale that use 30% to 50% less energy than those built to code at no incremental cost, reducing construction time and waste by as much as 50%, and improving builder productivity. The systems engineering approach considers the interaction between the building site, envelope, and mechanical systems, as well as other factors. It recognizes that features of one component in the house can greatly affect others and it enables the teams to incorporate energy-saving strategies at no extra first cost.

Rebuild America is a voluntary program that stimulates energy efficiency upgrades in existing commercial buildings, new education buildings, and existing high rise residential buildings. DOE supplies technical support and State Energy Offices supply limited financial support. Its goal is to reduce energy use and bills in such buildings by 20-30%.

Building Codes. The most important efficiency code for new low-rise residential buildings is the International Code Council's Model Energy Code, which is periodically reviewed and updated. In residential buildings, the focus is primarily on the building shell, although codes may also affect HVAC equipment and lighting.

The most important energy conservation standard for new high-rise residential and commercial buildings is that issued by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) and by the Illuminating Engineering Society of North America (IESNA). In the summer and fall of 1999, these organizations approved a new standard for commercial and high-rise residential buildings, ASHRAE/IESNA Standard 90.1-1999. This standard, which will be published in February 2000, will then be available for adoption by federal, state and local government agencies into building codes. Standard 90.1-1999 is an update of the previous Standard, ASHRAE/IESNA Standard 90.1-1989, (issued in 1989), and will produce substantial savings relative to it, according to ASHRAE.

In our analysis, however, our "baseline" energy standard is the 1989 version, the operative commercial building standard available to us while this report was being written. (ASHRAE issued final approval of the 1999 version in late October 1999). The 1989 standard is referenced in the Energy Policy Act of 1992, which directs the states to demonstrate that its commercial energy codes meet or exceed ASHRAE Standard 90.1-1989.

For the Moderate and Advanced scenarios, we developed an altogether different commercial standard to capture the energy savings potential inherent in commercial building standards. We didn't use ASHRAE/IESNA 90.1-1999, because most of its energy savings potential, which is in lighting, will be captured first by another policy instrument, namely the promulgation of minimum efficiency standards for fluorescent ballasts in 2004 (as we assume in our Moderate and Advanced scenarios).[6] Instead, we assume in our Moderate and Advanced scenarios that a new commercial standard is developed and adopted that features a 15% "whole building" reduction target. This standard, by design, is not prescriptive, and allows builders and designers maximum flexibility in reaching the target. Advances in handheld computer technology will facilitate adoption of and compliance with this new standard.

Equipment Standards. Equipment standards require that all new equipment sold meet minimum energy-efficiency standards. Water conservation measures, such as low-flow showerheads and faucets, are also considered since they reduce water-heating energy. The appliance standards considered here are based on three pieces of legislation: the National Appliance Energy Conservation Act of 1987 (NAECA), which addresses primarily residential appliances, the 1988 amendments to NAECA, which address magnetic fluorescent ballasts, and the Energy Policy Act of 1992 (EPACT), which primarily addresses commercial products.

In the residential sector, NAECA standards are currently in place for residential refrigerators and freezers, water heaters (gas, oil and electric), clothes washers, clothes dryers, dishwashers, heat pumps, central air conditioners, room air conditioners, furnaces (gas and oil), and boilers (gas and oil). EPACT set water conservation standards for showerheads and faucets that reduce residential hot water use. DOE periodically updates NAECA standards. Tighter standards are anticipated for residential clothes washers, water heaters, heat pumps and central air conditioners between 2000 and 2006, with some updates to follow in 2010.

In the commercial sector, EPACT set standards for lamps (4- and 8-foot fluorescent lamps and incandescent reflector lamps), motors (1-200 horsepower), and commercial heating and cooling, including packaged air-cooled air conditioners and heat pumps, packaged water-cooled air conditioners and heat pumps, packaged terminal air conditioners and heat pumps, water heaters, furnaces and boilers. The showerhead and faucet standard also affects commercial hot water use. The only commercial products covered under NAECA, fluorescent lamp ballasts, currently are subject to a standard that prevents sales of the lower efficiency core-coil magnetic ballasts (high-efficiency magnetic ballasts can still be sold). We assume in our scenarios that DOE will enact a revised standard for ballasts that takes effect in 2004.

State Market Transformation Programs Funded Through "Public Benefits (Line or pipe) Charges." State Market Transformation programs are quite diverse. As implemented in states that are experimenting with deregulation, they involve a small charge (1-2%) on every kWh that is transmitted across the grid (they could also in principle be applied to natural gas as well). Payment of the charge would be a precondition for interconnecting with the grid. This money then goes into a fund to pay for energy efficiency and renewable technology implementation programs.

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[6] In Fall 1999 (after the analysis for this study had been completed), efficiency advocates and ballast manufacturers negotiated an agreement that would result in an efficiency standard eliminating most U.S. magnetic ballast manufacturing by April 1, 2005 (except for ballasts manufactured as replacements for existing equipment), and eliminating all such manufacturing by July 1, 2010. The U.S. Department of Energy accepted this negotiated agreement in its Congressionally mandated standards-setting process.

Such programs can focus on new construction or on retrofits and replacements. State new construction programs can affect the thermal shell, HVAC, water heating and lighting, and may influence fuel choice for HVAC, water heating, cooking, and dryers. For existing homes, utilities have weatherization programs focusing on the building shell, rebates for high-efficiency HVAC, appliances and lighting. Rebates may also be used to subsidize fuel switching for hot water heating or conversion from electric resistance central furnaces to heat pumps.

Financing. An important subset of State Market Transformation Programs and some ENERGY STAR programs is special financing to spread the incremental investment costs over time and reduce the first cost impediment to adoption of energy efficient technologies. The ENERGY STAR new homes program, for example, already offers preferential financing that improves monthly cash-flow for purchasers of ENERGY STAR homes. These financing packages can apply to those end-uses that are structural parts of the building, like HVAC, thermal shell, and water heating.

In commercial buildings, Energy Savings Performance Contracting (ESPC) is another way to use creative financing to promote efficiency investments. In such contracts, an energy service company guarantees a fixed amount of energy cost savings throughout the life of the contract (typically 5 to 12 years, and up to 25 years for Federal government contracts) and is paid directly from those cost savings. The organization that owns the facility retains the remainder of the energy cost savings for itself.

Government Procurement. Procurement policies have the potential to accelerate the adoption of new technologies, and also directly save money for the government. Procurement can reduce costs for new technologies by allowing manufacturers to acquire production experience with them and hence “move down the learning curve”. In 1997 the Federal Acquisition Regulations were amended, directing that “agencies shall implement cost-effective contracting preference programs favoring the acquisition of...products that are in the upper 25 percent of energy efficiency for all similar products” (FAR, sec. 23.704). In addition, EPA and DOE are currently working to encourage state and local governments to reform their own purchasing practices to encourage adoption of more energy efficient devices. Another program that falls under this general category is the Federal Low Income Weatherization Program, which improves the energy efficiency of qualifying residences. We treat procurement policies as a key enabling program (particularly for ENERGY STAR) that are implicit in the Moderate and Advanced Scenarios, but we do not explicitly estimate their effects.

Tax Credits. We consider the effect of tax credits for high-efficiency equipment, as described in President Clinton’s Climate Change Technology Initiative. This initiative, first laid out in January 1998 and updated in Spring 1999, proposed tax incentives for efficient natural gas water heaters, electric central air conditioners, electric heat pumps, residential-sized heat-pump water heaters, and natural gas heat pumps. It also proposed tax credits for fuel cells, new homes with efficiencies that significantly exceed current building standards, rooftop photovoltaic systems, and solar water heating systems.

Accelerated R&D. R&D is an important enabling policy. The effect of accelerated R&D on the costs and potentials for efficiency improvements has been included in a schematic way in our analysis. This policy measure applies to all end-uses where public-private R&D partnerships can be effective in improving the rate of technological change associated with the energy efficiency of these products. We exclude office equipment, televisions, and other electronic equipment from this policy, because these technologies change at such a rapid rate, and because this industry's lifeblood is R&D and innovation. Some longer-term basic research in semiconductor physics may assist this industry, but such basic research is not included in our scenarios.

We assessed roughly twenty different key R&D technologies for buildings (see the following box), and of those chose five to represent whatever technologies are likely to be successful in a well designed R&D

portfolio (whole buildings R&D for residential buildings, whole buildings R&D for commercial buildings, mini-HID lamps for residences, CFL torchiere lamps, and heat pump water heaters). It is impossible to say whether these particular options are the ones that will be successful, but we believe that these five are a good proxy for those that would be successful. The details of how we modeled the effects of this policy are contained in the appendices, but in summary, we lowered costs for these technologies and assessed the additional market penetration associated with such cost reductions.

R&D Options for the Buildings Sector

*Systems integration in new construction (including community scale)
Improved industrialized housing methods
Fully integrated service module development
Phase change thermal storage
Integrated photovoltaic construction
Superinsulating materials
Electrochromic and other efficient window technologies
*"Smart Buildings" (advanced sensors, energy control and monitoring systems
Health impacts identification and mitigation
Characterization of energy efficiency - worker productivity interactions
PEM fuel cell adaptation for buildings
Small gas turbine applications for combined heat and power production
Advanced refrigeration components, refrigerants, lubricants and materials
Improved understanding and characterization of combustion processes
Advanced desiccants
Large commercial chiller improvements
*Residential heat pump water heater development
Residential absorption heat pump
VHF light sources
*Mini HID lamps
*Improved compact fluorescent lamp (CFL) torchieres
Improved lighting distribution systems
Building commissioning

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* indicates that R&D for this technology was included in the CEF building sector scenarios.

Carbon Trading System. This cross-cutting policy is implemented for all sectors in the Advanced Scenario. It reduces carbon emissions by promoting energy efficiency and fuel switching to less carbon intensive fuels.

4.3.3 Definition of Pathways

Our policy pathways combine many (but not all) of the policies discussed above in both Moderate and Advanced Scenarios. The Moderate Scenario presumes modest progress in implementing those policies and programs. The Advanced Scenario assumes that significant implementation effort beyond the Moderate case. In addition, the Advanced Scenario contains a $50/t carbon permit trading fee that reflects the adoption of an emissions trading system for carbon and other greenhouse gases. The content of these scenarios is summarized in Table 4.3. Appendices B-1 and C-1 contained detailed information about policies and technologies in each scenario.

Creating scenarios entails judgment. No one can forecast the future with certainty, and many of the relevant parameters are simply not known. We made judgments that we felt were plausible, based on the analysis teams' considerable experience in this area. Penetration rates in particular were usually developed in this manner, after reviewing the literature on experience with related programs and policies. We documented our assumptions in the appendices.

4.4 METHODOLOGY FOR ANALYZING IMPACTS

We rely on a three-step process for creating our analysis: first, we assess the potential impact of individual policies on energy demand in detailed spreadsheets. Then we change hurdle rates (implicit discount rates) and other parameters inside the buildings sector modules of CEF-NEMS (our version of the National Energy Modeling System)[7] so that the model mimics the energy savings calculated from the spreadsheets when these modules are run in stand-alone mode (equipment efficiency standards were implemented directly in the CEF-NEMS modules). Finally (for the Advanced Scenario only) we add a carbon permit trading fee of $50/t and the CEF-NEMS modules respond to that fee using the modified hurdle rates, reflecting a policy and market environment that is working towards substantial carbon reductions. This procedure follows that used in the earlier study by Koomey et al. (1998b).

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[7] As in other parts of this report, we use the term “CEF-NEMS” to refer to the NEMS model as modified for our policy analyses, and use the term “NEMS” whenever we discuss issues generic to the NEMS model in all its incarnations. The complete list is as follows: (AHAM, 1997; Anderson, 1999; Appliance, 1996; Appliance, 1998; Atkinson, 1996; Auten, 1999; Barbour, 1998; Barnes et al., 1996; Barnes et al., 1997; BCAP, 1999; BEA 1998; Berry, 1991; Berry, 1993; Berry, 1996; Berry et al., 1997; Brinch, 1996; Brown, 1993; Brown et al., 1998; Calwell, 1999; Davis Energy Group, 1994; ELPN et al., 1998; Energy Center of Wisconsin, 1997; EPRI, 1987; Eto et al., 1994; Eto et al., 1995; Geller et al., 1998, Geller et al. 1987; Gregerson, 1994; Haasl and Sharp, 1999; Hughes and Shonder, 1998; Jakob et al., 1994; Johnson et al., 1994; Katz and Warren, 1996; Kinney et al., 1997; Koomey et al., 1991; Koomey et al., 1994; Koomey et al., 1999a; Koomey et al., 1999b; Krause et al., 1989; LBNL, 1996; LBNL, 1997; Levine et al., 1995; Meier et al., 1993; Mills, 1991; Mr. Cool, 1998; Nadel, 1991; Nadel, 1992; Nadel et al., 1998; Nadel and Ticknor, 1992; Parker et al., 1999; Petrie and Childs, 1998; Richey, 1999; Richey and Koomey, 1998; Sanchez et al., 1998; Sezgen et al., 1995; Stern et al., 1985; Su and Zambrano, 1999; Suozzo and Nadel, 1998; Tomlinson and Rizy, 1998; Train et al., 1985; US Bureau of the Census, 1997; US Bureau of the Census, 1998; US DOE, 1990; US DOE, 1993a; US DOE, 1993b; US DOE, 1995a; US DOE, 1995b; US DOE, 1998b; US DOT, 1999; US EPA, 1999a; US EPA, 1999b; US EPA, 1999c; Vine and Harris, 1988; Vineyard et al., 1997; Vorsatz and Koomey, 1999; Wenzel et al., 1997; Westphalen et al., 1996; XENERGY, 1996).

Table 4.3 Buildings Sector Policies, By Scenario

Moderate Scenario	Advanced Scenario
➢ 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 penetration, more covered end-uses
➢ Increase enforcement and adoption of current building codes	➢ 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.
➢ Implement new efficiency standards for equipment beyond those already planned.	➢ More end-uses covered. Another round of standards for some products.
➢ Line charges for states implementing electricity restructuring (full national utility restructuring by 2008)	➢ Higher line charges for states implementing electricity restructuring (full national utility restructuring by 2)
➢ Government procurement assumed to increase in scope over current efforts. Increase DOE's Federal Energy management Program (FEMP) efficiency goals by executive order. Adopt renewable power purchase requirement for Federal facilities. (1)	➢ 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. (1)
➢ Implement tax credits as proposed by Clinton Administration	➢ 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.
	➢ Domestic carbon trading system with assumed permit price of $50 per metric ton of carbon, announced in 2002 and implemented in 2005

(1) Unlike other policies enumerated here, we do not explicitly model government procurement policy in this analysis. However, we recognize it here as an important and strategic enabling policy that is essential for the voluntary programs to achieve their estimated penetration levels.

4.4.1 Overall Approach

The most challenging part of this analysis is estimating the impact of policies on the market penetration of technologies under our Moderate and Advanced scenarios over the next two decades. To accomplish this difficult task, we use our best qualitative judgement, based on our collective experience with buildings efficiency programs, because there is simply no "scientific" means for predicting the precise impacts of most policy measures.

With respect to research and development, for example, the predictive challenge is aptly captured by the President's Committee of Advisors on Science and Technology (PCAST) in their report*, Federal Energy Research and Development for the Challenges of the Twenty-First Century* (PCAST 1997). PCAST frames the challenges as follows:

> "how much can energy R&D contribute to (national goals)…as a function of time and in relation to the sums invested? It is difficult, indeed impossible, to offer any precise answers to this question, not least because the answers depend strongly on the outcomes of R&D (by the nature of such activity) which cannot be predicted in detail." (page 1-16)

But while the precise prediction is not possible, the basic relationship between resources and outcomes is evident: "The evidence from all of these historical approaches supports the proposition that the leverage of R&D, against the challenges facing the energy system, is likely to be large." (PCAST, page 1-17) And the empirical record of Federal buildings energy efficiency research is compelling, with development of a number of high-performance technologies, including low-emissivity window coatings, high-efficiency refrigerator compressors, and fluorescent lamp electronic ballasts, all of which are widespread products in today's marketplace.

With respect to predicting the future impacts of voluntary information programs on consumer choice, there is also great uncertainty. As a recent U.S. DOE report observes of information and education policies:

> "…the ability of information programs to induce actual changes…depends on three factors: the extent to which the information is applicable to the decisions at hand and considered reliable, the extent to which the information identifies previously unknown cost-effective opportunities or positive product attributes, and the extent to which it is acted upon." (US DOE 1996, p. 3-17).

Establishing robust parameters for any one of those factors is challenging, but it is especially daunting to establish a firm causal link between the information provided, "and the extent to which it is acted upon."

Nonetheless, to illustrate the potential impacts of policies in the year 2015 such as advanced technology tax credits for heat pump water heaters, ENERGY STAR buildings, and accelerated research and development, one must make transparent, well-documented, and defensible assumptions about program impacts, and that is what we did.

4.4.2 Details of the Analysis of Policies Outside of CEF-NEMS

Our spreadsheet analysis of the buildings sector relies for its basic structure on the spreadsheet analysis documented in the study *Scenarios of U.S. Carbon Reductions: Potential Impacts of Energy Technologies by 2010 and Beyond* (Interlaboratory Working Group 1997). We updated the spreadsheets to reflect some of the improvements in the NEMS Annual Energy Outlook forecast since that study was published, including detailed breakdowns of the residential and commercial miscellaneous end-uses, explicit accounting for halogen torchieres in lighting, and extension of the analysis period to 2020.

The spreadsheets rely on careful stock accounting for buildings and equipment, and detailed characterizations of the technoeconomic potential for efficiency improvements by end-use, based on the latest technology data. Efficiency improvements are characterized in terms of the percentage savings that are cost effective relative to typical new equipment purchased in 2000, and a cost of conserved energy ($/kWh or $/Mbtu) for purchasing those efficiency options.

The technology and program effectiveness data for the building sector relies on a huge variety of sources. We combine information from these sources with experience and judgment to create the policy scenarios.

The calculations are carried through for each technology at a low level of disaggregation. Estimated energy savings per unit for each appliance are multiplied by the number of efficient units expected to be shipped in a given year, accounting for expected program penetrations and retirements and growth in the number of households and floor area of commercial buildings. These savings are then aggregated over all the end-uses to estimate the total savings for a given fuel type in each scenario. Details on the assumptions and calculation methods are contained in Appendices B-1 and C-1. Because of their importance to the overall results, we summarize equipment efficiency standards included in our scenarios in Table 4.4.

In the real world, only some fraction of this technoeconomic potential can be captured with real programs and policies. The original interlaboratory analysis of buildings used overall achievable fractions of 35% and 65% for the efficiency and high-efficiency/low carbon cases, respectively, implying that 35% or 65% of the technoeconomic potential could be captured in practice by 2010. In this analysis, we derive these implementation fractions by end-use by explicitly characterizing the pathways for specific policies. We also derive a program implementation cost, based on recent program experience. These key data are summarized in Table 4.5. The details of these calculations are contained in Appendices B-1 and C-1, and an end-use by end-use breakdown of these results is shown in Appendix D-1.

The achievable fractions in 2010 for residential and commercial buildings are about one-quarter in the Moderate Scenario, and around one-third in the Advanced Scenario. By 2020, as a result of stock turnover and advances in technology brought about by policies and programs, these achievable fractions go up to around forty percent in the Moderate Scenario and to over fifty percent in the Advanced Scenario. While the aggregate achievable fractions in this study never reach the 65 percent used in the advanced case for the interlaboratory analysis, the CEF analysis surpasses the 35 percent achievable fraction assumed in that study's efficiency scenario by 2020 in both the Moderate and Advanced Scenarios.

Table 4.4 Summary of New Equipment Efficiency Standards by Scenario

Sector	*Equipment type*	*Year*	*Efficiency/ Energy units*	*Baseline efficiency*	*Standard efficiency*	*Scenario*
Residential	CAC	2006	SEER	10.42	12	M,A
	ASHP heating	2006	HSPF	7.17	7.4	M,A
	ASHP cooling	2006	SEER	10.89	12	M,A
	RAC	2001	EER	9.1	9.7	M,A
	RAC	2010	EER	9.7	10.5	M,A
	Refrigerator/freezer	2010	kWh/year	665	495	M,A
	Refrigerator/freezer	2010	kWh/year	495	421	A
	Freezers	2010	kWh/year	455	391	M,A
	Freezers	2010	kWh/year	391	290	A
	Gas water heater	2004	EF	0.54	0.62	M,A
	Dishwasher	2010	kWh/year	496	431	A
	Televisions	2010	kWh/year	184	146	A
	Clothes washer	2004	Modified EF	0.817	0.961	M
	Clothes washer	2007	Modified EF	0.961	1.362	M
	Clothes washer	2004	Modified EF	0.817	1.362	A
Commercial	Packaged AC	2005	EER	9.4	10.3	M
	Packaged AC	2005	EER	9.4	10.3	A
	Packaged AC	2010	EER	10.3	11	A
	Fluorescent Ballasts	2004		Typical in 2000	Electronic	M,A

(1) CAC = Central Air Conditioner, ASHP = Air Source Heat Pump, RAC = Room Air Conditioner, AC = Air Conditioner, SEER = Seasonal Energy Efficiency Ratio, HSPF = Heating Seasonal Performance Factor, EF = Energy Factor.

(2) The baseline efficiency shown above is the average efficiency of new units in 2000, except for the 2010 standards for RACs, Refrigerator/freezers, and Freezers, where the baseline efficiency is the previous standard level. The projected efficiency of average new units in the year a particular standard comes into force is correctly analyzed in our scenario calculations, but for simplicity's sake, we show the year 2000 new unit efficiency in this table.

(3) Standard for televisions affects standby power only, reducing it to 3W.

(4) In Scenario column, 'M' stands for Moderate and 'A' stands for Advanced.

(5) The standard levels and timing of equipment efficiency standards shown in this table represent the authors' best judgment of feasible and cost effective standards for the two main scenarios considered in the study. They should in no way be construed to represent the position of the U.S. DOE on these standards, which will only be officially determined after appropriate rulemaking procedures are followed.

Table 4.5 Summary of Buildings Sector Program Effectiveness and Costs, by Scenario and Fuel

	Technoeconomic potential % savings relative to business as usual case		*Achievable percentage of technoeconomic potential*		*Technology cost*	
Sector & fuel	*2010*	*2020*	*2010*	*2020*	*$/MBtu 2010*	*$/MBtu 2020*
Residential--Moderate						
Electricity	28%	37%	28%	45%	6.00	5.46
Natural gas	5%	12%	21%	22%	2.11	2.27
Oil	6%	13%	0%	0%	N/A	N/A
LPG	6%	13%	0%	0%	N/A	N/A
Other	0%	0%	N/A	N/A	N/A	N/A
Total	14%	21%	24%	36%	5.23	4.88
Residential--Advanced						
Electricity	28%	37%	34%	65%	5.43	4.31
Natural gas	5%	12%	28%	36%	2.48	1.95
Oil	6%	13%	0%	18%	N/A	1.88
LPG	6%	13%	0%	0%	N/A	N/A
Other	0%	0%	N/A	N/A	N/A	N/A
Total	14%	21%	31%	55%	5.13	4.00
Commercial--Moderate						
Electricity	19%	26%	37%	54%	7.45	7.53
Natural gas	16%	26%	22%	25%	1.60	1.43
Oil	16%	26%	0%	0%	N/A	N/A
Other	0%	0%	N/A	N/A	N/A	N/A
Total	17%	25%	27%	37%	6.13	6.19
Commercial--Advanced						
Electricity	19%	26%	42%	62%	7.14	7.13
Natural gas	16%	26%	29%	40%	1.59	1.57
Oil	16%	26%	0%	0%	N/A	N/A
Other	0%	0%	N/A	N/A	N/A	N/A
Total	17%	25%	33%	48%	5.43	5.32

(1) Technology cost is the total incremental investment cost for the more efficient option, annualized and expressed as a Cost of Conserved Energy (CCE). CCEs are calculated using a real discount rate of 7% and lifetimes as shown in Appendix C-1.

(2) Technoeconomic potential savings and CCEs for electricity are expressed in terms of site energy at 3412 Btus/kWh, so no electricity supply side effects are included.

(3) All costs are in 1997 dollars.

(4) Program implementation costs of $0.6/MBtu of fuel and $1.7/Mbtu of site electricity are used (corresponding to $0.6/Mbtu of primary energy for electricity), as described in Chapter 1.

4.4.3 Modeling the Scenarios in CEF-NEMS

The revised analysis spreadsheets incorporate these parameters, and then yield energy savings by end-use in 2010 and 2020 for residential and commercial buildings in the Moderate and Advanced Scenarios. To match the CEF-NEMS projection in our scenarios to our detailed spreadsheet forecasts of energy savings by end-use and technology, we changed hurdle rates, technology costs, and growth trends for each end-use. We directly input the equipment efficiency standards to the CEF-NEMS buildings sector modules. These changes reflect the effect of a variety of non-energy-price policies that eliminate many of the barriers to investing in cost-effective efficiency technologies.

We match the CEF-NEMS run for each building sector module run in “stand-alone” mode against the spreadsheet results. The fuel price interactions in the integrated runs would make it difficult to exactly match against the spreadsheets. Running the CEF-NEMS modules in stand-alone mode eliminates this complexity. Appendix A-1 contains information on how we modified the CEF-NEMS input files and code to reproduce the energy savings from the spreadsheets.

On the demand side, NEMS interprets a series of “hurdle rates” (sometimes referred to as “implicit discount rates”) as a proxy for all the various reasons why people don't purchase apparently cost-effective efficiency technologies in the building sector. They include constraints for both the consumer (purchasing) and for the supplier (product manufacturing and distribution). Among the constraints are transaction costs, manufacturer aversion to innovation, information-gathering costs, hassle costs, misinformation, and information processing costs. The hurdle rates embody the consumers’ time value of money, plus all of the other factors that prevent the purchase of the more efficient technologies. In this regard, the NEMS modeling framework follows a long and rich history in the economics of energy efficient technology adoption (DeCanio 1998, Howarth and Andersson 1993, Howarth and Sanstad 1995, Koomey et al. 1996, Meier and Whittier 1983, Ruderman et al. 1987, Sanstad et al. 1993, Train 1985).

In the residential and commercial sectors, for example, the financial component of the reference case hurdle rate is about 15 percent (in real terms) with the other institutional and market factors pushing such rates to well above 100 percent for some end-uses. In our scenarios, we reduce the hurdle rates as appropriate for many end-uses to reflect the policies described above. When we reduce the hurdle rates in the CEF-NEMS model, we are increasing the responsiveness of the model to changes in energy prices. This change accurately (though indirectly) reflects a world in which aggressive programs and policies remove barriers to adoption of energy-efficient technologies.

In the advanced scenario, the $50/t carbon permit trading fee is modeled directly in the CEF-NEMS model, and the building sector modules respond using the revised hurdle rates that we input to those modules. The $50/t fee corresponds to about a 10% increase in base year electricity prices, and a 15% increase in natural gas prices, not accounting for price effects from fuel switching caused by the fee.

4.5 POLICY SCENARIO RESULTS

4.5.1 Overview

The results for our two policy scenarios are summarized in Tables 4.6-4.11 and in more detail in Appendix D-1. Energy and carbon emissions savings are dominated by those from electric end-uses. Carbon savings reflect savings in primary energy as well as the savings from fuel switching and other effects on the electricity supply side (which are driven by the carbon permit trading fee and other policies). Relative to the BAU case, absolute savings in primary energy are larger in the residential sector than in commercial buildings, for both Moderate and Advanced Scenarios. In percentage terms, the largest primary energy savings accrue in lighting (both residential and commercial), in residential "all other", and in residential space cooling.

In the Moderate Scenario in 2020, primary energy savings in buildings sector electricity are about one-fifth lower than site energy savings in percentage terms, indicating that the changes on the electricity supply side actually decrease the conversion efficiency of power generation. In the Advanced scenario in 2020, primary energy savings in buildings sector electricity are roughly nine percent higher than site energy savings in percentage terms, indicating a small improvement in conversion efficiency on the electricity supply side.

We can also decompose the carbon savings in electricity in the Advanced Scenario in 2020. About half of total buildings electricity-related carbon savings in 2020 in this scenario is attributable to demand-side efficiency improvements, while the other half is attributable to fuel switching and efficiency improvements on the electricity supply-side. Supply side fuel switching is about ten times more important than supply side efficiency improvements in reducing carbon emissions in this scenario.

4.5.2 Moderate Scenario

By 2010, total primary energy use in the building sector grows about 9% in the Moderate Scenario compared to 1997 levels, and grows to about 11% over 1997 levels by 2020, compared to growth of about 12% in the BAU case in 2010 and 20% by 2020. Carbon emissions are reduced compared to the BAU case, but without the effect of the carbon permit trading and other supply-side policies on the electricity sector fuel mix, carbon emissions in the building sector still increase after 2010. The total cost of delivering energy services, accounting for bill savings and the costs of efficiency programs and investments, is reduced by about one tenth relative to the BAU case in both 2010 and 2020.

4.5.3 Advanced Scenario

In the Advanced Scenario, primary energy use in 2010 is just above 1997 levels, and by 2020 it declines a bit relative to 2010. This result reflects the significantly greater commitment to carbon reductions in the Advanced Scenario. Carbon emissions decline significantly, and are below 1990 levels by 2010, and well below 1990 levels by 2020. A large fraction of this decline is the result of the electricity supply-side policies discussed in Chapter 7, but the remainder is attributable to the set of programs and policies described in detail in Appendices B-1 and C-1. The total cost of delivering energy services, accounting for bill savings and the costs of efficiency programs and investments, goes up by 2% relative to the BAU case in 2010, and down by 4% in 2020. In 2010, the carbon permit fee increases overall energy prices more than the efficiency programs reduce energy use, while in 2020, the energy savings are large enough to more than offset the increase in prices associated with the carbon permit fee.

Table 4.6 Primary Energy Use by Scenario and Fuel in the Buildings Sector

			2010					***2020***				
Sector & fuel	***1990***	***1997***	***BAU***	***Moderate***		***Advanced***		***BAU***	***Moderate***		***Advanced***	
	Q	**Q**	**Q**	**Q**	**% Δ**	**Q**	**% Δ**	**Q**	**Q**	**% Δ**	**Q**	**% Δ**
Residential												
Primary Electricity	10.2	11.7	13.8	13.1	-5.1%	12.1	-12.3%	15.4	13.3	-13.3%	11.2	-27.4%
Natural gas	4.5	5.2	5.5	5.5	-0.5%	5.2	-5.2%	6.0	5.9	-1.7%	5.5	-8.0%
Oil	0.8	0.9	0.7	0.7	0.0%	0.7	-4.1%	0.7	0.7	1.5%	0.6	-6.2%
LPG	0.4	0.4	0.4	0.4	0.0%	0.4	-4.7%	0.4	0.4	0.0%	0.4	-2.6%
Other	0.7	0.8	0.7	0.7	0.0%	0.7	0.0%	0.8	0.8	1.3%	0.8	-1.3%
Total primary	16.7	19.0	21.2	20.5	-3.4%	19.2	-9.6%	23.2	21.1	-9.2%	18.5	-20.5%
Commercial												
Primary Electricity	9.3	11.0	12.8	12.3	-4.4%	11.4	-11.2%	13.8	12.3	-10.8%	10.8	-22.1%
Natural gas	2.8	3.4	3.9	3.8	-2.6%	3.7	-4.9%	4.0	3.8	-6.5%	3.7	-8.4%
Oil	0.5	0.5	0.3	0.4	5.9%	0.3	-5.9%	0.3	0.3	9.7%	0.3	-16.1%
Other	0.4	0.3	0.3	0.3	0.0%	0.3	0.0%	0.3	0.3	0.0%	0.3	0.0%
Total primary	13.0	15.2	17.3	16.7	-3.7%	15.7	-9.5%	18.5	16.8	-9.4%	15.1	-18.6%
Total Buildings												
Primary Electricity	19.6	22.8	26.6	25.3	-4.7%	23.5	-11.7%	29.2	25.7	-12.1%	22.0	-24.9%
Natural gas	7.4	8.5	9.4	9.3	-1.4%	8.9	-5.1%	10.0	9.7	-3.6%	9.2	-8.2%
Oil	1.3	1.4	1.1	1.1	1.9%	1.0	-4.7%	1.0	1.0	4.2%	0.9	-9.4%
LPG	0.4	0.4	0.4	0.4	0.0%	0.4	-4.7%	0.4	0.4	0.0%	0.4	-2.6%
Other	1.1	1.1	1.1	1.1	0.0%	1.1	0.0%	1.1	1.1	0.9%	1.1	-0.9%
Total primary	29.8	34.2	38.5	37.1	-3.6%	34.8	-9.5%	41.7	37.8	-9.3%	33.5	-19.7%
Site Electricity												
Residential	3.15	3.65	4.58	4.27	-6.8%	4.07	-11.1%	5.28	4.44	-15.9%	3.94	-25.4%
Commercial	2.88	3.45	4.27	4.02	-5.9%	3.84	-10.1%	4.76	4.10	-13.9%	3.80	-20.2%
Total	6.03	7.10	8.85	8.29	-6.3%	7.91	-10.6%	10.04	8.54	-14.9%	7.74	-22.9%

(1) BAU = Business-As-Usual Scenario; Q = quadrillion Btus of primary energy.

(2) Buildings in the industrial sector are not included in these results.

(3) % Δ (change) is relative to the BAU scenario in that year.

(4) Electricity primary energy savings include both demand-side efficiency and supply side effects. For example, in the Advanced scenario in 2020, primary energy savings in buildings sector electricity are roughly nine percent higher than site energy savings in percentage terms, indicating a small improvement in conversion efficiency on the electricity supply side.

Table 4.7 Carbon Emissions by Scenario and Fuel in the Buildings Sector

			2010					*2020*				
Sector & fuel	***1990***	***1997***	***BAU***	***Moderate***		***Advanced***		***BAU***	***Moderate***		***Advanced***	
	MtC	**MtC**	**MtC**	**MtC**	**% Δ**	**MtC**	**% Δ**	**MtC**	**MtC**	**% Δ**	**MtC**	**% Δ**
Residential												
Primary Electricity	162	182	226	203	-10.0%	159	-29.5%	255	212	-16.5%	128	-49.6%
Natural gas	66	74	80	79	-0.6%	76	-5.0%	86	85	-1.5%	79	-8.1%
Oil	17	20	15	15	0.0%	15	-3.3%	14	14	0.5%	13	-6.0%
LPG	6	8	8	8	0.0%	7	-3.8%	7	7	-1.0%	7	-2.4%
Other	3	1	1	1	0.0%	1	0.0%	1	1	0.0%	1	0.0%
Total primary	253	286	330	307	-7.0%	258	-21.6%	363	320	-12.0%	229	-37.0%
Commercial												
Primary Electricity	148	172	210	191	-9.4%	150	-28.5%	228	196	-14.0%	123	-46.0%
Natural gas	41	49	55	54	-2.3%	53	-4.5%	58	54	-6.6%	53	-8.4%
Oil	10	14	11	12	3.6%	11	-5.4%	11	11	4.7%	10	-8.5%
Other	7	2	3	3	0.0%	2	-4.0%	3	3	0.0%	3	-3.8%
Total primary	206	237	279	259	-7.4%	216	-22.6%	300	264	-11.8%	189	-37.0%
Total Buildings												
Primary Electricity	311	354	436	394	-9.7%	310	-29.0%	483	409	-15.3%	252	-47.9%
Natural gas	107	123	135	133	-1.3%	129	-4.8%	144	139	-3.5%	132	-8.2%
Oil	26	34	26	27	1.5%	25	-4.2%	25	25	2.3%	23	-7.1%
LPG	6	8	8	8	0.0%	7	-3.8%	7	7	-1.0%	7	-2.4%
Other	10	4	4	4	0.0%	4	-2.6%	4	4	0.0%	4	-2.6%
Total primary	460	522	609	565	-7.2%	475	-22.1%	663	584	-11.9%	418	-37.0%

(1) BAU = Business-As-Usual case. MtC = Million metric tons of carbon emitted per year.

(2) Buildings in the industrial sector are not included in these results.

(3) % Δ (change) is relative to the BAU scenario in that year.

(4) Electricity carbon savings include both demand-side efficiency and supply side effects. For example, in the Advanced Scenario in 2020, about half of total buildings electricity-related carbon savings in 2020 is attributable to demand-side efficiency improvements, while the other half is attributable to fuel switching and efficiency improvements on the electricity supply-side.

Table 4.8 Primary Energy Use by Scenario and End-Use in the Buildings Sector

			2010					***2020***				
Sector & fuel	***1990***	***1997***	***BAU***	***Moderate***		***Advanced***		***BAU***	***Moderate***		***Advanced***	
	Q	**Q**	**Q**	**Q**	**% Δ**	**Q**	**% Δ**	**Q**	**Q**	**% Δ**	**Q**	**% Δ**
Residential												
Space heating	5.1	6.9	6.9	7.0	1.1%	6.7	-3.7%	7.2	7.3	0.8%	6.7	-7.1%
Space cooling	1.7	1.5	1.7	1.6	-3.8%	1.4	-15.7%	1.8	1.5	-14.0%	1.3	-26.8%
Water heating	2.4	2.6	2.7	2.5	-4.6%	2.4	-11.4%	2.8	2.5	-10.4%	2.3	-18.5%
Refrigerators/ freezers	2.2	1.6	1.1	1.0	-3.9%	1.0	-6.8%	1.0	0.9	-8.7%	0.8	-19.3%
Lighting	1.0	1.1	1.2	1.2	-3.3%	1.0	-13.6%	1.3	1.2	-12.6%	0.9	-30.2%
All other	4.4	5.3	7.7	7.1	-7.0%	6.7	-12.7%	9.0	7.6	-15.4%	6.4	-29.3%
Total	16.7	19.0	21.2	20.5	-3.4%	19.2	-9.6%	23.2	21.1	-9.2%	18.5	-20.5%
Commercial												
Space heating	1.9	1.9	1.9	1.9	-0.7%	1.8	-7.4%	1.9	1.9	-3.5%	1.7	-10.9%
Space cooling	1.8	1.1	1.1	1.0	-12.2%	0.9	-17.2%	1.1	0.9	-15.2%	0.8	-22.5%
Water heating	1.1	0.9	1.0	0.9	-6.0%	0.9	-8.7%	0.9	0.9	-6.8%	0.9	-9.8%
Office equipment	0.6	1.3	1.9	1.9	3.2%	1.8	-1.2%	2.2	2.3	4.8%	2.2	-3.7%
Lighting	3.7	3.9	3.9	3.7	-3.9%	3.4	-11.9%	3.9	3.4	-12.8%	2.9	-25.2%
All other	3.8	6.1	7.6	7.3	-4.5%	6.9	-9.7%	8.4	7.4	-12.4%	6.6	-21.9%
Total	13.0	15.2	17.3	16.7	-3.7%	15.7	-9.5%	18.5	16.8	-9.4%	15.1	-18.6%

(1) BAU = Business-As-Usual Scenario. Q = Quadrillion Btus of primary energy.

(2) Buildings in the industrial sector are not included in these results.

(3) % Δ is relative to the BAU Scenario in that year.
(4) Electricity carbon savings include both demand-side efficiency and supply-side effects, as discussed in the notes to Table 4.6.
(5) "All other" in residential includes many smaller end-uses that are explicitly represented in CEF-NEMS, including cooking, clothes dryers, clothes washers, dishwashers, color TVs, personal computers, and furnace fans. It also includes the CEF-NEMS residential "other uses" category, which consists of unidentified uses.
(6) "All other" in commercial includes smaller end-uses that are explicitly represented in CEF-NEMS, including ventilation, cooking, and refrigeration. It also includes the CEF-NEMS commercial "other uses" category, which consists of unidentified uses and other miscellaneous energy use.

Table 4.9 Carbon Emissions by Scenario and End-Use in the Buildings Sector

			2010					*2020*				
Sector & Fuel	*1990*	*1997*	*BAU*	*Moderate*		*Advanced*		*BAU*	*Moderate*		*Advanced*	
	MtC	*MtC*	*MtC*	*MtC*	*% Δ*	*MtC*	*% Δ*	*MtC*	*MtC*	*% Δ*	*MtC*	*% Δ*
Residential												
Space heating	79	99	98	98	-0.1%	90	-8.3%	103	102	-0.2%	88	-14.3%
Space cooling	27	23	27	25	-8.7%	18	-32.2%	29	24	-17.2%	15	-49.1%
Water heating	36	39	41	39	-6.8%	34	-18.5%	44	39	-11.8%	32	-28.6%
Refrigerators/ freezers	35	25	18	16	-8.8%	13	-25.0%	17	15	-12.1%	9	-44.1%
Lighting	15	17	20	18	-8.3%	14	-30.5%	22	19	-15.9%	11	-51.6%
All other	60	82	125	111	-11.7%	89	-29.0%	148	121	-18.5%	74	-49.8%
Total	253	286	330	307	-7.0%	258	-21.6%	363	320	-12.0%	229	-37.0%
Commercial												
Space heating	30	32	32	32	-0.6%	29	-10.0%	32	31	-3.4%	28	-14.9%
Space cooling	29	17	18	15	-16.7%	12	-32.9%	18	14	-18.3%	10	-45.4%
Water heating	17	14	15	14	-7.0%	13	-11.8%	15	14	-7.7%	13	-13.5%
Office equipment	10	20	31	30	-2.2%	24	-20.5%	37	37	1.1%	25	-33.2%
Lighting	59	61	64	58	-9.0%	45	-29.1%	64	54	-15.9%	33	-48.1%
All other	61	93	120	110	-8.3%	92	-22.9%	134	114	-15.0%	81	-39.6%
Total	206	237	279	259	-7.4%	216	-22.6%	300	264	-11.8%	189	-37.0%

(1) BAU = Business-As-Usual Scenario. MtC = Million metric tons of carbon emitted per year.

(2) Buildings in the industrial sector are not included in these results.

(3) % Δ is relative to the BAU Scenario in that year.

(4) Electricity carbon savings include both demand-side efficiency and supply-side effects, as discussed in the notes to Table 4.6.

(5) "All other" in residential includes many smaller end-uses that are explicitly represented in CEF-NEMS, including cooking, clothes dryers, clothes washers, dishwashers, color TVs, personal computers, and furnace fans. It also includes the CEF-NEMS residential "other uses" category, which consists of unidentified uses.

(6) "All other" in commercial includes smaller end-uses that are explicitly represented in CEF-NEMS, including ventilation, cooking, and refrigeration. It also includes the CEF-NEMS commercial "other uses" category, which consists of unidentified uses and other miscellaneous energy use.

Table 4.10 Penetration Rates by Scenario for Selected Technologies in the Buildings Sector

Sector & technology	*Scenario*	*2000*	*2005*	*2010*	*2015*	*2020*
				% of New Shipments		
Residential						
Heat pump WH	Moderate	0%	5%	7%	11%	15%
	Advanced	0%	5%	10%	21%	31%
Dedicated CFL Lighting Fixtures	Moderate	2%	4%	6%	7%	9%
	Advanced	2%	5%	9%	15%	23%
Horizontal Axis Clothes Washer	Moderate	7%	14%	100%	100%	100%
	Advanced	7%	100%	100%	100%	100%
Commercial						
Electronic ballasts	Moderate	53%	100%	100%	100%	100%
	Advanced	54%	100%	100%	100%	100%
High Efficiency Transformers	Moderate	25%	41%	56%	64%	71%
	Advanced	25%	100%	100%	100%	100%
				% of Equipment Stock		
Residential						
Heat pump WH	Moderate	0%	1%	2%	5%	8%
	Advanced	0%	1%	5%	12%	21%
Dedicated CFL Lighting Fixtures	Moderate	1%	2%	3%	5%	7%
	Advanced	1%	2%	5%	9%	15%
Horizontal Axis Clothes Washer	Moderate	3%	6%	34%	67%	91%
	Advanced	3%	18%	52%	83%	98%
Commercial						
Electronic ballasts	Moderate	30%	55%	82%	98%	100%
	Advanced	31%	58%	84%	100%	100%
High Efficiency Transformers	Moderate	16%	19%	25%	32%	41%
	Advanced	16%	24%	41%	57%	74%

(1) WH = water heater; CFL = compact fluorescent lamp.

Table 4.11 Annual Total Costs of Energy Services by Scenario in the Buildings Sector (B 1997$/year)

		2010					*2020*				
	1997	***BAU/ B$/yr***	***Moderate B$/yr***	***% Δ***	***Advanced B$/yr***	***% Δ***	***BAU/ B$/y***	***Moderate B$/yr***	***% Δ***	***Advanced B$/yr***	***% Δ***
Residential											
Annual fuel cost	137	146	133	-9%	143	-2%	151	132	-13%	132	-13%
Annualized incremental technology cost of energy efficiency	0	0	1.9	N/A	3.8	N/A	0	5.8	N/A	9.1	N/A
Annual program costs to promote energy efficiency	0	0	0.5	N/A	1.0	N/A	0	1.5	N/A	2.7	N/A
Annual total cost of energy services	137	146	136	-7%	148	1%	151	139	-8%	144	-5%
Commercial											
Annual fuel cost	98	103	89	-14%	102	-1%	103	84	-18%	92	-11%
Annualized incremental technology cost of energy efficiency	0	0	2.0	N/A	2.7	N/A	0	4.6	N/A	5.8	N/A
Annual program costs to promote energy efficiency	0	0	0.5	N/A	0.8	N/A	0	1.1	N/A	1.6	N/A
Annual total cost of energy services	98	103	92	-11%	106	2%	103	90	-12%	99	-4%
Total Buildings											
Annual fuel cost	236	249	222	-11%	245	-2%	254	216	-15%	224	-12%
Annualized incremental technology cost of energy efficiency	0	0	4.0	N/A	6.5	N/A	0	10.4	N/A	15.0	N/A
Annual program costs to promote energy efficiency	0	0	1.0	N/A	1.8	N/A	0	2.7	N/A	4.3	N/A
Annual total cost of energy services	236	249	227	-9%	253	2%	254	229	-10%	243	-4%

(1) BAU = Business-As-Usual case.

(2) Buildings in the industrial sector are not included in these results.

(3) Costs for R&D are not included in these sector results, but are included in the aggregate all-sector cost calculations in the summary results chapter.

(4) % Δ (change) is relative to the BAU scenario in that year.

(5) Energy service costs include cost of purchased fuels and electricity (which in the advanced case includes the cost of the carbon permit trading fee), program costs, and the annualized costs of incremental efficiency improvements.

4.6 DISCUSSION OF RESULTS

In this section, we focus on the results in the Advanced Scenario in 2020. The relative comparisons generally apply also to the Moderate Scenario, but where there are salient differences between moderate and Advanced Scenarios (or between 2010 and 2020 results), we note them parenthetically.

4.6.1 Key Technologies

Penetration rates and stock saturations for selected technologies in the two scenarios are shown in Table 4.10. Penetration rates of 100% reflect the imposition of a minimum efficiency standard. For horizontal clothes washers, for example, the efficiency standard mandating their use is assumed to come into force in 2007 in the Moderate Scenario, and in 2004 in the Advanced Scenario.

Each of the technologies in Table 4.10 plays a key role in the scenarios, with the high efficiency electronic ballasts, commercial transformers, and heat pump water heaters being particularly important.

A number of technologies offer the potential to fundamentally alter the current upward trend of buildings energy use over the next several decades, if they are commercialized and widely adopted in the market. The technologies described below illustrate important "breakthrough" potential, but this list is not exhaustive (see the following box), just illustrative (for a more complete inventory, see Nadel et al. (1998). Many of these technologies serve multiple end-uses simultaneously, and are thus difficult to model. They were not explicitly included in the results presented in this chapter (the one exception is that of photovoltaics, which were assessed independently in the electricity sector analysis).

4.6.2 Key Policies

Minimum equipment efficiency standards, voluntary programs, and R&D are the three most important contributors to energy savings, with building codes, tax credits, and incentive programs generally playing a supporting role. (See Table 4.12 below.) Typically, 90 to 95% of the energy savings is attributable to these three types of programs. For electronics end-uses, where rapid technological innovation and proven success of voluntary efforts hold sway, the voluntary programs capture most of the savings. As we expect, R&D grows in importance over time, and has its most significant effects after 2010.

For the residential sector, equipment standards account for between 35 and 50% of projected savings, and for the commercial sector, equipment standards account for about one-third of the savings. Voluntary programs capture about half of the savings in the commercial sector by 2010, but by 2020, this percentage declines to 25 to 35%, in the face of the increases in the effectiveness of whole buildings R&D. Voluntary programs account for roughly 40% of savings in the residential sector for 2010 and 2020 in both scenarios.

The results in Table 4.12 should be used with caution. The effects shown for R&D, for example, are only the direct effects modeled for our five representative technologies. In fact, R&D plays a key enabling role, and the success of other programs and policies in the Moderate and Advanced Scenarios would not be possible without it. In addition, the exact division of savings by policy type is dependent on assumptions and conventions that are arbitrary in some ways. For example, our assumption that equipment standards are implemented before voluntary and incentive programs leads to equipment standards claiming a larger fraction of the savings than they might if we made another (equally arbitrary) assumption about the order of implementation.

Breakthrough Buildings Technologies

- **Fuel cells** convert the chemical energy of a fuel into electricity without the use of a thermal cycle or rotating equipment. The preferred fuel is hydrogen, and fossil fuels must generally be converted to hydrogen before being used. Electric conversion efficiency is about 35-40% and can double in combined heat and power applications. Fuel cells can range in size from 50 watts to 250 kilowatts. Promising technologies include proton exchange membrane, phosphoric acid, and molten carbonate fuel cells.
- **Photovoltaic** cells convert light energy into electricity at the atomic level, at an efficiency of 7%-17%. *Building Integrated Photovoltaics systems* (BIPV) can be combined with roof tiles or other parts of building structures to supplement grid-supplied power, reduce energy costs, and provide emergency back-up power during utility power outages.
- **Microturbines** in the 10-500 kW range are scaled-down versions of the gas turbines that utilities have been using to serve peak loads. Electrical efficiencies could approach 35% under optimum conditions, and, as with fuel cells, those efficiencies roughly double in combined heat and power applications.
- **District Energy Systems with Combined Heat and Power** produce both electricity and usable heat, which results in significant reductions in energy use and emissions. Many existing district energy systems do not now generate electricity, but the potential electricity generation from such combined systems in the U.S. building sector totals about 19 GW by 2010 and 50 GW by 2020. Total primary energy savings for these potentials are 0.3 and 0.8 quads/year, respectively (Spurr 1999).
- **Thermally-Activated Heat Pumps** represent a new generation of advanced absorption cycle heat pumps and chillers for residential and commercial space conditioning. They enable highly efficient heat pump cycles to replace the best natural gas furnaces, reducing energy use by as much as 50%, while also providing gas-fired air conditioning (and lowering summer peaking electric loads).
- **Integrated Electric Multi-Function Heat Pumps** capture the waste heat from space cooling to provide “free” water heating. Savings approach 20-25% relative to an electric resistance water heater and electric heat pump system.
- **Electrochromic Glazing** is currently considered to be the most suitable technology for active energy control in building windows. A multi-layer coating deposited on the glass alters its optical properties depending on the magnitude of the voltage applied to it. Windows can thereby be “switched” on demand from clear to dark – thereby reducing cooling loads and allowing for integration of glazing and lighting systems.

Further reading:

1) *Emerging Energy-Saving Technologies and Practices for the Buildings Sector* (Nadel et al. 1998).
2) *PEM Fuel Cells for Commercial Buildings* (Brown 1998).
3) *Photovoltaics and Commercial Buildings – A Natural Match* (NREL 1998).
4) *District Energy Systems Integrated with Combined Heat and Power* (Spurr 1999) and *Combined Heat and Power: Capturing Wasted Energy* (Elliott and Spurr 1999)
5) Web site for the DOE's Electrochromics initiative: http://windows.lbl.gov/doeeci/

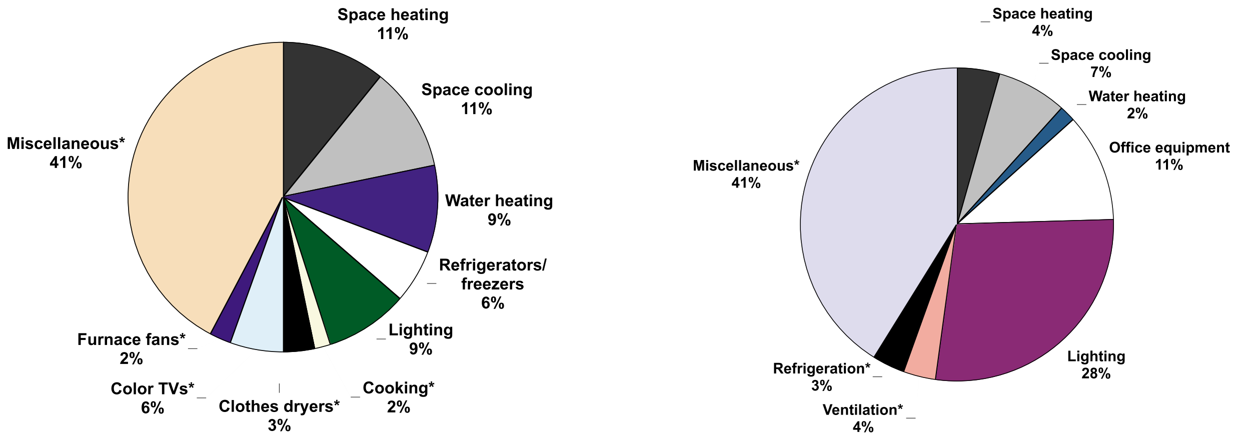
4.6.3 Key End-Uses

In residential buildings by 2020, by far the largest primary energy and carbon savings in absolute terms (relative to the BAU case) occur in the category "all other" uses (see the sum of end-uses with asterisks in Fig. 4.2). Next in rank order are space cooling, space heating, water heating, and lighting. In percentage terms, the largest primary energy and carbon savings occur in lighting, space cooling, and in "all other" end-uses. Recall that "all other" in the residential sector includes many smaller end-uses that are explicitly represented in CEF-NEMS, including cooking, clothes dryers, clothes washers, dishwashers, color TVs, personal computers, and furnace fans, as well as other unidentified uses.

In commercial buildings, lighting and "all other" end-uses dominate the energy and carbon savings in absolute terms, and lighting, cooling, and "all other" end-uses dominate the energy and carbon savings on a percentage basis. "All other" in the commercial sector includes smaller end-uses that are explicitly represented in CEF-NEMS, including ventilation and refrigeration, as well as other unidentified uses.

Even among the end-uses that are not explicitly identified in the CEF-NEMS framework (e.g., "miscellaneous uses"), we analyze potential savings for specific technologies (such as ceiling fans, pool pumps, and home electronics in residential buildings, and transformers, traffic lights, and exit signs in commercial buildings). Savings from reducing standby losses in home electronics are particularly important in residential "miscellaneous uses," and transformers and exit signs are particularly important in the commercial "miscellaneous uses." The details of these calculations are contained in Appendices B-1 and C-1.

Fig. 4.2 Carbon Emission Reductions in the Advanced Scenario in 2020, by Buildings End Use
(Reductions are Relative to the Business-as-Usual Forecast)



Residential Buildings

Constituents of the "All other" category shown in Tables 4.8 and 4.9 are marked with asterisks above. "Miscellaneous uses" include clothes washers, dishwashers, other home electronics, ceiling fans, pool pumps, and other unidentified end-uses.

Commercial Buildings

Constituents of the "All other" category shown in Tables 4.8 and 4.9 are marked with asterisks above. "Miscellaneous uses" include transformers, traffic lights, exit signs, cooking, district services, automated teller machines, telecommunications equipment, medical equipment, and other unidentified end-uses.

Note: Carbon savings from electrical end-uses include both demand-side efficiency and supply-side effects.

Table 4.12 Share of U.S. Energy Savings by End-use Sector and Policy Type

Year	*Scenario*	*Sector*	*Equipment Standards*	*Building Codes*	*Voluntary Programs*	*State/ Utility Programs*	*Tax Credits*	*R&D (Direct Effects Only)*	*Total*
2010	Moderate	Residential	53%	2%	38%	1%	3%	3%	100%
		Commercial	31%	0%	52%	0%	0%	17%	100%
	Advanced	Residential	45%	3%	38%	1%	9%	5%	100%
		Commercial	28%	2%	49%	0%	0%	20%	100%
2020	Moderate	Residential	47%	4%	38%	1%	1%	9%	100%
		Commercial	29%	2%	34%	0%	0%	35%	100%
	Advanced	Residential	36%	4%	44%	1%	2%	12%	100%
		Commercial	36%	3%	26%	0%	0%	35%	100%

(1) Sector totals weighted by site energy.

(2) Tax credits were not considered for commercial buildings.

4.6.4 High Discount Rate Sensitivity Case

What effect would a higher real discount rate have on the energy savings results reported here? As stated above, we used a 7% real discount rate in the calculations for the building sector. This discount rate reflects typical real interest rates for home mortgages and loans for other major purchases. It also corresponds to the typical rate of return for natural gas and electricity supply side investments over the past few decades, thus making the calculation of costs for energy efficiency options comparable to the costs of the supply-side options that they displace.

As a sensitivity case, we estimated the costs of conserved energy using a 15% real discount rate (a rate which is consistent with purchasing energy-efficient products at credit card interest rates) and recalculated the savings. In this case, total building sector energy savings (expressed either in site or primary energy) are reduced by no more than twenty percent by 2020 in our CEF-NEMS Advanced Scenario. The effect is relatively modest because many of the energy-efficient technologies have CCEs that are significantly lower than the cost of avoided fuels and electricity. The higher discount rate is not enough to push the CCE over the cost of avoided energy in many cases.

4.7 REMAINING ANALYSIS NEEDS

Because of time and resource constraints, many simplifications were necessary in conducting this analysis.

- No savings have been included for commercial building shell measures. Windows strongly influence heating, cooling, and lighting loads in all commercial buildings, and insulation can be important for smaller commercial buildings.
- No savings have been included for residential building shell measures in existing buildings.

- No savings have been included for the advanced cooking technology from Turbochef and Maytag, which reduces oven cooking times by two thirds to three quarters. This device combines microwave and convection oven technologies, and it is expected to become available for both residential and commercial applications by the year 2000.
- No savings have been included for the advanced heat exchanger technology currently being commercialized by Modine, which reduces air conditioner and heat pump energy use by 15-25% and *reduces* the cost of the heat exchanger.
- No savings have been included for distributed generation technologies like fuel cells and micro-turbines, which are likely to be important technologies in buildings in the next twenty years.
- No savings have been included for integrated systems that combine heating and water heating, or heating, cooling, and water heating.
- No savings have been included for large-scale district heating and cooling systems with combined heat and power. Recent analysis (Elliott and Spurr 1999, Spurr 1999) indicates that there is on the order of 20 GW of potential electricity generation for such systems in the U.S. These systems can result in significant carbon savings compared to conventional electricity generation (Krause et al. 1994).
- No savings have been included for large-scale tree planting. More data are needed on the effects of this policy on energy use.
- No savings have been estimated for commercial office equipment beyond the Business-As-Usual case, but opportunities may arise to use additional voluntary programs (similar to the highly successful current ENERGY STAR office equipment program) to promote efficiency as this end-use evolves over the next decade.
- No savings have been included for passive or active solar heating and water heating systems. Such systems have the potential to contribute significant carbon savings by 2020, particularly in the Advanced Scenario.
- No attempt has been made to correct for changes in internal gains associated with energy savings for appliances located within conditioned spaces. Recent work in U.S. commercial buildings (Sezgen and Koomey 1998) indicates that the heating penalties roughly offset the cooling benefits in both primary energy and dollar terms (when averaged across the entire commercial sector). There is no comparable analysis for average residences in the U.S., but an analysis for Europe (Krause et al. 1995) finds that this effect leads to small net energy penalties in residences.
- No attempt has been made to incorporate R&D on building commissioning, which has the potential to reduce operation and maintenance costs for buildings, and significantly improve energy performance.
- Because energy savings from miscellaneous electricity use are so important to the results of the buildings sector, it is crucial that more research be carried out, both to characterize how energy is used in the miscellaneous category and to identify technologies for improving the efficiency of sub-categories within the miscellaneous category of electricity use. The analysis presented here embodies significant improvements in data and analysis from even a few years ago, but more work is urgently needed here.
- The Annual Energy Outlook 1999 progress in new and existing residential shells needs to be investigated. The large increases in the efficiency of residential building shells that exist in the AEO99 reference case are probably too big in a scenario where fuel and electricity prices are flat or declining.

On balance, we believe that adding these items to the analysis would increase savings and decrease costs.

4.8 SUMMARY & CONCLUSIONS

This chapter summarizes the results of two policy scenarios (Moderate and Advanced). The analysis specifies in detail the policies and programs that would be needed to capture the projected energy savings by 2010 and 2020 in these scenarios.

The buildings sector contributes significant energy and carbon savings in the Moderate and Advanced cases. Primary energy savings for the building sector totals about 18% in the advanced case in 2020 relative to the business-as-usual case. Total carbon savings in that year, including both demand and supply-side effects, are almost 40% of business-as-usual emissions. These savings reduce carbon emissions from this sector to below 1990 levels in 2020.

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Chapter 5

THE INDUSTRIAL SECTOR[1]

5.1 INTRODUCTION

In this chapter we present scenarios for future industrial energy use, based on different assumptions for U.S. energy policies. We start with a reference scenario which is derived from the AEO99 (U.S. DOE, EIA, 1998a) and assumes no policy changes. We then analyze two policy-driven scenarios using the CEF-NEMS model. The CEF-NEMS model does not allow direct modeling of demand side policies in the industrial sector. Hence, extensive changes are made to the model inputs to reflect the actions due to new policies in the policy scenarios, as outlined below and in Appendices A-2 and B-2. The projected changes in inputs are based on analyses by industry, government and academic sources.

A scenario is a way to understand the implications of a possible future through modeling assumptions that reflect this future. By definition, considerable uncertainties exist in all scenario analyses and this is also true for the industrial sector where ever-changing dynamics drive decision-making.

The scenarios presented here reflect our own judgment, based on extensive studies and the input by external reviewers. They do not necessarily reflect the views of the industries that are discussed. The assumptions with respect to technologies and policy results are explicitly described in detail in this chapter and related appendices. We acknowledge that we are not able to analyze all issues that may affect the results. Although we present point estimates, the reader should bear in mind that uncertainties in the assumptions affect the results of the scenarios and that the results are not equally applicable to all companies in an industry. The analytical database for the industrial sector is limited and constrains the ability of modelers to do in-depth analysis in this sector. At the end of this chapter, we explicitly discuss uncertainties and further research required to assess the uncertainties.

5.1.1 Overview of Sector

The industrial sector is extremely diverse and includes agriculture, mining, construction, energy-intensive industries, and non-energy-intensive manufacturing. In 1997, the industrial sector consumed 35 quads of primary energy, accounting for 37% of the primary energy consumed in the U.S. that year. The industrial sector is comprised of 13 key subsectors: agriculture, mining, construction, food, paper, chemicals, glass, cement, steel, primary aluminum, petroleum refining, metals-based durables, and other manufacturing[2]. Fig. 5.1 shows the contribution of each industrial subsector to total industrial primary energy use in 1997. Carbon dioxide emissions from industrial energy use as well as process emissions from cement manufacture were 494 MtC, accounting for 33% of total U.S. CO_2 emissions (U.S. DOE, EIA, 1998a).

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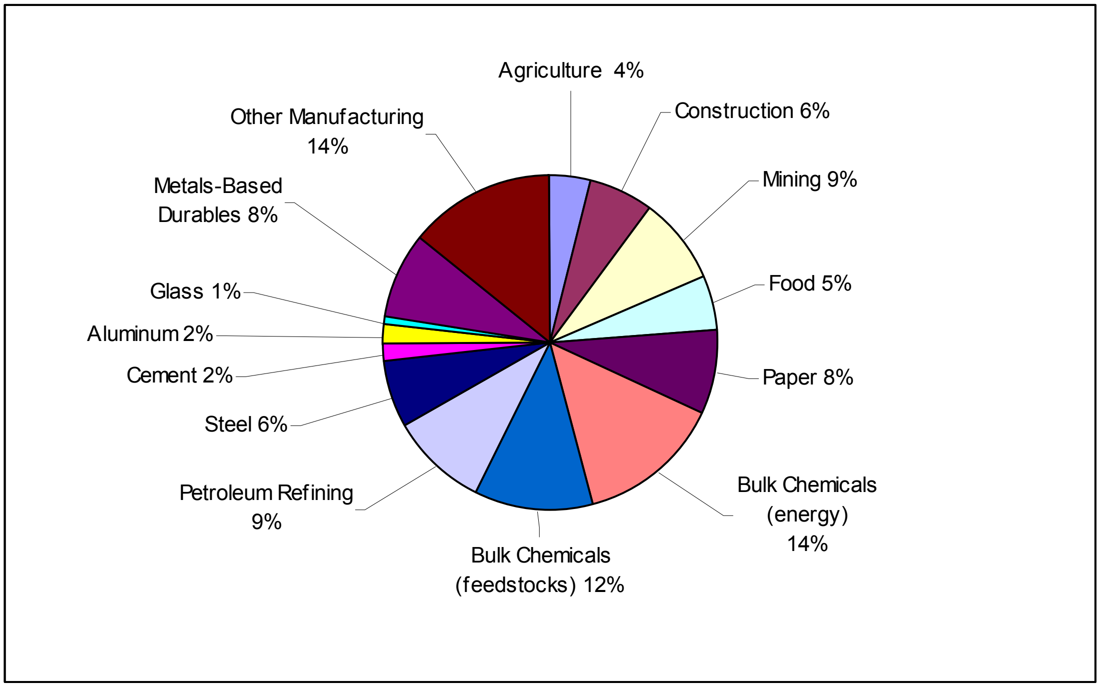
[2] The definitions of the subsectors and an explanation of how they relate to the U.S. Department of Energy's Office of Industrial Technology's Industries of the Future is provided in Appendix A.2. Energy intensive industries include pulp and paper, bulk chemicals, glass, cement, iron and steel, petroleum refining, as well as primary aluminum. Non-energy intensive industries include agriculture, mining, construction, food, metals-based durables, and other manufacturing.

Fig. 5.2 provides a breakdown of the share of CO_2 emissions by industrial subsector. The largest CO_2-producing subsector was also bulk chemicals (energy), followed by other manufacturing, petroleum refining, metals-based durables, mining, steel, construction, food, cement, paper, agriculture, aluminum, and glass, respectively.

The cement subsector is responsible for a higher share of CO_2 emissions than primary energy use due to the process emissions produced during calcination of limestone[3] while producing clinker. Process CO_2 emissions from calcination are added to the cement sub-sector energy-related CO_2 emissions. Other sectors also emit process emissions, which have been partially been accounted for (e.g. chemical industry) or excluded (e.g. limestone use in the steel industry) due to lack of reliable data. The share of CO_2 emissions from the paper sector is lower than the share of energy use, due to the significant consumption of biomass in this sub-sector. We assign zero emissions to the combustion of biomass due to assimilation if biomass is grown in a sustainable way. The share of CO_2 emissions from chemical feedstocks are also lower because a large part of the feedstocks are embodied in the chemical products produced and not directly released to the atmosphere**.**

Fig. 5.1 Primary Energy Use by Industrial Subsectors, 1997



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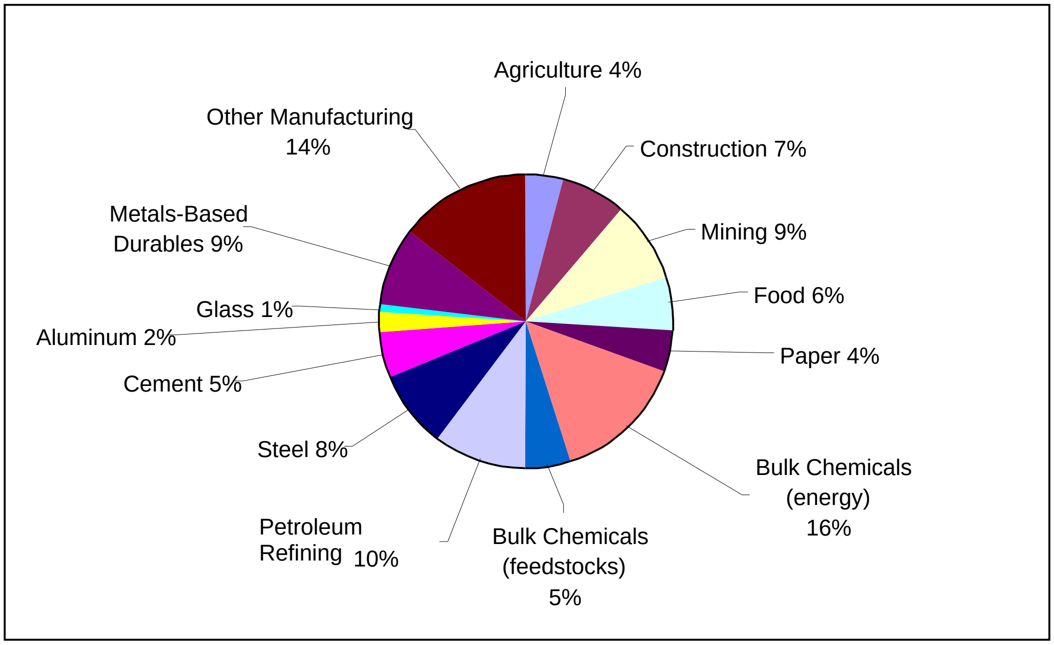
[3] The process emission from clinker production depends on the share of limestone in the raw materials used. The lime-content may vary, and hence the CO2 emission-factor. In this study we follow the IPCC-methodology which estimates the CO_2 emission at 138.3 kgC/tonne clinker (IPCC, 1996), which is equivalent to 125.4 kgC/ton clinker.

Fig. 5.2 Carbon Dioxide Emissions by Industrial Subsectors, 1997



5.1.2 Technology Opportunities Examples

Various bottom-up studies found cost-effective potentials for energy efficiency improvement varying from 5 to 12% by 2010 (Interlaboratory Working Group, 1997; Energy Innovations, 1997), and up to 20% by 2020 (Energy Innovations, 1997) compared to business as usual, while other studies assumed less potential (U.S.DOE, EIA, 1998b). Many studies identified a wide variety of sector-specific and cross-cutting energy efficiency improvement opportunities (Interlaboratory Working Group, 1997; Aluminum Association, 1997; American Chemical Society, 1996; American Forest and Paper Association, 1994; American Iron and Steel Institute, 1998; Cast Metal Coalition, 1998; Donnelly et al., 1997; National Mining Association 1998a; National Mining Association 1998b). Sector-specific measures include technologies and practices that are unique for a specific process or industrial sector. Cross-cutting measures include technologies that are used more generally (although some applications may be sector-specific) throughout industry, e.g. motors or cogeneration. In this section we describe specific examples of practices and technologies that can be implemented in industry. We focus on measures for three industrial sectors that we have studied in detail (steel, paper, and cement)[4], and one cross-cutting measure (CHP). Barriers may limit the speed of adoption of these technologies (see section 5.3.2).

Innovations in industrial technology aim not only to reduce energy use, but also to improve productivity, reduce capital costs, reduce operation costs, improve reliability as well as reduce emissions and improve working conditions. Hence, many of the technologies discussed below will reduce the production cost-basis of industries, and hence increase competitiveness in a globalizing economy.

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[4] The three sectors were selected on the basis of the modeling characteristics in NEMS, i.e. inclusion of technologies and unit-operations, as well as the availability of data on energy efficiency improvement potentials in these sectors. For the analysis of the three selected sectors we have used 1994 as the base year for the analysis of the baseline, as this was the last year for which the EIA has published the Manufacturing Energy Consumption Survey (MECS) at the time of the study.

Steel Industry. In 1994, steel mills in the U.S. produced 100.5 million tons of steel. Primary energy use for integrated steelmaking was more than three times greater than energy use in secondary (electric arc furnace, EAF) steelmaking, consuming 1364 TBtu compared to 403 TBtu. The primary energy intensity of integrated and secondary steel production in 1994 was 22.3 MBtu/ton and 10.1 MBtu/ton, respectively, for a total sector primary energy intensity of 17.5 MBtu/ton[5]. Total CO_2 emissions from steelmaking in 1994 were 34.4 million metric tonnes C (MtC), with 80% of these emissions from integrated steelmaking. The CO_2 intensity of integrated steelmaking was 0.5 tC/ton of crude steel while the CO_2 intensity for secondary steelmaking was 0.2 tC/ton crude steel, resulting in a total sector CO_2 intensity of 0.4 tC/ton crude steel.

To more carefully analyze the potential for reducing energy use and carbon dioxide emissions from steelmaking in the U.S., we compiled information on the costs, energy savings, and carbon dioxide emissions reductions of a number of technologies and measures. These technologies and measures fall into two categories: state-of-the-art measures that are currently in use in steel mills worldwide and advanced measures that are either only in limited use or are near commercialization (e.g. smelt reduction). We identified nearly 50 energy efficiency measures in the iron and steel industry, including process management systems and gas recovery systems (Worrell et al., 1999). We describe two of the options below: scrap preheating in the electric arc furnace and thin slab casting. Both technologies are used by various steelmakers in the U.S., but still show considerable potential for further adoption leading to increased energy savings in the U.S.

Scrap Preheating. Electricity consumption in EAFs is estimated at an average of 436 kWh/ton, and fuel consumption at 0.14 MBtu/ton of steel (Worrell et al., 1999). Scrap preheating is a technology that can reduce the power consumption of EAFs through using the waste heat of the furnace to preheat the scrap charge. Old bucket preheating systems had various problems, such as emissions, high handling costs, and a relatively low heat recovery rate. Modern systems have reduced these problems and are highly efficient. The energy savings depend on the preheat temperature of the scrap. Various systems have been developed and are in use at sites in the U.S. and Europe, i.e. Consteel tunnel-type preheater, Fuchs Finger Shaft, and Fuchs Twin Shaft. Twin shell furnaces can also be used as scrap preheating systems. All systems can be applied to new construction and to retrofit existing plants. The Consteel process consists of a conveyor belt with the scrap going through a tunnel, down to the EAF through a “hot heel”. Besides energy savings, the Consteel process results in an productivity increase of 33%, reduced electrode consumption of 40% and reduced dust emissions (Jones, 1997a). The FUCHS shaft furnace consists of a vertical shaft that channels the offgases to preheat the scrap. The scrap can be fed continuously (4 plants installed worldwide) or through a so-called system of “fingers” (15 plants installed worldwide). The Fuchs systems make almost 100% scrap preheating possible, leading to potential energy savings of 90-110 kWh/ton (Hofer, 1997)[6]. The energy savings depend on the scrap used and the degree of post-combustion (oxygen levels). The scrap preheating systems lead to reduced electrode consumption, yield improvement of 0.25-2%, up to 20% productivity increase and 25% reduced flue gas dust emissions (reducing hazardous waste handling costs) (CMP, 1997). Electricity use can be decreased to approximately 335-355 kWh/ton using the Consteel process (Herin and Busbee, 1996), without supplementary fuel injection in retrofit situation, while consumption as low as 310-330 kWh/ton has been achieved in new plants (Jones, 1997b). Using post-combustion the energy consumption is estimated to be 310 to 320 kWh/ton and 0.6 MBtu fuel injection (Hofer, 1996). The extra investments are estimated to be $2M (1989) for a capacity of 400,000 to 500,000 ton per year, resulting in specific investments of approximately $4.0 to $5.4/ton for the Consteel process. The annual costs savings are estimated to vary between $1.7/ton and $4.1/ton (Bosley and Klesser, 1991; Hofer, 1997). The simple payback period of installing a scrap preheater is estimated at

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[5] Primary energy is calculated using a conversion rate from final to primary electricity of 3.08, reflecting the difference between an average plant heat rate of 10,500 Btu/kWh and a site rate of 3412 Btu/kWh, including transmission & distribution losses.

[6] This compares to an average electricity consumption of EAFs of 436 kWh/ton steel in 1994 (Worrell et al.,1999).

1 – 2 years for large furnaces. Various U.S. plants have installed a Consteel process, i.e. AmeriSteel (Charlotte, NC), New Jersey Steel (Sayreville, NJ) and Nucor (Darlington, SC), and one plant in Japan. The installation at New Jersey Steel is a retrofit of an existing furnace. Fuchs systems have been installed at North Star (Kingman, AZ), North Star-BHP (Delta, OH), Birmingham Steel (Memphis, TN) and Texas Industries (Richmond, VA). In addition, North Star has ordered another preheater for their Youngstown (OH) plant.

Near Net Shape Casting/Thin Slab Casting. Near net shape casting implies the direct casting of the metal into (or near to) the final desired shape, e.g. strips or sections, and replaces hot rolling. In conventional steelmaking, steel is first cast and stored. The cast steel is reheated and treated in the rolling mills to be reshaped. Near net shape casting integrates casting and the first rolling steps. The current status of this technology is so-called thin slab casting. Instead of slabs of 120-300 mm thickness produced in a continuous casting machine, slabs of 30-60 mm thickness are cast. The cast thin slabs are reheated in a coupled furnace, and directly rolled in a simplified hot strip mill. Pioneered in the U.S. by Nucor at the Crawfordsville and Hickmann plants, various plants are operating, under construction, or ordered worldwide. Originally designed for small scale process lines, the first integrated plants constructed (U.S., Korea) or announced the construction of thin slab casters (Germany, Netherlands, Spain) with capacities up to 1.5 Mt/year. We base our calculation of costs and savings associated with this technology on the CSP-process developed by SMS (Germany) as it represents most of the capacity installed worldwide. Energy savings are estimated to be up to 4 MBtu/ton crude steel (primary energy). The energy consumption of a CSP-plant is 85 kBtu fuel per ton for the reheating furnace and electricity use of 39 kWh/ton (Flemming, 1995). The investments for a large scale plant are estimated to vary between \$100/ton and \$160/ton product (Anon, 1997a; Anon., 1997b; Schorsch, 1996). Cost savings may vary between \$22/ton and \$42/ton product (Ritt, 1997; Hogan, 1992; Schorsch, 1996), resulting in a simple payback period of approximately of 3 years. The potential additional capacity of thin slab casting in 1994 was estimated to be 20% of U.S. integrated production and 64% of secondary steel (Worrell et al., 1999).

Pulp and Paper Industry. The manufacture of paper and paperboard is an important element of a modern economy, and is also a highly capital and energy-intensive process. The pulp and paper industry converts fibrous raw materials into pulp, paper, and paperboard. The processes involved in papermaking include raw materials preparation, pulping (chemical, mechanical, or semi-chemical), bleaching, chemical recovery, pulp drying, and papermaking. In 1994, the U.S. pulp and paper industry consumed 2650 TBtu of primary energy (about 16% of total U.S. manufacturing energy use) to produce 91 million tons of paper (Anglani et al., 1999). The pulp and paper industry's 1994 CO_2 emission is estimated at 30.6 MtC, despite the extensive use of biomass (as a by-product of chemical pulping and wood waste use) which reduces the net CO_2 emissions (Anglani et al., 1999). We identified over 50 technologies and measures that can reduce the energy intensity (i.e. the electricity or fuel consumption per unit of output) of the various process stages of pulp and paper production, varying from improved maintenance to new paper machines (Anglani et al., 1999). We discuss two of these options below: extended nip press and black liquor gasification.

Extended Nip Press. After paper is formed, it is pressed to remove as much water as possible. Normally, pressing occurs between two felt liners. In an extended nip press (developed and marketed by Beloit Industries, WI), the lower roll is replaced with a device that presses the paper against the roll for about 10 inches (compared to 2 inches in a conventional roll press), allowing for higher pressure loads on the paper without damaging the paper (Lange and Radtke, 1996). This additional pressing allows for greater water extraction (about 5-7% more water removal), resulting in a level of 35% to 50% dryness (Elahi and Lowitt, 1988; Lange and Radtke, 1996). An additional advantage is that on a dryer limited machine, a press can increase yield by up to 25% as well as increase wet tensile strength (Lange and Radtke, 1996). Steam savings estimates range from 15% to 35%, or a reduction in steam demand of 4% for every 1% moisture savings in the press (Elahi and Lowitt, 1998; Lange and Radtke, 1996; Jaccard and Willis, 1996;

de Beer et al., 1994). Extended nip press producers include Beloit's ENP-C and Valmet, and Voith Sulzer Papertechnology (Kincaid et al., 1998). The distribution of the ENP technology has been limited by the presence of a large number of granite rolls in the pressing machines in the industry that can not tolerate high nip loadings (Lange and Radtke, 1996). The press is well suited to newsprint and light weight coated pressing, but less suited to bleached Kraft products due to high densification.

Black Liquor Gasification. Black liquor gasification is used to produce a useable gas from spent pulping solvent. This gas can be used in a traditional boiler, or may in the future be used in conjunction with gas turbines, increasing electricity production dramatically. Black liquor gasification is seen as an important technology area for the pulping industries (AFPA, 1994). There are two major types of black liquor gasification: low temperature/solid phase and high temperature/smelt phase. High temperature gasification takes place above 900°C while low temperature gasification takes place under 750°C. Today, black liquor gasifiers are used as an incremental addition in chemical recovery capacity in situations where the recovery boiler is a process bottleneck. In the future, gasifiers may be able to provide fuel for gas turbines and lime kilns (Nilsson et al., 1995; Lienhard and Bierbach, 1991). Energy savings are the result of producing a higher quality fuel and thereby improving the plant's steam production efficiency. We assume fuel savings of 5.0 MBtu/ton air-dried pulp (Elahi and Lowitt, 1988) while electricity use increases (Nilsson, et al., 1995). A 130 ton per day pulp capacity gasifier costs about $20 million (McCubbin, 1996). This technology is new; there is one commercially operating mill in Sweden and various pilot projects in the U.S. (Georgia-Pacific, Weyerhauser, and Champion) (McCubbin, 1996; Finchem, 1997).

Cement Industry. Annual cement production in U.S averages about 80 Million tons, fluctuating with developments in the construction markets. In 1994, 310 TBtu of fuels were used in the clinker kilns and 36 TWh of electricity were used for cement grinding and other production steps, resulting in total primary energy use of 420 TBtu. In 1994, the U.S. cement industry emitted 19 MtC as carbon dioxide (about 4% of total U.S. manufacturing carbon emissions). Half of the emissions are due to fuel combustion (mainly coal), and half are due to the calcination of limestone. In the cement industry, opportunities exist to substantially reduce the energy intensity and carbon dioxide emissions, both from energy use as well as from limestone calcination in the clinker making process. We have identified about 35 technologies and measures to reduce energy use in cement manufacturing (Martin et al., 1999). Because the cement industry is capital intensive, some opportunities can only be economically implemented when retiring old plants (e.g. new pre-calciner kilns to replace wet or long dry kilns). Other measures can be implemented as retrofits or be used to increase production capacity (e.g. production of blended cements).

Multi-stage Preheater Pre-Calciner Kilns*.* Older dry kilns may not have multi-stage preheating, leading to higher heat losses. Modern kilns generally have four to six stage preheating and pre-calciners, reducing fuel use to 2.5 MBtu/ton clinker (Cembureau, 1997a; Conroy, 1997; Klotz, 1997; Somani and Kothari, 1997). Installing multi-stage suspension preheaters (i.e. four- or five-stage) may reduce heat losses and thus increase efficiency. The addition of increased pre-heating and a precalciner will generally increase the capacity of the plant, while lowering the specific fuel consumption. Using as many features of the existing plant and infrastructure as possible, special precalciners have been developed by various manufacturers to convert existing plants, e.g. Pyroclon®-RP by KHD in Germany. Generally, the kiln, foundation and towers are used in the new plant, while cooler and preheaters may be replaced. Also, the kiln length may be shortened by 20% to 30% thereby reducing radiation losses (van Oss, 1999). As the capacity increases, the clinker cooler may also have to be adapted in order to be able to cool the large amounts of clinker. The conversion of older kilns is financially attractive when the old kiln needs replacement and a new kiln would be too expensive. Examples of kiln conversions can be found in Germany (Duplouy and Trautwein, 1997) and Italy (Sauli, 1993), and in Eastern Europe. In the U.S. modern clinker kilns incorporate multi-stage preheating and pre-calcining, as found in the Ash Grove plant in Seattle (WA) (Steuch and Riley, 1993) and Holnam's plant at Devils Slide (UT) (Conroy, 1997).

Fuel savings will depend strongly on the efficiency of the existing kiln and on the new process parameters (e.g. degree of precalcination, cooler efficiency), and may vary between 0.4 and 1.2 MBtu/ton clinker (Martin et al., 1999).

Blended Cement. Cement is an inorganic, non-metallic substance with hydraulic binding properties, and is used as a bonding agent in building materials. In the United States, portland cement accounts for about 95% of total production. The production of blended cements involves the intergrinding of clinker with one or more additives (fly ash, pozzolans, blast furnace slag, volcanic ash) in various proportions. The use of blended cements is a particularly attractive option since the intergrinding of clinker with other additives (supplementary cementitious materials) not only allows for a reduction in the energy used (and associated carbon emissions) in clinker production, but also reduces carbon dioxide emissions from calcination. Blended cements are very common in Europe, with blast furnace and pozzolanic cements accounting for about 12% of total cement production, portland composite cement[7] accounting for an additonal 44% (Cembureau, 1997b). In the U.S., some of the most prevalent blending materials are fly ash and blast furnace slag. A recent analysis of the U.S. situation cited an existing potential of producing 34 million tons of blended cement in 2000 using both fly ash and blast furnace slag, or 36% of U.S. capacity (PCA, 1997). This analysis is based on estimates of the availability of intergrinding materials and a survey of ready-mix companies to estimate feasible market penetration. We assume that the blended cement produced would have, on average, a clinker/cement ratio of 65%. This could result in a reduction in clinker production of 11.9 million tons, when producing 34 million tons of blended cement by 2020. The reduction in clinker production corresponds to specific fuel savings of 0.66 MBtu/ton. The extra energy needed for the drying of the blast furnace slags is offset by reducing the need to bypass kiln exit gases to remove alkali-rich dust (Alsop and Post, 1995). Blended cements lower alkali-silica reactivity thereby allowing a reduction in energy consumption needed due to removal of the alkali dusts. Although electricity consumption is expected to increase a little due to the added electricity consumption to grind the blending materials, this measure results in total fuel savings of 0.76 MBtu/ton cement (Martin et al., 1999).

Cross Cutting: Combined Heat and Power. Electricity and steam are used throughout the industrial sector. Relatively large steam users can be found in the food and chemical industries, as well as in petroleum refining. Steam is often generated in a boiler, while electricity is purchased from a utility. CHP (or cogeneration) has been used in industry to generate the two simultaneously. Modern technologies (e.g. aero-derivative gas turbines) have made CHP more efficient and more economically attractive, especially at smaller scales, than conventional steam turbine systems used in industries with a large steam use, e.g. paper, chemicals. Recent studies (DOE, 1997; Onsite, 1998; Kaarsberg and Elliott, 1998) identified CHP as one of the most important technologies to improve energy efficiency and reduce GHG emissions in the U.S. The primary energy savings from small scale CHP gas turbine units can be about 30% when replacing a conventional coal-fired power plant and about 15% when replacing combined cycles. The savings obtained by condensing and back-pressure steam turbines are considerably smaller. The potentials for CHP vary by sector, and even site, as they depend on site specific technical characteristics (e.g. steam load, demand pattern, heat to power ratio) and on non-technical issues (e.g. regulation, buy back tariffs, standby contracting). Most of the potential sites for new CHP units can be found in the 30 to 75 MW range (Khrushch et al., 1999). The CHP Challenge program of DOE and EPA aims to double the existent CHP capacity by adding over 40 GW of electric CHP capacity, of which most in industry[8].

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[7] Portland composite cement consists of 65% clinker, 30% additives, and 5% filler, as defined by the European cement standard ENV197-2.

[8] Although we assess the potential for cogeneration in this study, we have not yet been able to integrate the cogeneration results into the scenarios. Hence, we report separately on the cogeneration results in section 5.5.4.

5.2 BUSINESS-AS-USUAL SCENARIO

In the CEF-study we have adopted the economic scenarios as used by the EIA for the AEO99. We adopt the energy consumption data of the AEO99 reference case for the business-as-usual scenario for all industrial sub-sectors except for paper, cement, steel, and aluminum, the first three of which we analyzed in detail. For the paper, cement, and steel sectors, our estimates of physical energy intensities by process differed from those in the NEMS model; thus for these three sectors, we modified the NEMS baseline energy intensities (referred to as Unit Energy Consumption, UEC) and the annual rate of improvement in the UECs over time (referred to as Technology Possibility Curves, TPCs).

For the business-as-usual scenario for the paper, cement and steel sub-sectors, we modified the UECs and TPCs for both existing and new equipment based on a number of recent analyses (Worrell et al., 1999; Anglani et al., 1999; Martin et al., 1999). A detailed description of these modifications is provided in Appendix A.2. In addition, we revised the 1994 new plant UECs for the aluminum sector, based on current energy use in Hall-Heroult cells of 13.2 MWh (Ravier, 1986). We also changed the retirement rates for all sub-sectors, to reflect actual lifetimes of installed equipment. Although NEMS does not treat equipment lifetime endogenously, it is possible to define the retirement rate for process equipment. Table 5.1 provides retirement rates and associated plant lifetimes for the AEO99, and the CEF-scenarios for each industrial subsector. Retirement rates for industrial technologies in the AEO99 scenario seem to be low, when compared to other sources (BEA, 1993; Jaccard and Willis, 1996), or assessments of technical and economic lifetimes of technologies. Retirement rates for paper, cement, and steel are based on detailed assessments of equipment ages and future developments in these sectors. For example, the retirement rates in the steel industry were assessed on the basis of the age of current U.S. plants. The oldest working blast furnace in the U.S. in 1997 was 67 years old, followed by two other blast furnaces that were 50 years old, while the average age is estimated at 29 years (Worrell et al., 1999) (see Table 5.1, Basic Oxygen Furnaces)[9].

Table 5.1 Retirement Rates and Plant Lifetimes for Industrial Subsectors for AEO99 Reference Case, and CEF Scenarios

	Retirement (%/yr)		Lifetime (year)	
Sector	**AEO99**	**CEF**	**AEO99**	**CEF**
Agriculture	2.0	2.5	50	40
Mining	2.0	2.5	50	40
Construction	2.0	2.5	50	40
Food	1.7	2.1	59	47
Paper	2.3	2.3	43	43
Bulk Chemicals	2.3	2.5	43	40
Glass	1.3	1.4	77	70
Cement	1.2	2.0	50	50
Steel				
Basic Oxygen Furnaces	1.0	1.5	100	67
Electric Arc Furnaces	1.5	1.8	67	56
Coke Ovens	1.5	1.8	67	56
Other Steel	2.9	2.9	34	34
Primary Aluminum	2.1	2.3	48	43
Metals-Based Durables	1.5	1.9	67	53
Other Manufacturing	2.3	2.5	43	40

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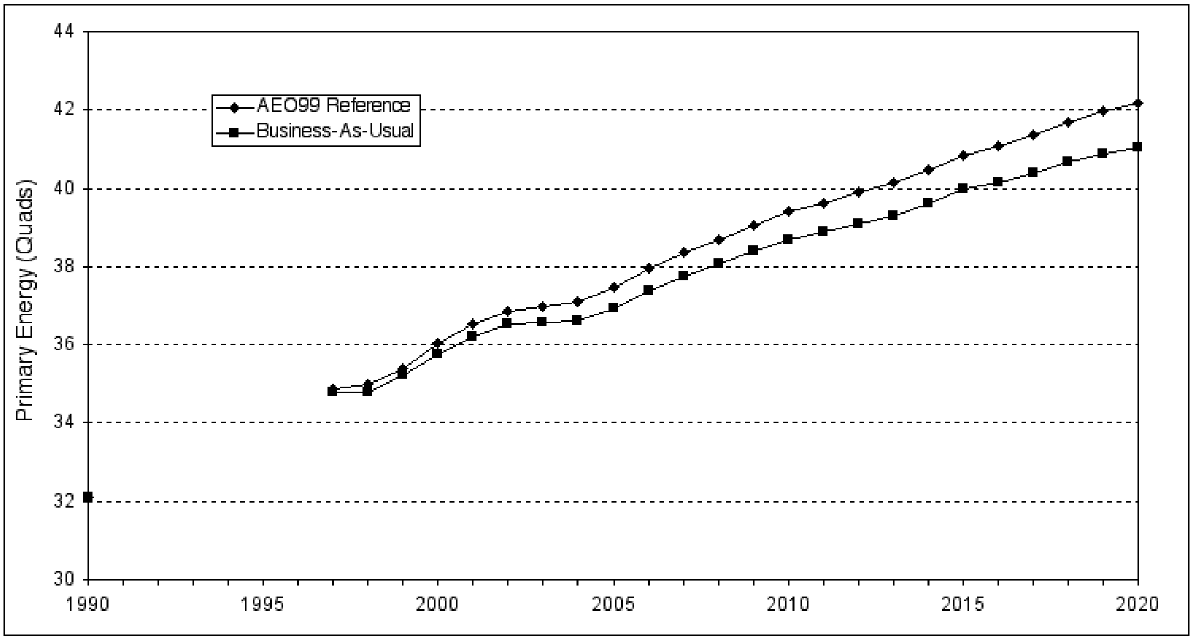
[9] Plants are often re-built during the lifetime, so it is difficult to determine the actual age of equipment. Generally, it reflects the age of the major construction. A blast furnace shell may have been built 50 years ago, it is re-lined every 7 to 8 years, and equipment may be replaced or added, increasing capacity and improving energy efficiency.

Fig. 5.3 shows the difference between the AEO99 reference case and our business-as-usual scenario that not only incorporates our adjustments in the paper, cement, steel, and aluminum sub-sectors, but also includes model feedback effects in other sectors. In 2020, our business-as-usual scenario projects primary energy use of 41.0 Quads, slightly lower than the 42.2 Quads projected by the AEO99 reference case.

Fig. 5.3 Comparison of AEO99 Reference Case and Business-As-Usual Scenario



5.3 POLICY IMPLEMENTATION PATHWAYS

5.3.1 Definition of Pathways

We analyze two policy implementation scenarios – a moderate scenario based on establishment of voluntary agreements with industry that set moderate annual energy efficiency improvement commitments and an advanced scenario setting higher voluntary energy efficiency improvement commitments. Voluntary sector agreements between government and industry are used as the key policy mechanism to attain energy efficiency improvements and to reduce greenhouse gas emissions because an integrated policy accounting for the characteristics of technologies, plant-specific conditions, and industrial sector business practices is needed. Policies and measures supporting these voluntary sector agreements should account for the diversity of the industrial sector while at the same time being flexible and comprehensive, offering a mix of policy instruments, giving the right incentives to the decision maker at the firm level, and providing the flexibility needed to implement industrial energy efficiency measures. Industry is extremely diverse, and even within one sub-sector large variations in the characteristics may be found. Non-energy intensive industries and agriculture consist of thousands of stakeholders[10]. While, voluntary sector agreements are used as the structure of energy efficiency policy throughout industry, such a policy instrument may be less effective in these sectors. Various instruments which support the

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[10] Voluntary agreements are typically used with limited sets of companies. In The Netherlands there is a voluntary agreement with a large number of stakeholders, i.e. agriculture in The Netherlands with 8000 companies. In this case the association has signed on behalf of all its members.

voluntary sector agreements, both at the federal level and state level, are put in place in the policy scenarios to reach the very diverse stakeholders.

Evaluation of voluntary industrial sector agreements in The Netherlands showed that the agreements helped industries to focus attention on energy efficiency and find low-cost options within commonly used investment criteria (Korevaar et al., 1997; Rietbergen et al., 1998). Although the agreements themselves proved to be successful and cost-effective (Rietbergen et al., 1998), various support measures were implemented within the system of voluntary agreements. It is difficult to attribute the energy savings to a specific policy instrument; rather, it is the result of a comprehensive effort to increase implementation and development of energy-efficient practices and technologies in industry by removing or reducing barriers. This emphasizes the importance of offering a package instead of a set of individual measures, which may give the idea of competing measures or instruments rather than a concerted action.

Table 5.2 outlines the various policies and programs that fall under the umbrella of voluntary industrial sector agreements in this analysis and describes how they are expanded under the moderate and advanced scenarios. These include expansion of a number of existing programs, such as the Industrial Assessment Centers and the Climate Wise Program, as well as establishment of new programs such as labeling for chlorine-free paper. For all programs, we increased funding by roughly 50% in the moderate scenario and roughly 100% in the advanced scenario. Table 5.3 identifies which programs influence each of the industrial sub-sectors that we focus on in this assessment. A brief description of the policies and programs used in this analysis is provided below. Appendix B.2 describes the goals of the individual programs, and what contribution they are assumed to have on reducing energy use or greenhouse gas emissions, and how they are linked to the CEF-NEMS modeling. The goals are estimated using different methodologies, which makes it difficult to compare or to evaluate.

The effects of increased program efforts are difficult to assess. Cost-effectiveness may improve due the increased volume, but may also be less effective as programs reach smaller energy users or lead to implementation of less-effective measures. The interaction of various measures deployed simultaneously is difficult to estimate ex-ante, or even ex-poste (Blok, 1993; Stein and Strobel, 1997). It is often more difficult to assess the impacts of individual programs than the estimated impact of a set of policies. For this study, we group individual programs into four categories: information dissemination, investment enabling, regulations, and research, development and demonstration.

Table 5.2 Policies and Programs for Reducing Energy Use and Greenhouse Gas Emissions from the Industrial Sector Under the Moderate and Advanced Scenarios

Policy/Program	Moderate Scenario	Advanced Scenario
Voluntary Industrial Sector Agreements		
Voluntary Industrial Sector Agreements	Voluntary programs to reduce GHG emissions (CO2 and non-CO2) in energy-intensive and GHG-intensive industries, for specific industrial process or buildings.	Voluntary programs to reduce GHG emissions (CO2 and non-CO2) in all industries, including benchmarking.
Voluntary Programs		
Expanded Challenge programs Motor and Compressed Air Challenge	Increased effort to assist in overall motor system optimization through increased education, technical assistance, training, and tools. Increased promotion of use of adjustable-speed drives.	Increased promotion of overall motor system efficiency and use of adjustable-speed drives by offering greater financial incentives.
Steam Challenge	Outreach, training, and development of assessment tools is increased.	Expanded to include outreach to smaller boiler users and to develop automated monitoring and controls.
CHP Challenge	Financial incentives, utility programs promoting CHP, and expanded removal of barriers (e.g. permitting) are added.	Program expands to include increased outreach, dissemination, and clearing-house activities
Expanded ENERGY STAR Buildings and Green Lights	Development of best practices management tools and benchmarking information. Floorspace covered by program increases by 50%.	Best practices management tools and benchmarking information expanded and more extensively marketed. Floorspace covered by program increases by 100%.
Expanded ENERGY STAR and Climate Wise program	Increased efforts in the currently addressed sectors and program expansion to include glass, steel, and aluminum, as well as selected light industries.	Program expanded to include light industries, agriculture, construction, and mining.
Expanded Pollution Prevention Programs	Expanded effort leads to increased recycling in the steel, aluminum, paper, and glass industries.	Number of partners grows to 1600 by 2020 (from 700 in 1997).
Information Programs		
Expanded Assessment Programs	Number of industrial assessment centers increases from 30 to 35 and number of assessments per center increases from 30 to 36 per year. Expanded to include business schools and community colleges. Added emphasis on increased follow-up.	Number of industrial assessment centers increases to 50 and number of assessments per center increases to 40 per year. Comprehensive energy plans for each audited facility added.
Product Labeling and Procurement	Development of labels for two products.	Labeling expanded to other products (e.g. glass bottles). Marketing of labels is increased and government procurement policies are revised to include labeled products.

Investment Enabling Programs		
Expanded State Programs State Industrial Energy Efficiency Programs	Current state level programs are expanded to include information dissemination, audits, demonstration programs, and R&D. Participation grows from less than half of the states to 30 states.	Programs expanded to include all 50 states.
Clean Air Partnership Fund	Expanded use of integrated approaches for complying with CAA. Expanded demonstration of new technologies.	GHG emissions reduction projects given higher priority.
Expanded ESCO/utility programs Standard performance contracting (line charge)	Expansion of line charges to 30 states and increased efforts to target small industrial customers.	Expansion of line charges to 50 states and further increased efforts to target small industrial customers.
Financial incentives Tax incentives for energy managers	Provides tax rebates of 50% of the salary of an energy manager to 5000 medium and large energy-using industries by 2020.	Tax rebates provided to 10,000 medium and large energy using-industries by 2020.
Tax rebates for specific industrial technologies	Increased rebates focus on implementation of advanced technologies.	Increased rebates focus on implementation of advanced technologies. Increased funding leads to accelerated adoption of these technologies.
Investment tax credit for CHP systems	Tax credit extended from 2003 to 2020, leading to expansion of CHP as well as third party producers at industrial sites.	Tax credit extended from 2003 to 2020, leading to expansion of CHP as well as third party producers at industrial sites.
Regulations		
Motors Standards and Certification	Mandates upgrade of all motors to EPACT standards by 2020. Extends standards to all motor systems and enforces 100% compliance. Promote national motor repair standard.	Extends standards to all motor systems and enforces 100% compliance. Mandates national motor repair standard.
State Implementation Plans/Clean Air Partnership Fund	Identifies control measures and regulations to adopt and enforce the control strategies.	Identifies control measures and regulations to adopt and enforce the control strategies.
Research & Development Programs		
Expanded Demonstration Programs	Demonstration programs expanded in currently addressed sectors and extended to mining and construction sectors. Number of demonstration programs increased from 10 to 15 per year.	Extent of demonstration programs further expanded in all sectors and incorporated into state demonstration programs. Number of demonstration programs increases to 18 per year.
Expanded R&D programs Industries of the Future	Increased R&D efforts in all industries currently in program.	Increased R&D efforts in all industries currently in program and expansion to a number of smaller "other manufacturing" industries.
Other OIT R&D programs	Program R&D efforts increased in all areas related to improving industrial sector energy efficiency.	Industrial sector energy efficiency R&D efforts further increased.
Domestic Carbon Dioxide Emissions Trading System	N/A	

Table 5.3 Policies to Reduce Greenhouse Gas Emissions in the Industrial Sector

	POLICIES					
	Voluntary Agreements	**Expanded Assessment Programs**	**Expanded Challenge Programs**	**Expanded Labeling Programs**	**Expanded Climate Wise Program**	**Expanded Pollution Prevention**
SCENARIO	Both	Both	Both	Both	Both	Both
END USE SECTORS						
Agriculture		X	X	X	X	
Mining	X	X	X		X	
Construction		X	X	X	X	
Food	X	X	X	X	X	
Paper	X	X	X	X	X	X
Chemicals	X	X	X		X	
Glass	X	X	X	X	X	X
Cement	X	X	X	X	X	
Iron and Steel	X	X	X	X	X	X
Aluminum	X	X	X	X	X	X
Metals-Based Durables	X	X	X		X	
Other Non-Intensive	X	X	X		X	

	POLICIES					
	Expanded State Programs	**Expanded ESCO/Utility Programs**	**Financial Incentives**	**Expanded R&D Programs**	**Expanded Demonstration Programs**	**Carbon Trading System**
SCENARIO	Both	Both	Both	Both	Both	Advanced
END USE SECTORS						
Agriculture	X		X	X	X	X
Mining	X		X	X	X	X
Construction	X		X		X	X
Food	X	X	X		X	X
Paper	X	X	X	X	X	X
Chemicals	X	X	X	X	X	X
Glass	X	X	X	X	X	X
Cement	X	X	X	X	X	X
Iron and Steel	X	X	X	X	X	X
Aluminum	X		X	X	X	X
Metals-Based Durables	X	X	X	X	X	X
Other Non-Intensive	X	X	X	X	X	X

Voluntary Industrial Sector Agreements. Voluntary agreements are “agreements between government and industry to facilitate voluntary actions with desirable social outcomes, which are encouraged by the government, to be undertaken by the participants, based on the participants’ self-interest” (Story, 1996). A voluntary agreement can be formulated in various ways; two common methods are those based on specified energy efficiency improvement targets and those based on specific energy use or carbon emissions reduction commitments. Either an individual company or an industrial subsector, as represented by a party such as an industry association, can enter into such voluntary industrial agreements.

In this study, the voluntary industrial sector agreements are defined as a commitment for an industrial partner or association to achieve a specified energy efficiency improvement potential over a defined period. The level of commitment, and hence specified goal, varies with the moderate and advanced scenario. The number and degree of supporting measures also varies with the two scenarios, where we expect the increased industrial commitment to be met with a similar increased support effort by the federal and state government. The effectiveness of voluntary agreements is still difficult to assess, due to the wide variety and as many are still underway. Ex-poste evaluations are therefore not yet available. We estimate the effect on the basis of various efforts undertaken. Voluntary industrial agreements in Japan and Germany are examples of self-commitments, without specific support measures provided by the government. Industries promised to improve energy efficiency by 0.6% to 1.5% per year in those countries (IEA, 1997a; Stein and Strobel, 1997). As the targets are set by sub-sector, only intra-sector structural changes are included in the targets, while inter-sector structure changes are excluded. The voluntary industrial agreements in The Netherlands have set an efficiency improvement goal of 2% per year (Nuijen, 1998; IEA, 1997b), excluding intra- and inter-sector structural change. Industries participating in the voluntary agreements in The Netherlands receive support by the government, in the form of subsidies for demonstration projects and other programs (Rietbergen et al., 1998). The voluntary agreements in The Netherlands were strongly encouraged by the government. They were also attractive to industry, as they allowed the development of a comprehensive approach, provided stability to the policy field, and were an alternative to future energy taxation (Van Ginkel and De Jong, 1995), or regulation through environmental permitting. For more details on voluntary industrial agreements, see Newman (1998); Rietbergen et al., (1998); Nuijen (1998); Mazurek and Lehman (1999). Voluntary industrial agreements may be less effective in light industries, which typically have a large number of different companies. However, voluntary agreements may work well with some of the large companies that dominate production and energy use in this sector. In The Netherlands Philips Electronics participates in an individual voluntary industrial agreement, as it solely dominates the metals durables industry.

Experience with industrial sector voluntary agreements exists in the U.S. for the abatement of CFC and non-CO_2 GHG emissions. For example, eleven of twelve primary aluminum smelting industries in the U.S. have signed the Voluntary Aluminum Industrial Partnership (VAIP) with EPA to reduce perfluorocarbon (PFC) emissions from the electrolysis process by almost 40% by the year 2000 (U.S. EPA, 1999b). Similar programs exist with the chemical, magnesium and semi-conductor industries, as well as voluntary methane emission abatement programs with the coal, oil and natural gas industry. New voluntary efforts include landfill operators and agriculture.

Voluntary Programs. The policy scenarios include expanded programs modeled after current policy programs, i.e. Challenge technology delivery programs, Energy Star Buildings and Green Lights, Climate Wise and specific pollution prevention programs.

- Expanded Challenge Programs
  - *Motor Challenge and Compressed Air Challenge.* The U.S. Department of Energy's Motor Challenge program was created in 1993 to promote voluntary industry/government partnerships to improve energy efficiency, economic competitiveness, and the environment. The main goal of the program is to work in partnership with industry to increase the market penetration of energy-efficient industrial electric motor-driven systems. A key element in the Motor Challenge strategy is to encourage a "systems approach" to industry's selection, engineering, and maintenance of motors, drives, pumps, fans, and other motor-driven equipment (Scheihing et al., 1998). The program focuses its resources on the key industrial sectors that are participating in DOE's Industries of the Future (IOF) strategy, as well as the water supply and wastewater sectors. The current Motor Challenge program focuses on eight energy- and waste-intensive sectors: forest products, steel, aluminum, metal casting, chemicals, glass, mining, and agriculture, and is targeting large plants in these industries (Scheihing et al., 1998). Starting in 1999, the Motor Challenge program has been expanded to include provision of enhanced technical assistance on steam and compressed air systems (U.S. DOE, 1999). The moderate and advanced scenarios call for increased funding for increased educational efforts and technical assistance. The program will increase its efforts to promote adoption of adjustable speed drives. Financial incentives will be added in the advanced scenario.

- *Steam Challenge.* The Steam Challenge program, a public-private initiative launched in April of 1998, was developed by DOE-OIT in partnership with the Alliance to Save Energy (ASE) and leading providers of energy-efficient steam technologies. The goal of Steam Challenge is to provide targeted information and technical assistance to help industrial customers retrofit, maintain, and operate their steam systems more efficiently and more profitably. Participation in Steam Challenge is open to steam system operators and managers, developers and distributors of steam systems equipment, and steam trade and membership organizations (U.S. DOE, OIT, 1999c). Increased funding in the moderate and advanced scenarios provides for expanded outreach, training, development of assessment tools, and development of automated monitoring and controls.

- *CHP Challeng.*[11]. DOE and EPA recently announced a target of doubling combined heat and power (CHP) capacity (including industrial, commercial, and federal facilities) in the United States by 2010. It seeks to open a national dialogue on CHP technologies to raise awareness of the energy, environmental, and economic benefits of CHP, and to promote innovative thinking about ways to accelerate the use of CHP (Laitner et al., 1999). State and regional officials will be key participants in this CHP Challenge. Future plans include a series of seminars with state officials, regional workshops, and a national CHP conference for policymakers and CHP practitioners to promote collaborative solutions (U.S. DOE, OIT, 1999d). Educational materials also are being prepared for state legislators and environmental groups. The CHP Challenge will coordinate with other government and industry programs to leverage ongoing activities relevant to CHP—for example, by working with the Federal Energy Management Program (FEMP) and facilities management agencies to expand the use of CHP technologies in government facilities. The Challenge also will assess related DOE technology demonstrations in advanced turbines, fuel cells, and combustion and heat recovery equipment (U.S. DOE, OIT, 1999d). Increased funding in the moderate and advanced scenarios allows for increased barrier removal, outreach, dissemination, evaluation assistance, and clearinghouse activities.

- ENERGY STAR Buildings and Green Lights
  The U.S. Environmental Protection Agency's ENERGY STAR programs help to eliminate information barriers and improve efficiency in investments in the buildings component of industrial energy use, which is especially important in light industries. ENERGY STAR programs are voluntary partnerships between EPA, the U.S. Department of Energy, product manufacturers, local utilities, and retailers to develop and market energy-efficient products (see also above). Partners help promote energy-efficient products by labeling them with the "ENERGY STAR" logo, which may be used as a marketing tool, and educating consumers about the benefits of energy efficiency. Participating companies are provided with access to information on products and practices to improve their efficiency. EPA will continue to add products to the list of those that qualify for the ENERGY STAR label (U.S. EPA, 1999b). The Green Lights program, a voluntary pollution prevention program sponsored by EPA and part of the ENERGY STAR program, aims at improving the efficiency of lighting systems. Green Lights partners agree to install energy efficient lighting where profitable as long as lighting quality is maintained or improved. Future expansion of ENERGY STAR will focus on initiatives that are more valuable to the industrial sector—for example, providing best practices management tools to industrial facilities and, if possible, developing and providing benchmarking information to help industries assess and compare their energy usage, and ultimately save energy (Lupinacci-Rausch, 1999). We assume that industrial building floorspace included in the ENERGY STAR Buildings and Green Lights programs increases by 50% under the moderate scenario and doubles under the advanced scenario.

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[11] We have assessed the potential for industrial cogeneration for the different policy scenarios (see section 5.5.4 for results). However, the cogeneration results have not yet been integrated in the overall results, reported in section 5.5.

- Expanded ENERGY STAR and Climate Wise Program
  U.S. Environmental Protection Agency sponsors various government-industry partnership initiatives, e.g. ENERGY STAR and Climate Wise, designed to stimulate the voluntary reduction of greenhouse gas emissions among participating manufacturing companies by providing technical assistance and helping organizations identify the most cost-effective ways to reduce greenhouse gas emissions. In the Climate Wise program companies submit an Action Plan that identifies specific cost-effective energy efficiency and pollution prevention measures. Companies then quantify and report their energy savings and emission reduction numbers annually. In return, participants in the Climate Wise program receive assistance in identifying actions that both save energy and reduce costs, have access to technical assistance, and receive public recognition for their efforts (e.g., through signing ceremonies, media briefings, articles in business journals) (U.S. EPA, 1999a, U.S. EPA, 1999b). Program expansions and funding are increased by 50% in the moderate scenario and doubled in the advanced scenario. The moderate scenario incorporates additional partners while the advanced scenario incorporates new manufacturing sectors, both scenarios contributing to the savings in existing and new plant equipment.

- Expanded Pollution Prevention Programs
  Although not directly aimed at energy use or GHG emissions, the WasteWise program may reduce energy use and GHG emissions through pollution prevention and increased recycling of energy intensive materials. The WasteWise program targets the reduction of municipal solid waste, such as corrugated containers, office paper, yard trimmings, packaging, and wood pallets. Participants, which range in size from small local entities to large corporations, sign on to the program for a 3-year period and commit to reduce waste, establish reduction goals, and monitor progress of waste reduction projects and activities. The U.S. EPA has also created the Design for the Environment (DfE) Program to build on the "design for the environment" concept pioneered by industry. Under this program, EPA encourages businesses to incorporate environmental considerations into the design and redesign of products, processes, and technical and management systems, as well as environmentally procurement programs (U.S. EPA, CPD, 1999; U.S. EPA, OCFO, 1999). Increased funding in the moderate and advanced scenarios is expected to lead to reductions in material demand, increased diversion of wastes to recycling instead of landfilling, and overall changing consumption and production patterns in the primary materials industries.

Information Dissemination Programs. Information dissemination programs include assessment programs and labeling programs, as well as elements of the “Challenge” programs, the Climate Wise program, and pollution prevention programs (see above).

- Expanded Assessment Programs
  The U.S. Department of Energy Office of Industrial Technology’s Industrial Assessment Center (IAC) program is an energy efficiency improvement initiative that also supports waste reduction and improvements in productivity for small and medium sized manufacturing firms[12]. There are now 30 universities operating IACs across the country. Since its inception in 1976, these centers have performed more than 8,000 assessments and provided 53,000 recommendations since 1976; about 42% of the suggested investments have been implemented (STAPPA/ALAPCO, forthcoming). The energy audits and assessments are performed by teams from engineering schools at Universities across the country, who help manufacturers identify opportunities to improve productivity, reduce waste, and save energy. Most clients of the IAC centers are currently in food processing and metals

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[12] The IAC Program defines small and medium sized enterprises as having gross annual sales of $75 million or less, consume energy at a cost of $1.75 million per year or less, or employ no more than 500 people.

manufacturing, due to the higher presence of small and medium sized enterprises in these sectors. Historically, IAC assessments have identified the most retrofit opportunities in lighting, HVAC and building envelopes, heat recovery and containment, compressors, and motors in small and medium sized enterprises (U.S. DOE, OIT, 1999b). Under the moderate and advanced scenarios, funding is increased so that additional IACs are established. Due to integration with both business schools and local community colleges, the number of assessments also increases and the work of the centers is expanded to include development of comprehensive energy plans for the audited industries. Developing such corporate energy plans to implement and maintain energy-efficient practices will focus industries on sustained efforts, modeled after programs run at various companies.

➢ Product Labeling and Procurement

Consumer information to encourage demand for environmentally benign products, e.g. eco-labeling, is a step towards more sustainable production that is taken in many countries. For example, the “Blue Angel” program has been in existence since 1977 in Germany, and is used for a wide array of products. The “Blue Angel” program labels products like unbleached, recycled paper, as well as many other common products (e.g. computers, paint). The “Green Seal” in the U.S. is a similar, but independent non-governmental, effort. The labeled products generally have a lower environmental impact than competing products, and often result in energy savings due to the use of less energy-intensive materials or recycled materials. To maintain objectivity standardized and independent procedures are needed. The design of the testing procedures may take a few years. Corporate and governmental procurement programs of labeled products are also established as 'market-pull' instruments. The federal government has established procurement programs for energy consuming equipment (FEMP). The described effort would expand the program to other products, e.g. cement for public construction projects. Under the moderate scenario, we assume the development of a federal eco-labeling program for development of a label for unbleached, recycled paper and for performance-based cement standards. Under the advanced scenario, the program will be expanded to various products.

Investment Enabling Programs. Investment enabling programs include state programs, ESCO/utility programs, and financial incentives.

➢ Expanded State Programs

- *State Industrial Energy Efficiency Programs.* Currently many states and regional bodies have local industrial innovation and competitiveness programs (NIMAP, 1999), of which a number specifically aim at industrial energy efficiency improvement. In this description we excluded utility or ESCO programs (see description under ESCO programs, below). Approximately 300 regional or state programs exist. Successful examples of energy programs can be found in e.g. Iowa, New York, Texas, and Wisconsin. The Energy Center of Wisconsin focuses on demonstration projects. The NYSERDA (New York State Energy Research and Development Authority) program in New York focuses more on industrial R&D, while the LoanSTAR program in Texas focuses on demonstrating energy retrofit technologies. The Iowa Energy Center focuses on agriculture and audits. The programs are active in information dissemination, auditing, demonstration, and R&D of industrial technologies. Recently, OIT has also started an effort to expand the IOF program to the state level. States Industries of the Future (SIOF) has activities in 50 states in various stages of development, and focus points (depending on the interests of local industries). Increased funding in the moderate and advanced scenarios will accommodate expansion of technology demonstration and practices across sub-sectors, auditing, active dissemination, and integration with other industrial innovation and environmental policies.

- *Clear Air Partnership Funds.* There are various ways to comply with the provisions of the Clean Air Act. Harmonized strategies to reduce air pollutant emissions that also reduce GHG emissions can be developed in all sectors, including the industrial sector (STAPPA/ALAPCO, 1999). Air pollution control measures are developed by state and local regulators and are described in a State Implementation Plan (SIP). A SIP contains plans for inventories of emissions, modeling of efforts needed to attain or maintain a specified emission level, a list of control measures, and regulations to adopt and enforce the control strategies (see Regulations, below). The Clean Air Partnership Fund will provide financial incentives to reduce air pollution and GHG emissions simultaneously. The GHG emission reduction will depend strongly on the measures that are implemented to reduce pollutant emissions, and are likely to vary by region (STAPPA/ALAPCO, 1999). While the moderate and advanced scenarios follow the same timeline as the baseline scenario, start of implementation of measures by the year 2000, increased funding makes integrated approaches more attractive for industries and allows new technology demonstrations without the current risk of non-compliance.

- Expanded *ESCO/Utility Programs*
  Following deregulation, 19 states have introduced public benefit charges. The revenue from the public benefit charges will be used to fund projects in energy efficiency, R&D, renewable energy sources, as well as to subsidize low-income households. The charge and the spending pattern will vary by state (Kushler, 1998; Kushler, 1999). We assume that the revenues will mainly be used to expand the work of Energy Service Companies (ESCOs) through standard performance contracting (Eto et al., 1998). Historically, utility demand-side management program performance has varied widely, and depends on factors like marketing, targeting of approaches, program procedures, level of financial incentives, and availability of technical assistance (Nadel, 1990). Utility programs seem to have mainly been targeted to larger customers. A recent analysis of bidding programs for commercial/industrial energy savings showed typical costs from $0.054 to $0.08 per kWh-saved (Goldman and Kito, 1994). For the business-as-usual scenario, we use a typical cost of $0.06/kWh-saved. Under the moderate scenario, we assume public benefit charges are used in 20 states by the year 2000 and expanded to 30 states by 2005. We assume that the typical costs in the moderate scenario will be $0.065 per kWh-saved, due to increased efforts targeting small industrial consumers. For the advanced scenario, the programs will have slightly higher typical costs of $0.07/kWh-saved, as it is more difficult to reach a larger group of customers.

- Financial Incentives
  - *Tax Rebates for Specific Industrial Technologies.* As part of the U.S. climate change proposal, President Clinton announced support for $6.3 billion in funding over 5 years for additional R&D efforts and tax cuts to stimulate energy efficiency and other technologies that reduce greenhouse gas emissions. The financial incentives and R&D expenditures would spur development and commercialization of advanced technologies and leverage larger private sector investments. Specific technologies that have been discussed for the tax rebate program include black liquor gasification, direct steelmaking technologies, and advanced aluminum cells. Other potential tax incentive initiatives in the industrial sector could include improved aluminum smelting technologies and major chemical production processes. These incentives could be made available for up to ten years, assuming that they are initiated in 1999 or 2000 (Elliott, 1999). Under the moderate and advanced scenarios, the expanded program will be aimed at the implementation of advanced technologies. In the early years this will include industrial cogeneration, roller kilns, autothermal reforming, black liquor gasification, near net shape casting. After 2005 it could also include advanced technologies, now under demonstration or development, e.g. smelt reduction, advanced (catalytic) membrane applications, and impulse drying. The higher funding level in the advanced scenario is expected to accelerate uptake of these technologies within the analysis period of the study.

- *Investment Tax Credit for CHP Systems.* This policy would establish an 8% investment credit for qualified CHP systems with an electrical capacity in excess of 50 kilowatts or with a capacity to produce mechanical power in excess of 67 horsepower (or equivalent combination of electrical and mechanical energy capacities). A qualified CHP system would be required to produce at least 20 percent of its total useful energy in the form of thermal energy and at least 20 percent of its total useful energy in the form of electrical or mechanical power (or a combination thereof). In the moderate scenario it is expected that the tax credit scheme is maintained at the 2000-2002 level throughout the scenario period (2020). In the advanced scenario it is expected that the tax credit scheme is started at a level of $100 Million for the period 2000-2005, and maintained at a higher level of $200 Million from 2005 till 2020. The investment credit remains at 8% for qualifying CHP units. After 2005, higher credit levels are available for advanced cogeneration systems, including advanced turbines, gas turbines for industrial furnaces, high efficiency systems using waste gases, and for industrial applications of fuel cells. The program is maintained throughout the modeled period, and is expected to contribute to the expansion of CHP in industry, as well as third party (merchant) producers at industrial sites.

Regulations

➢ Motors Standards and Certification.
The moderate scenario mandates upgrade of all motor systems to EPACT standards by 2020,and extends standards to all motors not currently governed by EPACT, although the effect of the latter may be limited (Xenergy, 1998). It also includes improved rewind practices by promoting a national repair standard (EASA-Q) and the institution of certification and licensing of rewind shops by 2004. Specifications for motor purchases are supplied and energy-efficiency requirements are increased to EPACT standards (by extending standards to all motors not currently governed by EPACT). The advanced scenario extends standards to all motor systems and enforces 100% compliance by 2020, improves rewind practices and mandates national repair standard (EASA-Q) into law by 2004, and mandates certification and licensing of rewind shops by 2004.

➢ State Implementation Plans/ Clear Air Partnership Fund
State Implementation Plans outline air pollution control measures to comply with the provisions of the Clean Air Act. These SIPs include a list of control measures and regulations to adopt and enforce the control strategies (STAPPA/ALAPCO, 1999). This regulatory element of the Clean Air Act SIPs augments the harmonized strategies to reduce air pollutant emissions and GHG emissions that are described above under Investment Enabling Programs.

Research, Development, and Demonstration Programs. New technologies that could have the largest impact in the period after 2010 include black liquor gasification (paper), impulse drying (paper), smelt reduction (steel), membranes (chemicals, food), heat pumps (chemicals, food), inert anodes (aluminum), new grinding technologies (non-metallic minerals, mining), process control and equipment (all sectors) high efficiency and high temperature CHP including gas turbines and fuel cells (DOE National Laboratory Directors, 1998; Interlaboratory Working Group, 1997; Blok et al.,1995). Expanded R&D efforts are likely to generate future energy savings over the modeled timeframe depending on the timing and scheduling of the R&D (Breger, 1997).

➢ Expanded Demonstration Programs
Demonstration programs, such as the U.S. Department of Energy's National Industrial Competitiveness through Energy, Environment, and Economics (NICE^3), improve industry energy efficiency, reduce industry's costs, and promote clean production. Grants support innovative technology deployment that can significantly conserve energy and energy-intensive feedstocks, reduce industrial wastes, prevent pollution, and improve cost competitiveness. The NICE^3 program currently focuses on the following industries (# of projects): agriculture (1), aluminum (6), chemicals

(13), forest products (10), glass (2), metal casting (4), petroleum (3), steel (8), other industries: electroplating/galvanizing (4), electronics (2), food (4), general manufacturing (10), printing (1), textiles (3) (U.S. DOE, OIT, 1999a). These programs are expanded under the moderate and advanced scenarios, with the increased funding leading to demonstration programs in additional industrial sub-sectors, incorporated into state programs, and providing more information dissemination services.

➢ Expanded R&D Programs
In this study we model the impact of R&D policies by assuming increasing availability of new technologies in the moderate and especially in the advanced scenario. In the advanced scenario the policies to increase energy efficiency will provide incentives to direct R&D efforts increasingly to energy and resource efficiency. The technologies mentioned above will affect the trends in efficiency of new technologies in all industrial sectors gradually (reflecting the trends in S-curves for technology development and penetration). R&D developments may also affect the costs and potential energy savings from retrofit of existing technologies, but less pronounced than for new technologies.

- *Industries of the Future.* The U.S. Department of Energy, Office of Industrial Technologies, Industries of the Future (IOF) strategy—creating partnerships among industry, government, and supporting laboratories and institutions to stimulate technology research, development, and deployment—is being implemented in nine energy- and waste-intensive industries: agriculture, aluminum, chemicals, forest products, glass, metal casting, mining, petroleum, and steel. The IOF strategy is based on the preparation of documents outlining each industry's vision for the future, along with technology “roadmaps” identifying the technologies that will be needed to reach that industry's goals. Potential technologies are assessed and selected for funding by DOE and the industries (U.S. DOE, OIT, 1999e). Industries of the Future programs are expanded in the moderate and advanced scenarios, leading to increased research and development of future technologies and savings in new plant equipment.

- *Other OIT R&D Programs.* The Office of Industrial Technologies currently funds basic research in the areas of Enabling Technologies and Distributed Generation. The Enabling Technologies include engineered ceramics/continuous fiber ceramic composites, advanced industrial materials, combustion systems, and sensors and control technologies. The Distributed Generation programs focus on industrial power generation and industrial distributed generation (U.S. DOE, 1999). In cooperation with the DOE Office of Fossil Energy, OIT supports the development and demonstration of high-efficiency gas turbines primarily designed for industry. Funding increases under the moderate and advanced scenarios lead to expanded program R&D efforts in all areas related to improving industrial sector energy efficiency.

Accelerated R&D in 2010-2010 Period

The policies and programs discussed above were originally designed for the period 2000-2010. It is assumed that similar policies will be maintained throughout the period 2010-2020. In addition, the results of accelerated R&D policies will impact energy efficiency improvement potentials after 2010. R&D will likely increase the potential for energy efficiency improvement, while reducing the costs for new technology. R&D is not expected to have profound effects in the analysis period up to 2010. However, R&D can substantially contribute to decreasing the costs of new technologies as well as promoting the development of new technologies designed to reduce energy use and carbon emissions between 2010 and 2020. It is difficult to model technologies under development in the same detail as commercially available technology.

Domestic Carbon Dioxide Emissions Trading System

In the advanced scenario a carbon trading system is assumed to be implemented, which would lead to a estimated value of carbon permits of 50$/ton C (see section 3.2.1.3).

5.3.2 Barriers Addressed

Voluntary industrial agreements, along with the associated package of industrial sector policies and programs outlined above, are designed to address a number of barriers to investment in energy efficiency and greenhouse gas emissions reduction options including willingness to invest, information and transaction costs, profitability barriers, lack of skilled personnel, and other market barriers. Table 5.4 outlines the programs and policies we use to support voluntary industrial agreements in this analysis and the barriers they address.

Willingness to Invest. The decision-making process to invest in energy efficiency improvement, like any investments, is shaped by the behavior of individuals or of various actors within a firm. Decision-making processes in firms are a function of its rules of procedure (DeCanio, 1993), business climate, corporate culture, managers' personalities (OTA, 1993) and perception of the firm's energy efficiency (Velthuijsen, 1995). The literature suggests that the fewest barriers to energy efficiency investment exist in the industrial sector, where managers are thought to be motivated by cost minimization (Golove, 1994). The behavior has been categorized in a study by EPRI in the U.S., which determined nine "types" of managers (EPRI, 1990), depending on industrial development type and management characteristics. In markets with strong growth and competition, efficiency with respect to energy and other inputs is necessary to survive. In contrast, stagnating markets are poor theatres for innovation and investment, and instead rely on already depreciated equipment to maintain low production costs. A survey of 300 firms in The Netherlands showed that a favorable market expectation was perceived as an important condition for investing in energy efficiency improvement. In markets where increased energy costs can still be recovered in the product price, firms do not have the incentive to invest in energy efficiency improvements. In the same survey it also appeared that firms often perceived themselves as energy efficient, even though profitable potentials for energy efficiency improvements were still found (Velthuijsen, 1995). Energy awareness as a means to reduce production costs does not seem to be a high priority in many firms, despite a number of excellent examples in industry worldwide. By including energy efficiency as a component of waste minimization, firms have identified more opportunities for savings (see box) (Nelson, 1994).

Company Programs

Dow Chemical in Louisiana introduced an annual waste reduction contest in 1981 among employees at the Plaquemine-site (LA). This contest has continued to find significant, highly cost-effective energy and materials savings projects each year, implying that even well managed firms do not automatically optimize their use of resources. Each year more profitable energy conservation and waste reduction projects are identified in an annual contest with rate of returns far over 100%. The additional efficiencies found at Dow Chemical suggest that great potential exists to improve the efficiency and reduce the emissions of the industrial sector, if organizational and other internal barriers can be overcome (Nelson, 1994).

Information & Transaction Costs. Cost-effective energy efficiency measures are often not undertaken as a result of lack of information or knowledge on the part of the consumer, lack of confidence in the information, or high transaction costs for obtaining reliable information (Reddy, 1991; OTA, 1993; Velthuijsen, 1995; Sioshansi,1991; Levine et al.,1995; Ostertag, 1999). Information collection and processing consumes time and resources, which is especially difficult for small firms. Many firms and individuals are uninformed regarding the possibilities for buying efficient equipment (Reddy, 1991), because energy is just one of many criteria in acquiring equipment. The information needs of the various actors are defined by the characteristics of the investors leading to a need for a diversified set of information sources. Public agencies and utilities play an important role in providing this information.

Financial Barriers. A large number of standard accounting procedures are available for firms to determine the economic feasibility and profitability of an investment. Surveys showed that many investors use instruments such as simple payback period, rate of return or net present value to evaluate energy efficiency projects. When energy prices do not reflect the real costs of energy, then consumers will necessarily invest less in energy efficiency unless such investments have additional benefits. Energy prices, as a component of the profitability of an investment, are also subject to large fluctuations. The uncertainty about future energy prices, especially in the short term, seems to be an important barrier (Velthuijsen, 1995). The uncertainties often lead to higher perceived risks, and therefore to more stringent investment criteria and a higher hurdle rate (Hassett and Metcalf, 1993; Sanstad et al., 1995). An important reason for high hurdle rates is capital availability. Capital rationing is often used within firms as an allocation means for investments, leading to even higher hurdle rates, especially for small projects with rates of return from 35 to 60%, much higher than the cost of capital (~15%) (Ross, 1986). DeCanio (1993) has shown that firms typically establish internal hurdle rates for energy efficiency investments that are higher than the cost of capital to the firm. On the energy supply side the costs of capital are much lower, leading to imperfections of the capital market. Utilities and investors in power supply typically operate with longer payback periods (Levine et al., 1994). These capital market imperfections lead to bias against end-use investments vis-a-vis energy supply.

Lack of Skilled Personnel. Especially for small and medium sized enterprises (SME) the difficulties of selecting and installing new energy-efficient equipment compared to the simplicity of buying energy may be prohibitive (Reddy, 1991). In many firms (especially with the current trend towards *lean* firms) there is often a shortage of trained technical personnel (OTA, 1993), because most personnel are busy maintaining production. A survey in The Netherlands suggested that the availability of personnel is seen as a barrier to invest in energy-efficient equipment by about one third of the surveyed firms (Velthuijsen, 1995). In addition, the possible disruption of the production process is perceived as a barrier, leading to high *transition or opportunity costs*. Transition costs may include the costs of not fully depreciated production equipment, although the capital costs of the new technology in itself may be economically attractive.

Other Market Barriers. In addition to the problems identified above, other important barriers include (1) the "invisibility" of energy efficiency measures and the difficulty of demonstrating and quantifying their impacts; (2) lack of inclusion of external costs of energy production and use in the price of energy, and (3) slow diffusion of innovative technology into markets. A full discussion of these topics is beyond our scope, see (Levine et al., 1994; Fisher and Rothkopf, 1989; Hirst and Brown, 1990; Sanstad and Howarth, 1994). Many companies are risk averse with regard to a possible effect on product quality, process reliability, maintenance needs or uncertainty about the performance of a new technology (OTA, 1993). Firms are therefore less likely to invest in new not yet commercially proven technology. Aversion of perceived risks seems to be a barrier especially in SMEs (Yakowitz and Hanmer, 1993). For commercial and industrial buildings that are rented, there are few incentives for the renter to improve the property that he/she does not own; similarly, the landlord is uncertain of recovering his/her investment, either in higher rents (as it is difficult to prove that improved thermal integrity will save the renter money in utility bills) or in the utility bills, as the bills depend on the behavior of the renter. Builders are often required to minimize first costs in order to win bids, and many building owners do not have sufficient expertise to recognize the benefit of higher first costs to reduce building operating costs (Golove, 1994). ESCOs are able to capture part of this efficiency gap.

Table 5.4 Policies to Address Barriers to Efficiency Improvement in the Industrial Sector

	POLICIES					
	Voluntary Agreements	**Expanded Demonstration Programs**	**Expanded Assessment Programs**	**Expanded Challenge Programs**	**Expanded Labeling Programs**	**Expanded State Programs**
SCENARIO	Both	Both	Both	Both	Both	Both
BARRIERS						
Willingness to Invest	X	X	X	X		
Information / Transaction Costs	X	X	X	X	X	X
Profitability		X		X		
Lack of Skilled Personnel			X	X		X
Pricing				X		
Innovation		X		X		X
Renter/Landlord						
	POLICIES					
	Expanded R&D Programs	**Expanded ESCO/utility Programs**	**Expanded Climate Wise Program**	**Expanded Pollution Prevention**	**Financial Incentives**	**Carbon Trading System**
SCENARIO	Both	Both	Both	Both	Both	Advanced
BARRIERS						
Willingness to Invest		X		X	X	
Information / Transaction Costs		X	X	X		
Profitability	X	X			X	X
Lack of Skilled Personnel		X				
Pricing					X	X
Innovation	X			X		
Renter/Landlord		X				

5.4 METHODOLOGY FOR ANALYZING POLICY IMPACTS

Our analysis begins with an assessment of policies and programs applicable to the industrial sector. We use voluntary industrial sector agreements between industry and government as the key policy mechanism to attain energy efficiency improvements and to reduce greenhouse gas emissions. As discussed above, these voluntary industrial sector agreements are supported by a comprehensive package of policies and programs designed to encourage implementation of energy-efficient technologies and practices.

Each industrial sub-sector is evaluated to determine the potential energy savings and GHG emissions reductions. Since voluntary industrial sector agreements are the umbrella under which a number of policies and programs contribute to decisions to implement energy-efficient technologies and measures, it is often difficult to allocate specific actions to specific policies or programs. Estimates are made to allocate the overall synergetic effects of actions taken due the supporting policies and measures. Table 5.5 outlines how the effects of the different policies and programs are reflected in the CEF-NEMS modeling and model inputs. Appendix A.2 and B.2 provide detailed information on the alterations made to the NEMS-model and on the industrial sector policies and programs. Uncertainties in the assumptions affect the final results of the scenarios. However, as it is not always possible to quantitatively estimate the uncertainties (see sections 5.6 and 5.7) and for reasons of presentation we only present point estimates.

AEO 99 projects energy intensity reductions of 1.0% per year in the baseline scenario, of which 80%, or 0.8% per year, are due to inter-sector structural change and the remaining 0.2% per year is due to efficiency improvements (U.S. DOE, EIA, 1998a). We have retained the AEO99 assumption of a 0.8% contribution inter-sectoral structural change in all CEF, and in the moderate and advanced scenarios modified the change due to efficiency improvements as discussed below.

Five industrial sub-sectors (paper, glass, cement, steel, and aluminum) are modeled in NEMS using physical production values to determine energy intensities. We evaluate three of these subsectors (paper, cement, and steel) in detail, relying on recent process-level assessments of energy use, carbon dioxide emissions, and efficiency potentials (Worrell et al., 1999; Martin et al., 1999; Anglani et al., 1999). We assess the other two sectors based on historic trends and efficiency potentials identified in recent U.S. and international literature. The remaining industrial sub-sectors (agriculture, mining, construction, food, chemicals, metals-based durables, and other manufacturing)[13] are modeled in NEMS using economic production values (value of output) to determine energy intensities. We evaluate these sub-sectors based on historic trends and efficiency potentials identified in recent U.S. and international literature.

5.4.1 Actions Addressed Within CEF-NEMS

All actions due to industrial sector policies were addressed to some degree within CEF-NEMS, including a carbon dioxide emissions trading system with an assumed carbon price of $50/ton in the advanced scenario. We first assessed the level of future energy savings under many policies (see Appendix B.2). Next we determined where and how these energy savings might be achieved in terms of modeling parameters and modeled these changes in CEF-NEMS, on an aggregation level appropriate for the CEF-NEMS model. We adjusted the following parameters of the CEF-NEMS model to reflect the likely impact of the policies on the implementation rate and decision-making process: energy efficiency improvements in existing equipment, energy efficiency improvements in new equipment, material inputs, boiler efficiency, use of CHP, and building efficiency. Some policies may affect one parameter, e.g. research and development is most likely to affect the energy efficiency improvement and availability of new equipment. On the other hand, a carbon trading system will affect the price of energy and will likely influence all parameters of the CEF-NEMS model.

Energy Efficiency Improvements in Existing Equipment. In addition to the over-arching voluntary industrial sector agreements, specific policies that result in more rapid adoption of energy-efficient technologies and measures for existing equipment are expanded assessment programs, expanded Motor and Compressed Air Challenge program, expanded state programs, expanded SIP and Clean Air programs, expanded ESCO/utility programs, expanded ENERGY STAR and Climate Wise programs, tax incentives for energy managers, and expanded demonstration programs.

The rate of adoption of energy-efficient technologies and measures for existing equipment is characterized in NEMS using technology possibility curves (TPCs)[14]. TPC values for existing equipment were modified in the moderate and advanced scenarios in all sectors (see Appendix A-2). For the paper, cement, and steel sectors, the modifications were made based on calculations made outside of CEF-NEMS (see below). For the agriculture, mining, chemicals, glass, and aluminum sectors, we relied on recent analyses (see Appendix A-2) of the energy efficiency improvement potentials in these sectors to determine TPCs for the moderate and advanced scenarios. For the remaining sectors (food, metals-based durables, and other manufacturing), we used the AEO99 HiTech Case TPC values for the advanced scenario and used values between the Base Case and the HiTech Case for the moderate scenario.

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[13] Because petroleum refining is not included in the NEMS industrial model (but rather in the transformation sector) it has been excluded in the analysis of the industrial sector.

[14] TPCs represent average annual rates of change (usually reduction) in the Unit Energy Consumption (UEC) values. TPCs and UECs are provided by process by fuel for each industrial subsector.

Table 5.5 Qualitative Representation of Policy and Program Impacts on CEF-NEMS Inputs by Industrial Subsector

	POLICIES								
	Demon-stration Programs	Assess-ment Programs	Challenge Programs - Motors and Air	Challenge Programs - Steam	Challenge Programs - CHP	Energy Star Buildings and Green Lights	Product Labels	State Programs	Clean Air Act SIPs
Agriculture	1,2,8	1	1,2,8	3,6,9	6,9			1,2,3	
Mining	1,2,8	1	1,2,8	3,6,9	6,9			1,2,3	
Construction	1,2,8	1	1,2,8	3,6,9	6,9			1,2,3	
Food	1,2,8	1	1,2,8	3,6,9	6,9	5		1,2,3,5	1,2,3,6,9
Paper	1,2,7,8	1,7	1,2,7,8	3,6,9	6,9	5	4	1,2,3,5	1,2,3,6,7,9
Chemicals	1,2,8	1	1,2,8	3,6,9	6,9	5		1,2,3,5	1,2,3,6,7,9
Glass	1,2,8	1	1,2,8	3,6,9	6,9	5		1,2,3,5	1,2,3,6,9
Cement	1,2,7,8	1,7	1,2,7,8	3,6,9	6,9	5	4	1,2,3,5	1,2,3,6,9
Steel	1,2,7,8	1,7	1,2,7,8	3,6,9	6,9	5		1,2,3,5	1,2,3,6,7,9
Aluminum	1,2,8	1	1,2,8	3,6,9	6,9	5		1,2,3,5	1,2,3,6,9
Metals-Based Durables	1,2,8	1	1,2,8	3,6,9	6,9	5		1,2,3,5	1,2,3,6,9
Other Manufacturing	1,2,8	1	1,2,8	3,6,9	6,9	5		1,2,3,5	1,2,3,6,9
Petroleum Refining	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a

	POLICIES								
	R&D - IOF	Other OIT R&D	ESCO/ Utility program	Climate Wise Program	Pollution Prevention	Tax Incentives for Energy Managers	Tax Rebates for Specific Industrial Techs	Investment Tax Credit for CHP Systems	Carbon Trading System
Agriculture	2	2,6	1,6,9	1,2,8		1		6,9	1-6,8,9
Mining	2	2,6	1,6,9	1,2,8		1		6,9	1-6,8,9
Construction				1,2,8				6,9	1-6,8,9
Food		2,3,6	1,5,6,9	1,2,8		1,5	2	6,9	1-6,8,9
Paper	2	2,3,6	1,5,6,7,9	1,2,7,8	4	1,5,7	2	6,9	1--9
Chemicals	2	2,3,6	1,5,6,9	1,2,8		1,5	2	6,9	1-6,8,9
Glass	2	2,3,6	1,5,6,9	1,2,8	4	1,5	2	6,9	1-6,8,9
Cement	2	2,3,6	1,5,6,7,9	1,2,7,8		1,5,7	2	6,9	1--9
Steel	2	2,3,6	1,5,6,7,9	1,2,7,8	4	1,5,7	2	6,9	1--9
Aluminum	2	2,3,6		1,2,8	4	1,5	2	6,9	1-6,8,9
Metals-Based Durables	2	2,3,6	1,5,6,9	1,2,8		1,5	2	6,9	1-6,8,9
Other Manufacturing			1,5,6,9	1,2,8		1,5		6,9	1-6,8,9
Petroleum Refining	n/a	n/a	n/a	n/a	n/a	n/a	n/a	9	1-6,8,9

Notes

Modeled within NEMS:

1: increased TPCs in existing equipment
2: increased TPCs in new equipment
3: increased boiler efficiency
4: increased use of recycled materials (throughput changes)
5: improved building energy efficiency
6: increased use of cogeneration (within NEMS)

Modeled outside NEMS:

7: improved TPCs in existing equipment (LBNL-detailed analysis in steel, cement and pulp and paper industries)
8: improved TPCs in existing equipment (ORNL motor system assessment for motors electricity use)
9: increased use of cogeneration (DISPERSE modeling of CHP-policies)

Energy Efficiency Improvements in New Equipment. Voluntary industrial sector agreements provide the overall impetus for making energy efficiency improvements in new equipment. Other programs (such as expanded demonstration programs, Motor and Compressed Air Challenge, expanded state programs, expanded SIP and Clean Air programs, expanded Industries of the Future Programs, expanded other OIT R&D programs, expanded ENERGY STAR and Climate Wise Programs, and tax incentives for specific industrial technologies) provide information and incentives for more rapid adoption of new, energy-efficient technologies and measures.

The rate of adoption of energy-efficient technologies and measures for new equipment is characterized in NEMS using TPCs. The TPCs were modified in the moderate and advanced scenarios in all sectors (see Appendix A.2). For the paper (Anglani et al., 1999), cement (Martin et al., 1999), steel (Worrell et al., 1999), agriculture, mining, chemicals, glass, and aluminum sectors, these modifications were based on recent analyses (see Appendix A.2) of the energy efficiency improvement potential in these sectors to determine TPCs for the moderate and advanced scenarios. For the remaining sectors (food, metals-based durables, and other manufacturing), we used the AEO99 HiTech Case TPC values (US DOE, EIA, 1998a) for the advanced scenario and used values between the Base Case and the HiTech Case for the moderate scenario.

Material inputs. Product labeling programs and pollution prevention programs will reduce primary resources inputs in the paper, glass, cement, steel, and aluminum subsectors as these industries move toward increased use of recycled materials. Material inputs in CEF-NEMS have been adjusted in the moderate and advanced scenarios to reflect such a shift. The AEO99 reference scenario shows only minor increases in recycled material inputs. For paper, the share of waste paper is increased over the 0.3%/year assumed in the AEO99 reference case, by 0.2% per year and 0.4% per year in the moderate and advanced scenarios, respectively. Historically, the share of recycled fiber has increased from 21.5% in 1970 to 33.2% in 1995, equivalent to an average increase of 1.7%/year (McLaren, 1997). As a result the amount of pulping and wood is reduced. Bleaching throughput is reduced by 0.1% per year in the moderate scenario and 0.2% per year in the advanced scenario. For steel, the share of electric arc furnace production is increased to 55% by 2020 in the advanced scenario versus 46% in the AEO99 reference case, in line with expectations of the industry (Barnett, 1998). For cement, we assume that 30.7 million tons of blended cement will be produced by 2010 (PCA, 1997), resulting in reduced clinker production throughout the analysis period. By 2020, clinker production is reduced by 6.9 million tons in the moderate scenario and by 16.4 million tons in the advanced scenario relative to the AEO99 reference case. For aluminum, increased recycling (Plunkert, 1997) is simulated by reducing production growth of primary aluminum production by 0.05% per year in the advanced scenario and by correcting energy use for the aluminum recycled.

Boiler efficiency. Expanded Steam Challenge, expanded state programs, expanded Clean Air programs and SIPs, and expanded OIT R&D programs will all contribute to improved boiler efficiency. Boilers in AEO99 are modeled with a set or fixed efficiency of around 80% for boilers using fossil fuels and 74% for by-product boilers. In reality boiler efficiency can vary widely, e.g. between 65% and 85% for coal boilers (CIBO, 1997). Also, in NEMS boilers are not retired, so the efficiency gains from new boilers are not captured in the model. Boiler efficiency can be improved by reducing excess air, installing combustion controls, or by improved boiler insulation. The CEF-NEMS model also does not retire old boilers, allowing implementation of new efficient boilers. Based on the assumptions in the BAU-scenario, and assessments of boiler efficiency improvements (CIBO, 1997; Einstein et al., 1999) we have determined improvement rates for the policy scenarios, reflecting the retirement of older boilers as well as the potential impact of the policy measures. In the moderate scenario boiler efficiency improvement increases 0.2% per year for fossil fuels, and by 0.1%/year for biomass and waste. In the advanced scenario the improvement rate is determined at 0.2%/year (oil), 0.3%/year (gas and coal) and 0.2%/year for waste and renewable fuels, respectively.

Building efficiency. ENERGY STAR Buildings and Green Lights, expanded state programs, expanded ESCO/utility programs, and tax incentives for energy managers will all lead to improvements in building energy efficiency. The NEMS model does not account for energy use in buildings in the agriculture, mining, or construction industries, but does include building energy use in all of the remaining industries. For these industries, we adopt the energy savings potential for the moderate and advanced scenarios identified in this study for commercial buildings.

5.4.2 Actions Addressed Outside of CEF-NEMS

Various actions due to policies were modeled outside of CEF-NEMS, although some results were fed into the CEF-NEMS model. We assessed the potential impacts of policies on retrofitting existing technologies in the paper, cement, and steel industry, and two related cross-cutting opportunities, i.e. cogeneration (CHP) and motor systems.

In the paper, cement, and steel **industrial sub-sectors** we assessed the technologies available to *retrofit* existing plants. In total, over one hundred technologies were characterized with respect to potential energy savings, costs, and potential degree of implementation. The analyses focus on commercial technologies that have been implemented by plants in the U.S. or other industrialized countries. The technologies have been ranked by cost-effectiveness in energy conservation supply curves. The curves have been used to assess the effect of the policies by adjusting the hurdle rate and energy prices. In the moderate scenario, it was assumed that all measures with zero or net-negative annual costs are implemented using a hurdle rate of 30%. In the advanced scenario, a hurdle rate of 15% was used to reflect the impact of the policy instruments that reduce transaction costs and reduce the financial risks of investments. It is assumed that the measures are fully implemented by the year 2020, allowing a flexible response strategy. This would allow the implementation of technologies to fit scheduled maintenance practices, reducing opportunity and transaction costs. The changes in energy intensity due to the implementation of the retrofit measures were implemented in the CEF-NEMS model as an annualized change relative to the reference year 1994. This allows credit for energy efficiency improvement achieved until today. The detailed assessments and supply curves are reported in separate reports for the cement (Martin et al., 1999), paper (Anglani et al., 1999) and steel industries (Worrell et al., 1999).

Combined Heat and Power Production (CHP)[15] is modeled separately to model the interaction with the power sector, effects of policy initiatives, and the replacement of retired industrial boilers. Expanded Steam Challenge, expanded CHP Challenge, expanded Clean Air programs and SIPs, expanded ESCO/utility programs, investment tax credits for CHP systems, and expanded OIT R&D programs will all contribute to increased use of cogeneration. The model allows the use of CHP for new steam generation capacity, due to growth of steam demand in the sectors. The CEF-NEMS model does not retire old boilers. Hence, brownfield applications of CHP can not be modeled inside the model, but are modeled outside the model (see below). As growth in steam demand in most sectors is slow in the policy scenarios, implementation of CHP in the model itself is very limited. Hence, for CHP we relied on the modeling outside the CEF-NEMS framework, to model the impact of CHP policies.

The CHP analysis was performed using Resource Dynamics Corporation's DISPERSE model[16] (see Appendix A-2). The results were compared with results of studies using other utility models, i.e. the IPM model run for US EPA. DISPERSE is a model that compares on-site power generation with the grid on the basis of costs. DISPERSE estimates the achievable economic potential for CHP applications by

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[15] Note that the definition of CHP may vary, e.g. PURPA used a different definition than CCTI. We use varying heat to power ratios for the different sectors, dependent on the characteristics of that sector, and the CHP units implemented, but would fall within the definitions commonly used.

[16] Distributed Power Economic Rationale Selection (DISPERSE) model.

comparing on-site generation economics with competing grid prices. The model not only determines whether on-site generation is more cost effective, but also which technology and size appears to be the most economic. As a result, double counting of market potential for a variety of competing technologies is avoided. This model has been developed over the past five years, and has been applied on a variety of projects for utilities, equipment manufacturers, and research organizations. Fuel and electricity prices are based on those of the CEF scenarios. The overall steam demand for the industrial sub-sectors is taken from the results of the baseline and policy scenarios. For modeling purposes it is assumed that steam use in each site follows the national developments. Various financial parameter assumptions are taken into account, including depreciation periods, tax rates, and insurance.

By permitting retirement of existing boilers where economically feasible, the model estimates cogeneration potential for the year 2020 ranging from 46 to 107 GW, permitting retirement of existing boilers where economically feasible. These estimates include both traditional (where all unit output is used on-site) and non-traditional (where sales of electricity to the grid is permitted) applications of CHP, and is limited to industrial sector applications. District energy applications of CHP are not included in this sector, and are considered in the buildings sector analysis. For each scenario, the DISPERSE model provides results for industrial production of electricity and steam, as well as the fuel consumption associated with the production. These are reported in section 5.5.4.

At this time it was not yet possible to fully integrate the DISPERSE results into CEF-NEMS[17]. Hence we were unable to assess the integrated impact on electricity generation and fuel mix. Section 5.5 reports on the overall results without the contribution of CHP, which is discussed separately in section 5.5.4.

5.5 SCENARIO RESULTS

5.5.1 Overview

In the reference scenario industrial energy use grows from 34.8 Quads in 1997 to 41.0 Quads in 2020, which is almost equal to that of the AEO99 (42.1 Quads), see Table 5.6. The difference between AEO99 and the CEF-reference scenario is due to changes in retirement rates, and changes in the energy consumption of the three sectors modeled in detail, i.e. cement, iron and steel, and pulp and paper. Energy use in the reference scenario shows a slight growth of 0.7%/year, while industrial output grows by almost 1.9%/year. Hence, the aggregate industrial energy intensity decreases by about 1.1%/year, or 23% over the scenario period. The intensity change in the AEO99 scenario is due to inter-sector structural change (almost three-fourths of the change), i.e. a shift to less energy intensive industries, and energy efficiency improvement (about one fourth). Carbon dioxide emissions from the industrial sector in the reference scenario increase by nearly 0.7%/year to 578 MtC (see Table 5.7).

The growth in the reference scenario can be found in other manufacturing industries (e.g. metals based durables, other manufacturing) and the non-manufacturing industries. Growth in energy use is due to the high economic growth of these sectors, and the slow improvement of energy efficiency (see also section 5.7). Food and bulk chemical industries also contribute to the growth. Energy use in the energy intensive industries grows slightly, or is even reduced, due to slower economic growth in these sectors, resulting in the inter-sector structural change of the economy. By 2020, energy intensive industries still consume 51% of total industrial energy use, down from 55% in 1997 (primary energy, including feedstocks).

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[17] Within the timeframe of this study it proved to be impossible to model the cogeneration results into CEF-NEMS model at the industrial sub-sector level. Future work is needed to balance the boiler representation used in DISPERSE-model with steam demand in CEF-NEMS and to integrate the DISPERSE-results in the integrated CEF-NEMS scenarios to estimate impact on power sector energy demand and fuel-mix, as well as second order effects, due to changes in fuel mix and energy demand.

The industrial fuel-mix changes slightly towards less carbon-intensive fuels (more natural gas, less coal). The iron and steel industry is the largest coal consumer. Relative low production growth, associated with reductions in coke use result in a downward trend of coal use, and a reduction in the imports of coke. The importance of biomass in the industrial fuel-mix increases from 5% to 6%, mainly due to improved utilization in the pulp and paper industry. Purchased electricity increases its share of the site fuel-mix, from 13% in 1997 to 14% in 2020.

The policy scenarios show a considerable decrease in energy use and carbon emissions. The policy scenarios assume similar economic growth patterns as in the reference scenarios. Increased energy savings are due to increased energy efficiency efforts and inter-sector structure changes, e.g. a switch to the less energy consuming electric steelmaking process in the steel industry. The advanced scenario results in a doubling of the energy intensity reduction found in the reference scenario, while the moderate scenario, leads to a 50% increase in the intensity improvement rates. In the sections below we will discuss the main features of the results of the policy scenarios. Uncertainties in the inputs influence the results. However, limited resources limited us to assess the uncertainties (see section 5.7).

5.5.2 Moderate Scenario

In the moderate scenario industrial energy use grows from 34.8 Quads in 1997 to 37.9 Quads in 2020, equivalent to a growth of 0.4%/year (excluding CHP). Total industrial energy use in 2020 under the moderate scenario is about 8% lower than the reference scenario. Under the conditions in the moderate scenario overall industry energy intensity falls by 1.5%/year. Intra-sector, inter-sector and energy efficiency improvement, contribute to the observed changes. The policies in the moderate scenario are assumed to be effective by the year 2000, and are increased in the period after the year 2000. This reflects in a relative strong growth in industrial energy use in the first years of the scenario period, followed by a reduction later in the scenario period. Annual carbon emissions are increasing to approximately 521 MtC, or a reduction of 10% relative to the reference scenario. The changes in carbon intensity are a bit larger due to the shift towards lower carbon fuels, as well as intra-sectoral structure changes in the cement, paper and steel industries.

Under the policies in the moderate scenario the light non-energy intensive industries will remain the largest contributors to future growth in energy demand, and carbon dioxide emissions. The high growth in the reference scenario is offset by considerable efficiency improvements (approximately 0.4%/year) in those industries under the moderate scenario (see also section 5.7). A small change in the fuel-mix will result in a larger reduction in carbon dioxide emissions in the light industries. While cement and the steel industries actually show a reduction in overall energy demand, the paper and other energy intensive industries are still slightly growing. Changes to less energy intensive processes and products in the cement and steel industry, combined with the relatively low growth, contribute to the decrease in total energy use and carbon dioxide emissions. The production of blended cements will reduce the carbon emissions in the cement industry at a higher rate than the reduction of energy use. The overall acceleration of energy efficiency improvement rates in these two sectors in the moderate scenario is relatively modest at 0.3%/year (see Fig. 5.4). The other energy intensive industries show a relatively strong improvement rate over the reference scenario, mostly due to increased energy efficiency improvement. This results in a 6% reduction in total energy use by the year 2020. Compared to the reference scenario, increased policy efforts in the pulp and paper industry result in a reduction by 3% and 6% of total energy use and carbon dioxide emissions, respectively. The larger decrease in emissions is due to switch to biomass as the prime energy source in this industry.

The overall fuel-mix in industry is changing more rapidly to low carbon fuels, when compared to the reference scenario. Coal and petroleum products show the strongest decrease, at a rate double of that of natural gas. While coal use stabilizes in the steel industry, reductions in coal use are mostly found in the non-energy intensive industries. By 2020 natural gas will provide almost a third of the primary energy needs of the total industry. The slight change in fuel-mix will result in lower carbon dioxide emissions.

Energy service costs, which include annual fuel costs, annualized incremental technology cost of energy efficiency improvement, and annual program costs to promote energy efficiency, decrease by approximately 9% by 2010 and 10% by 2020, relative to the reference scenario (see Table 5.9).

5.5.3 Advanced Scenario

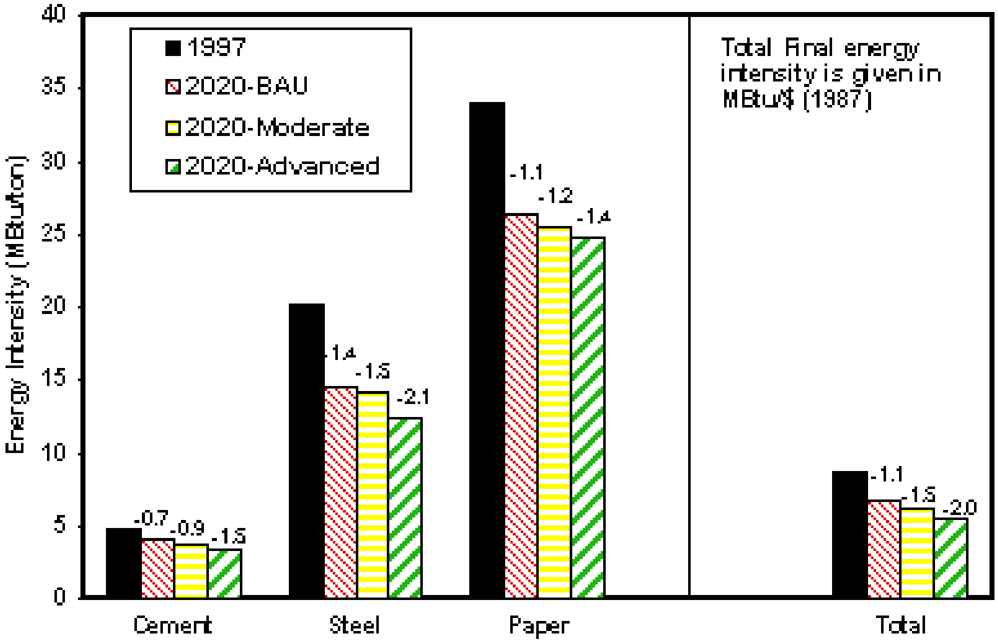
In the advanced scenario a stronger push to reduce GHG emissions will result in an active policy for energy efficiency improvement and GHG emission reduction. This is expected to result in considerable energy savings and carbon dioxide emissions. In the advanced scenario industrial energy use remains stable, decreasing from 34.8 Quads in 1997 to approximately 34.2 Quads in 2020 (excluding CHP). Total industrial energy use in 2020 under the advanced scenario is 16.5% lower than the reference scenario. Under the conditions in the advanced scenario overall industry energy intensity falls by 1.8% per year (see Fig. 5.4), of which 1.0% per year due to energy efficiency improvement. This compares well to the experiences in Germany, Japan and The Netherlands (see page 5.13), that voluntary industrial agreements can potentially contribute an efficiency improvement of 0.4% to 1.3% per year. Intra-sector, inter-sector and energy efficiency improvement, contribute to the total observed changes. Carbon emissions are actually decreasing to approximately 409 MtC, or a reduction of 29% relative to the reference scenario, especially due to de-carbonization in the power sector.

Compared to the reference scenario the largest reduction in energy use can be found in the cement, steel, non-energy intensive and other energy intensive industries. Energy efficiency improvement rate in the non-energy-intensive industries is about 0.9% per year, which reflects the total efficiency improvement (see also section 5.7). This is due to changes in process efficiency, as well as in energy use in industrial buildings. The change in the cement industry is mainly due to the more aggressive introduction of blended cements in the U.S. market, resulting in energy savings, as well as process CO_2 emission reduction in the clinker-making. Similarly, increased use of electric steelmaking will result in energy savings in the steel industry. Gradual introduction of new plants contributes a large part of the total energy savings in other industries.

In the advanced scenario the fuel-mix is expected to favor low carbon fuels, due to the emission trading system. This will lead to a 30% reduction in the share of coal, and 19% reduction in the share of oil, relative to the reference scenario. Large reductions in the carbon dioxide emissions are due to the lower carbon emissions in the power sector, especially in the electricity intensive sectors, e.g. aluminum and the non-energy intensive industries. This leads to a strong reduction in total carbon dioxide emissions. While increased CHP in industry is expected to impact the observed shift to natural gas, the CHP results have not yet been integrated in the current fuel-mix shift.

Annual energy service costs in the advanced scenario are reduced by 8% in 2010 and by 12% by 2020, translating to cost savings of approximately $8 Billion and $14 Billion respectively (see Table 5.9). The savings are significantly higher in 2020 than in 2010, due to the larger investments in energy R&D in the advanced scenario, which results in greater energy savings on the long term.

Fig. 5.4 Energy Intensity Changes in the Three Scenarios for Total Industry and for Cement, Steel and Pulp and Paper Industries for 2020*



*1997 Energy intensities are given for comparison.

Table 5.6 Primary Energy Use by Scenario, Sub-Sector, and Fuel in the Industrial Sector (in quadrillion Btus), Excluding the Effects of Increased CHP (see section 5.5.4)

			2010					*2020*				
Sector & fuel	*1990*	*1997*	*BAU*	*Moderate*		*Advanced*		*BAU*	*Moderate*		*Advanced*	
	Q	Q	Q	Q	%	Q	%		Q	%	Q	%
Iron and Steel												
petroleum		0.12	0.11	0.12	2.3%	0.04	-68.6%	0.10	0.10	-0.7%	0.02	-80.3%
natural gas		0.54	0.45	0.40	-9.8%	0.38	-15.6%	0.39	0.34	-14.1%	0.34	-14.2%
coal		0.87	0.80	0.81	1.1%	0.76	-4.4%	0.78	0.79	0.6%	0.76	-3.1%
primary electricity		0.56	0.53	0.50	-5.0%	0.44	-16.8%	0.50	0.45	-10.2%	0.40	-21.4%
Total primary		2.09	1.88	1.83	-3.1%	1.61	-14.4%	1.78	1.68	-5.8%	1.51	-15.1%
Paper												
petroleum		0.12	0.11	0.10	-7.7%	0.08	-31.4%	0.10	0.08	-13.2%	0.07	-29.1%
natural gas		0.67	0.50	0.52	3.8%	0.36	-27.4%	0.43	0.51	18.8%	0.43	0.3%
coal		0.39	0.31	0.28	-10.0%	0.12	-60.8%	0.27	0.23	-14.9%	0.11	-60.3%
renewables		1.48	1.81	1.78	-1.5%	1.94	7.1%	2.00	1.92	-3.7%	2.19	9.5%
primary electricity		0.83	0.80	0.78	-3.5%	0.66	-17.6%	0.79	0.73	-6.9%	0.57	-27.8%
Total primary		3.50	3.54	3.46	-2.2%	3.16	-10.6%	3.58	3.48	-2.8%	3.36	-6.1%
Cement												
petroleum		0.04	0.04	0.03	-3.9%	0.04	7.8%	0.03	0.03	-7.2%	0.03	3.0%
natural gas		0.02	0.02	0.02	16.3%	0.03	105.9%	0.01	0.02	24.3%	0.03	119.1%
coal		0.32	0.32	0.30	-3.9%	0.24	-22.9%	0.31	0.29	-8.0%	0.22	-30.9%
renewables		0.00	0.00	0.00	N/A	0.00	N/A	0.00	0.00	N/A	0.00	N/A
primary electricity		0.10	0.09	0.09	-1.0%	0.09	-2.5%	0.09	0.09	-2.9%	0.08	-11.6%
Total primary		0.47	0.46	0.45	-2.7%	0.40	-12.1%	0.45	0.42	-5.9%	0.36	-20.0%
Other Energy-Intensive												
Petroleum		5.1	5.8	5.5	-5.1%	5.2	-9.9%	5.9	5.3	-11.3%	4.7	-20.5%
Natural gas		4.7	5.1	5.1	0.0%	4.9	-4.8%	5.6	5.6	0.6%	5.3	-5.2%
coal		0.2	0.2	0.2	-19.1%	0.1	-49.5%	0.2	0.1	-36.1%	0.1	-64.7%
Renewables		0.0	0.0	0.0	N/A	0.0	N/A	0.0	0.0	N/A	0.0	N/A
primary electricity		3.1	3.2	3.0	-5.7%	2.6	-19.4%	3.2	2.8	-12.9%	2.2	-33.2%
Total primary		13.1	14.3	13.8	-3.6%	12.8	-10.7%	15.0	13.8	-7.6%	12.2	-18.2%
Non-Energy-Intensive												
Petroleum		3.0	3.8	3.6	-5.8%	3.5	-7.9%	4.2	3.8	-10.3%	3.6	-14.8%
Natural gas		4.8	5.8	5.4	-6.3%	5.2	-9.6%	6.4	5.7	-11.7%	5.3	-17.3%
coal		0.6	0.7	0.7	-6.8%	0.5	-26.7%	0.8	0.7	-11.5%	0.5	-35.9%
Renewables		0.4	0.5	0.5	0.6%	0.5	0.4%	0.6	0.6	1.3%	0.6	0.5%
primary electricity		6.7	7.6	7.4	-3.1%	6.9	-9.8%	8.2	7.8	-5.1%	6.8	-17.4%
Total primary		15.6	18.4	17.6	-4.7%	16.6	-9.8%	20.2	18.5	-8.4%	16.7	-17.1%
Total Industrial												
Petroleum		8.4	9.8	9.3	-5.3%	8.9	-10.0%	10.4	9.2	-10.8%	8.4	-18.8%
Natural gas		10.7	11.9	11.5	-3.3%	10.9	-8.4%	12.8	12.1	-5.4%	11.4	-11.2%
coal		2.4	2.4	2.2	-5.2%	1.8	-25.1%	2.4	2.1	-9.8%	1.7	-30.0%
renewables		1.9	2.3	2.3	-1.1%	2.4	5.6%	2.6	2.5	-2.6%	2.8	7.5%
primary electricity		11.3	12.2	11.8	-3.8%	10.6	-13.1%	12.9	11.9	-7.4%	10.0	-22.1%
Total primary	32.1	34.7	38.6	37.1	-4.0%	34.5	-10.5%	41.0	37.9	-7.4%	34.2	-16.5%

(1) BAU = Business-As-Usual scenario: Q = quadrillion Btus of primary energy
(2) % (change) is relative to the BAU scenario in that year.

Table 5.7 Carbon Emissions by Scenario, Sub-Sector, and Fuel in the Industrial Sector (MtC), Excluding the Effects of Increased CHP (see section 5.5.4)

			2010					*2020*				
Sector & fuel	*1990*	*1997*	*BAU*	*Moderate*		*Advanced*		*BAU*	*Moderate*		*Advanced*	
	MtC	MtC	MtC	MtC	%	MtC	%		MtC	%	MtC	%
Iron and Steel												
Petroleum		1.93	1.72	1.76	2.2%	0.53	-69.3%	1.52	1.49	-1.8%	0.29	-81.1%
natural gas		7.40	6.08	5.48	-9.8%	5.12	-15.8%	5.33	4.58	-14.0%	4.57	-14.1%
Coal		21.61	20.25	20.46	1.1%	19.37	-4.4%	19.83	19.95	0.6%	19.24	-3.0%
Electricity		8.63	8.72	7.94	-8.9%	5.78	-33.7%	8.53	7.31	-14.3%	4.62	-45.8%
Total		39.56	36.76	35.64	-3.0%	30.79	-16.2%	35.21	33.33	-5.3%	28.72	-18.4%
Paper												
Petroleum		1.99	1.65	1.52	-7.8%	1.11	-32.9%	1.43	1.22	-14.2%	0.97	-32.1%
natural gas		9.19	6.84	7.09	3.7%	4.95	-27.6%	5.83	6.93	18.9%	5.84	0.3%
Coal		9.75	7.95	7.16	-10.0%	3.12	-60.8%	6.82	5.80	-14.9%	2.71	-60.3%
Renewables		0.00	0.00	0.00	N/A	0.00	N/A	0.00	0.00	N/A	0.00	N/A
Electricity		12.87	13.35	12.35	-7.5%	8.76	-34.4%	13.34	11.86	-11.1%	6.63	-50.3%
Total		33.80	29.79	28.12	-5.6%	17.93	-39.8%	27.41	25.81	-5.8%	16.15	-41.1%
Cement												
petroleum		0.59	0.54	0.52	-4.0%	0.57	5.3%	0.49	0.45	-8.3%	0.49	-1.3%
natural gas		0.25	0.21	0.24	16.3%	0.43	105.5%	0.19	0.23	24.4%	0.41	119.1%
coal		7.80	8.02	7.70	-4.0%	6.19	-22.7%	7.92	7.29	-8.0%	5.49	-30.8%
renewables		0.00	0.00	0.00	N/A	0.00	N/A	0.00	0.00	N/A	0.00	N/A
electricity		1.49	1.52	1.44	-5.1%	1.18	-22.7%	1.49	1.38	-7.3%	0.91	-39.1%
total energy emissions		10.13	10.28	9.90	-3.7%	8.37	-18.7%	10.10	9.36	-7.3%	7.29	-27.8%
process emissions		10.98	11.83	11.32	-4.3%	11.32	-4.3%	12.20	11.60	-4.9%	10.56	-13.4%
Total		21.11	22.11	21.22	-4.0%	19.69	-11.0%	22.30	20.96	-6.0%	17.85	-20.0%
Other Energy-Intensive												
petroleum		50.8	53.7	50.7	-5.7%	45.9	-14.6%	51.5	44.2	-14.3%	36.2	-29.8%
natural gas		59.6	65.2	65.3	0.2%	61.9	-5.0%	70.8	71.7	1.3%	67.4	-4.7%
coal		4.4	5.0	4.0	-19.1%	2.5	-49.4%	5.7	3.7	-36.1%	2.0	-64.7%
renewables		0.0	0.0	0.0	N/A	0.0	N/A	0.0	0.0	N/A	0.0	N/A
electricity		47.9	52.7	47.7	-9.5%	33.8	-35.8%	54.5	45.4	-16.8%	25.1	-54.0%
Total		162.6	176.6	167.7	-5.0%	144.2	-18.4%	182.6	164.9	-9.7%	130.7	-28.4%
Non-Energy-Intensive												
petroleum		50.5	58.2	54.7	-5.9%	52.3	-10.1%	63.1	55.9	-11.5%	51.4	-18.6%
natural gas		65.8	79.0	74.0	-6.4%	71.2	-9.9%	87.4	77.2	-11.6%	72.2	-17.3%
coal		14.9	18.4	17.1	-6.8%	13.5	-26.6%	20.0	17.7	-11.5%	12.8	-35.8%
renewables		0.0	0.0	0.0	N/A	0.0	N/A	0.0	0.0	N/A	0.0	N/A
electricity		104.7	126.7	117.8	-7.0%	90.9	-28.2%	139.5	126.4	-9.4%	79.4	-43.1%
Total		236.0	282.3	263.6	-6.6%	228.0	-19.2%	310.0	277.2	-10.6%	215.8	-30.4%
Total Industrial												
petroleum		105.8	115.8	109.2	-5.7%	100.4	-13.3%	118.1	103.2	-12.6%	89.3	-24.4%
natural gas		142.2	157.3	152.1	-3.3%	143.6	-8.7%	169.5	160.7	-5.2%	150.5	-11.2%
coal		58.5	59.6	56.5	-5.2%	44.7	-25.0%	60.3	54.4	-9.8%	42.3	-29.9%
Renewables		0.0	0.0	0.0	N/A	0.0	N/A	0.0	0.0	N/A	0.0	N/A
Electricity		175.6	203.0	187.2	-7.8%	140.5	-30.8%	217.4	192.3	-11.5%	116.6	-46.4%
total energy emissions		482.1	535.7	505.0	-5.7%	429.2	-19.9%	565.3	510.6	-9.7%	398.7	-29.5%
total process emissions		11.0	11.8	11.3	-4.3%	11.3	-4.3%	12.2	11.6	-4.9%	10.6	-13.4%
Total	452	493.1	547.5	516.3	-5.7%	440.5	-19.5%	577.5	522.2	-9.8%	409.3	-29.1%

(1) BAU = Business-As-Usual scenario; MtC = Million metric tons of carbon

(2) % (change) is relative to the BAU scenario in that year.

Table 5.8 Energy Intensity Development in CEF-NEMS Scenarios, Expressed as Primary Energy Use per Unit of Output*

Economic Intensities (MBtu/$-output (1987-$) on a primary energy basis							
Scenario		Business-as-Usual		Moderate		Advanced	
Sector	1997	2010	2020	2010	2020	2010	2020
Refining	23.6	26.7	25.3	26.2	23.7	24.1	19.3
Food	4.3	3.9	3.7	3.8	3.6	3.5	3.3
Pulp & Paper	28.0	23.7	22.1	23.1	21.4	21.1	20.7
Bulk Chemicals	32.2	28.9	27.6	27.5	25.3	24.5	22.1
Glass	13.1	11.5	10.6	11.5	10.5	9.9	9.0
Cement	97.7	89.4	84.5	87.1	79.5	78.6	67.6
Iron & Steel	30.1	24.0	21.9	23.3	20.6	20.6	18.6
Aluminum	23.3	19.2	17.3	18.5	16.6	16.2	14.7
Agriculture	5.2	5.0	4.9	4.8	4.5	4.6	4.0
Construction	5.1	4.9	4.7	4.6	4.3	4.5	4.1
Mining	21.4	22.1	22.4	20.8	20.2	20.3	19.2
Metal Durables	2.0	1.8	1.6	1.7	1.5	1.5	1.3
Other Manufacturing	5.5	5.1	4.8	4.9	4.4	4.6	3.9
Total	8.7	7.4	6.7	7.1	6.2	6.6	5.6
Physical Intensities (MBtu/ton) on a primary energy basis							
Pulp & paper	33.9	28.4	26.4	27.8	25.6	25.4	24.7
Glass	17.2	15.2	14.1	15.2	14.0	13.1	12.1
Cement	4.7	4.6	4.0	4.1	3.8	3.7	3.2
Iron & Steel	20.2	18.2	14.5	15.5	14.3	13.7	12.3
Aluminum	125.3	105.7	93.1	99.1	87.4	86.9	79.0

* Bulk chemicals excludes feedstocks. The increased contribution of CHP is excluded in this analysis (see section 5.5.4).

Table 5.9 Annual Total Costs of Energy Services by Scenario in the Industrial Sector (B1997$/year)

		2010					*2020*				
	1997	*BAU*	*Moderate*		*Advanced*		*BAU*	*Moderate*		*Advanced*	
	B$/y	B$/y	B$/yr	%	B$/yr	%	B$/yr	B$/yr	%	B$/yr	%
Total - Industry											
Annual fuel cost	105	109	96	-12%	93	-15%	115	95	-17%	87	-24%
Annualized incremental technology cost of energy efficiency	0	0	2.7	N/A	5.8	N/A	0	6.0	N/A	10.4	N/A
Annual program costs to promote energy efficiency	0	0	1.0	N/A	2.2	N/A	0	2.1	N/A	3.9	N/A
Annual total cost of energy services	105	109	100	-9%	101	-8%	115	104	-10%	101	-12%

Notes:

(1) BAU = Business-As-Usual scenario

(2) Buildings in the industrial sector are not included in these results.

(3) % (change) is relative to the BAU scenario in that year.

(4) Energy service costs include cost of purchased fuels and electricity (minus any carbon permit trading fee Transfer payments), and the annualized costs of incremental efficiency improvements.

(5) The results exclude the increased role of industrial CHP (see section 5.5.4).

5.5.4 Cogeneration

The results of the cogeneration (or CHP) calculations could not yet be integrated in the CEF-NEMS framework. In this section we report on the results, and estimate the potential impact. By permitting retirement of existing boilers where economically feasible, DISPERSE estimates the CHP potentials by sub-sector. These estimates include both traditional, non-traditional applications of CHP, and is limited to industrial sector applications (hence, it excludes distributed CHP or district heating). As shown in Table 5.10, the market penetration of industrial CHP in the two CEF policy scenarios is estimated to be between 40 and 76 GW by 2020, and depends on the timing and impact of CHP policies (see Appendix B.2) designed to remove technical and market barriers.

Table 5.10 Estimated Market Penetration and Impacts of Industrial Cogeneration for the Years 2010 and 2020 for the Moderate and Advanced Scenarios

Market Impact	**Year 2010 Impacts**			**Year 2020 Impacts**		
	BAU	Moderate	Advanced	BAU	Moderate	Advanced
New Installed Capacity (GW)	**4.4**	**14.1**	**28.9**	**8.8**	**40.1**	**76.2**
Of which: natural gas	4.4	12.3	24.5	8.8	34.9	63.6
Of which: black liquor gasifier combined cycle	0	1.1	2.6	0	3.1	7.5
Of which: biomass gasifier combined cycle	0	0.7	1.8	0	2.1	5.1
Generated Electricity (TWh)	31	98	201	62	278	539
Fuel Consumed by CHP Systems (TBtu)	**274**	**901**	**1,853**	**551**	**2,542**	**4,985**
Of which: natural gas	274	793	1,595	540	2,232	4,237
Of which: biomass	0	108	258	11	310	747
Fuel Consumed by CHP Systems, above BAU Forecast (TBtu)	NA	627	1,579	NA	1,991	4,434
Fuel Displaced at the Utility by CHP Systems, above BAU Forecast (TBtu)	NA	648	1,909	NA	1,568	4,704
Boiler Fuel Displaced by CHP Systems, above BAU Forecast (TBtu)	NA	277	743	NA	873	2,097
Net Energy Reduction, above BAU Forecast (TBtu)	NA	**298**	**1,073**	**NA**	**450**	**2,367**
Net Carbon Reductions, above BAU Forecast (MtC)	NA	**4.9**	**26.1**	**NA**	**9.7**	**39.7**

In the BAU scenario, 8.8 GW of new CHP is projected, based on a continuation of current market penetration trends. Several technical and market barriers stand in the way of further use of CHP, as evidenced by the fact that over 80 percent of the potential capacity is projected as untapped. Most potential for CHP can be found in the paper, chemical, food and the non-energy-intensive manufacturing sub-sectors.

In the moderate scenario, the projected additional CHP-capacity grows to approximately 14 GW by 2010 and 40 GW by 2020. This includes 3 GW of integrated black liquor gasification cogeneration by 2020. It is expected that expanded research and development will result in black liquor gasifier combined cycle technology, which will result in several demonstration projects by 2010 and an installed base of 3.1 GW by 2020. In addition, this expanded R&D will result in the emergence of high efficiency gas turbines (resulting from the ATS program and efforts targeting the under 1 MW unit size) which is expected to increase CHP capacity in under 5 MW unit size ranges. Furthermore, policies designed to remove financial barriers, expedite siting and permitting, improve grid sell back price, and reduce interconnection costs are expected to contribute significantly to the expanded market potential and penetration.

In the Moderate scenario, newly installed CHP consumes almost 2 quads of energy (principally natural gas) more than in the BAU forecast, by 2020. This is offset by 0.9 quads of boiler fuel that is displaced by the CHP systems and 1.6 quads of energy that is displaced in the power sector. The net impact in 2020 is an energy savings of 0.5 quads and a reduction in carbon dioxide emissions of 9.7 MtC. (In 2010, the net reductions are 0.3 quads of energy and 4.9 MtC of carbon.)

In the Advanced scenario, the projected level of new CHP reaches approximately 29 GW by 2010 and 76 GW by 2020. Accelerated development of black liquor gasifier combined cycle units as well as cost and efficiency improvements in 5 MW and under gas turbines contribute significantly to the 107 GW of market potential. This includes 64 GW of natural gas based cogeneration, 7.5 GW of black liquor gasifier combined cycle capacity, and 5.1 GW of biomass gasifier combined cycle capacity. More aggressive policies designed to remove financial barriers, expedite siting and permitting, improve grid sell back pricing, and reduce interconnection and backup power costs all contribute to improved market penetration levels, as well as reduce the costs of the ATS. This leads to accelerated implementation of CHP, despite the lower steam demand due to energy efficiency improvement.

In the Advanced scenario, newly installed CHP consumes 4.4 quads of energy (3.7 quads of natural gas and 0.7 quads of biomass) more than in the BAU forecast. This is offset by 2.1 quads of boiler fuel that is displaced by the CHP systems and 4.7 quads of energy that is displaced in the power sector. The net impact in 2020 is an energy savings of 2.4 quads and a reduction in carbon dioxide emissions of 39.7 MtC. (In 2010, the net reductions are 1.1 quads of energy and 26.1 MtC of carbon.)

5.6 DISCUSSION OF RESULTS

5.6.1 Key Technologies

This study identified policies to improve industrial energy efficiency. The policies will help to implement efficient practices and technologies. Three sectors were modeled in detail, allowing an assessment of key technologies for these industries. Generally, a number of cross-cutting technologies can achieve large improvements, e.g. preventative maintenance, pollution prevention and waste recycling (e.g. steel, aluminum, cement, paper), process control and management, steam distribution system upgrades, improved energy recovery, cogeneration (CHP), and drive system improvements. However, a large part of the efficiency improvements are achieved by retiring old process equipment, and replacing it with state-of-the-art equipment. This is especially true for many capital-intensive industries (Steinmeyer, 1997). This emphasizes the need for flexibility in achieving energy efficiency improvement targets, as provided by the voluntary industrial agreements.

In the three sectors studied in detail, we can draw more specific conclusions on technologies. The detailed assessments showed that technologies exist to both improve existing as well as new plants (when retiring old capacity). In the steel industry, new electric arc furnaces are far more efficient than existing plants due to various technologies, while new casting technologies reduce material and energy losses further. New advanced smelt reduction technologies (assumed to be become available after 2010 in the advanced scenario) can lead to large energy savings (Worrell et al., 1999). In the pulp and paper industries, improved paper machines as well as reduced bleaching and increased recycling impact energy use, while black liquor gasification substantially changes the energy profile of pulping in the long term (Anglani et al.1999). 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. New grinding technologies will reduce electricity demand for cement making (Martin et al., 1999).

5.6.2 Key End-Use Sectors

Energy savings are found in all industrial sub-sectors. Production growth is lower in most energy-intensive industries than the less energy-intensive manufacturing industries. This leads to a reduction in energy use and CO_2 emissions by the energy intensive industries. Hence, most of the growth in energy use and emissions can be found in the light industries, growing to approximately 49% of primary energy consumption in the reference scenario by 2020. Energy efficiency improvements in the policy scenarios appear high, as the improvements in the baseline scenario are almost zero in the light industries (see section 5.7). While light industries would consume almost half of the energy by 2020 in the reference scenario, almost 50% of the total energy savings in the advanced scenario are also found in these industries. Energy saving potentials in the steel, cement and aluminum industry are also relatively large, due to the increased use of energy-efficient recycling technologies (or the production of blended cement using wastes in the chemical industry) and the introduction of efficient technology as old plants are retired. The potential savings in the food, paper, and chemical industries are mainly influenced by the savings achieved in the large generation, distribution and use of steam in those sectors. Cogeneration (see section 5.6.1) is expected to play an important role in these sectors. Energy efficiency improvement in petroleum refining is small, as this sector has not been investigated in this study (see section 5.7).

5.6.3 Key Policies

The characteristics of decision makers vary widely, as is evidenced by the literature on policies. Hence, there is no “deus ex machina” or “silver bullet” policy; instead, an integrated policy accounting for the characteristics of technologies and target groups addressed is needed. Acknowledging the differences between individual industries (even within one economic sector) is essential to develop an integrated policy accounting for the characteristics of technologies, conditions and target groups addressed. Policies and measures supporting these voluntary industrial agreements should account for the diversity of the industrial sector while at the same time being comprehensive and flexible, offering a mix of policy instruments, giving the right incentives to the decision maker at the firm level, and providing the flexibility needed to implement industrial energy efficiency measures.

In this study we have evaluated a large number of policy measures, based on current and potential future initiatives. The voluntary industrial agreements are assumed to integrate the various individual policy measures and provide access to the resources and policies. The framework will strengthen the effects and effectiveness of the individual policy instruments. Hence, it is difficult to highlight individual key policies.

Costs and cost-effectiveness of individual policies vary between the type of instrument applied, as well as the way in which it is implemented, as evidenced by the variety of industrial and commercial DSM programs (Nadel, 1990; Goldman and Kito, 1994). However, recognizing the different roles the policies play, and different barriers and stakeholders addressed by the policies, there is a need for the variety in programs. Key is a good and efficient organization of the policies, flexibility of the policies, as well as easy access to the provided resources. "One stop shops" as provided for some programs by DOE-OIT is a step in this direction, as is the collaboration of DOE and EPA in the development of various policy initiatives and technology development support measures.

5.7 REMAINING ANALYSIS NEEDS

The study highlighted various issues for future research related to modeling and policies based on the results of the study. The available resources limited a quantitative analysis of the uncertainties in scenarios. Hence, future analysis aims not only at areas that need further analysis, but also at assessing the uncertainties in the scenarios.

Currently most available energy models are not capable of explicitly modeling policies. Generally, models represent the actions following policy implementation. However, the link between policies and actions is not straightforward. Decisionmakers react differently to the implemented policies and measures, depending on their (perceived) situation. This will affect the effects and effectiveness of policies. Research in many countries (e.g. U.S., Canada, Germany, The Netherlands) is ongoing to assess and 'model' decisionmaking behavior. This has not yet resulted in commonly acceptable methodologies. To model the relationship between actions and policies requires substantial multi-disciplinary research.

Modeling. Modeling within the industrial sector was done primarily in the CEF-NEMS model, based on the EIA-NEMS model. The CEF-NEMS model allows technology modeling at a relatively disaggregated level in a number of the sectors, e.g. steel, cement, paper industries, while in other sectors, e.g. chemical, food, other manufacturing industries, the level of detail is limited to technology categories. In the latter industries energy intensities are often modeled on a monetary basis (energy use/$ value of output), limiting the opportunity to model technologies or policies. In modeling the scenarios we found various issues that warrant further research and adaptation of the model, which we discuss below.

Like most energy models, the NEMS-framework distinguishes industrial sub-sectors (typically a number of energy-intensive sectors and a few non-energy intensive sectors) to model technical changes in energy efficiency. However, the different sub-sectors may not accurately reflect the characteristics for decisionmaking processes in different companies. This limits the modeling within NEMS to modeling the expected actions (in the form of technical changes) that follow implementation of policies. Development of models able to assess the impact of policies is strongly encouraged to fill in this gap (see above), acknowledging the difficulty, and the lack of knowledge of the effectiveness of industrial energy policies (see below).

The integration of CHP-policies could not yet be fully integrated with the CEF-NEMS model. Hence, the feedback of increased industrial cogeneration (and district heating) on the power sector electricity production and fuel use could not be assessed in an integrated way. Preliminary CEF-NEMS assessments show a decrease in new central natural gas capacity, while coal use is only reduced slightly and renewables seem to remain stable. Based on these preliminary assessments, cogeneration could likely reduce total U.S. primary energy consumption by 2.4 Quads in 2020, and reduce GHG emissions by 40

MtC. However, an integrated CEF-NEMS model is needed to quantify the potential impact completely and correctly. The potential large contribution of cogeneration to energy efficiency improvement would warrant the need for further research to integrate the cogeneration in CEF-NEMS.

Industrial processes generate outputs that are used by other processes in the same industry, e.g. coke used in the blast furnace in the steel industry. However, the CEF-NEMS model does not correct endogenously for changes in resource productivity (e.g. decreased coke use in the blast furnace through increased direct fuel injection). We have modeled the impact of reduced resource needs manually in the model, but future research would need to investigate the option to model process connections.

Due to the lack of feedback between processes, it was difficult to model innovative technologies in the NEMS framework. Black liquor gasification in the pulping industry and smelt reduction in the steel industry are examples of technologies integrating various processes, while changing the inputs and outputs. Smelt reduction would even affect energy use in other sectors, e.g. pelletizing at the ore mining. We modeled the penetration of these innovative technologies and interactive effects within the sector by adjusting the UECs in the CEF-NEMS model. The role and modeling of innovative technologies in energy modeling is an important topic that needs more attention in general and in the NEMS-model.

Retirement rates for industrial technologies in the NEMS model seem to be low, when compared to other sources (BEA, 1993), or assessments of technical and economic lifetimes of technologies. Retirement rates are important in assessing future industrial energy use because new technologies often have significantly different energy use characteristics. The importance would warrant future analysis of actual age distribution of the main energy consuming processes in the sub-sectors.

Both retirement of old plants and retrofit of existing plants contribute to the energy savings and CO_2 emission reduction. However, we have not yet assessed the contribution of each of these elements to the total achieved energy savings in the different scenarios. This may generate valuable insights into the contribution of different policies and strategies in the industrial sector.

Carbon dioxide emissions are due to the combustion of fossil fuels. Fossil fuels are also used as feedstock, e.g. for plastics. The carbon from these feedstocks will not be released in the industrial process, but later when the product containing the feedstock is combusted (e.g. waste incineration). However, in some production processes the carbon in the feedstock is partially emitted, e.g. in ammonia and methanol manufacturing. The EIA-NEMS model correctly assumes partial emission factors for the feedstocks. Only detailed assessments of material flows can improve the assessment of how feedstock use in NEMS is accounted in the emissions calculations.

Energy use in industries is broken down (where appropriate) into process, buildings and boilers and power generation. In the current NEMS model boiler efficiency has been set at a standard efficiency rate, and hence does not improve over time, nor are boilers retired. We have simulated retirement of boilers by a slow improvement rate of the boiler efficiency.

Cogeneration is part of the boiler module of the NEMS model. The current NEMS model does not allow retirement of boilers, nor replacement by cogeneration units. It only allows cogeneration for new (increased) boiler capacity, and hence underestimates the role of cogeneration. We have modeled the potential role of the cogeneration in each of the industries based on the DISPERSE model, but have not yet integrated the results into CEF-NEMS.

Steam, fuels and electricity are used in the buildings. While building energy use is comparatively small in energy-intensive industries, it is large part of energy use in the light manufacturing industries. In NEMS, energy use in buildings is a set as energy use per employee, and only reacts to changes in number of employees in an industry, ignoring changes in building energy use, retirement of buildings, and also the potential impact of programs like EnergySTAR Buildings and Green Lights. We have modeled energy use in buildings in the moderate and advanced scenarios based on the saving potentials identified for commercial buildings. This may need more attention in future work.

Energy intensity declines over time in most industries, due to autonomous trends as well as policy effects. For some industrial sub-sectors (i.e. agriculture, mining, construction, metal based durables and non-intensive manufacturing) NEMS assumes no autonomous improvement trend in the baseline scenario. Only when energy prices increase over a specified threshold, would energy intensity decline. This is contrary to long term trends observed in most industries (see Appendix A.2).

Historical energy intensity trends observed in various sub-sectors do not reflect the trends found in the AEO 99 baseline (see Appendix A.2). Historical energy use in the construction industry (and hence cement industry) follows cycles in the industry and economy. However, in NEMS a continuous growth is assumed over the next decades. Improved calibration of NEMS scenarios with historical trends in production, energy intensity and energy use is needed to improve modeling results.

Policies. Detailed evaluations of industrial energy efficiency policies are rare (Convery, 1998; Martin et al., 1998; US DOE, 1996). Estimating the effects of energy efficiency policies on energy use and economic performance is a difficult task. The figures in this report are based on assessments, using different methodologies and assumptions, and evaluations by program managers. The results should be seen as a first estimate. Future analysis of the effects and effectiveness of industrial energy policies (ex-ante, and ex-post) is needed to improve the current results.

Literature on industrial energy efficiency improvement has focused on energy policies. As shown by the variety of policies evaluated in this study, a large number of other policies will affect industrial energy use. Study of the effects of other industrial or environmental policies on industrial energy use is needed to better quantify the effects of these policies.

Policies are never implemented in isolation. Individual policies may have feedback effects, which could either improve or reduce the effectiveness of other policies. A comprehensive set of well-designed policies is needed to address the wide variety of stakeholders in the industrial sector. Little is known regarding these effects. Case studies may be needed to assess the feedback effects.

Energy efficiency improvement may entail investment costs or other costs. Supply curves are often used to estimate the potential energy savings and associated costs, replacing linear cost functions used in earlier modeling. The previous Interlaboratory study used the LIEF model to estimate the investment costs for the industry as a whole (Interlaboratory Working Group, 1997). The LIEF model uses historical data to generate a cost function. Historical data may not reflect the future correctly. Detailed supply curves using costs and savings for technologies and practices would be better suited to achieve this. However, supply curves are not available for all sub-sectors. LBNL has developed supply curves for three sub-sectors that are studied in detail in this study; steel (Worrell et al, 1999), cement (Martin et al., 1999) and paper (Anglani et al., 1999). For the other sub-sectors we have used the results of the previous Interlaboratory study. Future research is needed to assess the potentials and associated investments of energy efficiency improvement in these sectors.

Industrial technology development is often aimed at improving productivity rather than improving energy efficiency. New technologies often improve energy and resource efficiency while reducing manufacturing costs considerably (Pye, 1998). Thin slab casting is an excellent example of a technology reducing production costs of steel products, as well as reducing energy use considerably (Worrell et al., 1999). The productivity gains are often difficult to quantify. In our detailed technology analysis of the three sub-sectors, we incorporated these costs in the assessments of the energy efficiency improvement potentials. However, future research is needed to better quantify the other benefits of energy efficiency measures.

Economic development follows cycles. However, most energy modeling tools (including NEMS) use continuous growth trends. The effects and effectiveness of policies will depend on the phase of the business cycle, especially when modeling short-term effects. The twenty-year time period in this analysis may be less sensitive to these effects, but the sensitivity can not be assessed. This would need additional analysis of business cycles, retirement rates, and investment policies.

The results of the scenario analysis have shown that strong economic growth in the light manufacturing industries may considerably affect future emissions in the industrial sectors. However, knowledge on energy efficiency and GHG emission reduction options in these sectors is very scattered. Assessment of energy efficiency opportunities in these sectors is needed. The large variety in processes used and the large number of industries involved also emphasizes the important role of states in designing energy efficiency policies capable of meeting the demands set by this variety. Future analysis may also need to focus on strengthening the role of states in designing and implementing energy efficiency policies.

The scenario results show also the important role of replacing retired capital and energy intensive equipment (typically with long lifetimes) in achieving large improvements in energy efficiency. Although policies may affect retirement rates, detailed evaluations are needed to assess the extent and impact of such policies on competitiveness and energy use. This underlines the need to assess the models and rates of diffusion of innovative technologies in different (energy) markets, and the impact that innovative industrial technology may have on retirement (and hence diffusion) rates and energy use.

Climate change abatement policies will not only be limited to policies and measures with respect to CO_2 emissions. Industry also emits varying quantities of the five other GHGs, distinguished in the Kyoto Protocol. An industrial GHG abatement strategy and policy will also include the other five GHGs. It is argued that this may lead to a more cost-effective strategy (Reilly et al.,1999). This study has only addressed the CO_2 emissions related to energy use and process emissions from clinker manufacture in the cement industry. Future work should address the contribution of abatement of other gases and the cost-effectiveness of such actions and policies.

5.8 SUMMARY

Industrial primary energy consumption is estimated at 34.85 Quads, or 37% of total primary energy use in the U.S. in 1997. Associated carbon dioxide emissions are estimated 494 MtC (including process emissions from the cement industry), or 33% of total U.S. carbon dioxide emissions. The industrial sector is extremely diverse, and includes energy-intensive manufacturing, non-energy-intensive manufacturing, and non-manufacturing (e.g. agriculture).

We have investigated three policy scenarios, entailing different degrees of commitment to environmental issues in the definition of U.S. energy policy. Under the business-as-usual scenario industrial energy consumption would grow to approximately 41 Quads in 2020. Under the moderate scenario, total energy use would be approximately 38 Quads in 2020 (-7%), while in the advanced scenario total energy use would be approximately 34 Quads (-17%). Carbon dioxide emissions would grow to 578 MtC by 2020 under the BAU-scenario, approximately 521 MtC (-10%) under the moderate, and 409 MtC (-29%) under the advanced scenario. This compares to estimated 1990 emissions of 452 MtC in the industrial sector. These figures exclude the contribution of CHP. CHP may lead to a net increase in industrial fuel use, but a net decrease in primary energy demand due to fuel use offsets for (onsite) steam and (grid) power generation. Energy efficiency opportunities are found throughout the industry.

The characteristics of decision makers vary widely. Therefore, an integrated policy framework accounting for the different characteristics of decision makers, technologies and sectors is necessary. The framework may consist of a variety of programs.

Future research needs are highlighted, both with respect to modeling as policy analysis and evaluation. The main issues are technology representation and efficiency trends in the model, and the need for detailed evaluation of the effects and (cost-) effectiveness of industrial energy efficiency policies.

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Chapter 6

TRANSPORTATION SECTOR[1]

6.1 INTRODUCTION

The U.S. transportation sector includes highway, air, rail, shipping, pipeline, and off-road transport as well as miscellaneous categories such as recreational boats and military fuel consumption. In 1997, the sector consumed about 25 quads of primary energy, 27 percent of total U.S. energy consumption. The sector is also the nation's primary oil consumer at 12.1 million barrels per day (mmbd) in 1997, about 65 percent of total U.S. consumption. Transportation is responsible for almost one-third of U.S. carbon emissions, substantial amounts of most air pollutants, and two-thirds of U.S. oil consumption (Table 6.1). In the same year, the sector had carbon emissions of 478 million metric tons (MtC), 32 percent of the U.S. total carbon emissions. In the face of strong continuing demand for transportation services, slow turnover of fleets, gasoline's dominance of light-duty vehicle fueling infrastructure, and low energy prices that provide only modest incentives for improved efficiency, U.S. transportation energy consumption and greenhouse emissions are expected to grow robustly over the next few decades.

Table 6.1 Contribution of the Transportation Sector to National Issues and Problems

National Issue	1997 Amount	1997 % of U.S. Amount
Climate Change – Carbon Emissions	473.1 Million metric tons carbon	32.0%
Air Pollution – CO	60.9 Million metric tons	76.6%
Air Pollution – Nox	10.5 Million metric tons	49.2%
Air Pollution – VOC	7.0 Million metric tons	39.9%
Air Pollution – PM-10	0.7 Million metric tons	2.2%
Air Pollution – PM-2.5	0.6 Million metric tons	7.4%
Air Pollution – SO2	1.3 Million metric tons	6.8%
Oil Dependence – Oil Use	24.11 Quads	66.3%

Source: Davis, S.C., 1999, tables 3.6, 4.1 and 1.10.

In this chapter, we estimate the impacts on transportation energy consumption and greenhouse emissions of a series of new government policies, embedded in two scenarios of increasing public concern over global warming and other energy and environmental issues. The Energy Information Administration's (EIA's) 1999 Annual Energy Outlook (AE099) Reference Case represents a "Business-as-Usual" (BAU) future with no policy changes (EIA, 1998). The two policy-driven scenarios are created by rerunning the EIA's NEMS model with extensive changes to its input and some changes in its code to reflect the new policies and changed social conditions in the scenarios.

The chapter is organized as follows. We first discuss some inherent limitations of estimating technological and market impacts of future policy measures. We then review the current status and trends in energy use and greenhouse gas (GHG) emissions in the U.S. transportation sector. Brief discussions of

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key technologies that seem likely to have major impacts over the next few decades come next. Supplementary material is presented in Appendix C-3. This is followed by a description of the BAU scenario. The next section addresses policies that could advance clean energy technologies and their acceptance, including a discussion of the barriers these policies are intended to overcome. How the policy pathways were implemented in the context of the NEMS model is the subject of Section 6.4. After that, we present in turn the Moderate and Advanced scenarios and the resulting CEF-NEMS projections. Several sensitivity cases were run to test the impacts of assumptions about key technologies and policies on the forecast results. The chapter concludes with some observations about where additional analysis might produce more valuable insights, followed by a attempt to summarize the key conclusions of the chapter.

6.1.1 Uncertainties and Limitations

In our view, it is critical that the reader understands the strong uncertainties associated with these analyses. First, the results depend critically on the costs and performance of technologies, some of which are under development, and these costs and performance values can be *highly* uncertain. In general, the range of uncertainty increases when technologies not already in use in commercial vehicles are included, as in the case here. Recent studies limited to a 10-year time horizon suggest that passenger car fuel economy can be improved to somewhere between 32 and 41 mpg at costs close to $750 per car, 1998 $ retail price equivalent (Greene and DeCicco, 1999). Studies considering longer time horizons or new technologies project mpg levels ranging from 38 to 52 at costs below $1,000 per car. None of the studies reviewed by Greene and DeCicco (1999) considers the full range of technologies included in this study, nor do they take account of technological advances since 1997. Cost and performance estimates more optimistic and less optimistic than those we use here can be found in the literature. And although we have not done a full sensitivity analysis of the effects of cost and performance assumptions, the sensitivity cases presented in Section 6.5, below, suggest that our conclusions are robust with respect to the cost, performance, or availability of any *single* technology. The effect of this uncertainty about the cost and performance of technologies is mitigated somewhat by the existence of a portfolio of technologies under development or in the early stages of commercialization that will compete for market dominance in the future. Historically, large reductions in cost and improvements in performance have occurred for a number of transportation technologies, and we believe it is reasonable to assume that some members of the portfolio will experience future cost reductions and performance improvements of a similar magnitude.

Second, there is no accepted analytical method to forecast the results of increases in research and development funding (EIA, 1999, p. xv), a crucial component of our policy strategy, and we are forced to rely essentially on judgment. The outcome of an RD&D program is inherently uncertain, depending on many factors such as market conditions, the amount of effort invested and the intelligence with which the effort is applied. As noted above, however, the existence of a substantial portfolio of technologies in the R&D “pipeline” offers a level of redundancy that adds to the probability of substantial improvements in performance and cost-effectiveness in several technologies. There are reasons to be optimistic. We note that since the Five-Lab Study, significant advances have been achieved in fuel cell technology, and two major automotive manufacturers have announced commercial introductions of hybrid vehicles five to ten years sooner than we had expected. At the same time, it is not reasonable to assume that all technologies can achieve the advances needed for market success. The best we can do is make an educated guess about which seem most likely to achieve breakthroughs, but we readily acknowledge the uncertainties in such judgments.

Third, consumer-purchasing behavior will obviously play a critical role in determining the future market share of crucial technologies, and how consumers will respond to new technologies is uncertain. Forecasters generally use market surveys to project consumer behavior, but much of the data about consumer preferences for new technologies comes from consumer responses to theoretical questions about whether they would purchase vehicles whose characteristics they know little about and have minimal experience with. Surveys of this sort are unreliable. Also, consumer preferences have undergone drastic changes at times; for example, recent sharp increases in consumer preference for safety features and for vehicles with proven records of high levels of safety. Similar changes are possible in the future but cannot be reliably predicted.

Fourth, the policies we examine in each scenario are assumed to be compatible with the qualitative scenario descriptions (and conversely, we leave out some policies because we assume they are incompatible with the descriptions), but the connection between societal conditions and public policy is by no means straightforward or non-controversial. For example, it is far from clear how far the Federal government will go in trying to force future improvements in automobile and light truck fuel economy. For several years the Congress, acting through the appropriations process, has expressly forbidden the Department of Transportation (DOT) from even analyzing potential changes in Corporate Average Fuel Economy (CAFE) rules. Further, the industry has shown strong opposition to increased CAFE standards. However, according to recent trade press reports, there is some (minority) sentiment in Congress to increase these standards. And some of our reviewers believe that regardless of public opinion about global warming, the U.S. market entry of practical hybrid-electric vehicles (scheduled to be introduced by 2000) and large increases in Japanese and European fleet fuel economy (responding to Kyoto initiatives) will lead to public demands that U.S. policy bring similar changes to the U.S. fleet. We have responded to the ambiguity in future policy shifts by assuming no change in CAFE rules for the Moderate scenario and examining two policy possibilities in the Advanced Scenario: Voluntary Agreements between the government and auto industry as a "base" Advanced policy, and still more stringent CAFE standards as a sensitivity case.

Of particular concern here is the difficulty of predicting how future purchasers of new light duty vehicles will trade off fuel economy against competing vehicle attributes such as acceleration performance, vehicle size, luxury features, and towing capacity. Previous forecasts of transportation energy use projected increasing light duty fleet fuel economy over time. Despite the widespread adoption of new technologies (see discussion of trends, below), these forecasts have been proven wrong and fuel economy has actually declined over time. There is an ongoing argument in the transportation community about whether market incentives (tax incentives for high efficiency vehicle purchases, reduced technology costs obtained by increasing R&D spending) will be sufficient to stimulate significant mpg gains, or whether regulatory action will be required to achieve such an increase.

Translating policies to CEF-NEMS model inputs often involves subjective judgments. As discussed below and in Appendix A, some of the modeling changes are close representations of the policies of conditions, for example reduced technology costs in the model to reflect a policy of technology subsidies or tax credits. Others are less analytical representations of the policies, for example, earlier technology introduction and reduced costs in the model to represent the effect of increases in research and development funding. The projected changes in dates of introduction and costs are based on industry announcements, technical analyses by government, private, and academic sources, consumer surveys, and other sources.

In the end, we must use our own judgment about these matters, tempered by external expert review. We are careful to be explicit about the assumptions we make about technology, consumer preferences, producer behavior and policies. All changes we have made to the NEMS model and its data inputs are documented in Appendix A[2].

The primary focus of this analysis is on energy consumption and GHG emissions, but the policies and technologies embodied in the two scenarios will also reduce oil imports, emissions of criteria air pollutants, other environmental damages associated with fossil fuel use.

6.1.2 Overview of the Sector

The U.S. transportation sector is dominated by highway travel, which consumes 75 percent of the total energy used by the sector and accounts for 75 percent of the sector's carbon emissions. In the highway sector, light-duty passenger travel is dominant, accounting for 74 percent of highway energy consumption and carbon emissions, and 56 percent of *total* transportation energy consumption and carbon emissions. Fig. 6.1 and Fig. 6.2 show the modal breakout of carbon emissions and energy consumption, respectively.

The characteristics of the various fleets in the sector and recent trends in energy use provide important clues to the likely future energy use in the sector and the potential for reducing GHG emissions. Some critical points:

- New light-duty passenger vehicles have been adopting fuel-efficient technologies over the past decade and a half, but increasing vehicle size, weight and especially performance have nullified the fuel economy gains these technologies might have brought.
- Important new technologies that enter the fleet include port fuel injection, 4 valves/cylinder engines, variable valve control, structural redesign using supercomputers, growing use of high strength steel and steel substitutes such as aluminum and plastics, and low rolling resistance tires.
- Counteracting trends include the growing sales share of light-duty trucks, especially Sport Utility Vehicles which now comprise 46 percent of light-duty vehicle sales, up from 17 percent in 1980; horsepower to weight ratios 45 percent higher than in 1980, a 20 percent increase in weight over 1980 vehicles (Heavenrich and Hellman, 1999); greater shares of 4-wheel drive installed on 47 percent of 1999 model year light trucks, and other luxury features, and continued increases in the stringency of emissions and safety standards.
- As a result of a decade of low gasoline prices, consumer surveys show that today's auto purchasers generally are uninterested in fuel economy.
- The "potential technology" portfolio for automobiles has been enhanced substantially by the Partnership for a New Generation of Vehicles (PNGV), a government/industry joint research and development program (NRC, 1999a). PNGV's effects are both direct and indirect – in addition to its own advances, it has stimulated competitive developments in Europe and Japan.
- Freight transport now consumes about 30 percent of U.S. transportation energy, with freight energy use but *not* gross ton miles dominated by heavy truck carriage (over 50 percent of energy use, about one-quarter of ton-miles) (Davis, 1998, table 2.13), the most energy-intensive mode aside from air freight. Air freight and freight truck energy use are the most rapidly growing freight modes because of the U.S. economy's shift towards higher value (and more time-sensitive) goods. A countervailing trend is greater use of multi-modal shipments, advanced by the rationalization of U.S. freight railroads and the benefits of improved computerized information systems.

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[2] These changes would have been far more difficult to make and the chances for mistakes would have been greatly increased had we not had the benefit of the expert advice and full cooperation of the NEMS model experts at the EIA. We are grateful for their invaluable assistance with the use of NEMS. Any remaining errors are, of course, our responsibility.

Fig. 6.1 1997 Transportation Carbon Emissions by Mode (477.9 MtC total)

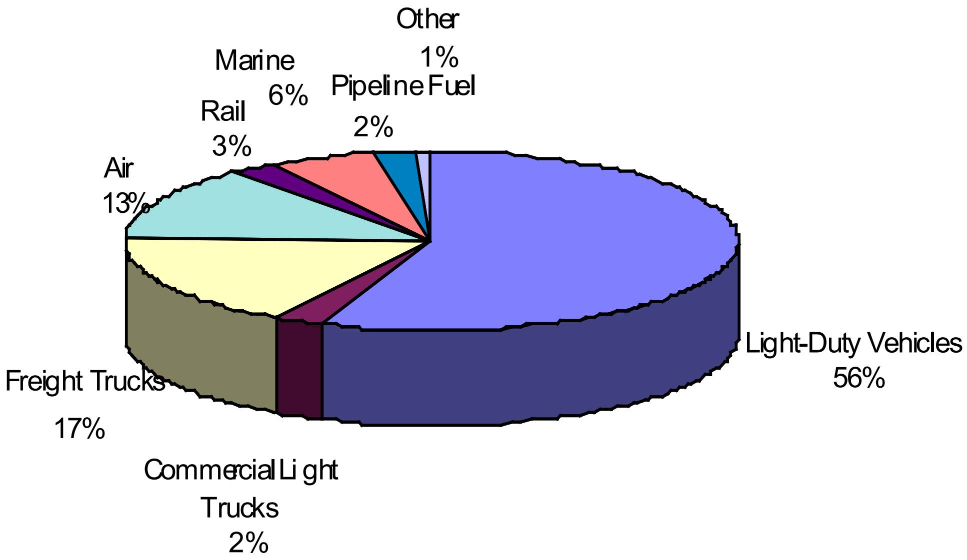
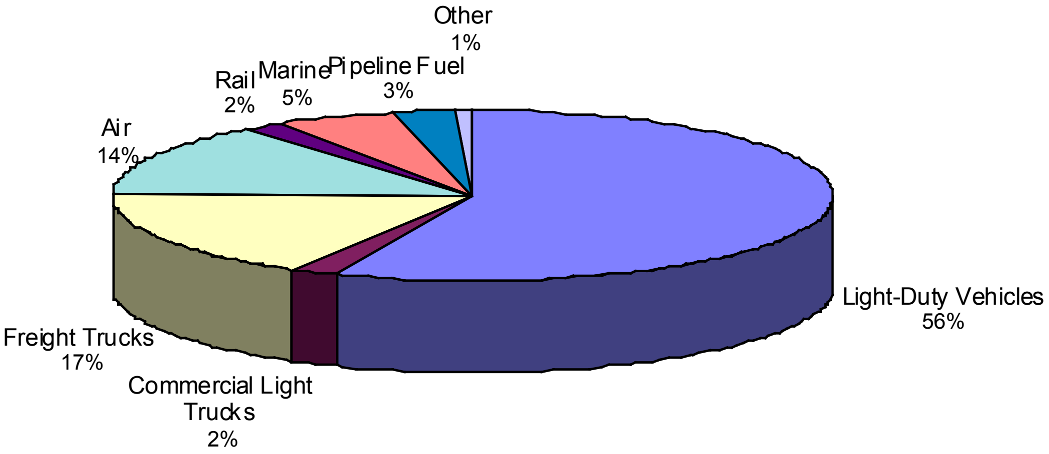


Fig. 6.2 1997 Transportation Energy Use, by Mode (25 Quads total)



6.1.3 Examples of Promising Technologies

The transportation sector has a wide variety of available and emerging technologies – the technology "portfolio" noted above – that offer the potential to reduce significantly the energy use and GHG emissions associated with transportation services. At the most mundane level, some "technologies" involve simply the constant redesign and improvement of existing technologies, for example, the steady reduction in engine friction from introduction of lighter materials in valve-trains, changes in machining, design, and assembly that yield improved tolerances, and other incremental changes. Others are technologies that have gained moderate market share – variable valve timing is an important example – but whose fuel economy benefits are not highly valued in today's market (variable valve timing is probably used today primarily for its ability to flatten an engine's torque curve, obtaining high torque throughout the engine's speed range). Finally, there are a range of technologies that are either just entering the marketplace or are under advanced development. Some of the most promising are described below.

Cellulosic Ethanol. About one billion gallons of ethanol produced from corn is currently used annually in U.S. transportation markets as a blend stock for gasoline (Davis, 1998). Although the efficiencies and fuel choices used over the fuel cycle in producing this ethanol vary widely (e.g., fuel choices for powering the distillery can be corn stover, natural gas, or coal), recent studies show that the use of this ethanol provides a moderate GHG advantage over gasoline of about 20 percent or so (Wang, 1999). Processes to produce ethanol from cellulose – from woody biomass or municipal wastes – for use as a gasoline blending agent or neat fuel offer to reduce greenhouse gases about 80 percent compared to gasoline (Wang et al., 1999). A Department of Energy (DOE) program at the National Renewable Energy Laboratory has been working intensively to improve the efficiency and cut the costs of producing ethanol to about half of current level (NREL, 1999). Program success could allow significant quantities of cellulosic ethanol to enter the market over the next decade, though a critical factor in its commercialization will be the world market price of oil.

Land requirements could ultimately limit cellulosic ethanol production. About 15 billion gallons of ethanol (1.2 Quads) could be produced annually by converting municipal and agricultural wastes with minimal land requirements (Lynd, 1997). If about 35 million of the roughly 60 million acres idled by Federal programs were used for energy crops, about 25-32 billion gallons, or about 3-4 Quads of ethanol could be produced annually (assumptions: 8.4 dry tons/acre/year crop productivity, 107.7 gallons of ethanol/ton yield) (Lynd, 1997). If only 10 billion gallons of ethanol were produced annually, this would leave 200 million dry tons of biomass for other uses, such as biomass power.

Hybrid Electric Drivetrains. A hybrid electric drivetrain combines an internal combustion engine or other fueled power source with an electric drivetrain including an electric motor and battery (or other electrical power source, e.g., an ultracapacitor). Potential efficiency gains involve recapture of braking energy (with motor used as generator, captured electricity stored in the battery); potential to downsize the engine, using the motor/battery as power booster; potential to avoid idling losses by turning off the engine or storing unused power in the battery; and increasing average engine efficiency by using the storage and power capacity of the electric drivetrain to keep the engine operating away from low efficiency modes. Toyota recently introduced a sophisticated hybrid subcompact auto, the Prius, in Japan and will introduce a version into the U.S. market within a year; Honda introduced its two-seater Insight hybrid in December 1999. Ford, GM, and Daimler/Chrysler all have hybrids in advanced development (Reuters, 1998; Jost, 1998; Bucholz, 1999a, 1999b).

Hybrids can be built in various configurations that trade off fuel efficiency, performance, and cost (for example, the most efficient configurations would downsize the engine, which would reduce the vehicle's towing capability). The most fuel-efficient configurations potentially could boost fuel economy by as much as 50 percent or so at near-constant performance under average driving conditions. Hybrids attain their greatest efficiency advantage – potentially greater than 100 percent – over conventional vehicles in slow stop-and-go traffic, so that very attractive applications might be urban taxicabs, transit buses, and service vehicles such as garbage trucks. Estimates of the fuel economy improvement in slow urban traffic of a hybrid medium truck over its conventional counterpart range from 55 to 124 percent; a (hybrid) heavy garbage truck could achieve gains as high as 140 percent (An et al., 2000).

Lower Weight Structural Materials. The use of alternative materials to reduce weight has been historically restrained by cost considerations, manufacturing process technology barriers, and the difficulty of these materials in meeting automotive requirements for criteria such as surface finish quality, predictable behavior during crash tests, or repairability. The last few years have seen significant developments in overcoming such barriers, through design changes such as a space frame-based structure, advanced new manufacturing technology for plastics and aluminum, and improved modeling techniques for evaluating deformablity and crash properties. Ford has displayed an advanced lightweight prototype (the P2000 Diata) that is a mid-size car with a weight of only 2000 pounds, as compared to vehicles weighing 3200 pounds today (Ford, 1997). Equipped with a direct-injection diesel engine it gets 63 mpg (Jost, 1998b). The Auto Aluminum Alliance, a working group within USCAR, has set a goal of 40 percent weight reduction via substitution of aluminum and is developing advanced manufacturing, repair and recycling technologies to attain that goal. Some aluminum intensive luxury cars have already been introduced (for example, the Audi A8) and Ford is known to be considering the introduction of such a vehicle in the mass market. Audi recently announced the introduction in Europe of the A2, the world's first volume-production aluminum car. According to the manufacturer, the car weighs 43 percent less than if built using steel and conventional processes (Birch, 1999c). In the U.S., Honda's Insight vehicle uses an all-aluminum body structure, which, along with a drag coefficient of 0.25 and 40 percent lower rolling resistance, is said to be responsible for 35 percent of the vehicle's improvement to 75 mpg (estimated 65 mpg in actual use in the United States) (Yamaguchi, 1999).

Aside from the "leading edge" structural redesigns discussed above, advanced design techniques and increased use of new materials can lead to lesser weight reductions throughout the fleet. For example, even without a shift away from steel, new ULS (ultralight-weight steel) designs claim up to a 36 percent reduction in weight for the basic automobile "body-in-white" structure at essentially zero cost (AISI, 1998).

Direct Injection Gasoline and Diesel Engines. Direct injection lean burn gasoline engines have already been introduced in Japan and Europe, but have been restricted here by a combination of tight emission standards and high sulfur content in gasoline. Honda's Insight hybrid vehicle, however, uses a lean-burn small-displacement gasoline engine, and has been certified to California's Ultra Low Emission Vehicle Standard (Yamaguchi, 1999). Mitsubishi for example, now manufactures 10 gasoline direct-injection (GDI) models in Japan, which reportedly reduce fuel consumption by 20 percent, with a 10 percent increase in power output (Demmler, 1999). The catalytic converters capable of reducing NO_x emissions from lean burn engines are very sensitive to fuel sulfur content, and no simple remedy has been found. Recently, Environmental Protection Agency (EPA) has proposed new Tier 2 standards that require the introduction of low sulfur gasoline, and have also increased the stringency of NO_x standards for 2004 and beyond. While the sulfur reduction allows GDI engines to be introduced, it is not yet clear that fuel efficiency benefits can be retained at the new NO_x levels. Preliminary evaluations suggest that benefits may be in the 12 to 15 percent range rather than the 16 to 20 percent range available in Japan and Europe, but even this assumes some advances in after-treatment technology. Engine costs, however, seem quite moderate, in the range of \$200 to \$300 (in retail price) more than a conventional engine. Evidence that emissions barriers are being broken down can be inferred from GM's intention to introduce a family of GDI light truck engines in 2001 (Robinson, 1999). An 8-10 percent fuel economy benefit is anticipated at a cost of \$265 to \$370 per truck.

Direct injection diesel engines have long been available for heavy trucks, but recently have become suitable for automobiles and light trucks as noise and emission problems have been reduced. These new engines are about 40 percent more fuel efficient, on a per gallon basis, than conventional gasoline engines (OTA, 1995) and about 25 percent more efficient on the basis of carbon emissions over the fuel cycle (Wang, 1999b). California's new emission regulations require diesels to attain the same (low) NO_x levels as gasoline engines, as well as stringent particulate levels; these and potential new federal standards present a challenge to diesel's viability (see the following box).

Further improvements in diesel technology also offer substantial promise in heavy-duty applications, especially heavy trucks but also including marine and rail applications. Current DOE research programs are aiming at achieving maximum efficiencies of about 50 percent in heavy-duty diesels, with low emissions (U.S. DOE, 1997).

Both gasoline and diesel direct injection engines have been shown to emit relatively large quantities of fine particles, even when total particulate weight is low. Current emissions standards are weight-based, but continuing research on particulate matter (PM) health effects conceivably could lead to new standards based on the number of particles rather than their weight. Such standards could pose a challenge to all direct injection engines.

Fuel Cells. Fuel cells have received considerable attention recently, with both Ford (Birch, 1999d) and Daimler/Chrysler (1999) announcing their intention to introduce such vehicles by the 2004 model year. Nissan has announced plans to introduce a methanol-reforming fuel cell vehicle in the Japanese market between 2003—2005 (Bucholz, 1999). General Motors Europe announced that it will have a fuel-cell-powered car ready for the European market by 2004 (Birch, 1999a) and Renault is planning a 2005 introduction date for its fuel cell car (Birch, 1999b). Fuel cells have been virtually the “Holy Grail” of clean powertrain technology, promising zero or near-zero criteria pollutant emissions with very high efficiency. The recent optimism has been driven by strong advances in technology performance, including rapid increases in specific power that now allow a fuel cell powertrain to fit into the same space as a conventional engine without sacrificing performance (Griffiths, 1999). However, fuel cells remain extremely expensive, and long-term costs are by no means clear; further, important technical roadblocks remain, e.g., operation in extreme weather conditions. Manufacturers are expressing optimism, however. For example, General Motors Europe has been quoted as believing that within 5-10 years after introduction the use of modular construction, falling costs and scale economies will make it possible to sell fuel cell vehicles at a lower price than cars with internal combustion engines (Birch, 1999a).

Another central issue is the fuel choice. Fuel cells need hydrogen, either carried onboard or produced by reforming methanol or gasoline. Carrying hydrogen may yield the cheapest and most fuel-efficient vehicle, but there is no hydrogen distribution and refueling infrastructure. A gasoline vehicle overcomes the infrastructure problem but is the most expensive and least efficient vehicle; further, developing an adequate gasoline processor remains a critical task, with significant improvements required in processor weight and size, cost, response time, efficiency, and output of carbon monoxide, which can poison the fuel cell stack (NRC, 1999a). Methanol may be a reasonable compromise, though it too requires a substantially improved fuel processor and, as yet, has no real infrastructure for distribution. Although vehicle fuel economy depends on far more than just the power plant, it appears that a fuel cell vehicle using methanol, with a lightweight, low drag body and low rolling resistance tires, should be capable of achieving 65 mpg (gasoline equivalent). Gasoline powered fuel cell vehicles using equivalent body structure, tires, and other components should be capable of about 60 mpg whereas similar fuel cell vehicles powered by compressed hydrogen could get 90 mpg. Both hydrogen and liquid fuel versions are likely to be initially more expensive than an equivalent conventional automobile.

Aircraft Technology. Several major technologies offer the opportunity to improve the energy efficiency of commercial aircraft by 40 percent or more. The Aeronautics and Space Engineering Board of the NRC (1992, p. 49) concluded that it was feasible to reduce fuel burn per seat mile for new commercial aircraft by 40 percent by about 2020. Of the 40 percent, 25 percent was expected to come from improved engine performance, and 15 percent from improved aerodynamics and weight. A reasonable preliminary goal for reductions in NO_x emissions was estimated to be 20-30 percent. Technologies such as laminar flow control to reduce drag, greater use of composite materials to reduce weight, and advanced propulsion concepts such as ultra-high bypass turbofan and propfan engines could all contribute.

Noting that the energy efficiency of new production aircraft has improved at an average rate of 1-2 percent per year since the dawn of the jet era, a recent IPCC (Lewis and Niedzwiecki, 1999) expert panel

Diesel's Future Viability

The future viability of diesel engines in the light-duty fleet, and perhaps in the heavy-duty fleet as well, will depend on the interplay of emission standards for NO_x and particulates and progress in diesel fuels, engine design, and emissions after-treatment technology (Mark and Morey, 1999). It will also depend on consumer acceptance, which is by no means guaranteed. Diesels have been selling well – and obtaining a price premium that appears to exceed that dictated by cost difference – in the light truck fleet. GM recently unveiled a new direct-injection diesel engine for light trucks in anticipation of industry-wide sales of 250,000 units/year in the near future (Broge, 1999). Diesels have a miniscule share of automobile sales, however, and may have to overcome consumer reluctance based on past mechanical failures and performance shortcomings. New turbocharged direct injection diesels bear little resemblance to diesels of the past, but their future acceptance by auto purchasers must be considered uncertain.

Emissions requirements are growing far more stringent for diesels (as for gasoline-fueled vehicles as well). California's new light-duty Low Emission Vehicle (LEV) NO_x standard for 2004 is 0.05 g/mi, versus 0.3 g/mi today, and applies equally to gasoline and diesel vehicles; its new 2004 particulate standard for diesels is .01 g/mi, versus .08 g/mi today. Federal "Tier 2" standards, now being promulgated, are expected to be similar, though they may provide some added flexibility that could help diesels. And the potential for still more stringent standards arises from the continuing research on the effects of diesel exhaust on health. Current knowledge is limited by deficiencies in several areas: quantitative measures of exposure to humans; data over a wide population; and confirming data on disease mechanisms (Nauss, 1999). If ongoing research yields strongly negative results, pressure will grow to restrict diesel emissions still more. An important issue here, however, is the extent to which potentially conflicting societal goals, in this case reduced health-associated emissions and reduced GHG emissions and oil use, are actually being weighed against each other in making policy choices about emissions standards. The National Research Council (NRC), in its recent PNGV review report (NRC, 1999a), states "the responsible government agencies participating in the PNGV have pursued their specific agency objectives without taking into account the interdependency of these issues."

In the face of the new standards and the potential for additional emissions requirements, diesel's viability depends strongly on advances in several areas (Howden, 1999; Lyons, 1999) in which considerable progress is being reported (e.g., Birch, 1999e, 1999f):

- Fuels: especially economical reduction of sulfur to at least 30 ppm and possibly considerably lower; also changes in density, aromatics and polycyclics content, cetane, etc.
- Engine design: particularly in combustion chamber design, improved exhaust gas recirculation, improved fuel injection.
- NO_x after-treatment: e.g., lean-burn catalysts, NO_x traps (absorbers), non-thermal plasma systems.
- Particulates after-treatment: e.g., regenerative PM traps and oxidation catalysts.

The PNGV currently is working on all of these systems, as are private companies in Europe, Japan, and the United States.

concluded that a significant though somewhat lower rate of improvement could be expected through 2050. The panel predicted about a 20 percent improvement in seat-kilometers per kg of fuel for 1997-2015 (Table 6.2).

Table 6.2 Historical and Future Improvements In New Production Aircraft Energy Efficiency (Percent)

Time Period	Airframe	Propulsion	Total	%/Year
1950-1997	30	40	70	1.13
1997-2015	10	10	20	1.02
1997-2050	25	20	45	0.70

Source: Lewis and Niedzwiecki, 1999, table 7.1.

The “blended wing body” is a revolutionary airframe design that transforms an aircraft into essentially a flying wing, resembling the military’s stealth aircraft in appearance. The extension of the cabin into the wing allows the drag associated with the traditional aircraft body to be reduced, and permits some weight reduction, as well. With this radical new design, fuel burn could be “reduced significantly relative to that of conventionally designed transports” (Lewis and Niedzwiecki, 1999, p. 7-13). With an aggressive R&D effort, an initial version could enter service in 2020 (ibid).

6.2 BUSINESS-AS-USUAL SCENARIO

In the BAU scenario for the transportation sector, we accepted the sectoral assumptions of the AEO99 Reference Case scenario despite some disagreements we have with certain portions of it, which are discussed in Section 6.2.2. The CEF-NEMS baseline scenario results have some slight differences with the AEO99 results because of the effect of changes made to the Reference Case in other economic sectors. These differences are quite small, less than one percent, and we will not discuss them.

6.2.1 Policies in the BAU Scenario

The CEF-NEMS baseline scenario (and the AOE99 Reference Case scenario) adopts the following policies:

1. Emissions standards: Tier 2 vehicle emission standards have not yet been promulgated by EPA and are not included in the scenario. These standards could have strong impacts on transportation technology introduction and market share, for example, stringent NO_x standards could hinder widespread introduction of efficient direct injection diesel engines into the light-duty fleet unless major advances in emissions control are achieved.
2. Alternative fuel requirements: EPACT rules for purchase of alternative fuel vehicles by fleet operators, including Federal and fuel provider fleets, are included. California’s Low Emission Vehicle Program, which includes requirements for zero emission vehicles (10 percent of sales by 2003), is assumed in place. Massachusetts and New York are assumed to have delayed their programs to conform to the California 2003 limits.
3. Kyoto Protocol: Potential policy actions that may be taken to satisfy the Kyoto Protocol are not included. However, Climate Change Action Plan programs are assumed to be in place and successful. These are: reform Federal subsidy of employer-provided parking; adopt a transportation

system efficiency plan; promote telecommuting; and develop fuel economy labels for tires. The first three are assumed to achieve a 1.6 percent reduction in vehicle miles traveled (vmt) by 2010; the tire labels are assumed to achieve a 4 percent/vehicle improvement in fuel efficiency for those vehicles switching to more efficient tires.

4. Fuel economy standards: no further increase in current auto and light truck standards.

6.2.2 Alterations to the EIA Base Case

As noted above, we made no alterations to the EIA Reference Case, although we do have concerns about various aspects of that Case. Two key concerns:

1. **Vehicle performance projections.** In the light-duty fleet, the last decade and a half has seen substantial increases in acceleration performance and corresponding increases in average horsepower and horsepower/weight values in the fleet. EIA has assumed that these factors will continue to increase over the lifetime of the estimate, leading ultimately to passenger cars averaging 250 horsepower by 2020. These performance increases dampen substantially the efficiency impact of new technologies forecast to enter the fleet during this period, so that the average new car fuel economy is forecast to increase from 27.9 mpg in 1997 to only 32.1 mpg in 2020 despite the penetration of a substantial amount of new efficiency technology. Some industry analysts consider this small an increase unrealistic in the face of programs like the PNGV, whose goal is to triple light-duty vehicle fuel economy, as well as the impending introduction of hybrid electric vehicles such as Toyota's Prius and Honda's Insight. On the other hand, current CAFE standards have appeared to act as a floor holding up fleet fuel economy at its current levels, and other analysts question whether fleet fuel economy will increase *at all* given expected continuation of very low fuel prices and the clear low valuation of fuel economy held by recent vehicle purchasers.
2. **Travel projections.** EIA is projecting a growth rate in car and light truck travel of 2.0 percent over 1997-2010, and 1.6 percent/yr over 1997-2020, versus a 1974-1995 growth rate of 2.8 percent/yr that has been remarkably robust except for brief periods during the oil crises. The slowdown presumably results from projections and assumptions about changes in population, aging of the population, female driving, and income, as well as the CCAP programs noted earlier. Interestingly, EIA states that the female/male-driving ratio reaches 100 percent by 2010 (from 56 percent in 1990) and that (recent) increased driving among retirees is taken into account – factors that should boost vmt. This issue is discussed in greater detail in Appendix E-2.

6.2.3 Results

Tables 6.3 and 6.4 present 10-year results for travel, efficiency, and energy used by mode, and energy used by fuel.

Table 6.3 Results of BAU Scenario

	1997	***2010***	***2020***
Level of Travel by Mode (Billion)			
Light Duty Vehicles (vehicle miles traveled)	2301	2886	3303
Commercial Light Trucks (vehicle miles traveled)	69	91	104
Freight Trucks (vehicle miles traveled)	177	243	270
Air (seat miles demanded)	1049	1813	2462
Rail (ton miles traveled)	1229	1516	1698
Marine (ton miles traveled)	756	877	961
Energy-Efficiency Indicator by Mode			
New Light-Duty Vehicle (MPG)[a]	24	25.5	26.5
New Car (MPG)	27.9	31.7	32.1
New Light Truck (MPG)	20.2	20.8	22
Light-Duty Fleet (MPG)	20.5	20.3	21.4
New Commercial Light Truck (MPG)	19.9	19.8	21
Stock Commercial Light Truck (MPG)	14.6	15	15.6
Aircraft (seat miles/gallon)	51	55.7	59.6
Freight Truck (MPG)	5.6	6.1	6.3
Rail (ton miles/kBtu)	2.7	2.9	3.1
Site Energy Use by Mode (Quadrillion Btu)			
Light-Duty Vehicles	13.9	18.1	19.6
Commercial Light Trucks	0.6	0.8	0.8
Freight Trucks	4.2	5.3	5.7
Air	3.4	5.2	6.4
Rail	0.5	0.6	0.7
Marine	1.3	1.6	2.0
Pipeline Fuel	0.7	0.9	1.0
Other	0.2	0.3	0.3
Total	24.9	32.8	36.4
Energy Use by Fuel Type (Quadrillion Btu)			
Distillate Fuel	4.6	6.0	6.6
Jet Fuel	3.3	5.1	6.3
Motor Gasoline	15.1	18.7	19.9
Residual Fuel	0.8	1.0	1.3
Liquefied Petroleum Gas	0.0	0.2	0.2
Other Petroleum	0.3	0.3	0.4
Petroleum Subtotal	24.10	31.32	34.67
Pipeline Fuel Natural Gas	0.7	0.9	1.0
Compressed Natural Gas	0.0	0.3	0.4
Renewables (E85)[b]	0.0	0.1	0.1
Methanol	0.0	0.1	0.1
Liquid Hydrogen	0.0	0.0	0.0
Electricity	0.1	0.2	0.2
Total Site Energy	24.9	32.8	36.4
Electricity Related Losses	0.1	0.3	0.4
Total Primary Energy	25.0	33.1	36.8

[a] Light-duty vehicles are passenger cars and light trucks combined.

[b] The CEF-NEMS model reports renewables blended with gasoline as "Motor Gasoline." For an accounting of cellulosic ethanol blended with gasoline, please see the discussion in section 6.5.1.

Table 6.4 Transportation Carbon Emissions: BAU (million metric tons C)

	1997	*2010*	*2020*
Carbon emissions by mode (MtC)			
Light Duty Vehicles	267.0	346.4	376.3
Commercial Light Trucks	11.3	14.5	16.1
Freight Trucks	82.4	100.8	108.0
Air	63.3	98.8	122.1
Rail	12.2	14.1	15.0
Marine	27.3	33.7	40.8
Pipeline Fuel	10.6	12.8	14.1
Other	3.8	7.4	7.7
Total	477.8	628.4	700.2
Carbon emissions by fuel type (MtC)			
Other	91.6	118.7	130.4
Jet Fuel	63.3	98.0	121.3
Motor Gasoline	289.7	358.2	381.5
Residual Fuel	15.9	21.7	27.7
Liquefied Petroleum Gas	0.7	3.0	3.8
Other Petroleum	3.0	3.6	3.9
Petroleum Subtotal	464.1	603.2	668.5
Pipeline Fuel Natural Gas	10.6	12.8	14.1
Compressed Natural Gas	0.2	3.7	4.9
Renewables (E85)	0.0	0.0	0.0
Methanol	0.0	1.3	1.9
Liquid Hydrogen	0.0	0.0	0.0
Electricity	2.9	7.4	10.7
Total	477.8	628.4	700.2

In the Baseline, carbon emissions grow from 478 MtC in 1997 to 700 MtC in 2020, a growth of 46.5 percent over the period. Similarly, energy use rises from 25.0 Quads in 1997 to 36.8 Quads in 2020, a 47.2 percent growth (Fig. 6.3).

The reasons for this strong growth in both energy use and carbon emissions are straightforward: the demand for travel is forecast to increase inexorably (though generally more slowly than the historic rate), whereas travel energy efficiency is forecast to increase only modestly over the period (Fig. 6.4 and Fig. 6.5). Specifically, the 1997-2020 vmt, smt (seat-miles traveled), and tmt (ton-miles transported) growth and efficiency improvements by transportation modes are:

Mode	% Growth in Travel	% Growth in Efficiency
Light-duty vehicles	43.5 (vmt)	10.4/4.4 (new/stock)
Freight trucks	52.5 (vmt)	12.5 (stock)
Air	136.7 (smt)	16.9 (stock)
Rail	39.3 (tmt)	14.8 (stock)
Marine	27.1 (tmt)	----

Fig. 6.3 Projected Growth in Transport Energy Use, 1996 - 2020, EIA Reference Case

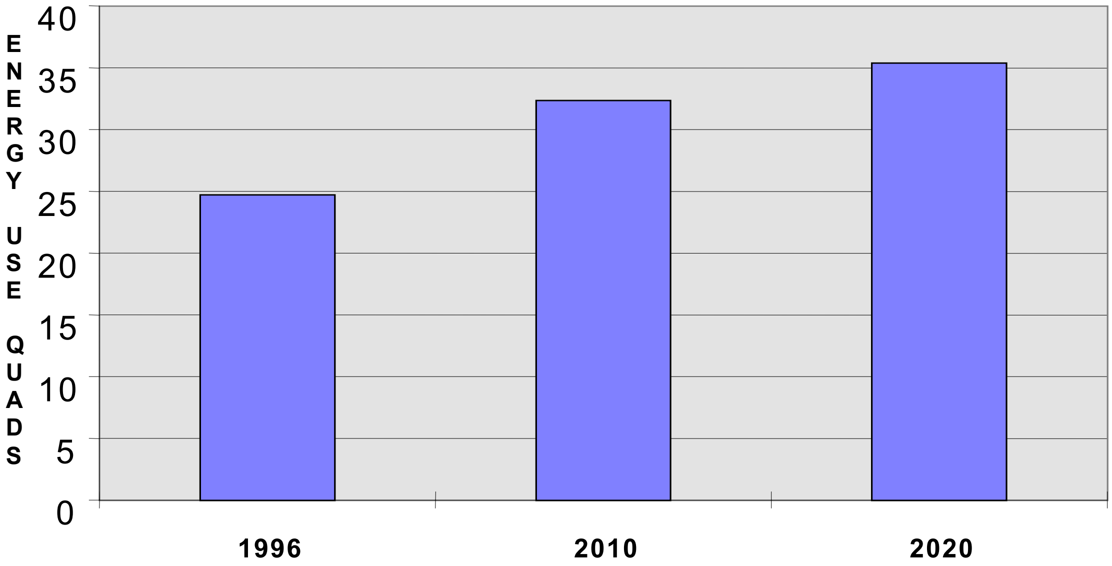


Fig. 6.4 Transportation Efficiency Indicators: Fractional Increase, 1996 - 2020

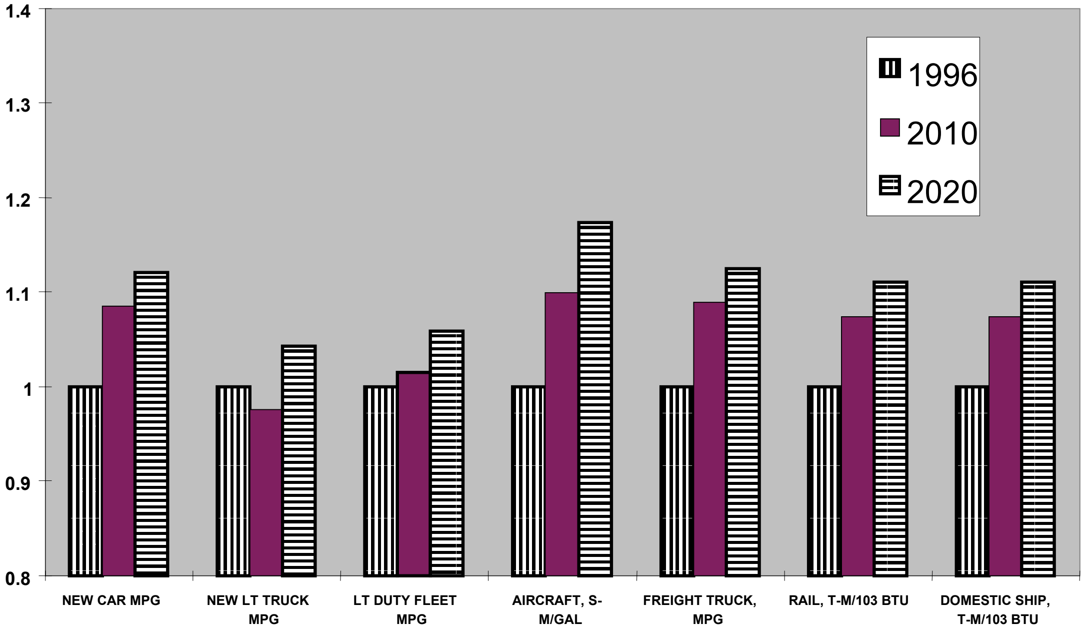
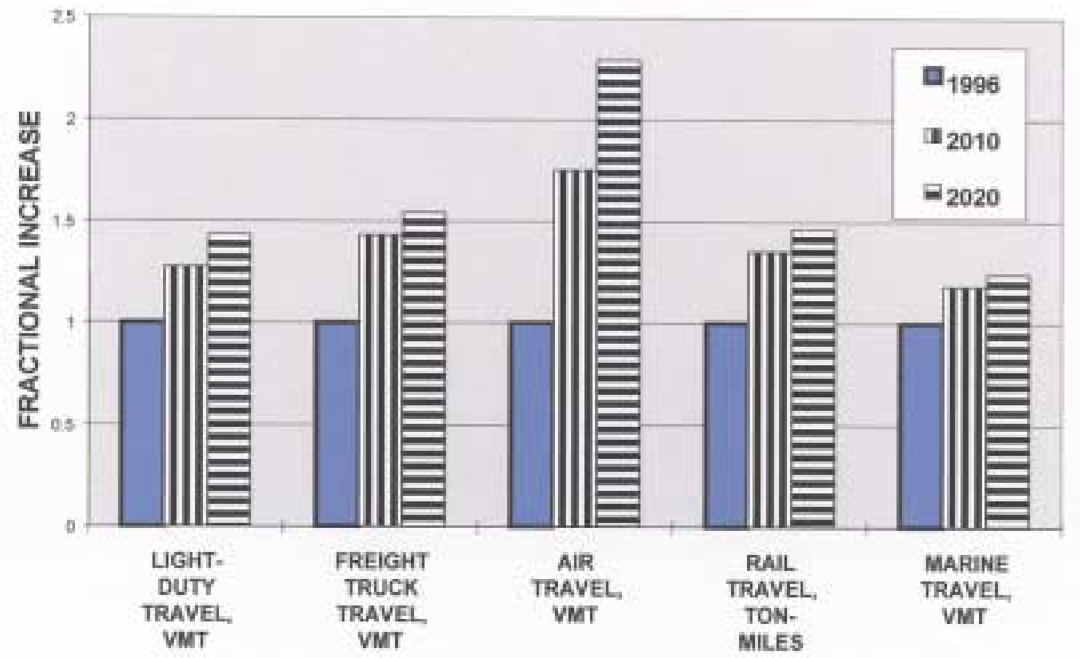


Fig. 6.5 Projected Travel Growth, 1996 - 2020, EIA Reference Case



The modest 23-year improvement in light-duty fleet efficiency is perhaps the most problematic aspect of the scenario results, because at present the auto industry appears poised to introduce a variety of exciting new technologies ranging from hybrid-electric drivetrains to fuel cells. The NEMS model does take account of new technologies, but the Baseline forecast projects modest market shares for many of them because of high first costs and, in some cases, delays in market introduction because of remaining development requirements. Thus, in the BAU Scenario, fuel cell vehicles do not enter the market until 2006, and do not reach 10,000 vehicle sales/year – an exceedingly modest number – until 2015. Thus, they play essentially no role in fleet fuel consumption throughout the period; there are only 110,000 fuel cell vehicles out of 254 million *total* vehicles in the 2020 light-duty fleet. Electric-diesel hybrids, another potentially important efficiency technology, are in the fleet in 2000 but, due to high costs, never exceed sales of 12,000 autos/yr or 25,000 light trucks/yr throughout the period.

6.3 POLICY IMPLEMENTATION PATHWAYS

6.3.1 Definition of Pathways

We have modeled two policy implementation pathways. The Moderate scenario contains policies that would fit a changed political climate that would allow low-cost policies aimed at reducing GHG emissions from the sector. The Advanced scenario contains policies that would fit a political climate that would allow somewhat more aggressive policies, including Voluntary Agreements that result from at least the *threat* of new, higher CAFE standards (a Sensitivity Case examines the effect of such standards). Table 6.5 lists the policies for the two scenarios.

The choice of policy options to be included in the scenarios reflects our assessment of the political feasibility and likely effectiveness of a wide variety of potential policies under the conditions defined in the scenario descriptions. Obviously this type of assessment is extremely subjective and uncertain:

seasoned politicians routinely miscalculate their ability to get proposed legislation enacted into law, and legislative surprises are a fact of life in political circles. As noted above, a case can be made that the policies we selected for light-duty vehicles – golden carrot awards in the form of the tax credits for high efficiency vehicles suggested by the Administration and, for the Advanced scenario, a Voluntary Agreement between automakers and the U.S. government to increase light-duty fleet fuel economy – are either too ambitious ("U.S. automakers will never willingly adopt Voluntary fuel economy targets") or too cautious ("why not include CAFE standards?"). As noted, we do explore the impact of new CAFE standards in a Sensitivity Case within the Advanced scenario. The polices we have examined are as follows:

Table 6.5 Transportation Policy Pathways

Moderate Scenario	Advanced Scenario
➢ 50% increase in government/industry R&D investment	• 100% increase in government/industry R&D investment
➢ Tax credit for high efficiency vehicles	• Same
➢ Acceleration of air traffic management improvements	• Same
➢ Program to promote investment in cellulosic ethanol production	• Same
➢ Invigorated government fleet program promoting alternative fuels and efficiency	• Same, more rigorous requirements
➢ No change in LDV fuel economy standards	• Voluntary Agreements to improve fuel economy, for LDVs, freight trucks, and aircraft (Sensitivity Case: new CAFE standards)
➢ Telecommuting stimulation	• Same
	• Domestic carbon trading system with assumed permit price of $50/tC • Variabilization polices (pay-at-the-pump auto insurance) • Intelligent traffic systems controls

Air Traffic Management Improvements. The EPA and FAA have a joint program aimed at rationalizing air traffic management to substantially reduce the time spent waiting "on line" on the ground and circling around airports while waiting for landing slots. This program, known as CNS/ATM (Communications, Navigation, and Surveillance/Air Traffic Management) involves substantial changes in flight procedures coupled with installation of a network of ground and airborne technologies involving digital communication and computer interpretation of flight instructions, and satellite systems that precisely locate aircraft. Successful implementation of this program will substantially reduce both energy losses and emissions of criteria pollutants. A recent FAA analysis estimates savings in energy use of up to 6 percent for North America (FAA, 1998); we have adopted a five percent savings as our target level for 2020. Additional benefits beyond reduced fuel cost and greenhouse emissions include significant reductions in criteria emissions (9 percent for NOx, 12 percent for CO, and 18 percent for HC), improved aircraft utilization, and time savings for passengers.

CNS/ATM involves six technology groups:

- P-FAST – Passive final approach spacing tool, designed to narrow the allowable gaps between aircraft.
- SMA – Surface movement advisor, a tool designed to more efficiently move aircraft from touchdown to gate or gate to takeoff.
- CDM – Collaborative decision making, designed to find optimal reroutings when aircraft meet unexpected conditions and must change flight plans.
- TMA – Traffic Management Advisor, another collaborative decision-making tool that will predict delays at an airport and reschedule traffic at other airports to avoid overloading the first airport.
- URET – User request evaluation tool, which performs after-the-fact analysis of flight performance
- CTAS – Center Terminal Automation System, incorporating parts of P-FAST and TMA for smaller airport operations.

FAA has adopted promotion of CNS/ATM as a goal of its Strategic Plan ("Achieve progress toward global implementation of satellite-based communication, navigation, surveillance, and air traffic management (CNS/ATM) by assisting planning and implementation efforts in each world region." (FAA, 1996)). However, there currently is no formal mechanism for implementing this program, and the FAA budget appears insufficient to include the large capital investments needed. In a BAU environment, with continuing low prices for jet fuel, implementation would likely be slow despite its benefits. If FAA analysis is correct, however, the program should easily pay for itself in fuel savings, improved aircraft utilization, and other savings. Therefore, we expect rapid implementation to fit easily within both the Moderate and Advanced scenarios.

Carbon Permit Program. Carbon permit programs define acceptable levels of carbon emissions and allocate these emissions to carbon emitters by auctioning permits or allocating the permits to individual sources, with trading allowed. The impact of a carbon permit program that results in a $50/metric ton price for carbon in 2005 through 2020, a price that translates to about $0.12/gallon of gasoline given gasoline's carbon content, is reflected in the Advanced scenario. This modest increase in gasoline price – about 10 percent if prices remain low – will yield a small reduction in projected levels of transportation demand and carbon emissions.

Studies done in the 1970s and early 1980s of fuel price effects on fuel demand (Dahl, 1986) found that fuel demand was very responsive to fuel price over the long term – that a 10 percent increase in price would cause a drop in fuel use of approximately the same percentage, with half the drop coming from improved vehicle efficiency and half from reduced travel. More recent estimates, discussed in Plotkin and Greene (1997) project only about a 5 to 6 percent decrease in fuel use from a 10 percent price increase. Thus, a 50 cents per gallon increase in gasoline price – about the level added by the combination of carbon permit system and 2010 "Pay-at-the-Pump" (PATP) insurance policy discussed below (added to a baseline $1.25/gallon) might be expected to reduce gasoline use by perhaps 20 percent over the long run. The latter values reflect the full experience in gasoline markets over the past three decades and should be more credible. Note that a 50 cents per gallon gasoline price increase would cost a typical driver (12,000 miles/yr. 20 mpg) about $300/year.

Cellulosic Ethanol Commercialization Program. The use of cellulosic ethanol in vehicles would be extremely useful in reducing GHG emissions because, over the fuel cycle, such use generates a small fraction of the emissions generated by the equivalent use of gasoline – about 10 or 20 percent depending on assumptions. The DOE has an active research program aiming to develop commercializable processes for producing ethanol from energy crops, forest and agricultural residues, and municipal wastes (NREL, 1999). If successful, cellulosic ethanol would first be used primarily as a blending agent with gasoline, with added value as an octane enhancer and oxygenate.

Current market incentives for ethanol use include exemption from most federal taxes on gasoline for gasoline/ethanol blends, mandated oxygenate levels in Federal reformulated gasoline (RFG) required in ozone nonattainment areas (and other areas that have joined the RFG program), alternative fuel fleet requirements mandated by EPACT, and CAFE credits associated with the sale of alternative fuel vehicles. The latter two incentives affect vehicle production and sales only, and do not currently have any effect on ethanol production.

In the scenarios, we use the 1990 AEO assumptions about extension of the current "gasohol" tax break: that it will not expire in 2007 but continue at the nominal level of $0.51 per gallon. The value of the credit will thus be eroded by inflation over time to $0.27 per gallon in 2020. We also assume a program of loan guarantees, tax breaks, or subsidies to reduce or eliminate the added risk of investment in new ethanol plants. In addition, we envision substantial reductions in the *cost* of cellulosic ethanol production (to 50 percent of current corn ethanol costs (based on Bowman and Leiby, 1998; NREL, 1999; and NRC, 1999a) resulting from focused research on ethanol production processes associated with increases in transportation R&D funding in both scenarios. A recent assessment of DOE's bio-ethanol research program by the National Research Council (1999b) made several recommendations for redirecting and expanding the effort, including:

1. improvement in pretreatment efficiency to minimize enzyme requirements,
2. development of less expensive more effective digestive enzymes,
3. improved design to minimize costs, improve efficiency, and maximize coproduct value,
4. research in bioengineering and genomics to improve yield, pest resistance and stress resistance, and
5. research into feedstock changes to improve processing and conversion efficiency.

Tax Credit for High Efficiency Vehicles. A set of tax credits has been proposed for purchasers of significantly more fuel-efficient vehicles. The proposed schedule is shown in Table 6.6, where efficiency improvement levels are matched with vehicle technologies. The model assumes the tax credit will be phased out as sales increase much beyond 50,000 units per year, which would be expected to greatly reduce the penetration of hybrids relative to a tax credit that did not have a cap.

Table 6.6 Schedule of High Fuel Economy Tax Credits and Associated Technologies

MPG Increase	Technology	Credit
1/3	Gasoline hybrid	$1,000
2/3	Diesel-electric	$2,000
Twice	Gasoline and methanol fuel cell	$3,000
Three times	Hydrogen fuel cell	$4,000

The modeled tax credits reflect the Administration's early tax proposals. The current Administration proposal has changed the credits to reflect the "degree of electrification" of the powertrain rather than the efficiency gain. We have not attempted to model this latest proposal. Existing tax credits for battery electric vehicles are assumed to continue in effect in all scenarios.

Invigorated Government Fleet Programs. EPACT regulations require Federal and State vehicle fleets and some private fleets (of alternative fuel suppliers) to introduce alternative fuel vehicles on a rigorous schedule. AEO99 assumes that the EPACT schedules will be met. However, these fleets are well behind schedule in their compliance, and few if any analysts believe that full compliance will occur. Consequently, in accepting the AEO99 Reference Case as our Baseline Case, we are implicitly assuming that a shift in government policy concerning fleet vehicle purchases will allow full compliance; BAU would *not* yield compliance with EPACT schedules.

R&D Spending Increase. The Federal government, primarily the DOE, currently spends several hundred million dollars annually in support of the development of advanced vehicle technology, including fuel cells, hybrid drivetrains, advanced diesel power plants, advanced materials, and so forth. Other agencies, e.g., Department of Transportation (DOT), National Aeronautics and Space Administration (NASA), Department of Defense (DoD), and so forth, sponsor additional research in other transportation areas. Traditionally, Federal R&D funding for aircraft and highway vehicle technology has been much greater than in other areas, e.g., funding in rail and maritime freight hauling has been minimal.

The most prominent Federal transportation R&D program in recent years has been the PNGV, a joint federal/industry program under which both partners have contributed about $300 million/year. The NRC has concluded that the PNGV has made substantial progress in reaching its goal of an (up to) 80 mpg family car, for example, the three industry partners now have prototype family-size cars capable of about 60 mpg on the EPA test cycle. However, NRC also concluded that PNGV has significant challenges remaining, in particular emissions and cost problems with direct-injection engines, high costs for power electronics and electric motors, cost and performance problems with high-power batteries for hybrid vehicles, and immature technology for multi-fuel processing for fuel cells. The Council’s overall conclusion is that the dollar amounts provided to the PNGV are “far below the level needed to meet the challenges on a timely basis” (NRC, 1999a). An increase in funding for this and other highway vehicle programs under the auspices of DOE’s Office of Transportation Technologies (OTT) may allow better results from the ongoing R&D programs in the form of earlier commercialization of new technologies, reduction in first costs, and increased performance (in fuel economy and other consumer attributes). Similar increases in programs under other federal agencies, e.g., NASA, DoD, DOT, etc. should provide similar results.

The following box (Increased Transportation R&D Investment) describes some key characteristics of a 50 or 100 percent increase in Federal transportation R&D spending.

Telecommunications Programs. Telecommuting involves the substitution of telecommunications services for commuting in the workplace; that is, workers would work out of home or satellite offices and communicate with their offices via computers. The primary candidates for telecommuting appear to be white collar workers with a managerial and professional specialty, or workers in sales and clerical jobs, e.g., workers who deal primarily with creating, distributing, or using information (OTA, 1994). Over 50 percent of U.S. jobs fit this description, e.g. upward of 70 million jobs could theoretically be candidates for telecommuting. DOT projections indicate there could be as many as 50 million telecommuters by 2020 (U.S. DOT, 1993). Aside from commuting trips, telecommunications will also affect other trip categories, e.g. shopping (internet sales, for example).

Increased Transportation R&D Investment

The Federal government currently spends several hundred million dollars per year on research aimed primarily at improving energy efficiency and reducing GHG emissions in the transportation sector. The U.S. DOE is a major sponsor of this R&D, with its OTT contributing $244 million to the effort in FY99.

To be effective, a 50 or 100 percent increase in this federal transportation R&D budget will require both a careful targeting of funds to critical research areas, and a gradual rampup of funds to allow for careful planning, assembly of research teams, and expansion of existing research teams and facilities. Well-focused and intelligently managed technology R&D programs average societal rates of return on the order of 50 percent per year (PCAST, 1997). The Moderate and Advanced scenario proposals envision a 5-year rampup time.

Examples of promising research areas for increased funding include:

Light Duty Highway Vehicles

- Direct injection engines, particularly NOx after-treatment for GDI engines, NO_x and PM emissions reduction in CIDI engines.
- Proton exchange membrane fuel cell systems, particularly reforming liquid fuels, hydrogen storage options, contaminant removal from reformate, fuel cell balance of plant, and systems integration.
- High power energy storage systems for hybrids, including reactivation of research on ultracapacitors and flywheels.
- Power electronics and electric motors.
- Advanced lightweight materials, particularly vehicle manufacturing technologies and vehicle design.
- Fuels, esp. lower cost, more energy-efficient production of cellulosic ethanol, hydrogen, and clean liquid fuels from natural gas.
- Advanced onboard storage technologies for hydrogen (see above) and natural gas.
- Electric vehicle batteries, especially lithium polymer but also cost reduction and performance enhancement of nickel metal hydride batteries, safety and electrolyte and cathode performance for lithium-ion batteries.

Medium-duty delivery vehicles and transit buses

- Hybrid-electric drivetrains
- Advanced TDI diesel engines, especially emission control.
- Natural gas storage and system design
- Advanced lightweight materials

Heavy-duty highway vehicles

- Advanced diesel engines and emission controls
- Advanced aerodynamic drag reduction technologies
- Ultra-low rolling resistance tires
- Accessory load reduction strategies
- Low friction drivetrains

Air travel

- Laminar flow control and other advanced aerodynamic technologies
- Blended wing-body aircraft
- Unducted fan engines
- Thermodynamic improvements to turbine engines
- NO_X control technologies

Maritime

- Compressed and liquefied natural gas onboard diesel-powered coastal vessels
- Molten carbonate fuel cell propulsion, with liquefied natural gas as a fuel
- PEM fuel cell propulsion with hydrogen fuel

Rail travel

- Fuel cell propulsion systems
- Advanced electric motors
- Oxygen-enrichment systems for locomotive diesel engines
- Advanced diesel engines
- Advanced rail lubrication systems
- Intermodal/rail competitiveness research, including improved door-to-door service management and improved equipment management through advanced command, control, communication, and information systems.

Sectoral analysis

- Further development of the transport sector models in the National Energy Modeling System

Although telecommuting will eliminate many work trips, it can have "take back" effects such as stimulation of sprawl (workers can live in rural areas if they don't commute, or commute only once or twice a week). Further, telecommuting clearly will have different receptions from workers depending on their family situations, personalities, and other factors. At moderate levels of telecommuting, and where it is largely voluntary, telecommuting's reception should be quite positive since it allows workers freedom from commuting and greater flexibility in dealing with family requirements. On the other hand, some analysts believe that there may be a backlash to increased telecommuting due to negative impacts on workers including lack of communication, social isolation, loss of benefits, lack of career advancement, and stress from mixing work and home life (OTA, 1994). Obviously, the design of the specific programs will have a great impact on the willingness of workers to participate.

A 1994 DOE study on the direct and indirect impacts of expanded telecommuting estimated that, by 2010, telecommuting could save about one percent of total motor fuel use (Greene et al, 1994). The DOE study adopted the earlier DOT study's estimate of 30 million telecommuters by 2010, telecommuting 3 to 4 days per week, and assumed that 80 percent of them would be working at home. Although the direct impact of this level of telecommuting was estimated to be the avoidance of nearly 70 billion miles of commuting per year, DOE estimated that about half of the potential fuel savings would be lost to increases in travel demand due to improved traffic flow and the travel impacts of increased urban sprawl caused by the telecommuting.

Some public policy measures have been proposed to promote telecommuting, notably Regulation XV, proposed by the Southern California Air Quality Management District in 1987 but not enacted, that would have required larger employers (with over 100 employees) to adopt plans for alternative commuting options, and the travel demand management funding provided by ISTEA at the Federal level (OTA, 1994). Policies that would promote telecommuting include eased IRS provisions to allow "teleworkers" to more easily deduct computer and telecommunications equipment as a business expense on personal income taxes, and tax credits for businesses' startup costs for telecommuting programs, e.g., worker training and equipment costs. Policy changes at the local level include easing of restrictions on home-based work and amendment of zoning requirements to allow a reduction in the minimum number of parking spaces in office buildings, to account for telecommuting (OTA, 1994).

Intelligent Traffic Systems Controls. Intelligent traffic systems controls, including intelligent roadway signing, staggered freeway entry, and electronic toll collection, are being introduced into U.S. cities, and their use is expanding. In the Advanced scenario, both increased R&D and government investment in these systems above anticipated levels lead to a wider range of systems available and faster expansion of their use.

Voluntary Agreements. As discussed more extensively in the Industry chapter, voluntary agreements are "agreements between government and industry to facilitate voluntary actions with desirable social outcomes." Such agreements are more common outside of the United States; the most relevant for this case is the agreement between the European automobile manufacturers' association, ACEA, and the European Union to cut carbon dioxide emitted from car exhausts by 25 percent/vehicle over the next 10 years (EC & ACEA, 1999). This pledge would increase average new car fuel efficiency from 30.6 mpg today to 40.7 mpg by 2008. Among the car companies agreeing to this are subsidiaries of American manufacturers. In the Advanced scenario, we assume that all manufacturers of light-duty and heavy-duty highway vehicles will commit to voluntary standards to increase fuel economy. The light-duty standards are 40 mpg in 2010 and 50 mpg in 2020 for automobiles, and 26 mpg in 2010 and 33 mpg in 2020 for light trucks. Heavy-duty standards are not specified at this time.

Obviously, the precise form of any voluntary standards would be determined in negotiations between the industry and the Federal government. We presume that such standards would allow "trading" of mpg credits among companies and would make no distinctions between domestic and import fleets, to avoid market distortions. Whether standards are in the form of a single target value applying to every company or a variable target that accounted for market segment differences among companies would affect the identity of “winners and losers” among the companies, but would likely not affect the industry-wide outcome very much.

“Variabilization” Policies. The objective of variabilization policies is to transfer the incidence of what are currently fixed costs of motor vehicle operation to variable costs. Perhaps the most significant of these proposed policies is “Pay-at-the-Pump” (PATP) automobile insurance. If only about one-fourth of the total cost of automobile insurance were variabilized by means of a tax on gasoline, it would amount to $0.25 to $0.50/gallon additional cost. Other potential targets of variabilization are free parking, or road revenues currently raised by property or general sales taxes. We propose to focus in this analysis on PATP, as representative of this class of policies because it produces a substantial change in fuel prices and is readily modeled in NEMS.

Numerous variations on the basic idea of PATP have been proposed (El-Gassier, 1990; Sugarman, 1991; Dougher and Hogarty, 1994; Gruenspecht et al., 1994; Khazzoom, 1997) with the intent to approximate a per-mile insurance fee by means of a surcharge on gasoline. Since at least some of the risk drivers impose on other travelers *is* proportional to miles driven, PATP could effectively internalize at least a portion of a public safety externality, thereby increasing economic efficiency (Kavalec and Woods, 1997). Whether this can be achieved depends on a number of complex factors, including the efficiency of the existing system. Charging per gallon is an imprecise way of charging per mile because of the large variation in mpg across the vehicle fleet. On the other hand, larger, heavier vehicles, which generally represent the less fuel-efficient portion of the fleet, impose greater risks on other travelers, an argument for larger insurance premiums. To date, these issues remain largely unresolved. However, one clear benefit of PATP will be an elimination of *some* part of the problem of uninsured drivers, since PATP can automatically provide partial coverage to all drivers.

Our design for the PATP fee is simple. For the year 2003 to 2012, a surcharge of $0.34 per gallon of gasoline equivalent energy is added to the price of all motor fuels. From 2013 on, the surcharge is increased in one large step to $0.51 per gallon of gasoline equivalent energy to roughly correct for the increasing efficiency of the light-duty vehicle fleet.

6.3.2 Barriers to Energy Efficiency

Barriers to increased energy efficiency and reduced GHG emissions in transportation energy use include external costs and benefits, imperfect information, and imperfect competition. Fuel prices and transportation services do not reflect total social costs such as air pollution and climate change. Uncertainty about the costs and benefits to consumers of increased efficiency, caused by uncertainty about future fuel prices and a lack of explicit information about the incremental costs of higher efficiency may lead to under-investment in fuel economy technology. The inability of companies to capture the full benefits of advances in the science and technology of efficiency leads to under-investment in R&D. And the financial risks to manufacturers posed by the introduction of new technologies requiring substantial design changes that may or may not be well received by consumers can lead to the under-adoption of new technology in an oligopolistic market.

Underpriced Fuels and Transportation Services. A strong case can be made that energy fuels are underpriced, because market prices do not take full account of a variety of social costs associated with fuel use, and especially oil use (transportation is 95 percent dependent on petroleum products for fuel). Those externalities most directly tied to fuel use are greenhouse gases from direct fuel use by vehicles; air, water, and land pollution, including greenhouse gases, associated with discovering, extracting, processing, and distributing gasoline and other transportation fuels; and the energy security and economic impacts associated with the uneven geographic distribution of oil resources, that is, military expenditures associated with Persian Gulf political instability; monopsony costs associated with artificially high oil prices; and the costs to the U.S. and world economies associated with occasional oil price shocks.

Transportation services also are underpriced, for reasons that include but go beyond underpriced transportation fuels. Social costs more closely tied to transportation *services* than to energy use include air pollution – excluding greenhouse gases – associated with vehicle use, environmental impacts associated with transportation infrastructure, societal costs associated with transportation accidents (especially on the highways), the costs of highway congestion, and so forth. These costs as well as the costs of petroleum use in transportation have been examined by a number of analysts, most notably Delucchi (1997), and for the United States probably run into the hundreds of billions of dollars annually.

Imperfect Information. In making vehicle purchases, consumers and businesses experience difficulty in making rational choices about trading off the costs and benefits of different levels of energy efficiency. One cause is the difficulty in determining the true costs of higher efficiency *despite* the information on fuel economy posted on new autos and light trucks. Vehicle purchasers are rarely given explicit choices in efficiency coupled with explicit price differences associated with these choices. Instead, these price differences are buried in base prices or in the price of complete subsystems such as engines, with efficiency differences always coupled with substantive differences in other critical consumer attributes such as acceleration performance, level of luxury, vehicle handling, and so forth. Additionally, properly trading off fuel savings versus changes in vehicle price involves trading off the time-discounted value of the fuel savings against the present cost of the vehicle – a calculation that many vehicle purchasers are not familiar with. Note, however, that if consumers were extremely concerned about energy savings and determined to base their purchasing decisions on them, automakers and dealers would have a strong incentive to provide them with the information that is now lacking in the marketplace, as well as with vehicle choices that provided clearer tradeoffs. It can be argued that the lack of such information and choices is simply the consequence of consumer disinterest in improved fuel economy in the context of low fuel prices.

It is also worth noting that new car purchasers – who have a dominant influence on the design decisions of automakers – are not representative of the driving public, many of whom purchase their vehicles secondhand. In particular, new car purchasers are substantially wealthier than average drivers, which should skew their purchase preferences away from considerations of fuel use and towards considerations of ride quality, power, and other vehicle qualities.

Another potential source of difficulty in making rational vehicle choices is the substantial uncertainty associated with future fuel prices. Over the past two decades, the price of a barrel of oil has varied by fourfold, reaching highs in the early 1980s and lows within a few years thereafter. Recently, oil prices have more than doubled from near historic lows, and energy analysts widely acknowledge that disturbances to oil markets could cause future prices to escalate rapidly to multiples of even today's higher prices (and stay there for periods ranging from a few weeks to a few years). Also, there is growing controversy about the potential for oil resource shortages, coupled with higher prices, possibly beginning within the lifetime of most vehicles purchased today.

Difficulty in Capturing the Market Benefits of Technology Advances. Another barrier to firms' investments in research to develop energy efficient technology is the ability of other firms to appropriate technological advances. By this we mean that increases in knowledge of new designs and technology are easily transferred to other industry entities without necessarily benefiting the individuals or company that provided the research investment that lead to the innovation. Further, companies that absorb the market risk of introducing new technology generally will not reap the full benefits of trailblazing new markets because the attention and car owner trust brought about by a successful market launch may be transferable to a competitor's version of the new technology. Both attributes tend to yield under-investment in technology development and reluctance to introduce new technologies in areas where markets are not well established.

Risks to Manufacturers. Redesigning motor vehicles for substantial fuel economy improvements requires massive capital investments. In an intensely competitive car market a negative reaction by consumers, even to subtle aspects of a new technology, could result in massive financial losses to manufacturers. Manufacturers will therefore be understandably reluctant to commit to rapid, sweeping design changes to improve fuel economy, a matter of relatively small concern to motorists.

Table 6.7 outlines the programs and policies adopted in the two scenarios, and the barriers they address.

Table 6.7 Policies to Address Barriers to Efficiency Improvements in Transportation

		Barriers to Efficiency Improvement				
Policies	**Scenario**	**Underpriced Fuels**	**Underpriced services**	**Rational choices**	**Technology fungibility**	**Manufacturers risk**
R&D spending increase	Both	X	X		X	
Voluntary agreements	Advanced	X	X			X
Pay-at-the-pump	Both	X	X			
Tax credits for efficient vehicles	Both	X	X		X	
Air traffic management	Both	X			X	
Government fleets	Both	X		X		X
Cellulosic ethanol	Both	X				
Emissions and fuels standards	Both	X	X	X		X
Carbon trading system	Advanced	X				
Tele-commuting	Both		X			
Intelligent traffic systems	Advanced	X	X			

6.4 METHODOLOGY FOR ANALYZING POLICY IMPACTS

This section outlines the methods used to translate the policies of the Moderate and Advanced scenarios to inputs and changes to the CEF-NEMS model. A detailed description of each modification to NEMS input data or source code can be found in Appendix A-3.

6.4.1 Policy: Air Traffic Management Improvements

This policy is expected to achieve a five percent reduction in air traffic fuel use. This is simulated by increasing the rate of increase in the efficiency of existing stock, an effect historically due primarily to retrofitting existing airframes with newer, more efficient engines. The intention here is to reflect a general improvement in aircraft operating efficiency due to more effective flight planning and reductions in excessive time spent waiting in the air or waiting on the ground due to traffic congestion. Specifically, the annual rates of change in fleet-wide efficiency were increased from 0.18 percent to 0.34 percent for wide-body aircraft, and from 0.44 percent to 0.60 percent for narrow-body planes.

6.4.2 Carbon Permit Program

The carbon permit program is implemented at the national level in the integrated runs of CEF-NEMS. A charge of $50 per metric ton of carbon is imposed to simulate the effect of a tradable permit program. Although there are no programming changes made to the transportation sector modules, the carbon charge raises the price of transportation fuels, reducing transportation demand and shifting technology choices within the transportation sector.

6.4.3 Cellulosic Ethanol Commercialization Program

Several key assumptions were added to NEMS to reflect the success of research to reduce the costs of cellulosic ethanol and programs to promote its use. The AEO99 Reference Case continues tax credits for ethanol but in nominal dollars so that the value of the credits in constant dollars decreases gradually with time. We retain this assumption in all scenarios. The AEO99 also includes risk premiums for investment in cellulosic ethanol production to reflect the uncertainties associated with the market for a new fuel supported, in part, by government subsidies. We assume that a loan guarantee or subsidy program is created by the federal government to eliminate these added risks, so that funds can be borrowed for investment in ethanol production at prime rates. Finally, the AEO99 assumes that by 2020 the costs of producing ethanol from cellulose can be reduced by 20 percent over the current costs of production from corn, about $1.40 per gallon of ethanol. We assume that a 50 percent cost reduction is possible by 2020, more in line with the goals of the DOE's R&D program, and consistent with the most optimistic estimates reported by the National Research Council, $0.70 per gallon in 2015 (NRC, 1999, table 2-2).

6.4.4 Tax Credit for High Efficiency Vehicles

The tax credit was implemented in NEMS by reducing the low-volume prices of alternative fuel vehicles by the amounts indicated in Table 6.5 above. In matching low-volume prices only, we are assuming that the tax credits will be phased out as sales increase much beyond 50,000 units per year. The gasoline hybrid is an exception, since it is handled by the FEM subroutine rather than the AFVM. The FEM does not allow for phasing out of the credit with increasing sales volume, and so the $1,000 credit is maintained throughout.

6.4.5 Invigorated Government Fleet Programs

The principal effect of invigorated government fleet programs for alternative fuel vehicles is reflected in increased retail availability of alternative fuels. The availability of alcohol fuels and hydrogen were increased gradually from negligible levels today to 50 percent by 2020. Details are provided in Appendix A-3.

6.4.6 R&D Spending Increase

The effect of increased spending on research, development, and demonstration is represented by:

1. Advancing the introduction dates for new technology (for light-duty vehicles by 30 percent in the Moderate case and, with the additional incentive of the voluntary standards for higher fuel economy, by 40 percent in the Advanced case),
2. Adding a few new technologies (two advanced materials technologies for light-duty vehicles, two new technologies for heavy-duty vehicles, and a wing-body aircraft design for the air mode),
3. Incrementally reducing the cost, and
4. Increasing the mpg performance of selected technologies.

Details of the changes made to the original NEMS assumptions are provided in Appendix A-3.

NEMS currently has the capability of modeling a large but not unlimited number of fuel efficiency technologies. There are technologies we have not modeled, and within those modeled, only some are assumed to undergo significant price reductions under the Moderate and Advanced scenarios. **This is not to imply that we have perfect foresight of which technologies will be commercially successful, and which will respond substantially to increases in research emphasis.** Clearly we do not, and we imagine that, were the societal conditions and policies postulated in the scenarios actually to come about, the U.S. fleet of transportation vehicles would be far from a perfect match of the fleet characteristics projected by CEF-NEMS in this exercise. While we have made our technology assumptions with care, we recognize that some we have included will not be realized while others we have excluded will succeed in the marketplace. It is entirely possible, for example, that significant improvements in natural gas vehicle storage technologies, coupled with changes in gas availability and other factors, could lead to a far greater penetration of the fleet by natural gas vehicles than is projected here. Similarly, a breakthrough in lithium-polymer battery technology, perhaps coupled with greater-than-expected cost reductions in power electronics and electric motors, could lead to a larger penetration of the fleet by electric vehicles. And inadequate progress in emission controls for diesel vehicles, or further tightening of fine particulate matter standards based on new health effects research or greater demands by the public, could lead to far *smaller* penetration of diesel technology (we explore this possibility in a “no diesel” sensitivity run of the Advanced scenario, below). We cannot overcome these uncertainties. However, as noted earlier, there exists a large enough portfolio of promising efficiency technologies to provide some comforting redundancy. By using the great deal of information available about the status of the technology portfolio and the historic record of technological progress for similar technologies, we believe we can make a reasonable estimate of the likely *overall* effect of increased R&D even if we get the precise details wrong.

6.4.7 Telecommuting Programs

As discussed previously, the 1999 AEO vmt projection reflects a rate of growth (1.6 percent/yr.) that is quite low by historical standards (3.1 percent from 1970-96; 3.0 percent from 1986-96), and we believe a higher rate, perhaps closer to 2.0 percent, would be more realistic. In a sense, then, it could be argued that some transportation demand management programs, including telecommuting programs, are already implicitly included in the Reference Case. And even given the implementation of vmt reduction programs that could credibly be implemented under the definitions of the Moderate and Advanced scenarios, we are skeptical that they could reduce vmt enough to achieve the EIA 1.6 percent rate of increase. Thus, we have chosen not to further reduce this rate in the scenarios, but simply to consider the

1.6 percent rate in the two policy scenarios to be somewhat more realistic than the same rate in the Reference Case.

6.4.8 Intelligent Traffic Control Systems

To simulate the effect of increased usage of ITS systems in the Advanced scenario, we reduced by one percentage point the degradation factor in NEMS that translates EPA values of fuel economy into "on-road" values. The factor accounts for congestion and other factors that increase fuel usage over the value that would be computed using the EPA values.

6.4.9 Voluntary Agreements

In the advanced case only, voluntary fuel economy targets are implemented with changes to NEMS inputs intended to simulate greater manufacturer attention to fuel economy relative to other vehicle attributes. The dates for first introduction of future fuel economy technologies were foreshortened by 40 percent. However, no date was moved closer to the present than 2003. The weight increases projected in the AEO99 Reference Case (20 percent for passenger cars and 30 percent for light trucks) were reduced to actual increases through 1998 for both vehicle types. In addition, for the Moderate scenario, the AEO99 factors that relate the demand for performance to changes in vehicle horsepower were changed to (lower) factors developed by Energy and Environmental Analysis, Inc. (EEA), which helped develop this version of NEMS; for the Advanced scenario, the EEA factors were cut in half to reflect the pressure on automakers to restrict power increases in order to be able to comply with the Voluntary Agreement. As a result, in both scenarios, the demand for larger engines was considerably reduced, though horsepower increases were still allowed through 2020. Given the substantial reductions in vehicle weight in this scenario, there is still scope for significant increases in performance as measured by the ratio of horsepower to weight. Similar changes were made to accelerate the introduction of fuel economy technology in heavy-duty vehicles, as described in detail in Appendix A-3.

Finally, the EIA Reference Case assumption that consumers estimate the value of fuel economy based on only the first four years of fuel savings, discounted to present value at 8 percent real, was changed to a discounting of fuel savings over the full 12 years of expected vehicle life at a 15 percent per year, real discount rate. The function of these parameters in the NEMS models is to represent manufacturers' decisions about how consumers will perceive the value of fuel economy, rather than to actually represent consumers' decision-making. Thus, these changes are intended to reflect changes in manufacturers' willingness to adopt fuel economy technology driven by their commitment to a Voluntary Agreement rather than a change in consumers' attitudes towards higher mpg.

6.4.10 "Variabilization Policies" (Pay-at-the-Pump Insurance)

For the Advanced scenario only, variabilization policies were simulated by adding a Pay-at-the-Pump insurance surcharge to all motor fuels. This surcharge pays for a minimum level of liability insurance for all motor vehicles, leaving the net cost of highway travel roughly constant. What is usually paid as part of an annual or semi-annual fixed cost now is "variabilized" and paid for with the purchase of fuel.

6.4.11 New CAFE Standards (Sensitivity Case)

The NEMS Transportation Sector Model permits the specification of alternative CAFE standards for passenger cars and light trucks[3]. We specified identical standards for domestic and imported vehicles, and set the non-compliance fine to $150 per mpg (vs. $50 per mpg for the current standard) by which a manufacturer's corporate average fuel economy falls below the standard. If domestic or imported passenger cars or light trucks fail to meet the standard in any year, NEMS adds the fine to the dollar value of higher fuel economy for that class in its technology selection subroutine, increasing the market penetration of fuel economy technologies. In addition, NEMS advances the first date of technology adoption by one year, to reflect the belief that manufacturers faced with a known standard will accelerate the introduction of technologies, if necessary.

The CAFE constraint operates only on the NEMS submodel dealing with gasoline-fueled vehicles; alternative fueled vehicles (including diesels) are treated in a separate model of NEMS, and NEMS does not apply the CAFE constraint to this submodel. This means that obtaining a given level of fleetwide fuel economy requires some trial and error, experimentation with different levels of "gasoline-only" CAFE constraints until the total fleet reaches the desired mpg average. For example, obtaining a 65 mpg CAFE for the automobile fleet required the use of a 55 mpg target CAFE in the gasoline vehicle submodel.

6.5 SCENARIO RESULTS

6.5.1 Moderate Scenario

In the Moderate scenario, primary energy consumption increases from 25.0 Quads in 1997 to 34.1 Quads in 2020, a 36.4 percent increase or about 7 percent less than the energy consumption projected in the Baseline Case. Similarly, carbon emissions increase from 478 MtC in 1997 to 646 MtC in 2020, a 35.1 percent increase and about 7 percent less than in the Baseline Case.

Table 6.8 presents the 10-year results in travel, energy efficiency, and energy consumption for the several transportation modes, and energy consumption by fuel type. Table 6.9 presents carbon emissions by mode and fuel type.

The seven percent drop (from the Baseline) in energy consumption and carbon emissions has a few key components:

- **Greater improvement in light-duty fuel economy.** Light-duty fleet mpg improves by 2.8 versus 0.9 in the BAU scenario (Table 6.7). This results primarily from the estimated efficiency improvements and cost reductions achieved by the 50 percent increase in R&D funding in the Moderate scenario. The model year 2020 mpg values attained are, respectively, 38.0 mpg (versus 32.1 mpg in the Baseline scenario) for autos and 24.8 mpg (vs. 22 mpg) for light trucks.
- **Improved freight truck efficiency.** Freight truck mpg rises to 7.6 mpg in 2020 from 5.6 mpg in 1997 (vs. 6.3 mpg in the Baseline), yielding a 16 percent reduction in freight truck fuel consumption in 2020 (Table 6.7). This improvement results from the vigorous R&D push for advanced heavy-duty diesel technology, as well as a variety of other technologies.

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[3] We attempted to use this feature in the 1997 "5-Lab" study, but found that it did not function properly. With the assistance of Mr. Dan Mezler of EEA, Inc., we were able to identify and correct a "bug" in the program so that the CAFE features functioned as intended. This is apparently the first instance of the use of CAFE constraints in the NEMS model.

Table 6.8 Results of Moderate Scenario

	1997	*2010*	*2020*
Level of Travel by Mode (Billion)			
Light Duty Vehicles (vehicle miles traveled)	2301	2892	3320
Commercial Light Trucks (vehicle miles traveled)	69	91	104
Freight Trucks (vehicle miles traveled)	178	245	272
Air (seat miles demanded)	1050	1818	2471
Rail (ton miles traveled)	1235	1508	1666
Marine (ton miles traveled)	757	882	967
Energy Efficiency Indicator by Mode			
New Light Duty Vehicle (MPG)[a]	24	27.4	30.5
New Car (MPG)	27.9	34.7	38.0
New Light Truck (MPG)	20.2	22.1	24.8
Light-Duty Fleet (MPG)	20.5	20.9	23.4
New Commercial Light Truck (MPG)	19.9	21.1	23.5
Stock Commercial Light Truck (MPG)	14.6	15.3	16.5
Aircraft (seat miles/gallon)	51.1	56.7	62.6
Freight Truck (MPG)	5.6	6.5	7.6
Rail (ton miles/kBtu)	2.7	3.1	3.5
Site Energy Use by Mode (Quadrillion Btu)			
Light-Duty Vehicles	13.9	17.7	18.2
Commercial Light Trucks	0.6	0.7	0.8
Freight Trucks	4.2	5.0	4.8
Air	3.4	5.1	6.1
Rail	0.5	0.6	0.6
Marine[b]	1.3	1.6	2.0
Pipeline Fuel	0.7	0.8	0.9
Other	0.2	0.3	0.3
Total	24.9	31.9	33.7
Energy Use by Fuel Type (Quadrillion Btu)			
Distillate Fuel	4.6	5.7	6.1
Jet Fuel	3.3	5.0	6.0
Motor Gasoline	15.1	18.1	17.8
Residual Fuel	0.8	1.0	1.3
Liquefied Petroleum Gas	0.0	0.1	0.2
Other Petroleum	0.3	0.3	0.4
Petroleum Subtotal	24.10	30.38	31.75
Pipeline Fuel Natural Gas	0.7	0.8	0.9
Compressed Natural Gas	0.0	0.2	0.3
Renewables (E85)[c]	0.0	0.1	0.2
Methanol	0.0	0.2	0.3
Liquid Hydrogen	0.0	0.0	0.0
Electricity	0.1	0.2	0.2
Total Site Energy	24.9	31.9	33.6
Electricity Related Losses	0.1	0.3	0.5
Total Primary Energy	25.0	32.2	34.1

[a] Light-duty vehicles are passenger cars and light trucks, combined.

[b] In review, we discovered that the efficiency improvements described in the text for marine transport had not been input to the model due to an oversight. These improvements would have reduced marine energy use by approximately 0.04 quads in 2010 and 0.1 quads in 2020.

[c] The CEF-NEMS model reports renewables blended with gasoline as “Motor Gasoline.” For an accounting of cellulosic ethanol blended with gasoline, please see the discussion in section 6.5.1.

Table 6.9 Transportation Carbon Emissions: Moderate Scenario (million metric tons C)

	1997	*2010*	*2020*
Carbon emissions by mode (MtC)			
Light Duty Vehicles	267.0	337.6	348.0
Commercial Light Trucks	11.3	14.2	15.2
Freight Trucks	82.4	95.3	91.0
Air	63.3	97.5	117.2
Rail	12.3	13.6	14.2
Marine[a]	27.3	33.5	40.6
Pipeline Fuel	10.6	12.1	12.7
Other	3.8	7.2	7.1
Total	477.9	611.0	646.0
Carbon emissions by fuel type (MtC)			
Other	91.6	113.4	121.5
Jet Fuel	63.3	96.7	116.4
Motor Gasoline	289.7	347.5	340.3
Residual Fuel	15.9	21.7	27.6
Liquefied Petroleum Gas	0.7	2.3	2.7
Other Petroleum	3.0	3.6	3.9
Petroleum Subtotal	464.1	585.1	612.5
Pipeline Fuel Natural Gas	10.6	12.1	12.7
Compressed Natural Gas	0.2	3.0	3.8
Renewables (E85)*	0.0	0.0	0.0
Methanol	0.0	2.9	5.3
Liquid Hydrogen	0.0	0.0	0.0
Electricity	3.0	7.8	11.7
Total	477.9	611.0	646.0

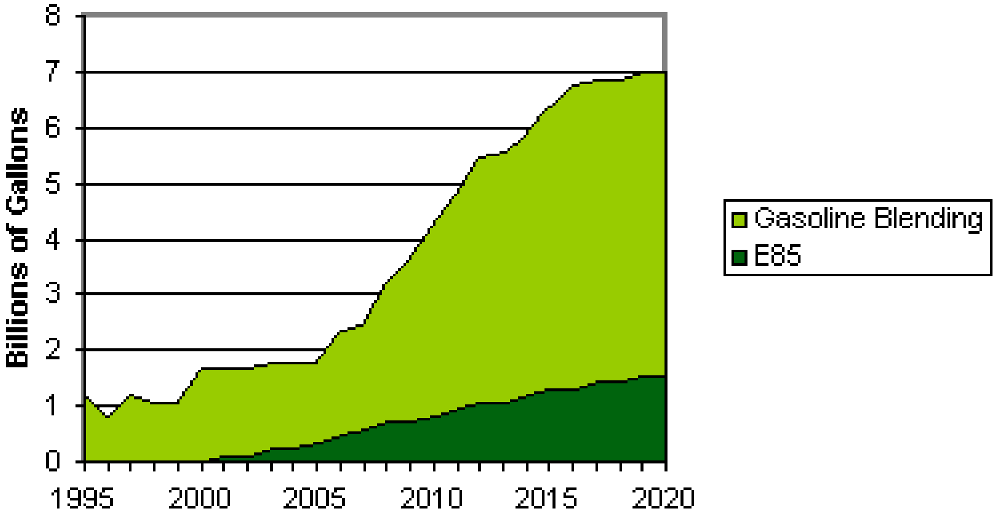
[a] In review, we discovered that the efficiency improvements described in the text for marine transport had not been input to the model due to an oversight. These improvements would have reduced marine carbon emissions by approximately 0.8 MtC in 2010 and 2.0 MtC in 2020.

- **A modest drop in projected air travel energy use** from improvements in operational efficiency, resulting from a more rapid implementation of current plans for operational advances.

The light-duty fleet experiences significant changes in composition from the baseline fleet. In particular, diesel sales increase substantially – for 2020, over 2,100,000 vehicles/yr in the Moderate scenario vs. less than 200,000/yr in the Baseline scenario. Also, alternative fuel vehicles expand much more rapidly than in the Baseline. By 2020:

- Alcohol flex-fuel ICEs sell 1,175,000 units/yr vs. about 317,000/yr in the Baseline
- Alcohol ICEs sell 350,000/yr vs. 92,000/yr
- Both diesel-electric hybrids and fuel cell vehicles of all types play essentially no role, vs. a modest role (e.g., 29,000 diesel electric hybrids sold/yr in 2010) in the Baseline. This is a result of changes to the NEMS Alternative Fuel Vehicles model parameters (see Appendix A-3 for details) rather than a result of changed conditions in the scenario.

Fig. 6.6 Use of Ethanol for Motor Fuel
MODERATE CASE



6.5.2 Advanced Scenario

In the Advanced scenario, primary energy consumption increases from 25.0 Quads in 1997 to 28.9 Quads in 2020 (Table 6.10), a 16 percent increase; the 2020 transportation energy consumption is about 21 percent less than the Baseline 2020 value. Carbon emissions increase from 478 MtC in 1997 to 545 MtC in 2020, a 14 percent increase; the 2020 emissions are about 23 percent less than in the Baseline. The slightly smaller percentage increase in carbon emissions than in energy consumption implies that the Advanced scenario has managed to reduce carbon intensity somewhat from the level in the Baseline scenario, due to increased use of cellulosic ethanol and other alternative fuels.

Table 6.10 presents the 10-year results in travel, energy efficiency, and energy consumption for the several transportation modes, and energy consumption by fuel. Table 6.11 breaks down carbon emissions by mode and fuel type.

Table 6.10 Results of the Advanced Scenario

	1997	*2010*	*2020*
Level of Travel by Mode (Billion)			
Light Duty Vehicles (vehicle miles traveled)	2301	2829	3184
Commercial Light Trucks (vehicle miles traveled)	69	90	103
Freight Trucks (vehicle miles traveled)	178	246	273
Air (seat miles demanded)	1067	1781	2425
Rail (ton miles traveled)	1236	1352	1428
Marine (ton miles traveled)	758	883	968
Energy Efficiency Indicator by Mode			
New Light Duty Vehicle (MPG)[a]	24	32.8	41.6
New Car (MPG)	27.9	41.5	51.4
New Light Truck (MPG)	20.2	26.4	33.9
Light-Duty Fleet (MPG)	20.5	22.8	28.3
New Commercial Light Truck (MPG)	19.9	24.3	29.2
Stock Commercial Light Truck (MPG)	14.6	16	18.7
Aircraft (seat miles/gallon)	52	59.9	65.8
Freight Truck (MPG)	5.6	6.8	9
Rail (ton miles/kBtu)	2.8	3.4	3.9
Site Energy Use by Mode (Quadrillion Btu)			
Light-Duty Vehicles	13.9	15.9	14.4
Commercial Light Trucks	0.6	0.7	0.7
Freight Trucks	4.2	4.8	4.0
Air	3.4	4.8	5.8
Rail	0.5	0.5	0.5
Marine	1.3	1.6	2.0
Pipeline Fuel	0.7	0.9	0.9
Other	0.2	0.3	0.3
Total	24.9	29.5	28.6
Energy Use by Fuel Type (Quadrillion Btu)			
Distillate Fuel	4.6	5.9	5.7
Jet Fuel	3.3	4.7	5.7
Motor Gasoline	15.1	16.1	13.7
Residual Fuel	0.8	1.0	1.3
Liquefied Petroleum Gas	0.0	0.1	0.1
Other Petroleum	0.3	0.3	0.4
Petroleum Subtotal	24.10	28.13	26.83
Pipeline Fuel Natural Gas	0.7	0.9	0.9
Compressed Natural Gas	0.0	0.2	0.2
Renewables (E85)[b]	0.0	0.0	0.0
Methanol	0.0	0.1	0.2
Liquid Hydrogen	0.0	0.0	0.1
Electricity	0.1	0.2	0.2
Total Site Energy	24.9	29.5	28.5
Electricity Related Losses	0.1	0.3	0.4
Total Primary Energy	25.0	29.8	28.9

[a] Light-duty vehicles are passenger cars and light trucks, combined.

[b] In review, we discovered that the efficiency improvements described in the text for marine transport had not been input to the model due to an oversight. These improvements would have reduced marine energy use by approximately 0.07 quads in 2010 and 0.18 quads in 2020.

[c] The CEF-NEMS model reports renewables blended with gasoline as "Motor Gasoline." For an accounting of cellulosic ethanol blended with gasoline, please see the discussion in section 6.5.1.

Table 6.11 Transportation Carbon Emissions: Advanced Scenario

	1997	*2010*	*2020*
Carbon emissions by mode (MtC)			
Light Duty Vehicles	267.0	304.5	274.3
Commercial Light Trucks	11.3	13.4	13.1
Freight Trucks	82.4	91.7	76.5
Air	63.3	91.4	110.2
Rail	12.3	11.5	10.9
Marine[a]	27.3	33.3	40.2
Pipeline Fuel	10.6	12.2	13.1
Other	3.8	7.0	6.6
Total	477.9	565.1	544.9
Carbon emissions by fuel type (MtC)			
Other	91.6	116.0	113.3
Jet Fuel	63.3	90.6	109.4
Motor Gasoline	289.7	308.2	261.9
Residual Fuel	15.9	21.6	27.5
Liquefied Petroleum Gas	0.7	2.1	2.2
Other Petroleum	3.0	3.6	3.9
Petroleum Subtotal	464.1	542.1	518.2
Pipeline Fuel Natural Gas	10.6	12.2	13.1
Compressed Natural Gas	0.2	2.8	3.2
Renewables (E85)*	0.0	0.0	0.0
Methanol	0.0	1.8	3.0
Liquid Hydrogen	0.0	0.0	0.0
Electricity	3.0	6.2	7.4
Total	477.9	565.1	544.9

[a] In review, we discovered that the efficiency improvements described in the text for marine transport had not been input to the model due to an oversight. These improvements would have reduced marine carbon emissions by approximately 1.5 MtC in 2010 and 3.6 MtC in 2020.

The 21 and 23 percent drops (from the Baseline) in energy consumption and carbon emissions, respectively, have the following components:

- **Improvements in light-duty fuel economy.** The on-road fuel economy of the fleet improves by 7.8 mpg by 2020, vs. 0.9 mpg in the Baseline (Fig. 6.7). New car mpg (Fig. 6.8) increases to 51.4 mpg by 2020 (vs. 32.1 mpg Baseline) and light truck mpg (Fig. 6.9) increases to 33.9 mpg (vs. 22.0 mpg). These increases in fuel economy result from the combination of Voluntary Agreements, tax credits for high efficiency vehicles (as originally proposed by the Administration), a significant economic incentive afforded by the increase in gasoline prices associated with carbon credits and the PATP price add-on, and technology cost reductions and performance improvements associated with a doubling of the R&D budget.
- **Freight truck efficiency gains.** Freight truck efficiency rises to 9 mpg in 2020 from about 5.6 mpg in 1997, vs. 6.3 mpg in the 2020 Baseline and 7.6 mpg in the 2020 Moderate scenario. This yields a 30 percent reduction in energy consumption from the 2020 Baseline and a 17 percent reduction from the Moderate scenario results.
- Further modest improvements in aircraft and rail energy efficiency.

- **A drop in railroad freight movement.** From the Baseline level of 1,698 billion ton miles in 2020 rail freight traffic decreases to 1426 billion ton-miles in the Advanced scenario due to reduction in coal use, and therefore shipments to power plants.

Fig. 6.7 Light-Duty Vehicle Stock Fuel Economy

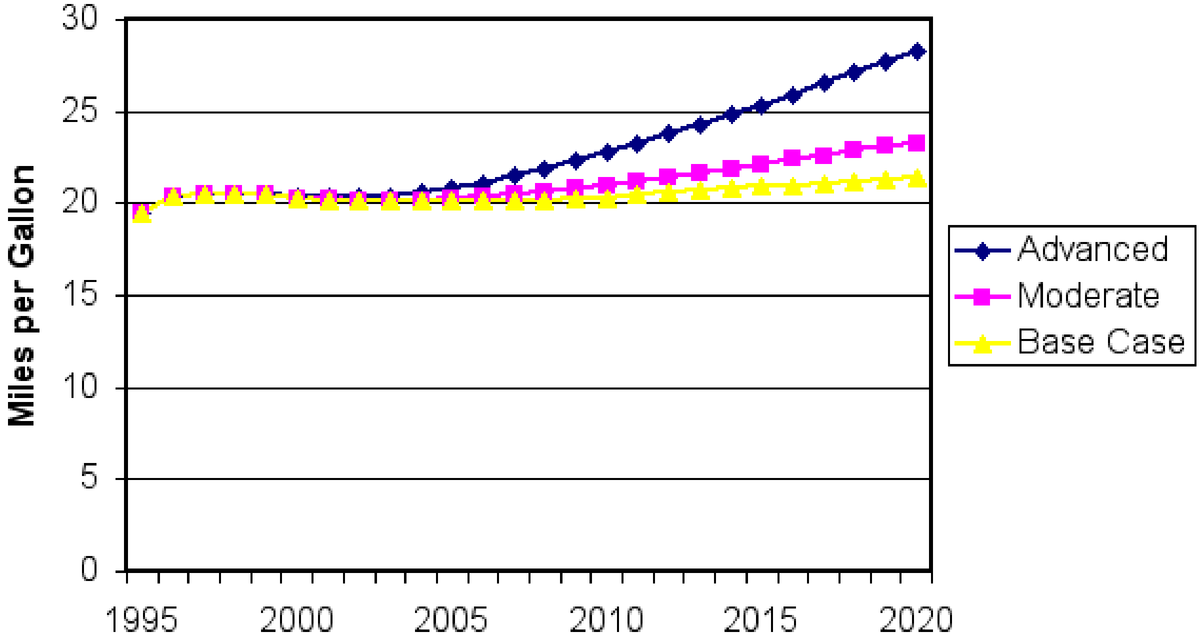


Fig. 6.8 New Passenger Car Fuel Economy

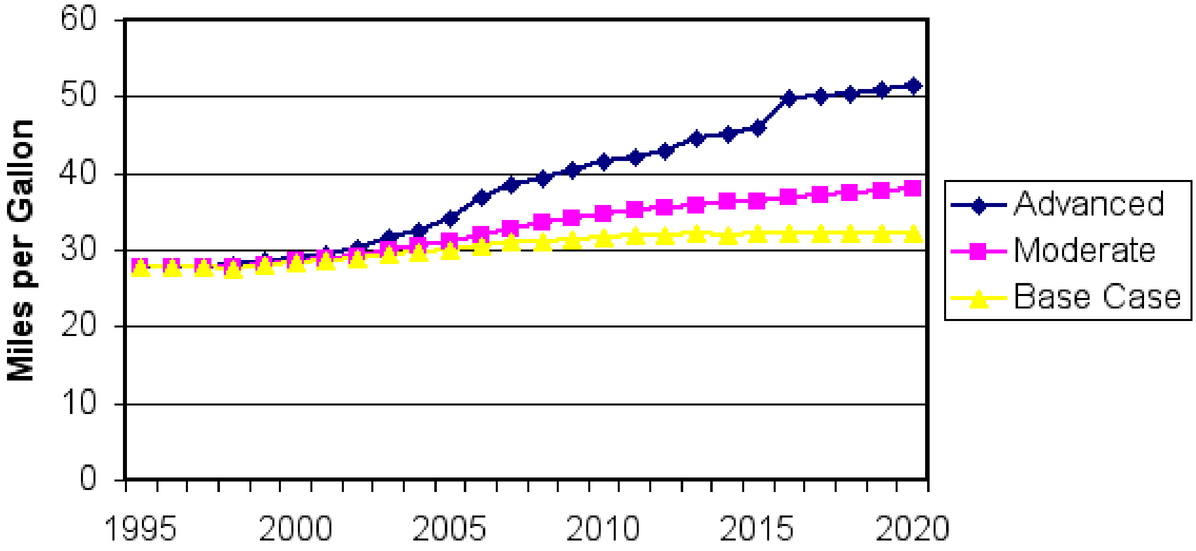
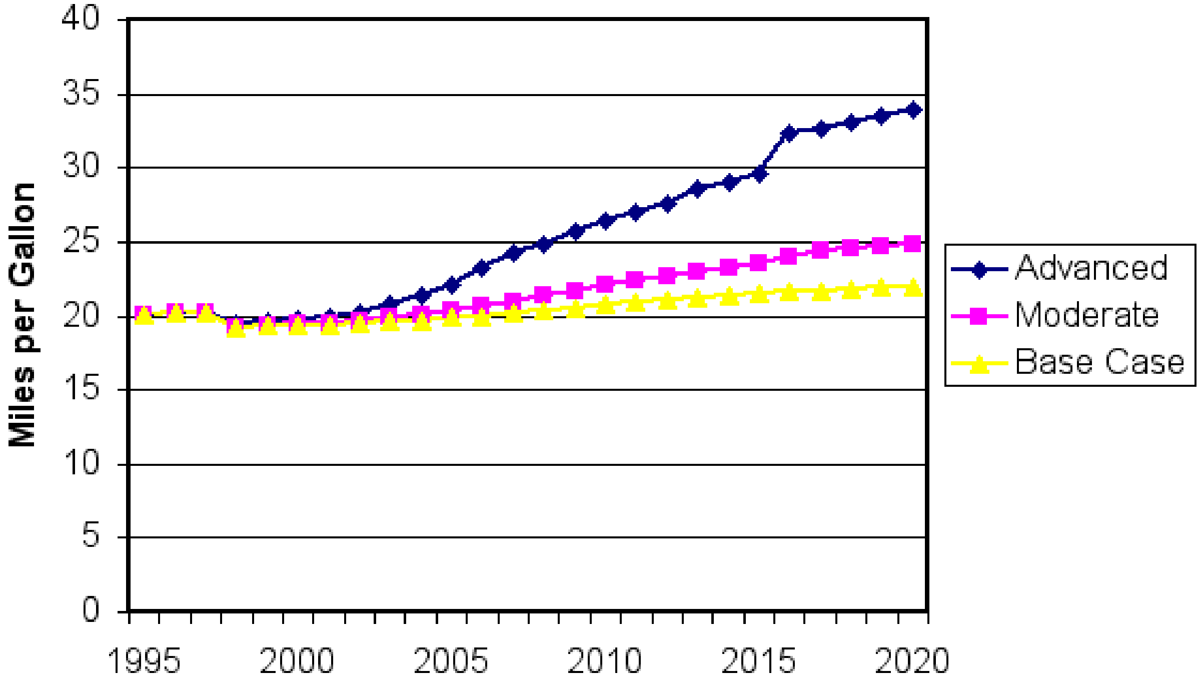


Fig. 6.9 New Light Truck Fuel Economy



Interesting changes in the light-duty fleet composition occur in the Advanced scenario, including:

- Fuel cell vehicles achieve a significant market share after 2015 (Fig. 6.10). In 2020, 2.2 million fuel cell passenger cars and light trucks are sold in the Advanced scenario (10 percent of light-duty vehicles sold that year). About 0.9 million are passenger cars while 1.3 million are light trucks. By 2020 there are 9.4 million fuel cell vehicles in a total population of 255 million light-duty vehicles.
- Fuel economy improvements to gasoline-powered vehicles were led by a variety of engine technology improvements, especially advanced valve-timing and lift controls, friction reductions, direct-injection, and 4- and 5-valve designs. Next in relative importance were gasoline-hybrid technology and materials substitution, especially aluminum and plastics (Fig. 6.11).
- 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.
- Hybrid vehicles have an earlier impact, accounting for 13 percent of light-duty vehicle sales in 2010 and 15 percent in 2020.
- Even in 2020, the 47 percent of new light-duty vehicles are powered solely by gasoline internal combustion engines.
- TDI diesels continue to play a major role in the light-duty vehicle fleet, with sales exceeding 1 million after 2005 and standing at 2.6 million per year in 2020. By 2020, there are 30 million TDI diesel light-duty vehicles on the road which, together with 7 million diesel-electric hybrids, comprise almost 15 percent of the light-duty vehicle population.

- Diesel-electric hybrids achieve a modest market share early on, and retain it through 2020. New light-duty vehicle sales exceed 350,000 by 2007, peak at over 700,000 in 2013, and decrease to just over 380,000 in 2020 as the fuel cell vehicles begin to succeed.

Fig. 6.10 Alternative Fuels and Vehicles Market Shares, Advanced Scenarios

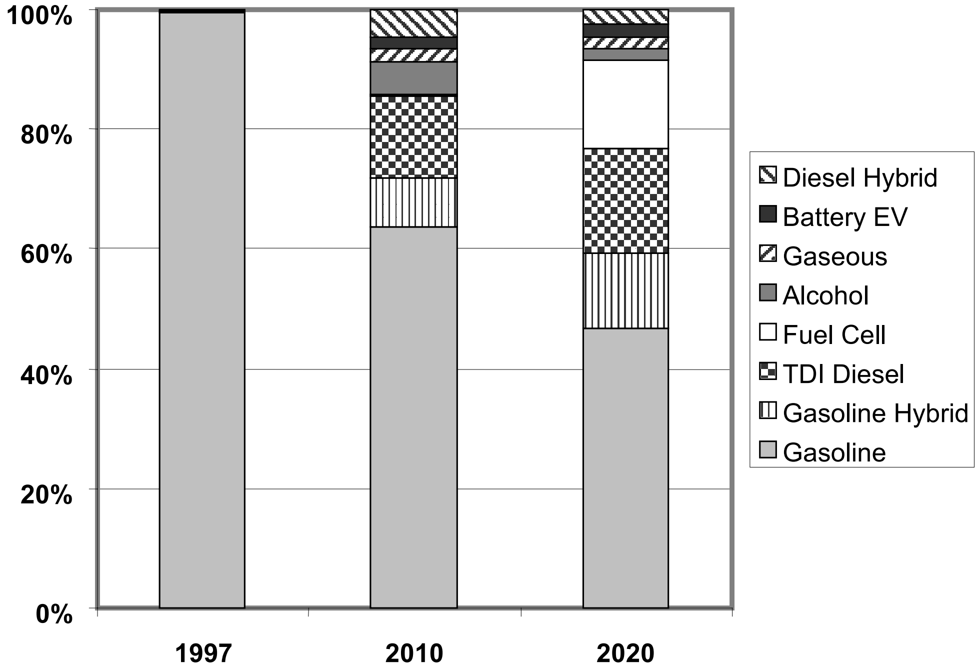
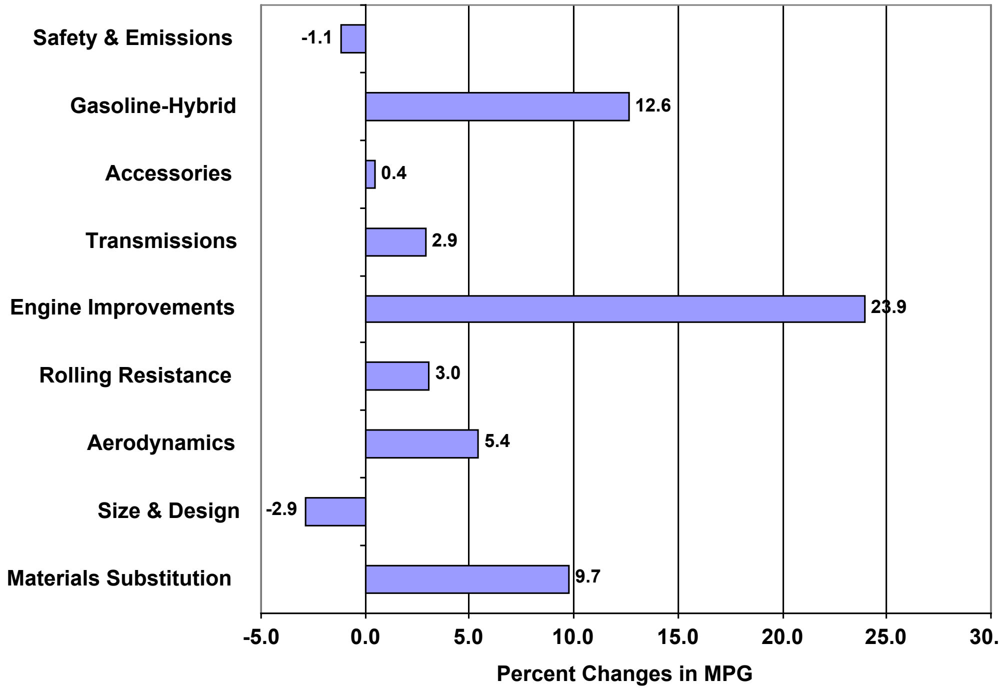
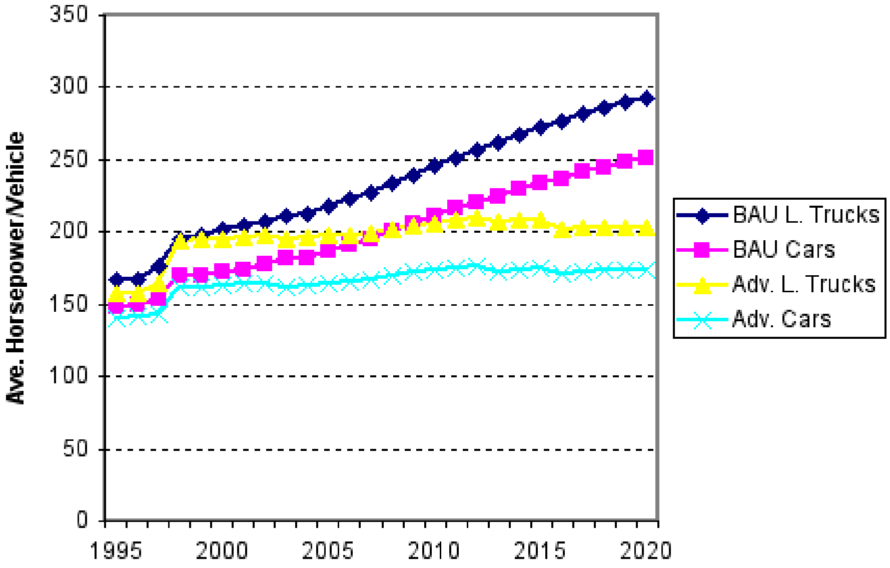


Fig. 6.11 Sources of Passenger Car MPG Improvements: Gasoline Engine Technology Only, Advanced Scenario, 2020 (28.6 to 44.1 MPG)



- The enormous growth of vehicle horsepower is restrained in the Advanced scenario. In 1998, the average horsepower of new passenger cars sold in the United States was 155 (NHTSA, 1999). In the BAU case, passenger car horsepower increases to 251 by 2020 (Fig. 6.12). Light truck horsepower increases even more, from 189 in 1998 to 293 in 2020. The Advanced Case 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.

Fig. 6.12 Projected Engine Power of Light-Duty Vehicles



Cellulosic Ethanol – Advanced. Use of ethanol for motor fuel increases from 1.1 billion gallons in 1999 to 3.9 billion in 2010, to 6.4 billion gallons in 2015, and 7.3 in 2020 (Fig. 6.13). Ethanol's share of the gasoline market also increases from 3.8 percent in 2015 to 4.7 percent in 2020 (5.3 percent to 6.6 percent, by volume). The much lower demand for gasoline in the Advanced scenario depresses demand for ethanol. Comparison of Tables 6.7 and 6.8 shows that gasoline use in the Advanced scenario is down 12 percent in 2010 and 24 percent in 2020 versus the Moderate scenario. Ninety-five percent of the demand for ethanol as a motor fuel is for gasoline blending. Once again, these projections do not account for the potential impact of an MTBE ban, which would tend to increase demand for ethanol as a blending stock.

A potential policy for stimulating renewable fuels use is a target for the percentage of renewable fuels in highway fuels. Senator Daschle has proposed a requirement that all gasoline sold in the nation have a renewable fuel component. A recent version of the draft legislation requires that all gasoline in commerce contain a 2.1% "fuel derived from a renewable source" component and a separate 1.0% cellulosic ethanol component, to be phased in by 2008. Although cellulosic ethanol *is* renewable, the legislation appears to require a total renewable content of 2.1+1.0, or 3.1 percent. For the gasoline demand forecast by the EIA Reference Case, this target would translate into a requirement for at least 4.7 billion gallons of renewable fuels (presumably mostly ethanol) by 2010, versus a projected production without such a policy of less than 2.5 billion gallons[4]. The requirement would be less than this for the

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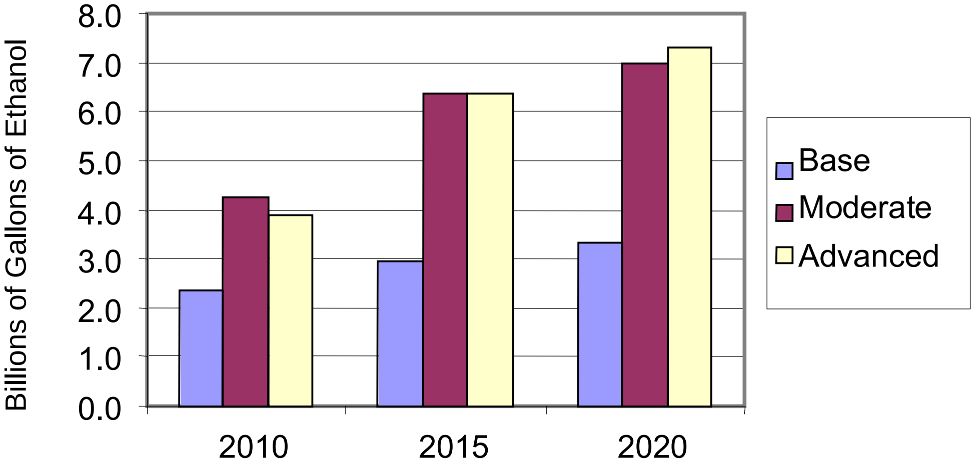
[4] Assuming that the requirement is volumetric, that is, 2.1 gallons of ethanol or other renewable fuel for every 100 gallons of gasoline.

Moderate and Advanced Scenarios (approximately 4.5 and 4.0 billion barrels, respectively), because future gasoline demand is lower in these scenarios.

Fig. 6.13 Ethanol Use for Motor Fuel



Requirements of this sort can have two opposite effects. They can raise costs by requiring producers to turn to more expensive feedstocks or production facilities. And they can lower costs by stimulating increased R&D that can allow access to new, less expensive feedstocks or reduce processing costs. In the context of the two policy scenarios, however, we have already assumed that increased R&D funding has yielded a 50 percent decrease in overall ethanol production costs, producing a significant increase in ethanol use as a blending stock in gasoline. For both scenarios, ethanol use is projected to be about 4 billion gallons in 2010 *without* the stimulation of a renewable fuels requirement (see Fig. 6.12). In other words, we project that the market-driven level of ethanol production in our policy scenarios would be similar to the production level required under the proposal by Senator Daschle.

6.5.3 Advanced Scenario Sensitivity Cases

No Diesel Case. In both the Moderate and Advanced scenarios, the market shares of advanced diesel engines increase significantly. The diesel's acceptability in the future will depend on its ability to meet stringent emissions standards. It is by no means certain that a practical, clean diesel able to meet increasingly stringent standards, can be developed. At present, diesels produce more NO_x and particulate emissions than gasoline engines of comparable power. Unless these emissions can be reduced to acceptable levels, the light-duty diesel will not have a place in a clean energy future (see, e.g., Mark and Morey, 1999).

This is an excellent example of the uncertainties inherent in projecting future transportation energy use and GHG emissions. It might appear that the success of diesel technology is crucial to achieving both scenarios' reductions in energy use and GHG emissions, since except for the fuel cell, no single technology offers larger fuel economy benefits. The TDI diesel achieves a full 40 percent fuel economy improvement over a conventional gasoline vehicle of the same size and performance, while the diesel-electric hybrid increases miles per gallon by approximately two thirds. To examine the dependence of the scenarios' outcome on diesel technology, we ran a sensitivity case based on the Advanced scenario but removing the light-duty diesel from the vehicle mix. **In comparing this new case to the original scenario, both sets of results are from "unintegrated runs," that is, the runs are not precisely the same as those shown in the previous section because the effects of changes in other sectors on the transportation sector are not incorporated.** This should have little effect on the results.

In the (unintegrated) Advanced scenario, sales of TDI diesels increase from 60 thousand in 1999 to 2.2 million annually in 2010 and over 3.1 million in 2020 (Fig. 6.14). Sales of diesel-electric hybrids in the scenario grow from 0 in 2002 to peak at over 800,000 units in 2013. Diesel sales contribute to an overall increase in combined new passenger car and light truck fuel economy from 24.0 MPG in 2000 to 33.5 MPG in 2010 and 41.9 MPG in 2020. In the unintegrated Advanced scenario, energy use by all light duty vehicles increases from 14.5 in 1999 to 15.5 quads in 2010, then falls to 14.1 quads in 2020.

We simulated the absence of light-duty diesel technologies by raising their prices in the Advanced scenario by $10,000 per vehicle after 2003. The NEMS AFV model responded by reducing their predicted sales to 0. Fig. 6.15 shows how vehicle sales have changed in this scenario. The effects on light-duty vehicle fuel economy and energy use, however, were relatively modest. With no diesels, the fuel economy of light-duty vehicles increased from 24.0 in 2000 to 31.4 in 2010 and to 40.5 in 2020, just 1.4 MPG below the scenario with advanced diesels (Fig. 6.16). Energy use by all light-duty vehicles increased to 15.7 quads in 2010, then declined to 14.6 in 2020, just 0.5 quads higher than the Advanced scenario (Fig. 6.17).

The relatively modest impact of removing the diesel option can be attributed to three factors.

- Although diesel sales are substantial, they are still a minority of passenger car and light truck sales. With 24 percent of 2020 light-duty vehicle sales, the impact of these high-efficiency vehicles on sales-weighted harmonic mean fuel economy is attenuated[5].
- Second, removal of the diesels causes an increase in the sales of other high-efficiency technologies, for example, fuel cells. Sales of fuel cells and battery electric vehicles in 2020 increase from 2.7 million in the Advanced scenario to 4.3 million in the No Diesels scenario. This substitution of other advanced technologies for the diesel mitigates the impact of its loss.
- Third, diesel cars and light trucks are a much smaller fraction of the on-road vehicle population than of new vehicle sales. Even a twenty-year forecast does not allow sufficient time for both market maturation and turnover of the vehicle stock. Thus the impacts in 2020 of withdrawing diesels is smaller than it would be in the longer run.

This sensitivity case suggests that the Advanced scenario results are relatively robust to the success or failure of a single technology, even one as important as the diesel. Similar results can be seen in tests of sensitivity to fuel cell cost assumptions discussed below. Instead, the scenario is dependent on a combination of technological advances and scenarios, brought about by a general level of technological success and societal commitment to developing clean energy technologies and energy sources.

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[5] To illustrate how the weighted harmonic mean may differ from intuition, that a 20 mpg vehicle averaged harmonically with a 40 mpg vehicle does not result in a 30 mpg average, as one might expect, but in a 26.7 mpg average. You would need to average a 20 mpg vehicle with a 60 mpg vehicle to obtain a combined harmonic average of 30 mpg.

**Fig. 6.14 Sales of Alternative Fuel Vehicles:
Stand-Alone Advanced Case**

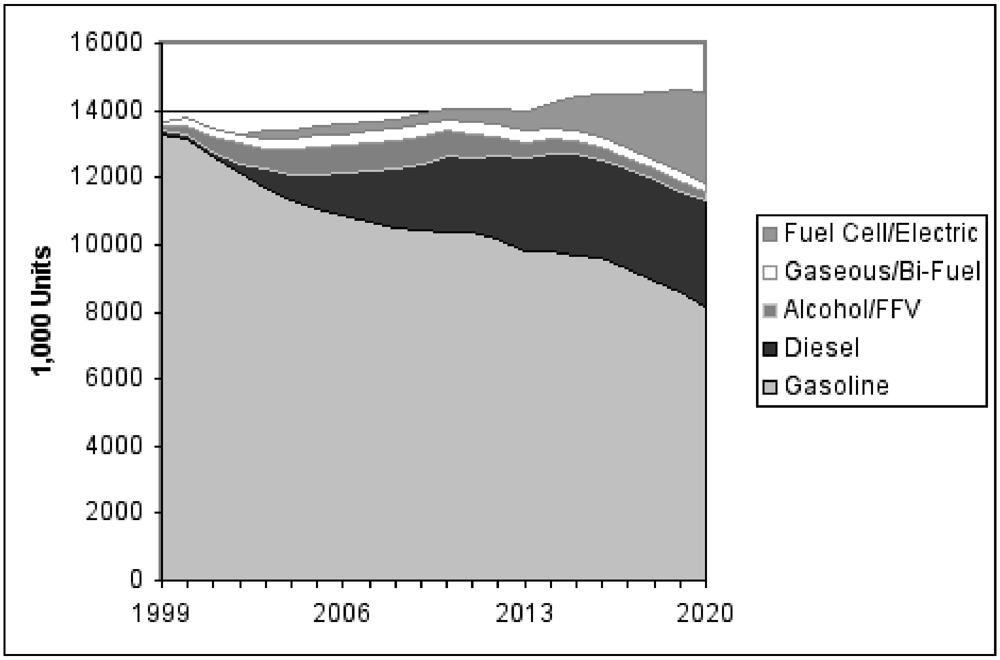


**Fig. 6.15 Sales of Alternative Fuel Vehicles:
No Diesel Case**

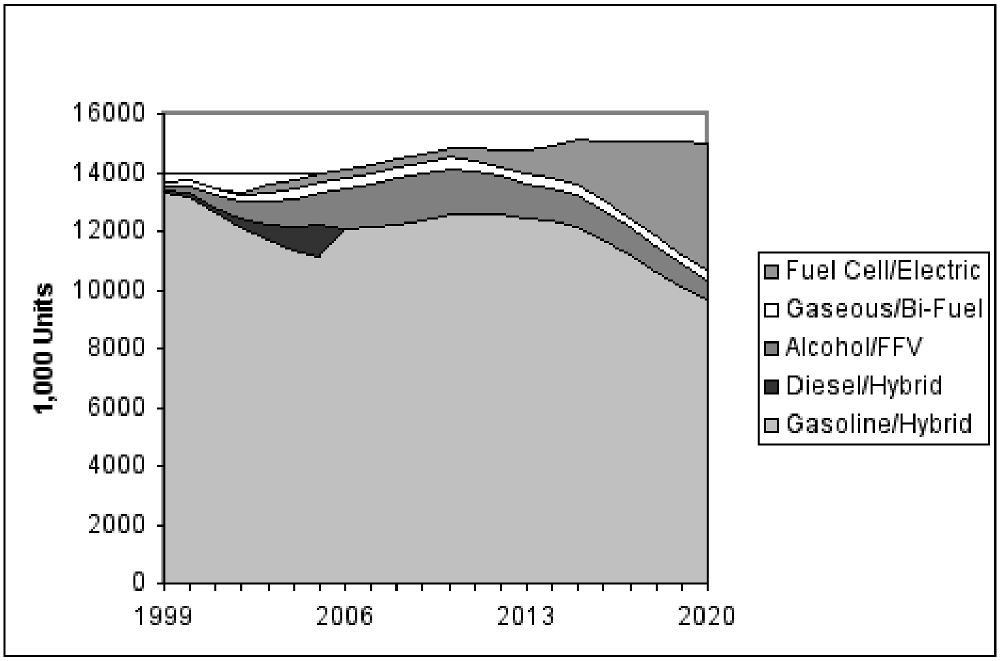


Fig. 6.16 New Light-Duty Vehicle Fuel Economy: Advanced vs. No Diesels Scenarios

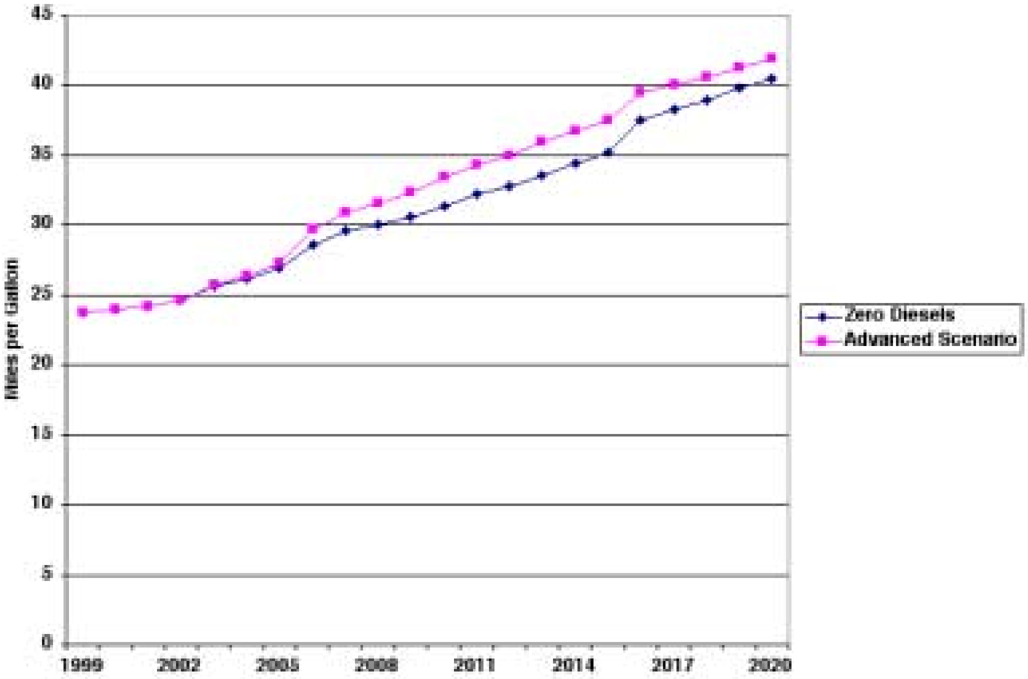
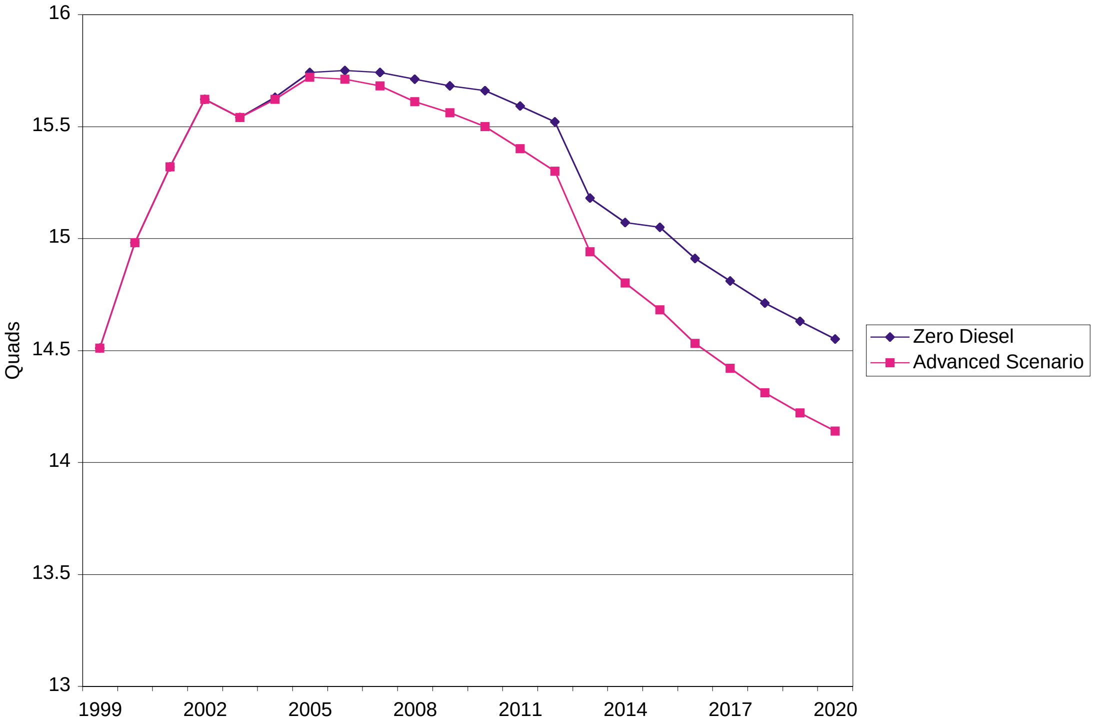


Fig. 6.17 Light-Duty Vehicle Energy Use: Advanced vs. No Diesels Scenario



CAFE Sensitivity Case. In this section we report the results of a stand-alone sensitivity case to illustrate the potential impacts of mandatory fuel economy standards. According to economic theory, voluntary environmental standards require at least the threat of mandatory standards to be taken seriously by firms (Segerson and Miceli, 1998). While such theories often omit the importance to firms of less tangible economic incentives for accepting voluntary standards, such as creating and maintaining a positive public image, the possibility of more stringent mandatory standards is undoubtedly a strong incentive for firms to commit to voluntary standards. For this reason, and because mandatory standards are now in effect in the United States and played a major role in the light-duty vehicle fuel economy improvements achieved over the past 25 years (e.g., Greene, 1998), it is appropriate to assess how mandatory standards might influence the levels of fuel efficiency, fuel consumption and carbon emissions in the Advanced scenario[6].

For this case, we simulate a new combined passenger car and light truck standard beginning in the year 2005[7]. Starting in 2005, the standards increase gradually to 50 mpg for combined passenger car and light truck sales (Fig. 6.18). Domestic and import fleets are also combined, and credit trading between companies is allowed. For this CAFE Sensitivity case, we eliminated the financial subsidies for 50 percent to three times more efficient vehicles included in both the Moderate and Advanced scenarios, on the grounds that the CAFE standards would supersede such incentives. The fine for non-compliance with the new standard is $150 per 1 mpg by which a manufacturer's corporate average fuel economy falls below the standard (the current standard has a fine of $50/mpg).

In comparison to the Advanced scenario, new light-duty vehicle fuel economy is about 10 mpg higher in the CAFE Sensitivity Case, reaching 52 mpg in 2020 (Fig. 6.18). The effects on the stock of light-duty vehicles are more modest because of the substantial time it takes to roll over the light-duty fleet by retiring older vehicles and adding new ones (Fig. 6.19). For the fleet as a whole, fuel economy in the CAFE case is about four mpg greater than in the Advanced scenario, and annual energy use by the fleet is more than one and one-half Quads lower.

Imposing CAFE constraints tends to increase the use of advanced fuel economy technologies in passenger cars and trucks. In the Advanced scenario, gasoline hybrids comprise 12.7 percent of gasoline vehicle sales in 2010 and 23.0 percent in 2020. In the CAFE Case, this jumps to 31.1 percent and 56.6 percent, respectively (Table 6.12). Use of direct injection gasoline engines also increases markedly, as do the market shares of advanced materials (primarily aluminum and plastics) and advanced drag reduction technologies[8].

This greater use of fuel economy technologies does increase the average price of new vehicles. For example, for gasoline-powered vehicles[9], the cost of fuel economy technologies in the Advanced scenario averages $811 per passenger car in 2010 and $1,548 in 2020, versus $1,337 in 2010 and $2,383 in 2020 in

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[6] In this section, as in the "No-Diesel" case, we compare results not to the integrated Advanced Scenario, but to a stand-alone version which is only slightly different but more directly comparable to the sensitivity cases which are all run in stand-alone mode.

[7] The NEMS model, AEO99 version allows separate passenger car and light truck standards to be specified, but only for gasoline-powered vehicles. Details of the modifications to NEMS inputs to simulate the combined standard are provided in Appendix A-3.

[8] Advanced materials include NEMS materials categories V-VII. Advanced drag is Drag Reduction V.

[9] We have not been able to devise a way to calculate the additional costs of alternative fuel technologies using outputs produced by NEMS. In principle, the AFV purchases are the outcome of market decisions by consumers, so that in the context of NEMS, the value of the AFVs to consumers exceeds their cost. Thus, in focusing on the cost of gasoline vehicle technologies, we are focusing on the only area where, at least in theory, costs could exceed direct benefits to consumers.

Fig. 6.18 Fuel Economy in the CAFE Sensitivity Case

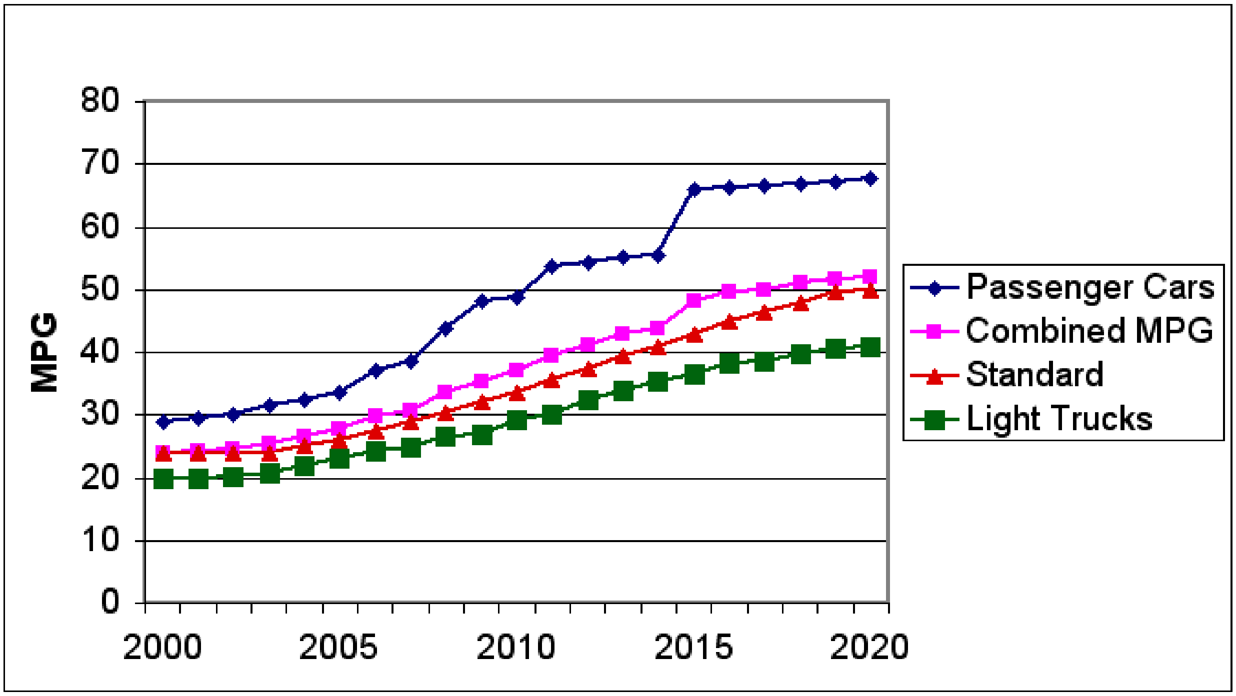

Fig. 6.19 Light-Duty Stock Fuel Economy and Energy Use, CAFE Sensitivity Case

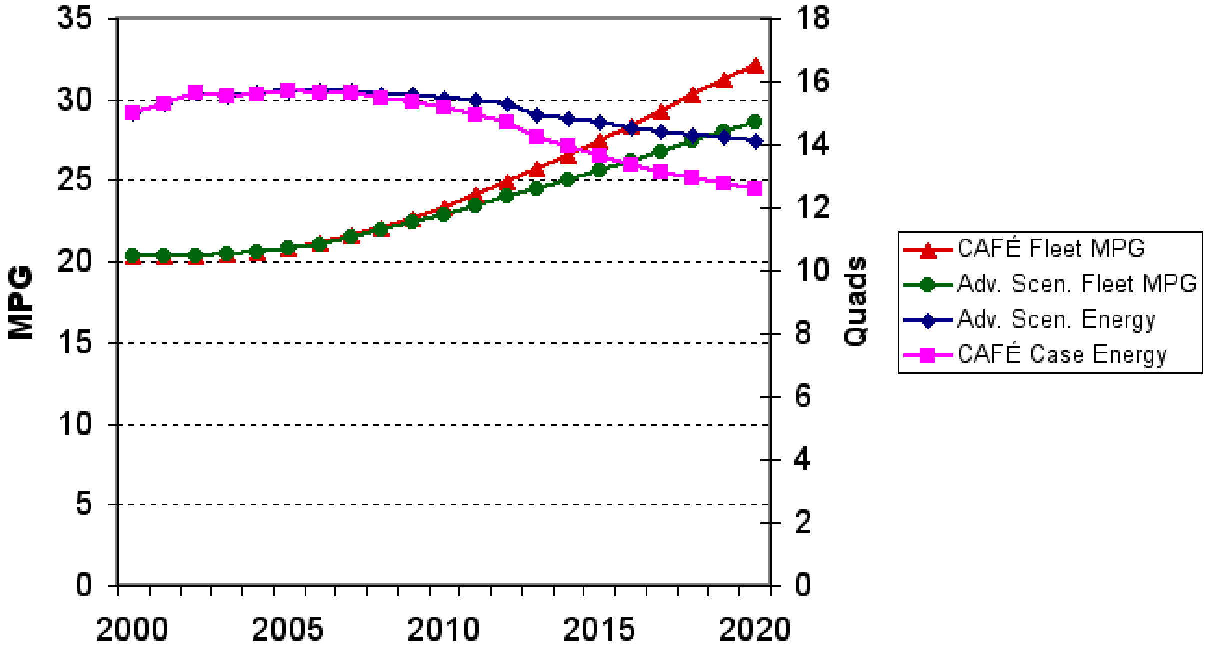

Table 6.12 Market Penetrations of Selected Fuel Economy Technologies in Passenger Cars in the CAFE Scenario

Technology	2010 Advanced	2010 CAFE	2020 Advanced	2020 CAFE
Gasoline Hybrid	12.7%	31.1%	23.0%	56.6%
Gasoline Direct Injection 4-cyl.	9.5%	16.5%	22.9%	36.1%
Gasoline Direct Injection 6-cyl.	5.3%	11.1%	13.2%	27.5%
Advanced Materials	0.0%	0.0%	34.2%	53.8%
Advanced Drag Reduction	8.2%	9.5%	36.5%	58.6%

the CAFE case. For light trucks, the CAFE case requires $1,365 worth of fuel economy technologies in 2010 and $3,305 in 2020, as compared with $1,028 and $2,040 in the Advanced scenario. The approximate values of fuel savings for the resulting changes in mpg are summarized in Tables 6.13 and 6.14 (these estimates should be considered rough approximations, since it was not practical to exactly replicate the NEMS model's accounting for technology notes and horsepower adjustments[10]). Even with the higher CAFE standards, the total value of fuel economy savings by consumers exceeds their cost in 2010. In 2020, however, estimated costs exceed estimated benefits, at a 15 percent annual discount rate.[11] In comparison to a base passenger car at 27.6 mpg, the 44.2 mpg 2010 CAFE case vehicle would emit 4.8 fewer MtC per year at a net savings because reductions in fuel costs outweigh the added vehicle cost. The 53 mpg 2020 vehicle would emit 6.4 fewer MtC annually, at an average net cost of $16/MtC. The *marginal* costs of carbon reduction are much higher, however. The costs per ton of C saved by model year 2020 versus 2010 vehicles is about $300. The estimates for light trucks show a similar pattern.

6.5.4 Impacts on U.S. Oil Dependence

Transportation is not the sole user of petroleum in the U.S. economy, but it is the dominant user. In 1998, the U.S. transportation sector accounted for over 66 percent of U.S. petroleum consumption. Moreover, transportation uses nearly all the high-value, light products that drive petroleum markets. In the reference case, the transportation sector's dominance of petroleum demand actually increases to 71 percent of U.S. consumption by 2020. Here we briefly review the impacts of changes in all sectors on U.S. oil dependence. Changes in the transportation sector, however, are by far the most important.

Policies and technologies implemented in the Moderate and Advanced scenarios significantly reduce U.S. petroleum consumption and imports though care must be taken in interpreting the predicted decline in imports, as explained below. Total U.S. oil consumption rises to 24.5 mmbd in the BAU scenario, but falls to 19.4 mmbd in the Advanced scenario (Fig. 6.20). In the BAU scenario, U.S. petroleum imports rise from 10.6 million barrels per day (mmbd) in 2000 to 15.9 mmbd in 2020. Of this, 4.0 mmbd are in the form of petroleum products, 12.0 mmbd are crude oil. CEF-NEMS suggests that total imports would be 14.0 mmbd in the Moderate scenario, of which only 2.2 mmbd are products. In the Advanced scenario, only 11 mmbd are imported in 2020. Under BAU, U.S. oil imports increase from 49 percent of U.S. demand today, to 65 percent in 2020. In the Advanced scenario the share of imports also increases, but to only 56 percent.

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[10] These estimates were computed by adding up the market share-weighted fuel economy improvement benefits of each technology and multiplying one plus the sum times an adjusted base mpg. The base year 1997 mpg was adjusted to account for factors such as increased weight and horsepower and safety and emissions mandates that would otherwise cause mpg to decrease over the period in question. The estimates are only approximate in that no adjustment was made for synergies among technologies. Had these been taken into account, the estimated fuel economy gain and therefore the value of fuel economy improvements would have been slightly smaller.

[11] Use of the term discount rate is somewhat inappropriate in this context, since what it actually represents is the consumers' rate of return on capital, taking into consideration that the consumer's investment in fuel economy technology is a depreciating asset.

Table 6.13 Retail Costs and Value of Fuel Savings for Light-Duty Vehicle Fuel Economy Improvements, Advanced Scenario (GASOLINE ENGINE TECHNOLOGIES ONLY)

	Fuel Economy Improvement		
	BASE	**2010**	**2020**
Passenger Cars			
% Gain		33.4%	54.1%
MPG	27.6	38.1	44.1
Annual Fuel Savings		$308	$427
C Emissions Reductions (mtC)		3.6	5.0
		Technology Cost	
All Changes		$1,488	$2,227
Fuel Economy Technologies		$811	$1,548
Present Value Fuel Savings		$1,285	$1,780
Cost per tonne C		-$131	-$46
Marginal Cost per mtC 2010 to 2020			$174
	Fuel Economy Improvement		
	BASE	**2010**	**2020**
Light Trucks			
% Gain		35.6%	57.4%
MPG	19.6	27.7	32.1
Annual Fuel Savings		$460	$629
C Emissions Reductions (mtC)		5.4	7.4
		Technology Cost	
All Changes		$1,629	$2,641
Fuel Economy Technologies		$1,028	$2,040
Present Value Fuel Savings		$1,921	$2,625
Cost per tonne C		-$166	-$80
Marginal Cost per mtC 2010 to 2020			$156

Assumptions

Miles/Year	Rate of Decrease in Annual Use	On-Road MPG Factor	Vehicle Lifetime	Discount Rate	Gasoline Price $/gal.	Gasoline Price $/gal.
15,640	6.7%	0.85	12	15.0%	$1.67	$1.71

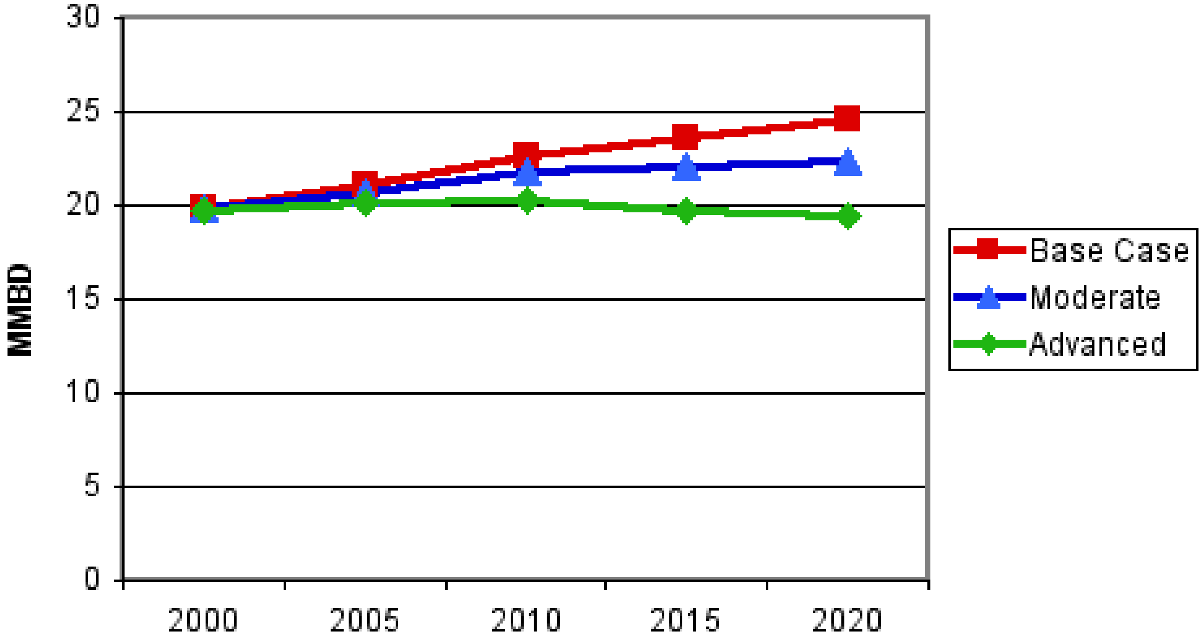
Table 6.14 Retail Costs and Value of Fuel Savings for Light-Duty Vehicle Fuel Economy Improvements, CAFE Sensitivity Case (GASOLINE ENGINE TECHNOLOGIES ONLY)

	Fuel Economy Improvement		
	BASE	**2010**	**2020**
Passenger Cars			
% Gain		53.6%	85.3%
MPG	27.6	43.9	53.0
Annual Fuel Savings		$414	$547
C Emissions Reductions (mtC)		4.8	6.4
		Technology Cost	
All Changes		$2,036	$3,110
Fuel Economy Technologies		$1,337	$2,383
Present Value Fuel Savings		$!,728	$2,28
Cost per tonne C		-$81	$16
Marginal Cost per mtC 2010 to 2020			$317
	Fuel Economy Improvement		
	BASE	**2010**	**2020**
Light Trucks			
% Gain		43.5%	85.2%
MPG	19.6	29.3	37.8
Annual Fuel Savings		$518	$773
C Emissions Reductions (mtC)		6.1	9.0
		Technology Cost	
All Changes		$1,906	$3,928
Fuel Economy Technologies		$1,365	$3,305
Present Value Fuel Savings		$2,161	$3,224
Cost per tonne C		-$131	$9
Marginal Cost per mtC 2010 to 2020			$294

Assumptions

Miles/Year	Rate of Decrease in Annual Use	On-Road MPG Factor	Vehicle Lifetime	Discount Rate	Gasoline Price $/gal.	Gasoline Price $/gal.
15,640	6.7%	0.85	12	15.0%	$1.67	$1.71

Fig. 6.20 U.S. Primary Petroleum Consumption

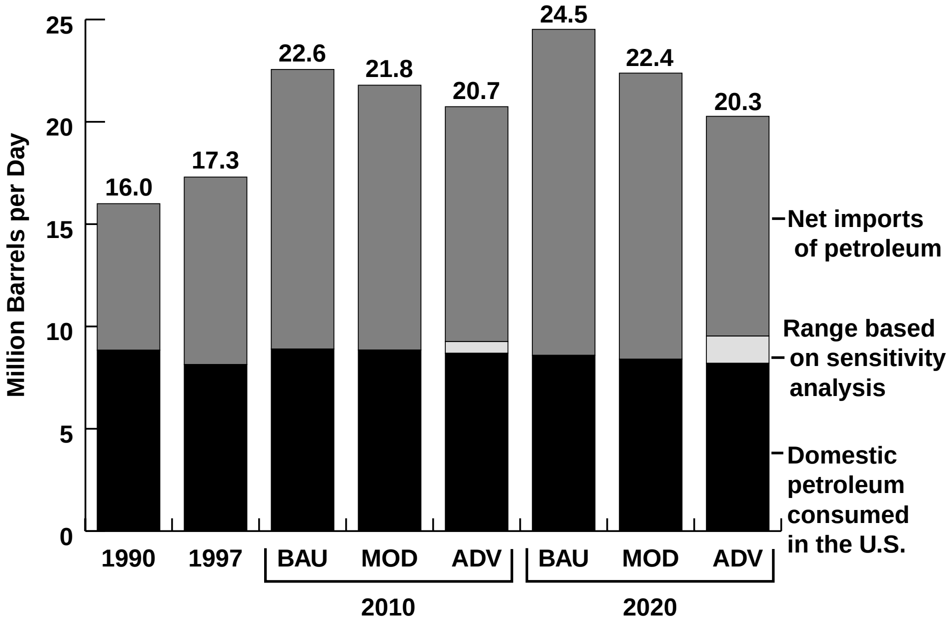


Because the CEF-NEMS model does not estimate the impacts of reduced U.S. oil demand on world oil prices, it will overestimate the reduction of oil imports but underestimate the economic benefits. Significant reduction in U.S. oil demand, such as predicted in the Moderate and Advanced scenarios, would exert downward pressure on world oil prices, other things equal. At lower prices, U. S. oil suppliers would produce somewhat less oil, tending to diminish the reduction in imports predicted by the CEF-NEMS assuming constant oil prices. At the same time, the economic benefits would be greater than those described here, because the price of every barrel of oil consumed, not just the imports, would be lower.

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 crude oil and petroleum products in 2020 from $135 B/year to $89 B/year (Fig. 6.21). Thus, the change in balance of payments is $45 B in favor of the U.S. The assumed price of imported crude oil and petroleum products in all scenarios in the year 2020 is $22.73 per barrel. Even the integrated runs do not estimate the full impacts of reductions in U.S. oil demand on world oil prices, because the benefits of reduced consumption in the form of lower prices for both imported and domestic oil cannot be estimated by CEF-NEMS.

World oil prices are higher than the marginal cost of production, as a result of the concentration of oil production. Pricing above marginal costs produces a transfer of wealth from consumers to producers. In the BAU scenario, OPEC's share of the world oil market increases from 39 percent in 2000 to 51 percent in 2020. If one assumes that the price of oil in competitive world oil markets would be about $10 per barrel (see, e.g., Greene et al., 1998, p. 58) then the annual transfer of wealth from U.S. oil consumers to world oil exporters would be $74 B in the BAU scenario and $51 B in the Advanced scenario, for a net annual savings of $23 B to U.S. consumers in avoided wealth transfer. Note that while this wealth transfer is not an economic loss from a global perspective, it is a real loss from the perspective of the U.S. economy.

Fig. 6.21 U.S. Consumption of Domestic and Imported Crude Oil and Petroleum Products



6.5.5 Analysis of Alternative World Oil Market Outcomes in the CEF Advanced Scenario

The Advanced scenario estimates significant reductions in U.S. oil imports as a result of reductions in U.S. oil demand. In part, the predicted reductions are a result of the conventions of the CEF-NEMS model's representation of world oil market behavior. These conventions hold world oil price trajectories constant, essentially assuming that non-domestic production falls commensurate with the decline in U.S. demand. Without a fall in world oil prices, U.S. producers do not change their output.

In contrast, OPEC and other countries might not cut production to accommodate the full reduction in U.S. oil demand. In that case, the additional supply of oil would cause world oil prices to decrease. The lower world oil prices would cause U.S. and other competitive producers to reduce output, and would also cause U.S. and other oil consumers to increase demand for oil. In the end, U.S. oil demand would be slightly higher and oil imports would not be reduced by as much as in the Advanced scenario, but the lower prices would be an additional benefit for the U.S. economy.

A simple model of world oil supply and demand is used to illustrate these effects. Linear, lagged adjustment equations are used to represent U.S. and rest-of-world (ROW) oil supply and demand. ROW oil supply does not include OPEC, but ROW demand does. Price elasticities vary with price and quantity in a linear model. Representative (Greene et al., 1998) short-run elasticities for the U.S. and ROW are summarized in Table 6.15. Long-run elasticities are ten times as large.

Table 6.15 Short-run Oil Supply and Demand Elasticities Used in the Simulation

	Supply and Demand Short-run Elasticities at Various Fuel Prices				
	(Price (97 $/BBl)	Demand MMBD	Short-run Elasticity	Supply MMBD	Short-run Elasticity
U.S.	$20	17.10	-0.038	9.68	0.028
	$28	16.84	-0.054	9.79	0.039
	$35	16.60	-0.069	9.88	0.049
ROW	$20	50.25	-0.038	31.83	0.024
	$28	49.49	-0.054	32.13	0.033
	$35	48.80	-0.069	32.40	0.041

First, the model was calibrated to match the Advanced scenario oil market conditions. Next, OPEC production was increased to the level of the Business-As-Usual (BAU) scenario, and a new supply and demand equilibrium found by adjusting the price of oil to clear the market. The key results are new levels for: (1) world oil price, (2) U.S. oil supply, (3) U.S. oil demand, (4) U.S. oil imports, and (5) U.S. expenditures on oil. Expenditures on oil are not a full measure of the economic benefit of lower oil prices. The correct measure would be the sum of consumers' and producers' surpluses throughout the economy, but such a measure is beyond the scope of this analysis.

At nearly 5 mmbd, the reduction in U.S. oil demand identified in the Advanced scenario would be sufficient to affect world oil markets, placing downward pressure on oil prices and potentially changing production levels domestically and internationally. How world oil markets react to this reduced demand depend in large part on how OPEC, representing a large share of 2010 to 2020 world oil production, responds. Other areas of production, both in the U.S. and in the rest of the world (ROW) tend to have higher costs of production and their individual production decisions have less of an impact on world energy prices.

Rather than attempt to characterize a specific world oil market response to reduced U.S. demand, this study reports two estimates which characterize a possible range of responses. OPEC countries are modeled as the swing world oil producers based on their typically lower costs of production and large market share.

- In the Advanced Scenario, CEF-NEMs holds world oil prices constant; the model assumes that OPEC oil production falls sufficiently to avoid any decline in world oil prices.

- At the other end of this range, the Adjusted Advanced scenario models OPEC countries as holding production at their BAU levels, allowing world oil prices to fall. In this case, both U.S. and ROW oil producers respond to this price reduction, to varying degrees, by reducing their expected production levels. At the same time, U.S. consumers respond by consuming a bit more oil than expected in the Advanced scenario.

These two results bracket the likely range of world oil prices and U.S. imports, and by extension, U.S. production levels. From Table 6.16 it is clear that regardless of the response by world oil markets, U.S. oil demand falls substantially. In 2020 in the Adjusted Advanced case, the overall drop in U.S. oil consumption is 4 mmbd rather than the nearly 5 mmbd expected in the Advanced case. U.S. oil production is about 5% lower than expected in the Advanced scenario. However, total U.S. expenditures for oil, domestic and international are lower in the Adjusted Advanced scenario than in the Advanced scenario.

Fig. 6.22 Effect of Increased OPEC Supply on World Oil Price in the Advanced Scenario

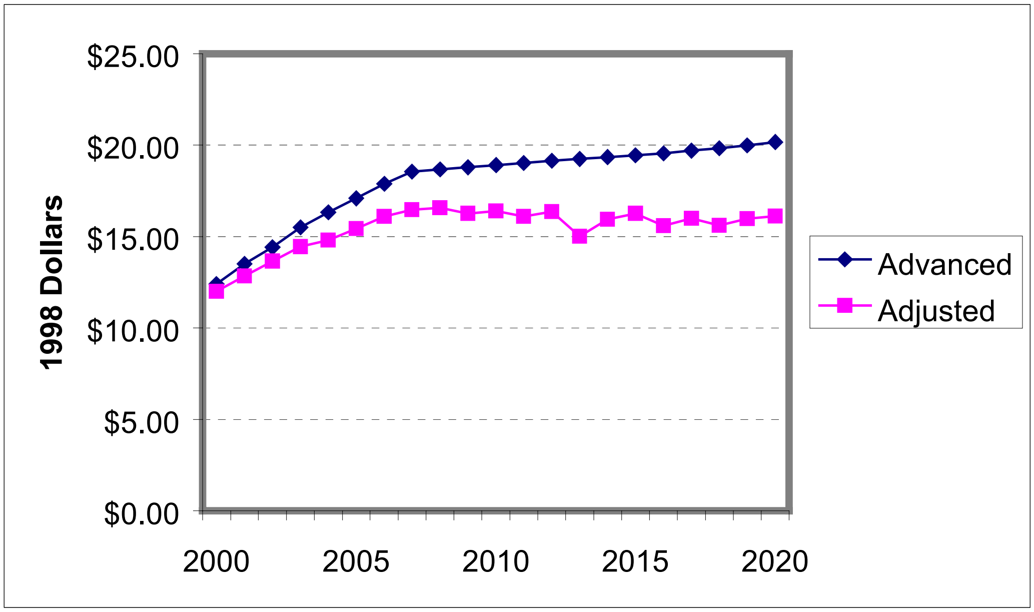


Table 6.16 Effect of Increasing OPEC Oil Supply in the Advanced Scenario

Year	Price Maintained 1998 $/bbl	U.S. Oil Supply mmbd	U.S. Oil Demand mmbd	U.S. Net Imports mmbd	Oil Expenditure B 1998 $
2000	$12.40	9.23	19.88	10.63	90
2005	$17.08	8.93	20.20	11.27	126
2010	$18.90	8.86	20.34	11.48	140
2015	$19.44	8.74	19.76	11.02	140
2020	$20.17	8.59	19.33	10.74	142
	Production Maintained 1998 $/bbl	**U.S. Oil Supply mmbd**	**U.S. Oil Demand mmbd**	**U.S. Net Imports mmbd**	**Oil Expenditure B 1998$**
2000	$12.01	9.22	19.87	10.65	87
2005	$15.43	8.86	20.37	11.51	115
2010	$16.39	8.69	20.74	12.05	124
2015	$16.27	8.45	20.44	11.99	121
2020	$16.11	8.2	20.27	12.07	119
	Change in U.S. Demand mmbd	**Change in U.S. Imports mmbd**	**Change in Oil Expenditure B 1998 $**	**Change in Oil Price 1998 $/bbl**	
2000	0.01	0.02	3	-$0.39	
2005	0.17	0.24	11	-$1.65	
2010	0.40	0.57	16	-$2.51	
2015	0.68	0.97	19	-$3.17	
2020	0.94	1.33	23	-$4.06	

In the BAU case, U.S. petroleum consumption increases from 19.9 mmbd in 2000 to 24.6 mmbd in 2020, and imports increase from 10.7 mmbd in 2000 to 15.9 mmbd in 2020. In the Advanced scenario, consumption is actually lower in 2020 (19.3 mmbd) than in 2000 (19.9 mmbd), and imports increase from 10.6 in 2000 to only 10.7 mmbd in 2020 (for details, please see Table 6.16). However, if OPEC production is increased from the Advanced scenario level to match the BAU scenario level, the price of oil falls from $20.17/bbl in 2020 to $16.11/bbl., with smaller decreases in the years leading up to 2020 (Figure 6.22). As a result of the lower price of oil, U.S. consumption in 2020 increases from 19.3 mmbd to 20.3 mmbd. U.S. supply falls from 8.6 mmbd to 8.2 mmdb. The increase in U.S. consumption and decrease in U.S. supply combine to raise 2020 U.S. oil imports from 10.7 mmbd to 12.1 mmbd. Not surprisingly, this new level of imports falls between the BAU scenario (15.9 mmbd) and the unadjusted Advanced scenario (10.7 mmbd). While imports are higher than in the original Advanced scenario, the lower price of oil on all barrels consumed, domestic and imported, in the adjusted Advanced scenario saves the U.S. economy $23 billion in total oil expenditures in the year 2020.

The sum total of undiscounted oil expenditures savings for the adjusted versus original Advanced scenario from 2000 to 2020 is over $300 billion. This is despite the fact that the United States is consuming more oil in the adjusted (increased OPEC supply) Advanced scenario.

Several caveats should be noted. No representation is made that these illustrations are an accurate prediction of what OPEC and other countries would actually do. History suggests that price shocks are more likely than the smooth price paths used in all our scenarios. On the other hand, analyses by Greene, et al. (1998) and Schock et al. (1999) indicate that the kinds of reductions in oil demand and advances in energy technology reflected in the Advanced scenario would reduce the impact of any given supply reduction on the U.S. economy. Clearly, the results of this analysis depend on the accuracy of assumptions about world oil supply and demand functions made. While we have tried to choose elasticities consistent with the published literature, other choices of elasticities would lead to different results. The direction and nature of the conclusions would not change, however. Under any plausible assumptions, world oil prices would decrease, U.S. demand would increase, U.S. supply would decrease, U.S. imports would therefore increase, but U.S. expenditures on oil would be reduced.

6.5.6 Costs of Light-Duty Vehicle Fuel Economy Improvements

The benefits of fuel savings, reduced GHG emissions, lower levels of air pollution, improved energy security, and so on, should be weighed against the full costs of achieving these benefits, discounted over the forecast period. Unfortunately, not only are the full benefits difficult to measure, but estimating costs are also problematic for two reasons. First, as we have noted above, estimates of the future costs of technologies are rare and always uncertain. Second, the CEF-NEMS model outputs do not provide sufficient information to estimate costs for modes other than light-duty highway vehicles, and even in that case only a partial estimate can be made. As we suggest below, enhancing the model’s ability to produce cost estimates should be a high priority.

Estimates of the costs of fuel economy improvement can be made for light-duty gasoline vehicles only. This is unfortunate, because a significant fraction of the MPG gains achieved by light-duty vehicles in the Advanced scenario can be attributed to what the CEF-NEMS classifies as Alternative Fuel Vehicle technologies: the TDI Diesel, fuel cell vehicles, etc. No way has been found to compute the incremental costs of increased AFV market success using existing CEF-NEMS outputs. (In theory, the value to consumers of these technologies exceeds their costs or they would not have purchased them.) Costs for gasoline vehicles, however, can be calculated by combining outputs describing the market shares of fuel economy technologies by vehicle class with the input data on their costs and fuel economy improvement potentials. A spreadsheet was constructed to make these computations and the results are presented here for the Advanced scenario, and the CAFE sensitivity case. Assumptions about vehicle use, discount rates, etc. match those used in the CEF-NEMS model for the Advanced scenario. These spreadsheet calculations do not account for synergies among technologies as the NEMS model does. This should produce a very small overestimate of the overall fuel economy benefit.

Given that the CEF-NEMS model explicitly trades off the price of technologies against the value of their fuel savings in estimating market shares, it should not be a surprise to find that, overall, the value of fuel savings exceeds the costs of achieving it in both 2010 and 2020 for both passenger cars and light trucks. As shown in Table 6.13, the passenger car MPG increases from 27.6 in 2000 to 38.1 in 2010 is worth $1,285 to consumers in present value, but cost them only $811. By 2020, however, the difference is reduced: $1,780 in present value benefits versus $1,548 in initial costs. For light trucks, the cost comparisons are even more favorable. For $1,028 in vehicle price, light truck owners receive $1,921 present value worth of fuel savings in 2010. In 2020, $2,040 in initial expenditure returns $2,625 present value savings.

The vehicle lifetime carbon emissions reductions attributable to fuel economy improvements are also shown in Table 6.13. Key assumptions are constant miles driven and no discounting of future carbon emissions. Since the value of fuel savings to consumers exceeds the cost in every case, the average cost per metric ton of carbon reductions is always negative. The marginal costs of C savings achieved in 2020 versus 2010, on the other hand, are considerable, $174/MtC for cars and $156/MtC for light trucks. However, the cost to consumers includes taxes and PATP insurance, which together adds some $0.70 to the price per gallon. The value to society of fuel savings would not include these components but should include other societal costs of gasoline use, which we have discussed above.

Table 6.14 shows the same calculations for the CAFE Sensitivity Case. These results were discussed above.

6.5.7 Fuel Cell Sensitivity Cases

Of all the technologies considered for the transportation sector, fuel cell vehicles combine the most promise for increasing energy efficiency and reducing greenhouse gas emissions with the greatest uncertainty with respect to their cost and performance. Recent dramatic improvements in both areas may explain why several manufacturers have announced commercial introduction of fuel cell vehicles in the 2003-2005 period. When the “5-Lab” study was conducted just two years ago, such a prediction seemed to us too unlikely to be included even in our High-Efficiency, technologically optimistic scenario. Yet fuel cell technology still has a long way to go before it can compete with conventional internal combustion engines. In the sensitivity cases presented here we measure the impacts of fuel cell system costs, and particularly the rate of reduction in costs, on predicted market success.

For fuel cells to be cost-competitive with ICE powerplants, their costs will have to be dramatically reduced from current levels. In principle, we see no reason why this cannot be accomplished given continued research advances, experience and learning in production, and economies of scale. The key components of a fuel cell system are: (1) the fuel cell stack, (2) the electric motor and associated controllers, etc., (3) the reformer and hydrogen storage buffer in the case of a methanol or gasoline-powered system, and (4) the hydrogen storage tank in the case of a hydrogen FCV. Since these components will make the internal combustion engine drivetrain unnecessary, there will also be a credit for the elimination of these components.

Our cost estimates are based on a study by Directed Technologies, Inc. (Thomas et al., 1998) for the U.S. Department of Energy based on a bottom-up design and costing methodology (details of the equations used may be found in Appendix A-3). For each component, they analyzed the least costly materials and processes, emphasizing the reduction of the parts count and the minimization of manufacturing costs. They intended their cost estimates to apply in the vicinity of the year 2004. We assume a learning curve, according to which fuel cell costs begin in 2005 at two times the levels estimated by Thomas et al. (1998), and in the Advanced scenario decline rapidly to those levels in 2011, then continue decreasing at a decreasing rate, reaching about 70 percent of the Thomas et al. (1998) estimates in 2020. The value of the internal combustion engine credit, however, is assumed to remain constant over time, except that it varies with the weight of the vehicle. We apply a 75 percent overhead mark-up to the net cost, the sum of the fuel cell system cost and the ICE credit.

All system components and their costs depend on the weight of the vehicle. We illustrate these costs in Table 6.15 for passenger cars with weights typical of the years 2010 and 2020 in the Advanced scenario. The learning curve cost factor is 112 percent in 2010 and 69 percent in 2020. In 2010, the heavier fuel cell vehicle requires 67 kW if powered by hydrogen, 76 kW if powered by gasoline. The additional stack size primarily reflects a loss of fuel cell efficiency when operating on reformer gas versus pure hydrogen, but also some increase in weight. The stack cost alone ranges from $2,840 to $3,060. The gasoline and methanol versions also require reformers, while the hydrogen version requires an expensive fuel tank to store the hydrogen. In 2010, the incremental cost of the fuel cell system, including overhead, ranges from $4,190 to $4,390. When the cost factor falls to 69 percent in 2020, costs drop dramatically, for two reasons. First, as the costs of the fuel cell unit approach that of the ICE powerplant, the net cost approaches zero. The 75 percent overhead multiplier magnifies the benefit each $1 fuel cell system cost reduction. Second, the fuel cell system costs are more sensitive to weight than the cost of the ICE powerplant. As a result, while fuel cell system costs are cut in half between 2010 and 2010, the net cost of the fuel cell systems falls by 75-80 percent.

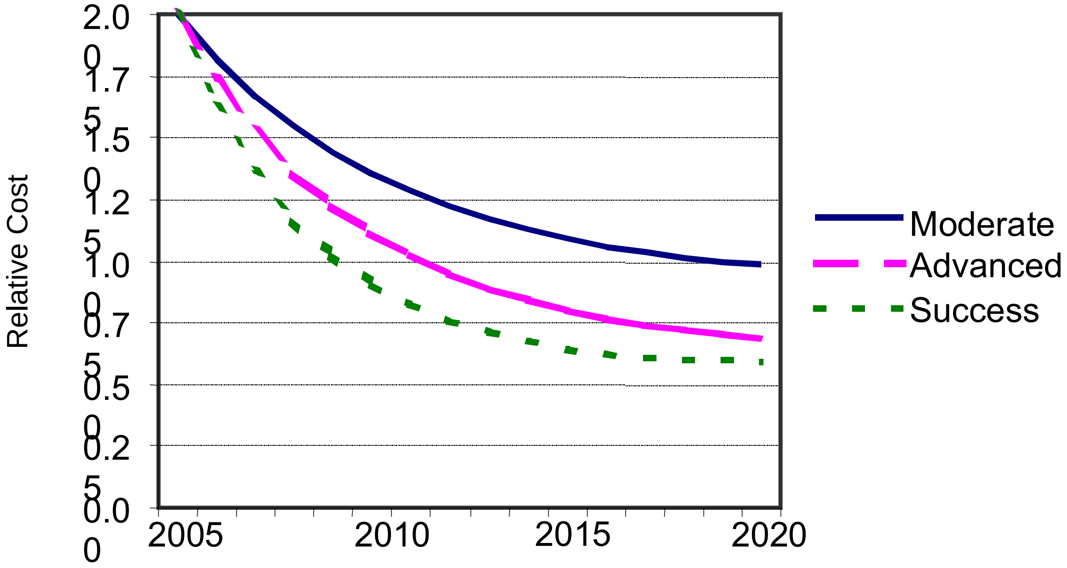
Table 6.17 Case Fuel Cell Vehicle Costs and Fuel Economy

	Gasoline		Methanol		Hydrogen	
	2010	**2020**	**2010**	**2020**	**2010**	**2020**
Cost Factor	112%	69%	112%	69%	112%	69%
Vehicle Weight (pounds)	2790	2195	2790	2195	2790	2195
Stack Size (kW)	76.1	59.9	73.6	57.9	67.2	52.9
Stack Cost (1998 $)	$3,061	$1,650	$2,999	$1,620	$2,843	$1,544
$/kW	$40	$28	$41	$28	$42	$29
Motor Cost (1998 $)	$99	$521	$968	$510	$909	$481
Reformer Cost (1998 $)	$960	$483	$932	$469		
Hydrogen Tank (1998 $)					$1,147	$559
Fuel Cell System Cost (1998 $)	$5,012	$2,654	$4,898	$2,599	$4,899	$2,585
ICE Credit (1998 $)	-$2,502	-$2,097	-$2,502	-$2,097	-$2,502	-$2,097
Net Cost + Overhead (1998 $)	$4,392	$976	$4,193	$879	$4,195	$854
Fuel Economy (GE MPG)	48.8	62.1	56.0	71.2	75.3	95.7

Fuel cell vehicles costing several thousand dollars more than conventional vehicles have negligible impacts in our BAU and Moderate scenarios. But when costs approach those of gasoline ICE vehicles in the Advanced scenario, sales levels rise to 2.2 million units per year in 2020. Beginning with the "stand-alone" Advanced case, we estimated impacts on fuel cell sales of two alternative assumptions, both based on the fuel cell cost analysis of Directed Technologies, Inc. (1998), described in Appendix A-3.

Three alternative learning curves were assumed: (1) the Moderate scenario curve in which costs decline to 1.0 times the 2005 mass-production cost levels, (2) the Advanced scenario curve in which costs decline to 0.7 times the 2005 mass-production level by 2020, and (3) a "Fuel Cell Success" curve in which costs decline to 0.6 times the 2005 mass-production level (Fig. 6.23). In the Fuel Cell Success case, a gasoline fuel cell vehicle costs $1,000 less than a conventional gasoline ICE vehicle in 2020, a hydrogen or methanol fuel cell vehicle costs $1,100 less. In addition, in the Fuel Cell Success case we assume that fuel cell vehicles have equivalent passenger and cargo space to gasoline ICE vehicles, full availability of hydrogen by 2020, and equivalent maintenance costs for gasoline and methanol fuel cells, 25% lower maintenance costs for hydrogen fuel cell vehicles.

Fig. 6.23 Assumed Fuel Cell Learning Curves



The results of these changes are striking. Assuming Moderate scenario fuel cell costs but all other Advanced scenario policies results in negligible fuel cell vehicle sales (180,000 units) even by 2020 (Fig. 6.24). The Fuel Cell Success case assumptions increase annual sales to close to over 2 million units in 2015 and almost 4 million units in 2020, a 25 percent market share that is still headed upward in 2020. In the Advanced case, 15 percent of the fuel cell vehicles sold in 2010 are powered by hydrogen.

By 2020 hydrogen's share increases to 49 percent. In the Fuel Cell Success case, two-thirds of the fuel cell vehicles sold in 2020 are powered by hydrogen.

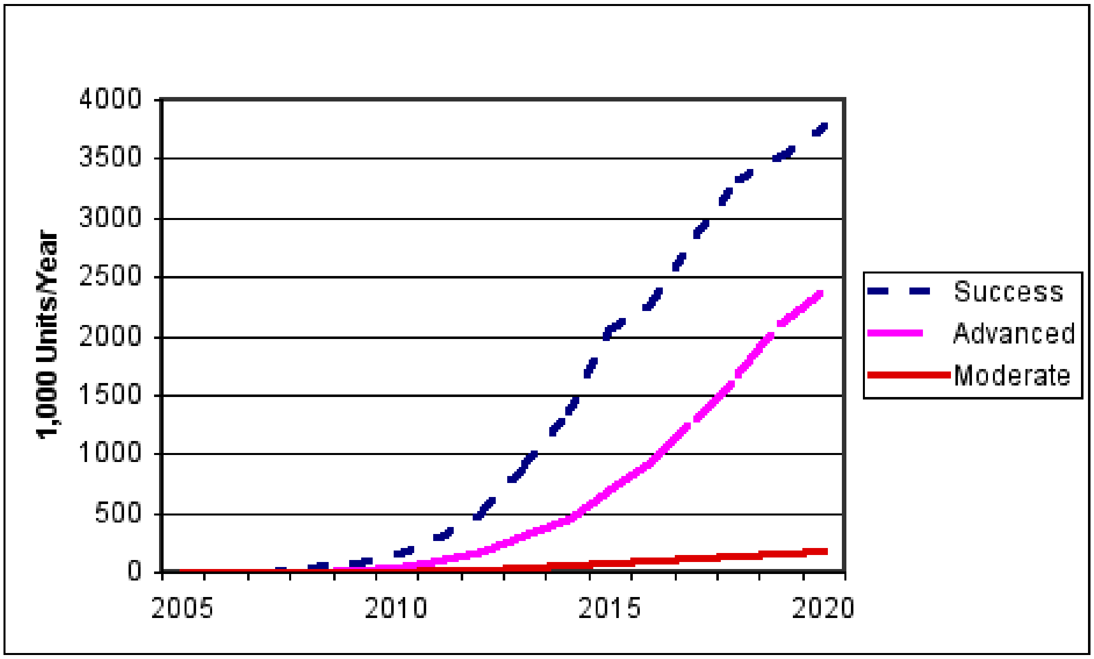
Clearly, the success of fuel cell vehicles is highly uncertain at the present time. Despite dramatic progress in the past five years, automotive fuel cell technology still has a long way to go before it will be competitive with conventional gasoline vehicles in terms of both cost and performance. These sensitivity cases illustrate just how sensitive market success is likely to be to cost. Much will also depend on how consumers react to the less readily quantified differences between fuel cell and conventional vehicles, such as noise, vibration, reliability, and so on.

6.6 REMAINING ANALYSIS NEEDS

The transportation sector analysis would benefit by three types of improvements:

- Additional CEF-NEMS runs that explore the sensitivity of results to changed technology assumptions and that "tease out" the individual effects of new policies from the effects of a changed "state of society" reflected in the scenario descriptions, and the specific effects of individual policies;
- Enhancing certain CEF-NEMS reporting capabilities; and
- Development of new methodologies to evaluate the impacts of new technologies and policies.

Fig. 6.24 Fuel Cell Sensitivity Cases



6.6.1 Additional Model Runs

Time and resource constraints prevented us from conducting a number of useful CEF-NEMS runs for the transportation sector. Among the more important runs are:

1. "Changed baseline" runs that maintain the EIA Reference Case's "no new policies" assumption but that include modifications made in the CEF-NEMS model, such as those to the Alternative Fuels Model coefficients, and allow for a higher growth rate for vehicle travel. The new baseline run would: (1) clarify what portion of the reductions in greenhouse gases and other effects are caused by the alterations made to the CEF-NEMS model, and (2) allow policies to be evaluated against a more widely accepted view of future vehicle travel growth.
2. Runs that selectively remove key policies one at a time, to ascertain their individual impacts.
3. Additional sensitivity runs, similar to the "no diesel" run, to test the sensitivity of GHG reductions and costs thereof to the success or failure of the set of technologies considered. These will measure

the effects of different technology assumptions, e.g. lower or higher costs for key technologies, changes in the portfolio of successful technologies, changes in the dates of introduction, etc., on the outcomes.

6.6.2 Add to CEF-NEMS Bookkeeping Capabilities

The NEMS model provides an impressive amount of output, describing a vast array of the model's calculations. However, for the purposes of the CEF Study, several additional outputs are needed. The most important of these are:

Calculation of the costs of fuel economy improvements for *both* Fuel Economy Model and Alternative Fuel Model calculations. Most but not all of the data necessary to make these calculations is available from existing NEMS outputs as standards tables or as options. In addition, several assumptions must be made and the calculations are complex and time consuming.

- Modifications to the CEF-NEMS model code could provide precise, automated computation of the costs for passenger cars and trucks.
- Reporting of renewable ethanol use in the transportation sector tables. At present, use of ethanol as a blending stock is reported in the "Motor Gasoline" totals in transportation sector tables. It would also be desirable to identify renewable ethanol as coming from corn versus cellulosic feedstocks.
- Accounting for transportation use of hydrogen and for the processes used to produce the hydrogen. At present, hydrogen used by motor vehicles is reported as "liquid hydrogen," which is not the only form in which it may be used. Also, the production of hydrogen for use in the transport sector is not accounted for in the CEF-NEMS.
- Although the NEMS model documentation implies that emissions of criteria pollutants are estimated for transportation, that capability is currently not implemented due to difficulties in maintaining its currency. Given the changing state of knowledge in this field, as well as the continuously evolving status and outlook for emissions regulations, maintaining an up-to-date capability to forecast transportation emissions is a major effort. Fortunately, there are on-going research programs on this subject, most notably at Argonne National Laboratory and at the University of California, Davis, that could be drawn upon for annual updating of emissions factors. As the CEF Study works to fulfill its goal of considering the full range of environmental benefits of clean energy technologies, this issue must be addressed.

6.6.3 Development of New Methods

The Clean Energy Futures Study could benefit from the development or implementation of improved analytical methods in several areas, especially:

- More rigorous and explicit methods of harmonizing assumptions about technological advances and policy contexts across the sectors. Over the past 25 years, analysts of different sectors of the economy have developed sometimes surprisingly different methods for forecasting technological change and assessing its impacts. This often leads to striking differences across sectors in key areas such as the degree of optimism about technological progress or the political will to impose binding policies.
- More rigorous methods for assessing the impacts of multiple technologies based on fundamental technological breakthroughs. Methods are need that will allow for the connections among alternative technologies to be taken into account. For example, an advance in storage

technologies for compressed hydrogen might also have implications for other vehicles using gaseous fuels; advances in electrochemical energy storage would have implications for both hybrid and battery electric vehicles. Improved methods for deriving the implications of technological advances on a range of alternative vehicle technologies are needed.

- More explicit methods for linking R&D effort to technological change should be implemented. Admittedly, this linkage is not well understood and would be difficult to predict in any case. Nonetheless, more rigorous, explicit linkages should be developed, with the goal of making assumptions clearer and more readily comparable to historical experience.
- Technology adoption for gasoline versus alternative fuel vehicles is handled differently in the current CEF-NEMS model. A few of the differences have been addressed in changes made to the CEF-NEMS Alternative Fuels Model, described in appendix A-3. An improved methodology is needed to treat technological changes for light-duty vehicles in an integrated framework, so that policies such as feebates or fuel economy standards can be effectively addressed, and so that technological potentials can be consistently assessed.
- Technology adoption algorithms for freight trucks and aircraft should be enhanced to follow the methods used for light-duty vehicles. Within the CEF-NEMS Transportation Sector Model, technology adoption is handled very differently across modes of transport. In general, mechanistic technology penetration curves for freight trucks and aircraft are triggered when fuel prices exceed a target level (this statement is an oversimplification, but captures the essence of the method). For light-duty vehicles, the trade-off between initial cost and future fuel costs is explicitly represented (other attribute trade-offs are also represented to varying degrees), and differences among consumers' evaluations of these trade-offs are recognized. The method used for light-duty vehicles is not only believed to be theoretically superior, but also allows for more rigorous policy analysis.

6.7 SUMMARY AND CONCLUSIONS

Energy use and carbon emissions from transportation have grown steadily over time and appear likely to continue to grow without new policies or sharp changes in fuel prices and availability. The direct physical causes of this growth have been:

- Travel demand has continued to grow strongly as incomes and population have risen; for example, personal vehicle vmt grew by 2.8 percent/yr during 1974-1995.
- Light-duty fuel economy has stagnated over the past decade (and perhaps would have fallen without the presence of fuel economy standards).
- Vehicle technology has changed over time, but much of the technology has been used for purposes other than higher efficiency.

Several factors will strongly influence future levels of transportation energy use and GHG emissions. On the favorable side, a variety of technology options currently are available to reduce energy use and emissions, and a substantial portfolio of advanced technologies is under development. Obtaining large emissions reductions will require counteracting a number of factors, however:

- Inexpensive fuel and consequent disinterest in fuel economy among light-duty vehicle purchasers
- Fuel efficiency tradeoffs with vehicle characteristics that *are* of interest to vehicle purchasers – acceleration performance, vehicle size, consumer features such as 4-wheel drive, and so forth.

- Time required for redesign, retooling, and fleet turnover; the full benefits of new technologies take years to develop.
- High costs and/or important technological and market risks associated with some of the most promising fuel economy technologies.

In other words, both market factors and the status of technology options are crucial to reducing transportation energy use and greenhouse emissions. Policies that change market incentives for consumers and vehicle manufacturers, and policies that can boost technology development are both crucial to reducing CO_2 emissions.

We have examined the impacts of a number of transportation policy changes on future transportation energy use and greenhouse emissions. The accuracy of the forecasts presented here is dependent on the assumptions we have made about future potentials for technology change across a range of future transportation technologies currently under development, and about the effectiveness of various policies. Although we have chosen these assumptions with care, we admit readily that technology forecasting is a highly uncertain art, and further that the outcomes of some of the chosen policies, particularly increased R&D funding, should be interpreted more as educated guesses than as precisely calculated results. Nevertheless, we note that the types of improvements we project are in line with historical improvements in transportation technology. Further, our sensitivity results show that the results are robust in the face of failure of a key technology; this is a critical result because we cannot claim that our choice of technological "winners" is necessarily the correct one.

The results show that transportation energy use and greenhouse emissions will continue to grow at a rapid rate without substantive policy changes. For the Baseline scenario, energy use rises from 25 Quads in 1997 to 36.8 Quads in 2020, and carbon emissions rise from 478 MtC to 700 MtC during the same period – increases of over 45 percent. In the Moderate scenario, which focuses primarily on advancing technology development and does not attempt to strongly influence markets, transportation energy use still grows to 34.1 Quads in 2020, and carbon emissions to 646 MtC in 2020, in both cases growth of more than one third from 1997 levels. Only in the Advanced scenario, where policies focus on *both* developing technology and influencing markets, does growth in energy use and greenhouse emissions slow markedly. In that scenario, transportation energy use rises only 16 percent by 2020, to 28.9 Quads, and carbon emissions rise only 12 percent, to 545 MtC. As noted, these results are not affected markedly by the elimination of an important technology, the direct injected diesel, because other technologies increase their market share when the diesel is eliminated.

Significant emissions reductions from transportation will take time. This is partly because technological adoption and fleet turnover are slow processes in this sector, and partly because even the higher fuel prices associated with the carbon permits and "pay at the pump" insurance have not curbed the steady growth of transport demand. Understanding how demand for mobility is likely to evolve and how it can be influenced without sacrificing accessibility is an important area that needs further investigation. Even in the Advanced scenario in the year 2020, key technologies such as hybrid vehicles, fuel cell vehicles, blended wing-body aircraft, and more, are a minority of new vehicle sales and a far smaller minority of vehicle populations. If these technologies are the beginning of a revolution in transportation technology, that revolution will have only just begun by 2020.

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Chapter 7

THE ELECTRICITY SECTOR[1]

7.1 INTRODUCTION

7.1.1 Overview of the Electric Sector

In 1997, the generation of electricity in the U.S. consumed the equivalent of 34 quads of primary energy, or 36% of all the energy used in the U.S. Of this, 23 quads was provided by fossil fuels, with 18.6 quads from coal, 3.4 from natural gas and 0.9 from petroleum. This fossil fuel use produced 532 million metric tonnes of carbon (MtC), 11.6 million metric tons of sulfur dioxide emissions, and 5.3 million metric tons of nitrogen oxide emissions. These values do not include the contributions from cogeneration, which would raise the values even higher.

There are essentially four mechanisms to reducing the impact of the electric sector in these areas. These include:

- reducing the demand for electricity,
- increasing the efficiency of individual fossil-fired power plants and transmission,
- reducing or sequestering the emissions from these plants, and
- switching to less- or non-carbon intensive sources of generation.

Significant opportunities exist to reduce the demand for electricity. These opportunities are addressed in the end-use chapters of this report. This chapter will focus on the other three mechanisms and the policies that could affect them.

7.1.2 Restructuring of the U.S. Electric Sector

Identification and evaluation of policy pathways to reduce emissions in the electric sector is both facilitated and complicated by the current restructuring of the sector. The U.S. electricity industry is being transformed from a highly-regulated, vertically-integrated, industry to a largely competitive deintegrated industry, at least in the generation sector. Transmission and distribution functions are expected to remain largely cost-of-service regulated. Because this transformation is far from complete, it is difficult to predict the structure the sector will possess in the future, much less the impact that alternative policies could have on these characteristics.

Clearly, the set of players will expand from the historical set of utilities and regulators to include distribution companies, independent system operators, generation companies, power brokers, energy service companies, etc. The decisions made by the profit-maximizing owners of individual generating units are likely to be quite different than the system-wide cost-minimizing decisions made in the past by utility owners of large generation and transmission systems and the respective public utility commissions. In unregulated markets characterized by short-term matching of offers to sell electricity with demand for electricity, and without guaranteed returns, investors in generation will evaluate opportunities on a shorter time scale with risk considered largely through higher costs of capital, and returns based on marginal pricing. Separate ownership or control of generation and transmission systems under different forms of

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economic regulation, risk, and reward, may create a different system structure than one where both components have prices regulated.

There already has been a reduction in R&D efforts and demand-side management programs by utilities preparing for the competitive environment. Some utilities are also divesting themselves of generation assets and becoming regulated transmission/distribution companies providing open access to all generators as mandated by the Federal Energy Regulatory Commission (FERC) in response to the 1992 Energy Policy Act. Finally, states are beginning to mandate such restructuring; the Clinton Administration is pushing legislation to facilitate it; and consumers are beginning to express preferences not only for low-cost power, but for environmentally-clean power.

Other factors are also forcing the U.S. electricity industry to change. These factors include low natural gas prices, substantial improvements in the efficiency of gas-fired combustion turbines and combined cycle systems, broad public sentiment favoring deregulation of economic sectors wherever possible, and heightened interest and concern for the environment and its protection.

7.1.3 Technology Opportunities

Policies and market structure do not generate emissions or consume imported oil, technologies do. Thus, policies put forth in the hope of meeting national goals are intended to encourage the use of "clean energy" technologies. Table 7.1 summarizes these technology opportunities for the electric sector along with issues that may stall their development. Because of the age of the current fleet of power plants (2/3 were built before 1970), there is a great opportunity for these new, more efficient technologies to be deployed as existing plants are retired and replaced. Combined heat and power or cogeneration plants are not shown in Table 7.1 since they are treated in the buildings and industry end-use chapters of this report.

Table 7.1 Electric Sector Technology Opportunities

Technology	1997 gen market share	1997 avg. grams carbon / kWh	Possible future improvement	Issues/comments
Coal boilers	56%	260	New plant efficiency could be as high as a third greater than the efficiency of existing plants Existing plant efficiency could be improved but to a lesser extent Carbon sequestration	Few new coal plants are currently planned Existing plants are cheapest source of fossil power Refurbishments are costly Depending on pending environmental constraints, older plants may be retired Seq. in early research stage
Coal IGCC	~0	210	Possible combination with fuel cell yields high efficiency and carbon separation achieving near zero carbon and criteria air pollutant emissions	Close to commercial 3 commercial demonstration plants operating in U.S.
Gas Turbine	<5%	170	New plant efficiency >40% efficiency; current plants ≈32%	Largely peak load (with some intermediate), thus has lower impact on total emissions

Technology	1997 gen market share	1997 avg. grams carbon / kWh	Possible future improvement	Issues/comments
Gas combined cycle	<4%	100	Market share can be substantially increased over time New plant efficiencies could increase to 60% to 70% with a ternary cycle; current models are 43% –57% efficient With carbon separation could achieve near zero carbon	Designed for intermediate and base load; could replace retiring coal plants and inefficient gas plants Large resource base Fuel deliverability and cost may become issue in future
Fuel cells	0%	>=0 depending on fuel source	Can be combined with other cycles With carbon separation could achieve carbon and criteria air pollutant emissions near zero	First cost needs to be reduced further Technology improvements needed
Nuclear	20%	0	Improved efficiency and life extension of current plants possible at low cost New small plants may better meet market needs	Public concern with safety Spent fuel storage and disposal could limit future operations More than 50% of plants require license renewal by 2020
Hydro	10%	0	Increased efficiency and enhanced environmental performance with advanced technology	Large potential (60 GW) Concerns with environmental impacts from public and natural resource management agencies
Wind	<1%	0	Costs competitive on kWh basis in near future in some markets	1998 growth rate of 35% worldwide Intermittency may limit role
Biomass cofiring	<1%	~0 for biomass portion	Use can be increased relatively easily to 2 – 4 % of coal generation	Requires biomass collection infrastructure; negligible coal plant retrofits required at low levels of biomass to coal.
Geothermal Hydrothermal	<1%	0	Resource identification	Competitive today at good resource site; resources limited
Photovoltaics	0	0	75% cost reductions possible in long term (EPRI, 1997)	Large 2020 potential in buildings assuming net metering
Solar thermal	<1%	0	Limited cost-reduction potential	Only southwestern U.S.

7.2 POLICY IMPLEMENTATION PATHWAYS

Deployment of these “clean energy technologies” can be accelerated by overcoming market barriers and failures through policy interventions. For the BAU scenario, no policies beyond those currently in place are assumed, consistent with the EIA’s assumptions in AEO99. Policies evaluated as part of the Moderate and Advanced scenarios are shown in Table 7.2. A brief description of each follows the table with specific parameter values in Appendix C-4. In addition, other policies that may be useful but could not be accurately modeled quantitatively in CEF-NEMS are discussed in Section 7.2.2. Some sensitivities to the scenarios were run that modified the below policies or added approximations of other policies. These are discussed in Section 7.5.3.

Table 7.2 Electricity Policy Pathways Analyzed

Moderate Scenario	Advanced Scenario
➢ 1.5¢/kWh production tax credit (PTC) for wind and biomass power to 2004. 1.0¢/kWh credit for biomass cofiring.	➢ Same, for all non-hydro renewable electricity options to 2004.
	➢ Renewable Portfolio Standard – represented by 1.5¢/kWh PTC in 2005-2008 to model cap in administration proposal
➢ Wind deployment facilitation	➢ Same
➢ Enhanced R&D – represented by the electric technology cost and performance of the AEO99 high renewables and high fossil cases	➢ Additional technology advances beyond those of the Moderate scenario ➢ Include sequestration option.
➢ Up to 1% net metering.	➢ Up to 5% net metering.
➢ Full national restructuring in 2008.	➢ Same.
	➢ SO_2 ceiling reduced in steps by 50% between 2010 and 2020 to represent tighter PM standards
	➢ Carbon cap with assumed consequent permit price of $50 per metric ton of carbon, starting in 2002 with full value by 2005.

7.2.1 Policy Pathways Quantitatively Analyzed

Production tax credit. In the Advanced scenario, a production tax credit of 1.5¢/kWh (1992$) is assumed for the first 10 years of operation from all non-hydro renewable electric generators installed through 2004. The tax credits lower the cost of production; the additional cost to the Treasury is discussed in section 7.5.4. In the Moderate scenario, only wind and biomass power qualify, consistent with the

President's Climate Change Technology Initiative proposals. In addition, for both scenarios a 1¢/kWh credit is given for cofired biomass during the years 2000-2004.

Renewable Portfolio Standard (RPS). The President's proposed (April 1999) legislation on competition in the electric sector includes a mandate to generate 7.5% of all electricity sales from either wind, biomass, solar, or geothermal for the years 2010 through 2015. However, a 1.5¢/kWh cap on the price premium for the renewable power is established. If the price difference between renewable energy and other alternatives is more than the cap, then it could come into play and lower the portfolio percentage which could end up less than 7.5%. Although CEF-NEMS has the capability to include an RPS, it cannot directly model the 1.5 cents/kWh cap and it has problems combining RPS with marginal-cost-based rates. As a surrogate to the CEF-NEMS method of modeling the RPS, we extended the PTC of 1.5¢/kWh to capacity added between 2005 and 2008. Because the biomass cofiring tax credit only applies in the years specified, as opposed to the following ten years, it was extended to 2014. We calculated the added cost and carbon saved due to the tax credit extension and determined it to be between $60 and $70/tC. For this reason, the credit was only applied in the Advanced scenario.

Policies to facilitate wind deployment. There are a number of issues associated with wind deployment and operation within a competitive electric market that could be mitigated through focussed policies. These include policies to facilitate siting on Federal land (for example, reducing the National Environmental Protection Act (NEPA) filing requirements which currently require avian, archeological, and flora/fauna studies), to expedite challenge procedures and limit liabilities for all sites (for example, there is concern that criminal charges could be pressed for the death of any endangered avian species), to design independent system operator protocols to accommodate wind intermittency (for example, the establishment of a trading market to firm up intermittent power sources), etc[2].

Enhanced R&D. Federal R&D budgets for renewable, nuclear, and fossil generation technologies are assumed to increase 50% in the Moderate scenario, and 100% in the Advanced scenario. The Moderate scenario funding increases together with industry learning are assumed to yield technology cost and performance equal to that of the EIA's high renewables and high fossil cases defined in EIA's 1999 Annual Energy Outlook (EIA, 1998a). EIA states in the AEO99 that the values used for the high fossil cases in the AEO99 were chosen "to reflect potential improvements in costs and efficiencies as a result of accelerated research and development." However, in recent comments they have said that these were simple sensitivities only loosely reflective of enhanced R&D. The improved renewable technology values were based on "more optimistic Department of Energy renewable energy assumptions" (EIA, 1998a). These renewable assumptions are consistent with the EPRI/DOE Renewable Energy Technology Characterizations report (EPRI, 1997). In the Advanced scenario, the renewable technology cost and performance assumptions remained the same as those in the Moderate scenario, while the fossil generator data were based on information received from the DOE Office of Fossil Energy, consistent with their Vision 21 performance goals (DOE/FE, 1999; Parsons, 1998; Dye, 1999). Because the amount of improvement due to R&D is not assured, sensitivities were done using less optimistic advances in the fossil and renewable technologies. These are discussed in section 7.5.3.

The capital cost of the advanced gas combined cycle (AGCC) is the same in the Advanced scenario as in the Moderate scenario. The efficiencies are the same for all scenarios in 2000 but gradually improve more rapidly and to a higher value in the Advanced scenario to reflect extra effort on improvements through R&D. One source of improvement is the addition of a fuel cell to the front of the AGCC, creating a

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[2] To reflect these policies, changes were made to the model's parameters for all three scenarios, including the BAU. However, the changes did not affect the BAU scenario because the constraints on wind capacity caused by these parameters were not limiting its growth. Consequently, these changes can be thought to apply only to the Moderate and Advanced scenarios.

ternary cycle. This does not begin to penetrate the AGCC market until post-2005. AGCC efficiencies are at 55% in 2005 in the Advanced scenario and improve to 70% by 2015 while in the moderate and BAU scenarios, the AGCC efficiency peaks at approximately 55% in 2010.

The advanced nuclear technology was modified for the Moderate and Advanced scenarios. In the Moderate scenario, the fifth-of-a-kind cost of advanced nuclear technology was kept the same as in the BAU (and AEO99 reference) case, but to reflect a policy that the advanced nuclear plants would be jointly developed with international partners, the cost of the initial plants were not increased as much[3]. In the Advanced scenario, the capital cost of the advanced nuclear was reduced by roughly 10% to represent reductions in construction costs through advanced designs and R&D. Sensitivities were run on the Advanced scenario that further lowered the cost of the initial nuclear plants by subsidizing the capital cost premium of these plants over the fifth-of-a-kind plant cost. These are discussed in section 7.5.3.

Specific correlations between R&D amounts and technology improvements were not used in this study. Rather, recognized technology targets by experts were used to establish the potential improvements with higher improvements assumed with increased funding. More precise technology achievements as a function of research funding over a long time period are difficult if not impossible to attain. The costs and efficiencies of the fossil, nuclear, and renewable plants are listed in Appendix C-4.

Net metering. Consistent with the President's recently (4/19/99) proposed legislation on competition in the electric sector (DOE, 1999), this policy assumes a minimal level of net metering is allowed by the states. It is applicable only to systems of 20 kW or less in residential and commercial applications. Net metering means that on-site generation exceeding site loads can be fed back to the grid at values equal to the purchase price, i.e. the meter can be run "backwards" when on-site generation exceeds on-site loads. Net metering creates incentives for distributed generation which can have environmental and reliability benefits through higher efficiencies and reduced transmission and distribution requirements. Allowing customers to resell power at the retail price means that distribution costs are not recovered by the distribution company, requiring those costs to be recovered from sales to other customers. For this reason, net metering may face resistance and limits are often placed on the maximum amount of net metering allowed. The current analysis allows net metering of only residential buildings using PV[4].

Restructuring. This policy assumes that all states implement competitive wholesale markets for electric power by 2008 in the Advanced scenario and the Moderate scenario. This translates to pricing based on real-time marginal costs instead of regulated, average-cost-based rates. This is as opposed to the BAU case, in which marginal cost-based pricing is applied in the five regions of California, New York, New England, the Mid-Atlantic Area Council (consisting of Pennsylvania, Delaware, New Jersey, and Maryland), and the Mid-America Interconnected Network (consisting of Illinois and parts of Wisconsin and Missouri). Restructuring can cause other changes to the market, such as higher costs of capital, lower reserve margins, and flatter load shapes. It also allows the non-quantified benefits of choice of supplier and competition. This may create dynamic efficiencies that spur development of lower cost and higher value energy services to customers. A recent study by the Northeast Midwest Institute gives more details on the potential for efficiency improvements in a restructured market (Kaarsberg, 1999). Market forces are already at work in today's environment changing the generation mix to more efficient and cleaner plants. For example, the top two types of plants built in 1998 were combined cycle gas turbines and wind plants.

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[3] The Technical Optimism factor was reduced from 1.19 to 1.00. Technical optimism factors are a multiplier of the capital cost of the first few plants that gradually decline to unity by the fifth plant.

[4] In the industrial chapter, it is assumed that a portion of the electricity generated by combined heat and power systems is sold back to the grid at 60% of retail rates in the Moderate scenario and 80% in the Advanced scenario.

Stricter particulate matter (PM) emission standards. This policy assumes that PM standards are tightened in response to increasing concerns of their impact on health and the environment. The CEF-NEMS does not include PM emissions, however, one of the major precursors to the formation of small (< 10 microns) particulates is SO_2, which can be constrained in CEF-NEMS. Following the example of the EPA's analysis of mercury and particulate emissions (EPA, 1999), we restricted SO2 emissions to 50% below the current requirements. However, we delayed the ramping down to between 2010 and 2020, in part to shift policy impacts to the latter part of the study period.

Carbon trading system. In the Advanced scenario a cap is assumed on carbon emissions from all sectors of the economy. The cap is announced in 2002, implemented in 2005, and continued indefinitely. See chapter 1 for more details.

7.2.2 Additional Policy Pathways

There are additional electric-sector policies and opportunities (see Table 7.3) not included in our scenarios that we either modeled in our sensitivity analyses (see section 7.5.3) or which are discussed only qualitatively in this section. These include green power markets, distributed power markets, other market diffusion policies for renewable energy, various nuclear issues, emissions regulation mechanisms, hydroelectric power expansion, transmission and distribution (T&D) technology improvements, fuel switching from coal to gas, and efficient coal technology incentives.

Table 7.3 Additional Electricity Policy Pathways

Policy/Opportunity Areas	Potential Policies
Market Issues	Green Power market formation and standards Distributed power market facilitation
Renewable Market Diffusion	Supply Push policies (see Table 7.5 for details) Demand Pull policies Regulatory policies International Market policies Renewable Portfolio Standard
Hydroelectric Power Expansion	Increased R&D Extend renewable incentives to hydro
Nuclear Issues	Additional relicensing streamlining Spent Fuel Disposal resolution Ownership flexibility Decommissioning fund tax treatment
Emissions Regulation	Output-based allowance distribution Stricter emissions limits
Transmission & Distribution Technology Improvements	Increased funding of high temperature superconducting technologies
Clean Coal and Coal–to–Gas Technology Development	Recovery of sunk costs in a switch from coal to gas Production tax credits for efficient coal Investment tax credit for efficient coal Pool for risk-sharing of technology development

Market Issues. Green power markets represent a growing opportunity for renewables. Evidence to date shows that green products have had some success in markets newly opened to competition (Wiser, 1999). Niche markets clearly exist for green power. Residential demand has been most prominent, though nonresidential demand has been more significant than many expected. Nonetheless, it will clearly take time for the green market to mature, and there remain legitimate concerns about the ability of customer-driven markets to support significant amounts of renewable energy. Unfortunately, there is currently insufficient data with which to predict the long-term prospects for green power sales with any accuracy (Wiser, 1999). This analysis does not presume to explicitly forecast the impetus that green marketing alone can provide, but rather we assume that green marketing together with other programs will spur the development of a renewable energy infrastructure and a consumer awareness and comfort with the technology. A Renewable Portfolio Standard in effect overrides a green power market by mandating a level of renewable resources. Only if green power marketing would provide a higher penetration than the RPS alone would our analysis under-represent the potential of this market.

Distributed power markets also represent an opportunity for dispersed generation. The primary candidate technologies include reciprocating engines, gas-fired turbines, fuel cells, and photovoltaics. To a limited extent we have captured some of this potential in our modeling of photovoltaics in the buildings sector. However, there also exists a large market for non-customer owned generation within the distribution system. Such generation could have a wide range of impacts on carbon emissions and local air pollution. On the positive side, distributed generation technologies may be non-emitters, like photovoltaics, or lower emitters, like fuel cells. Emissions would also be reduced since less generation would be required due to the absence of losses in the transmission of power. On the other hand, more emissions might result from the use of smaller less-efficient combustion turbines, and criteria pollutant emissions would be moved closer to population centers. These opposing impacts, together with the difficulty of modeling this very site-specific opportunity, have kept us from assessing this opportunity or the facilitating policies that could spawn it. However, a range of possible impacts is provided in the integrating chapter 1.

Combined heat and power (cogeneration) has been included in the industrial sector (Section 5.5.4) instead of the electric sector. Yet, it represents a significant contributor to the overall electricity output of the country. Table 7.4 shows the amount of capacity and energy that could be available from this source as determined by the analysis described in Appendix E-5 that was conducted outside of the CEF-NEMS model. Due to difficulties in modeling CHP in CEF-NEMS, these sources are not included in the production numbers in this chapter. If it were possible to include these values in the CEF-NEMS model runs, then our projections of electric sector capacity expansion would be significantly reduced. By 2020, additional cogeneration could reduce non-cogeneration production by another 16% from what is already included in the CEF-NEMS runs.

Table 7.4 Additional Cogeneration Capacity and Electrical Generation (from Table 5.10)

	2010			2020		
	BAU	**Mod.**	**Adv.**	**BAU**	**Mod.**	**Adv.**
Capacity (GW)	4	14	29	9	40	76
Generation (TWh)	31	98	201	62	278	539
% of non-cogeneration production (from Table 7.9)	0.8%	2.7%	5.7%	1.4%	7.3%	15.7%

Renewable Market Diffusion. Another category of options not explicitly considered here focuses on the process by which renewable technologies enter the market place. Since renewable technologies are not widespread in the market, they face a number of barriers common to all emerging technologies. These barriers include lack of information about the technologies, uncertainty about technology performance, and incompatibility with existing infrastructure. These market barriers can be addressed by a wide variety of policies. These include direct policies such as those shown in Tables 7.2 and 7.3 above, as well as more indirect policies like information programs that affect the diffusion process strongly in its early stages.

The range of these diffusion-related policies is illustrated by the results (see Table 7.5) of a recent scenario-based workshop, which focused on policies to encourage the significant penetration of renewable technologies in the U.S. in the next several decades. Many of these policies interact with each other to accelerate the diffusion process. As shown by Table 7.2, in this study we have quantified only the major policies that directly impact the economics of renewable technologies. A related working paper (Kline and Laitner, 1999) examines the issues involved in assessing the impact of the more indirect policies related to market diffusion.

Table 7.5 Renewable Market Diffusion Policies from Scenario Workshop

Supply Push	Demand Pull
• Large scale public/private partnerships in RD&D • Expand Climate Wise and Energy Star programs into renewable energy technologies • Refine and disseminate renewable energy resource data • Standardized procedures for selling and interconnecting intermittent renewables to the electric grid • Demonstrations of hybrids in distributed applications • Other large-scale demonstrations through public/private partnerships	• Green power certification • Power source disclosure requirements • Public/private partnerships for biofuels (and other technologies) • Competition to develop new user-side infrastructure to support renewables • Government purchases of renewables • Popular marketing campaign (e.g. Popular Mechanics)
Regulatory Measures	**International Markets**
• System Benefit Charges and guidance to accelerate renewable energy penetration. • Develop, promote methodology for evaluating distributed generation benefits of renewables • Integrate renewables into emissions enforcement procedures • Outreach/education for state legislatures • Outreach to federal agencies • Push dissemination of atmospheric research results	• International demonstrations by public/private partnerships • Promote (first quantify) environmental benefits of renewable energy technologies to developing countries

Nuclear Issues. A third set of policies that we have not analyzed quantitatively relates to nuclear power. Such policies include a definitive resolution to the spent fuel storage/disposal issue, licensing reform in the area of ownership requirements, and federal mechanisms to ensure full funding of nuclear plant decommissioning without penalties due to corporate restructurings or ownership transfers. These polices can be reflected in the analysis through further lowering of relicensing costs or ongoing O&M costs, but additional analysis is needed to quantify them, if such costs are even included in the BAU costs provided by EIA. Further discussion can be found in Appendix E-3.

Spent fuel storage/disposal policy. Many nuclear plants are faced with a near-term problem of lack of storage space for their spent nuclear fuel. Some state regulations stipulate that a nuclear power plant cannot operate if it does not have sufficient on-site storage capacity. Uncertainty about how and when the federal government will meet its obligation to provide storage and disposal facilities for used nuclear fuel represents one of the most significant business risk factors for nuclear power plants. The Department of Energy has been conducting an exhaustive scientific assessment of a permanent disposal site at Yucca Mountain, NV, but it is more than 12 years behind schedule, and no site has been selected for an interim storage facility. While resolution of this issue is needed for the permanent storage of wastes, lack of a disposal facility will not cause premature shutdowns in and of itself. Alternative technical solutions to avoid shutdowns are available but require acceptance by the stakeholders involved.

Licensing reform regarding foreign ownership requirements. Sections 103d and 104d of the Atomic Energy Act prohibits foreign ownership of commercial nuclear facilities. In the evolving power market such restrictions impact competition. They could be removed, except where they pertain to national security concerns. As a barrier to entry, these restrictions limit the number of potential investors in U.S. nuclear assets, resulting in a downward bias in the value of such assets and a likelihood of premature shutdown. Existing owners that are not willing to continue operating a plant but unable to sell it to those most willing to, may choose to retire the plant instead.

Federal mechanisms to ensure full funding of nuclear plant decommissioning. Because decommissioning of nuclear power plants is a public health and safety issue, a federal mandate and mechanism could be established to ensure recovery of unfunded decommissioning obligations—via a non-bypassable charge—when a nuclear asset is sold. In addition, the Internal Revenue Code could be amended to ensure that, with the sale of a nuclear asset, the transfer of decommissioning funds are not taxed as capital gains. Without these mechanisms, nuclear plant economics are negatively affected.

Emissions Regulation Mechanisms. Other possible policies that could support non-emitting generators hinge on the economic recognition of their clean air compliance value. One such policy, an output-based emission standard, would allocate emissions allowances to all producers on the basis of their electricity production output, rather than the fuel input used. This change in the distribution of allowances would force emitters to purchase from non-emitters the required allowances for their production. Non-emitters would benefit both from the sale of their allowances and the higher marginal prices for electricity (since emitters would include the cost of allowances in their variable costs.) The impact would depend on the relative demand and supply of allowances, and consequent market price. The difficulty in modeling the inter-sectoral and cross-sectoral trading needed for such an approach limits our ability to analyze it.

Hydroelectric Power Expansion. Hydropower is often characterized as either a fully developed energy resource that needs no new attention in national energy strategies or as an energy source that should be discouraged because of its adverse environmental effects. Neither of these points of view are completely accurate. While hydropower currently supplies about 98% of the electric generation from renewables, it still can provide significant, additional benefits to control of greenhouse gas (GHG) emissions. There are approximately 60 GW of undeveloped hydropower available in the U.S., distributed across three types of projects: 1) equipment upgrades at existing hydropower facilities, 2) new development of generation facilities at existing dams, and 3) new development at new dams or diversions. With advanced technologies that are becoming available (e.g., fish-friendly turbines), the first two of these types of projects would have net benefits in terms of improved environmental performance and GHG reductions.

The third category of undeveloped resource is more problematic, because of the new construction involved. However, the estimate of those hydropower resources employed an environmental screen by state resource managers to exclude sensitive and protected sites (Rinehart et al., 1997) (i.e., environmentally unsuitable sites are not included in this estimate).

The magnitude of undeveloped hydropower is relatively large, especially with respect to near-term potential. Approximately half of this resource could be developed by 2010 if hydropower is included among the renewables targeted for encouragement. New initiatives for conducting life-cycle analysis and defining low-impact hydropower are being developed by scientific organizations, environmental groups, and energy marketers, for marketing hydropower as "green" energy in the retail power market.

To achieve new, environmentally preferable hydropower, continued federal funding for RD&D projects is needed. DOE's Advanced Hydropower Turbine Systems Program has been successful in the development of innovative technologies that will enhance the environmental performance of hydropower projects and in attracting both interagency cooperation and industry cost-sharing. On the policy side, environmentally preferable hydropower needs to have full access to the market incentives for other renewables, if hydropower's GHG contributions are to be realized.

Estimating supply functions for hydropower is inherently difficult because of the highly site-specific nature of development costs (e.g., FERC, 1988). Resource studies to date (e.g., Rinehart et al., 1997; DOE Hydropower Assessment Program 1999) have not included the type of information needed to provide the level of economic analysis possible with other renewables. Additional federal and/or private resources should be invested in an expanded hydropower resource assessment, so that its true potential can be factored into national planning. Any new resource assessment should be done in cooperation with both the industry and environmental groups. Indications are that the hydropower industry is ready and willing to participate.

One example of the unresolved controversies that plague the hydropower industry is the fate of hydroelectric generation during the relicensing process at non-federal projects. Every 30 to 50 years, non-federal hydropower projects must obtain a new operating license from FERC. This relicensing process is an opportunity to add new environmental operating constraints, such as minimum flow requirements or fish ladders or screens. It is also a time when generating equipment can be upgraded or decommissioning can be considered. A basic question is how is contemporary relicensing affecting the total generating capacity of hydropower in the U.S.? Answers range from an average of 8% loss in capacity (Hunt and Hunt, 1997) to less than 1% change. Anecdotal evidence from individual proceedings indicates that many opportunities to upgrade equipment at relicensing are being foregone, probably due to local economic decisions and regulatory uncertainty. The latter has drawn attention from Congress. Pending legislation designed to resolve some of this uncertainty may be enacted, but the cost of relicensing will remain high. Environmental mitigation costs are also quite high in relicensing, but there are no definitive studies that can quantify these costs. Hydropower is a resource that should be tapped to the extent feasible, both environmentally and economically, in order to address GHG controls, especially on the near term.

Other new policy options that could be pursued for hydropower include the following:

- regulatory reform to ensure that environmental mitigation requirements in relicensing are justified,
- incentives for equipment upgrades of existing facilities for both power production and enhancements to environmental performance, and
- development of objective criteria for evaluating the environmental performance of hydropower projects in relation to other regional energy projects.

T&D Technology Development. Electric power T&D systems transfer generated power from central power stations and distributed generators to customers elsewhere on the power grid. Energy losses in the U.S. T&D system were 7.2% of total generation in 1995, representing 2.5 quads of energy and 36.5 MtC of carbon emissions (DOE National Laboratory Directors, 1997). High voltage direct current transmission, high temperature superconducting (HTS) cables and transformers, more efficient line transformers, and real-time control using automated controls could all improve the efficiency of the T&D system. Projections indicate that the most significant impacts of these technologies (20-25 MtC savings per year) will occur beyond 2020, as existing equipment is replaced and new technologies are available for capacity expansion. However, some savings, 3-6 MtC/yr, could occur if currently available technologies become more economical and accepted. Domestic research is aimed at improving HTS cables and transformers through longer cable lengths at lower cost and improved cryogenic refrigeration. Several demonstrations are already underway, including a replacement of distribution lines in a crowded urban location in Detroit, MI (EPRI, 1999).

Coal Technology Development. Carbon emissions at existing coal-fired power plants could be reduced through efficiency improvements (via clean coal technologies) or reliance on carbon capture/ sequestration technology (when it becomes commercially economic). Another option is to convert such plants from coal to natural gas. Some fuel switching is already occurring, where coal-fired power plants are being purchased and converted to natural gas combined cycle (NGCC) facilities (e.g., Detroit Edison converted its 200 MWe Connors Creek plant, which became operational in June 1999). Such conversions reduce not only carbon emissions but also criteria air pollutants, and permit capacity expansion in airsheds that would otherwise prohibit new generating capacity. Electric generating companies compare the projected cost of continued operation (of the coal-fired power plant) with additional compliance equipment against the cost of switching to gas to meet future electric load and environmental requirements.

In general, the economics of switching from a plant designed to use an inexpensive fuel (coal) for a more expensive one (gas), while requiring significant capital expenditures, are not favorable. Also, space restrictions, access to natural gas pipelines, and local permits can preclude such conversions. In addition to these site factors, the sunk cost in the coal-fired power plant (e.g., boiler, coal handling equipment, emissions control equipment) could make such a conversion uneconomic. Such sunk costs may not be recoverable, either in a regulated rate-of-return environment or competitive power market (via a competitive transition or stranded cost charge). In a regulated market the equipment may be declared no longer “used and useful” so it would be withdrawn from the rate base. In a competitive power market, the investment represents a sunk cost that does not enter into future “going forward” costs when compared against the value of switching to gas.

A potential policy pathway is to reimburse generators who switch to gas for the coal-related sunk costs, either through a tax credit or an electricity surcharge, such as a stranded cost or competitive transition charge. A potential problem with such a policy is the possibility of “free riders,” – generators who take advantage of the reimbursement but would have switched anyway based solely on economic criteria. Such a policy option would require further examination before it could be recommended (or implemented).

Carbon emissions reduction could also be accomplished through deployment of more efficient coal technologies—that either replace retirement-age pulverized coal-fired boilers, or serve new load growth instead of less efficient technologies. While coal—by its nature—has a high carbon content, clean coal technologies (CCT) have a lower carbon emissions rate than pulverized coal (PC) boilers used today. For example, a 34% efficient pulverized coal boiler has a carbon emission rate of 260 g/kWh, while a 42% efficient integrated coal gasification combined cycle (IGCC) facility has a rate 20% lower, or 210 g/kWh.

So for every Gigawatt-hour (GWh) of electricity generated by IGCC (relative to a PC boiler) 50 metric tons of carbon would be avoided (not emitted). By 2020, advanced coal-fired plants may achieve 60% efficiency through R&D, reducing their carbon emission rate to 150 g/kWh, and saving 110 tons per GWh relative to an average current-day coal plant.

However, most CCTs are not currently considered “commercial” for power generation applications, so their capital and operating costs have a technology risk premium. (In the AEO99 the risk premium —the difference in capital cost between the first-of-a-kind and fifth-of-a-kind plant— is equivalent to $515/kW.) This technology risk premium makes CCTs more expensive than the current technology of choice, natural gas combined cycle (NGCC).

A number of studies have examined alternative incentive mechanisms to accelerate the deployment of CCTs (see Spencer, 1996 for a review). Three studies derived the level of CCT incentives necessary to be cost-competitive with NGCC (South, et al, 1995; Spencer, 1996; and CURC, 1998). The Coal Utilization Research Council (CURC) determined that the following incentives are necessary for the first 1,500 MW of each type of CCT:

- Investment tax credit: tax credit equal to 20% of owner’s equity investment, applicable to first 4 years of construction.
- Production tax credit: tax credit based on design average net heat rate, with an incentive (0.70 - 1.30 cents/kWh depending on heat rate) for years 1-5, and a lower incentive (0.45-1.10 cents/kWh depending on heat rate) for years 6-10. The production tax credit would apply to the years 1-10 of operation.
- Financial Risk Pool: the Federal government would establish a financial risk pool applicable in years 1 thru 3 of operations to offset costs arising from technology non-performance (relative to design) during start-up and initial operation. The total amount of recoverable costs is limited to 5% of total project installed cost.

While these financial incentives are needed to make CCTs competitive with NGCC (using a cash flow analysis), the level of incentives exceed the carbon value targets inherent in the Moderate and Advanced scenarios of this study. For example, a production tax credit of 0.25¢/kWh over 10 years is equivalent to $24/tC, and a 0.50¢/kWh production tax credit is equal to $48/tC. Thus, implementation of the full set of incentives proposed by CURC would translate into a carbon value greater than $200/tC. This value could be reduced depending on the amount of additional capacity that these incentives would spur after they have expired.

7.2.3 Barriers Analysis

Barriers to the potential improvements in electricity technology have been broadly classified in Table 7.6 and defined just below the table. Also listed are some of the policies to be analyzed using the CEF-NEMS model. The mark in the cells of the table mark where a potential policy responds to the barrier identified.

Table 7.6 Barriers and Policies

	Production Tax Credit	Wind Facilitation	Enhanced R&D	Net metering	Nation-wide Restructuring	Stricter Air Emission	Carbon Trading
1) Generation costs do not include all costs of emissions						X	X
2) Regulated market structure does not reward innovation well	X		X		X		
3) Regulated market structure limits competition	X			X	X		
4) Public benefits of R&D are not captured by investors			X				
5) System planning and operations do not handle non-dispatchability well	X	X		X			

1) **Emissions costs:** The absence of full costs of emission damages from fossil generators distorts the electricity generation markets towards fossil fuels. Existing control costs are embedded in the cost of electricity. While current EPA regulations enforcing the Clean Air Act and other Federal legislation impose control costs on the marginal emitter of criteria pollutants like SO2 and NOx, these control costs are not the same as the damage costs. And inasmuch as the regulations allow some older fossil generators to continue to emit, not all existing fossil generators incur operating cost penalties. Furthermore, there are several emissions produced by fossil fuel combustion that are not capped today. These include carbon, mercury, and smaller particulates (2.5 micron). No costs are currently included to account for damages from these pollutants.

2) **Innovation rewards:** The traditional, regulated electricity market allows utilities a reasonable return on their investment, as defined by regulators. With a relatively low-risk return based on capital investment, there is little direct monetary incentive to lower costs or improve efficiencies. Guaranteed returns can even provide an incentive to hang on to non-cost-effective plants until they are fully amortized, and to replace cost-effective plants that are fully amortized. The industry has relied on regulatory pressure to keep costs down, and to use regulatory lag to reward innovation. There is a reward for innovations that lead to increased sales of electricity (or reductions through demand side management). These have led to industry-wide improvements over time, but the rewards were shared over all industry rather than garnered by individual innovators.

3) **Competition:** In addition, the regulated electricity market established exclusive franchises that limited the amount of competition. The "regulatory compact" of limited competition for regulated rates worked well to keep prices reasonable and extend the benefits of electrification to all, especially

when economies of scale were large and thus large monopolists could lower prices better than small firms. However, this system lessened the opportunity for innovation through competition.

4) **R&D:** While the traditional regulated utility structure did not strongly drive innovation, it did provide capital for research and development. In today's more competitive electric sector, R&D funding has decreased dramatically. The barrier to increased R&D is the public goods aspect of R&D. Companies will not fund the optimal societal level of basic R&D of new technologies, since many of the benefits of such research will flow to their competitors and to other parts of the economy. This is true of many industries, and is one of the main rationales for government-funded long-term, pre-competitive research in industries that have a vital role in the U.S. economy.

5) **Non-dispatchability:** The electric system requires extensive control over the level of production in order to match demands precisely. Intermittent sources and generation sources outside of the direct control of the system operators are not easily incorporated into system planning and operations. Consequently, there has been a devaluing of their contribution to the system, which has created a barrier to their widespread acceptance.

7.3 METHODOLOGY

7.3.1 Modifications to CEF-NEMS for the BAU Scenario

Besides the policy scenarios to be analyzed, a new Business As Usual (BAU) scenario was established for this CEF study. The BAU scenario was developed through limited modifications to the AEO99 Reference scenario. These modifications to the Electricity Market Module (EMM) of CEF-NEMS were made to represent technologies and markets more realistically. A brief general description of the EMM can be found in Chapter 3. The changes for the electric sector to the BAU scenario are documented below:

Wind. In CEF-NEMS some of the EMM constraints imposed by NEMS on wind market penetration have been altered. These changes were made to more accurately reflect what the authors feel to be the current market for wind. These changes did not deal with the actual operation of a wind plant (e.g., operating cost, capacity factor) but with market-related growth limitations imposed in NEMS. While these changes were made for all three scenarios, i.e., including the BAU scenario, they had no impact on the BAU scenario results because very little wind penetrates in that scenario and therefore the constraints in the EMM linear program are not binding. Thus these modifications could alternatively be considered to reflect a set of policy changes in the Moderate and Advanced scenario that facilitates wind deployment (see Table 7.2) The constraints modified are listed below in Table 7.7 and described in detail in Appendix C-4.

Table 7.7 Modifications to NEMS Constraints on Wind

NEMS EMM	CEF-NEMS EMM
Maximum construction of 1GW in a region in a single year	Deleted
Short-term supply elasticity: 70% increase in capital costs for national growth above 14% per year	Reduced to 5% penalty for annual national growth between 20 and 30% and 15% penalty above 30% growth.
Intermittency: Max wind generation < 10% regional generation	Replaced by capital cost multiplier below
Capital cost increased by a factor of 3 for 90% of all wind resource due to site access, intermittency, & market factors	Capital cost increased by as much as 60% as regional market penetration rises from 10% to 20%

Biomass cofiring. All the scenarios shown here, including the BAU scenario, allow biomass cofiring of coal plants (the AEO99 reference case did not).

Nuclear. For the AEO99, "In the reference case, it is first assumed that a retrofit costing $150 per kilowatt will be required after 30 years of operation to operate the plant for another 10 years." (EIA, 1998b) If its "going forward" cost, including the 10-year $150/kWe incremental capital charge, is less than the minimum cost of new baseload capacity, then the nuclear unit is assumed to continue in operation through its 40-year license period. If not, then the plant is assumed to be retired at the 30-year date. The $150/kWe charge is intended to account for large equipment replacement expenditures, such as, for example, a steam generator in the case of a pressurized water reactor (PWR). If a PWR has had a steam generator replaced in the several years prior to year 30 then the $150 charge is not applied. In addition, in the AEO99 reference case, "A more extensive capital investment ($250 per kilowatt) is assumed to be required to operate a nuclear unit for 20 years past its current license expiration date." (EIA, 1998b) It is assumed that the operating license will be extended from 40 to 60 years if the sum of the going-forward cost and a capitalization of the life extension cost over 20 years is less than the minimum cost of constructing replacement baseload capacity. Otherwise the plant is retired.

The nuclear plant refurbishment and relicensing costs have been modified in the CEF-NEMS to reflect more closely the empirical estimate of $180/kW for these activities. (See Appendix E-3 for the calculation.) This entailed retaining the $150/kW charge at year 30, but reducing the year 40 charge to $50/kW to approximate the total $180/kW charge for life extension and license renewal. Recent comments from EIA state that the $150/kW and $250/kW costs are not capital expenditures but are to represent age-induced increases in operating costs. The evidence of age-induced increases in nuclear facilities is mixed. By lowering the 40 year value, we do not include this extra expense.

Geothermal. Construction of geothermal capacity is modeled on a site-by-site basis within NEMS. If any capacity is added to a site, there is a waiting period constraint before any additional capacity can be added at that site. In the AEO99, this waiting period was set at six years, greatly slowing the speed that any geothermal could be added. In addition, the NEMS model uses a logit function for allocating capacity additions between technologies. This serves to avoid the "knife-edge" problem of one technology receiving all capacity additions even if it is just slightly below the cost of others. However, the function can cause a very small amount of capacity to be added at all geothermal sites. The waiting period then forecloses any additions for another six years, thereby greatly reducing the amount of geothermal capacity that can be built over the study period. For the scenarios in this study, we changed the length of the waiting period to zero so that capacity can be added the next year if it is economical to do so.

7.3.2 Policy Modeling within CEF-NEMS

As discussed in Chapter 3, most of the results developed for the electric sector were modeled almost entirely in the EMM of CEF-NEMS. A brief general description of the EMM can be found in Chapter 3. Table 7.8 shows the analysis approach used for policies specific to the electric sector. The detailed parameter settings that varied between the Moderate and Advanced scenarios can be found in Appendix C-4 along with details on their derivation. Policies were not examined individually, but rather as a set within each of the three scenarios – BAU, Moderate, Advanced.

Table 7.8 Modeling of Policies

Policy	Modeling Approach
Production Tax Credit	For each renewable technology, the present value of the 10 year tax credit is levelized over plant lifetime and inserted as the EMM parameter for tax credits
Renewable Portfolio Standard	The PTC for non-hydro renewables (above) was extended from 2004 to 2008. The biomass cofiring tax credit was extended to 2014.
Expanded R&D	Two steps are involved: 1) To estimate how much expanded R&D will improve a technology's cost and performance, existing, published estimates of future technology improvements were used. 2) These estimates were inserted into the technology parameters of the EMM that characterize each technology.
Net Metering	CEF-NEMS competes fuel cells and PV with retail electricity prices in the residential sector. Limits can be placed on the amount of sales displaced by such on-site generation
Restructuring	Marginal cost pricing is used in EMM for all regions Discount rates are increased in EMM Amortization periods are shortened in EMM Reserve margins are decreased in EMM
Tighter SO_2 Limits	The allowed ceiling for SO_2 was reduced from 895 million tons in 2010 to 448 million tons in 2020 in steps of 45 million tons per year
Carbon Trading System	Within CEF-NEMS, fuel costs are raised based on the expected price of carbon allowances. These costs are used in all sectors' analyses, not just the electric sector.

7.4 SCENARIO RESULTS

7.4.1 Overview

The scenarios as described have been run through the CEF-NEMS model, in conjunction with the scenarios defined in the end-use sectors. The key results of the three scenarios are shown in the following tables and figures.

Table 7.9 Generation by Scenario by Electric Generators (TWh) (no cogeneration)

			2010			2020		
Fuel	**1990**	**1997**	**BAU**	**Mod.**	**Adv.**	**BAU**	**Mod.**	**Adv.**
Total	2850	3190	3920	3680 (-6%)	3520 (-14%)	4420	3800 (-12%)	3440 (-22%)

Note: BAU = Business-as-Usual scenario; Mod. = Moderate scenario; Adv. = Advanced scenario. Numbers in parentheses represent the percentage change compared to the BAU scenario.

Table 7.10 Primary Energy Use by Scenario and Fuel in the Electric Sector (quadrillion Btu) (no cogeneration)

			2010			2020		
Fuel	**1990**	**1997**	**BAU**	**Mod.**	**Adv.**	**BAU**	**Mod.**	**Adv.**
Coal	16.1	18.6	21.2	20.2 (-4%)	14.4 (-32%)	22.4	20.7 (-8%)	10.9 (-51%)
Natural Gas	2.88	3.4	6.6	5.0 (-24%)	6.1 (-9%)	8.8	5.9 (-34%)	7.2 (-18%)
Distillate	0.02	0.1	0.0	0.0 (-0%)	0.0 (-33%)	0.0	0.0 (-33%)	0.0 (-33%)
Residual	1.23	0.8	0.2	0.1 (-26%)	0.1 (-37%)	0.2	0.1 (-20%)	0.1 (-47%)
Nuclear	6.20	6.7	6.2	6.2 (-0%)	6.7 (9%)	5.6	4.9 (-11%)	6.4 (15%)
Hydro[b]	3.6[a]	3.6	3.3	3.3 (-0%)	3.3 (0%)	3.3	3.3 (-0%)	3.3 (0%)
Non-hydro renew energy[b]	a	0.8	1.5	2.3 (55%)	3.8 (161%)	2.3	3.2 (41%)	4.6 (98%)
Electricity Imports	0	0.3	0.3	0.3 (-0%)	0.3 (6%)	0.3	0.3 (-0%)	0.3 (0%)
Total	30.07	34.3	39.3	37.5 (-5%)	34.8 (-11%)	42.9	38.6 (-10%)	32.8 (-24%)

Note: BAU = Business-as-Usual scenario; Mod. = Moderate scenario; Adv. = Advanced scenario. Numbers in parentheses represent the percentage change compared to the BAU scenario.

[a] 1990 Hydro includes non-hydro renewable energy.

[b] Hydro, solar, and wind primary energy use assume a fossil-fuel heat rate equivalent of 10,280 Btu/kWh. Nuclear plants assume a value of 10,623 Btu/kWh.

Table 7.11 Generation by Scenario and Fuel in the Electric Sector (TWh) (no cogeneration)

			2010			2020		
Fuel	**1990**	**1997**	**BAU**	**Mod.**	**Adv.**	**BAU**	**Mod.**	**Adv.**
Coal		1800	2020	1940 (-4%)	1400 (-31%)	2170	2000 (-8%)	1060 (-51%)
Petroleum		80	22	17 (-23%)	14 (-36%)	18	15 (-17%)	11 (-39%)
Natural Gas		300	890	680 (-24%)	880 (-1%)	1270	830 (-35%)	1140 (-10%)
Nuclear Power		630	580	580 (0%)	630 (9%)	520	460 (-11%)	600 (15%)
Renewables		390	410	460 (13%)	590 (45%)	440	500 (13%)	630 (42%)
Hydro		350	320	320 (0%)	320 (-0%)	320	320 (0%)	320 (0%)
Wind		3	8	37 (386%)	140 (1760%)	9	51 (495%)	160 (1770%)
Biomass		4	26	37 (43%)	47 (83%)	31	26 (-17%)	48 (55%)
- Dedicated		4	11	15 (35%)	22 (100%)	19	16 (-12%)	32 (69%)
- Cofired		0	15	22 (49%)	25 (70%)	13	10 (-24%)	17 (33%)
Geothermal		16	24	37 (55%)	50 (109%)	47	67 (41%)	67 (41%)
Other		15	28	28 (0%)	28 (0%)	31	31 (0%)	31 (0%)
Other		-3	-1	-1 (0%)	-1 (0%)	-1	-1 (0%)	-1 (0%)
Total		3190	3920	3680 (-6%)	3520 (-10%)	4420	3800 (-14%)	3440 (-22%)
Net Imports		32	30	30 (0%)	32 (7%)	27	28 (4%)	30 (0%)

Note: BAU = Business-as-Usual scenario; Mod. = Moderate scenario; Adv.= Advanced scenario. Numbers in parentheses represent the percentage change compared to the BAU scenario.

Table 7.12 Carbon Emissions by Scenario and Fuel in the Electric Sector (MtC) (no cogeneration)

			2010			2020		
Fuel	**1990**	**1997**	**BAU**	**Mod.**	**Adv.**	**BAU**	**Mod.**	**Adv.**
Petroleum	26.8	17.6	4.6	3.4 (-26%)	2.9 (-37%)	3.7	3.0 (-19%)	2.1 (-43%)
Natural Gas	41.2	44	95	72 (-24%)	87 (-9%)	127	85 (-33%)	98 (-23%)
Coal	409	471	545	521 (-4%)	370 (-32%)	578	531 (-8%)	282 (-51%)
Total	477	532	645	597 (-7%)	460 (-29%)	709	622 (-12%)	382 (-46%)

Note: BAU = Business-as-Usual scenario; Mod. = Moderate scenario; Adv.= Advanced scenario. Numbers in parentheses represent the percentage change compared to the BAU scenario.

Table 7.13 Capacity of Selected Technologies in the Electric Sector (GW) (no cogeneration)

			2010			2020		
	1990	**1997**	**BAU**	**Mod.**	**Adv.**	**BAU**	**Mod.**	**Adv.**
Coal Steam	300	305	307	303	262	320	305	225
Other Fossil Steam	144	139	81	76	56	77	56	33
Combined Cycle	8	16	126	107	122	199	134	149
Combustion Turbine/Diesel	46	78	149	142	135	184	145	133
Nuclear Power	100	99	78	78	87	72	64	83
Renewable	82	88	93	103	136	98	111	145
Hydro	75	78	79	79	79	79	79	79
Wind	2	2	3	12	43	4	15	47
Biomass	2	2	2	3	4	3	3	5
Geothermal	3	3	4	5	7	7	9	9
Other	1	4	5	5	5	5	5	5
Other	18	20	22	22	22	22	22	22
Total	698	744	855	831	819	971	837	789

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

Table 7.14 Other Air Emissions in the Electric Sector (no cogeneration)

			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	4.3
SO$_2$Allowance Price ($/ton)	—	77	224	211	98	114	96	161
NO$_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.

Table 7.15 Electric Sector Fuel and End-Use Electric Prices ($/MBtu)

		2010				2020			
	1997	**BAU**	**Mod.**	**Adv.**	**Adv. w/o C**	**BAU**	**Mod.**	**Adv.**	**Adv. w/o C**
Petroleum Products	2.88	3.79	3.78	5.01	3.94	4.19	4.16	5.56	4.49
Natural Gas	2.70	3.01	2.67	3.40	2.68	3.04	2.53	3.09	2.37
Coal	1.27	1.06	1.05	2.34	1.05	0.93	0.92	2.20	0.91
Electricity (¢/kWh)	6.9	6.1	5.6	6.6	5.9	5.5	5.3	6.1	5.5

Note: BAU = Business-as-Usual scenario; Mod. = Moderate scenario; Adv.= Advanced scenario. Advanced scenario prices include carbon values.

Fig. 7.1 Total Generation Including Cogeneration (TWh) (no cogeneration)

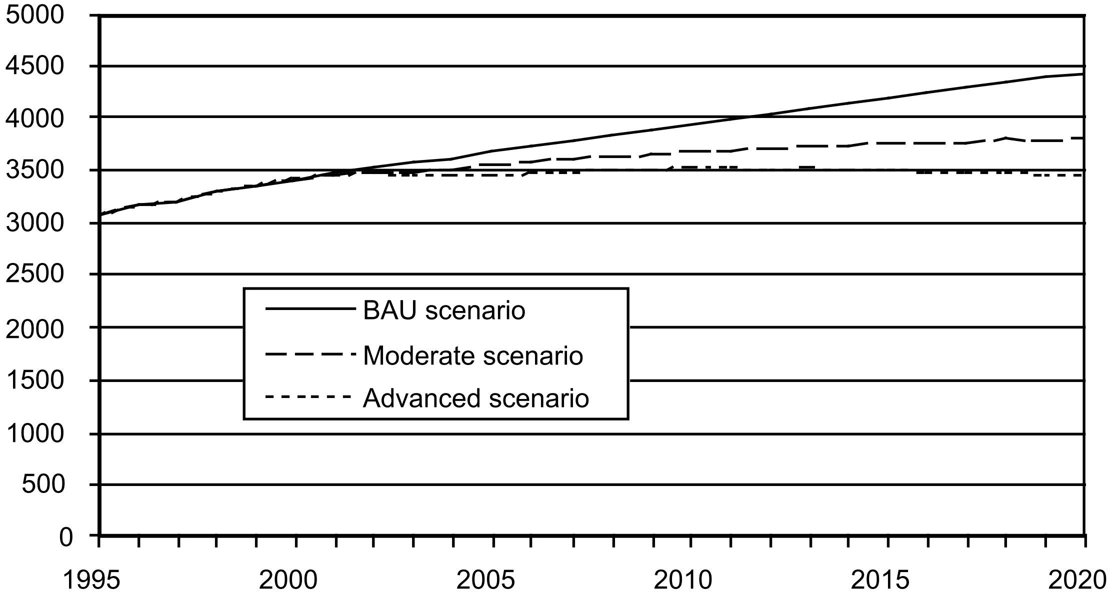


Fig. 7.2 BAU Scenario Total Generation by Fuel (TWh) (no cogeneration)

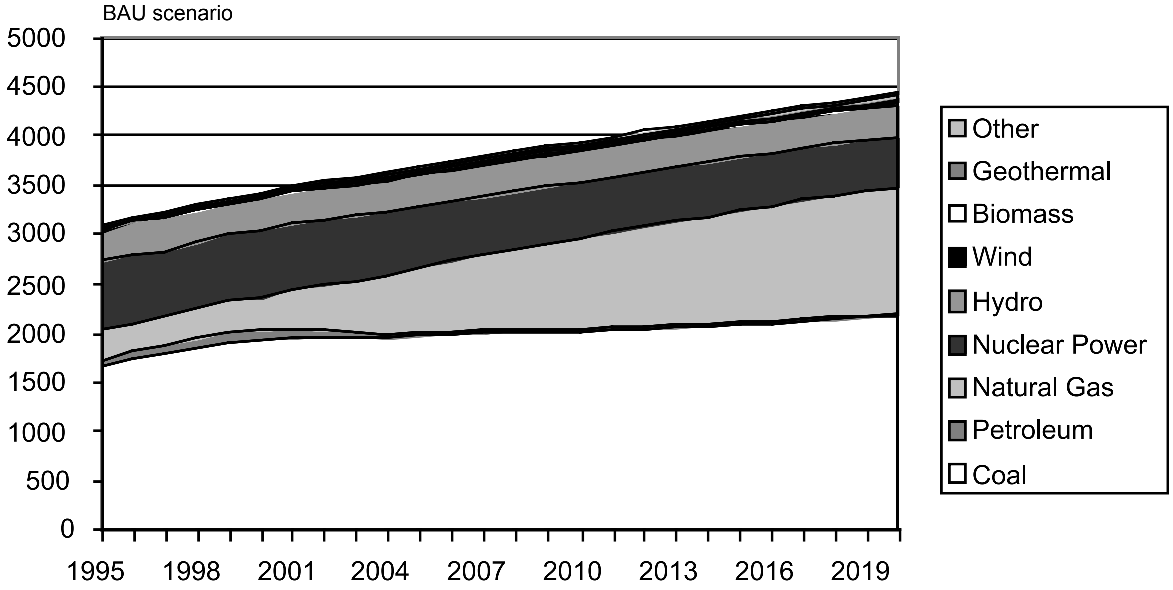


Fig. 7.3 Moderate Scenario Total Generation by Fuel (TWh) (no cogeneration)

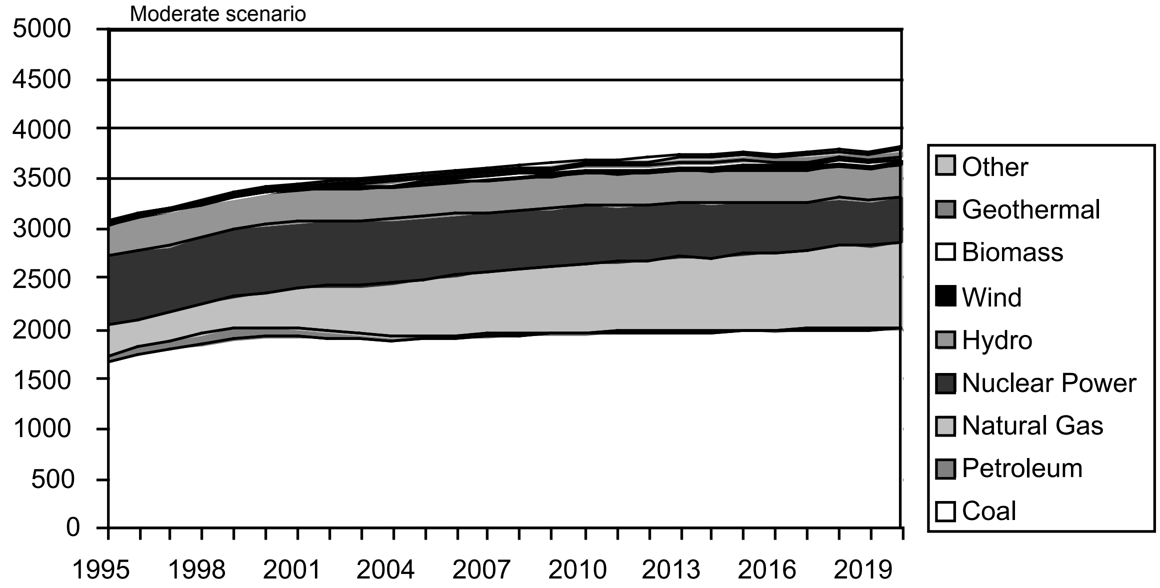


Fig. 7.4 Advanced Scenario Total Generation by Fuel (TWh) (no cogeneration)

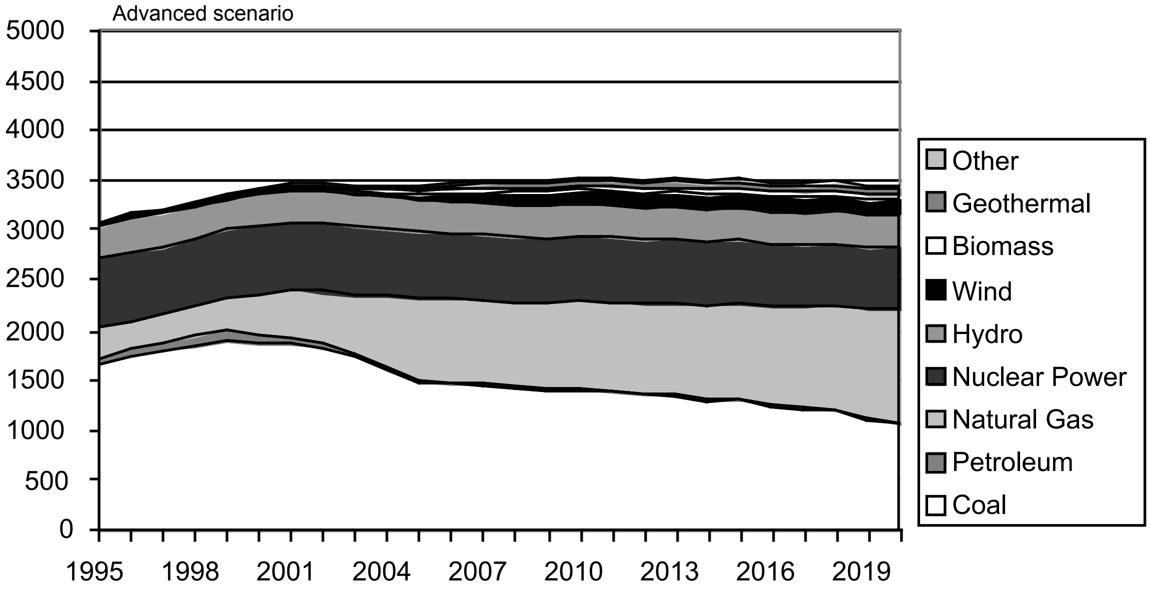


Fig. 7.5 Gas-Fired Generation Weighted Average Heat Rate (Btu/kWh)

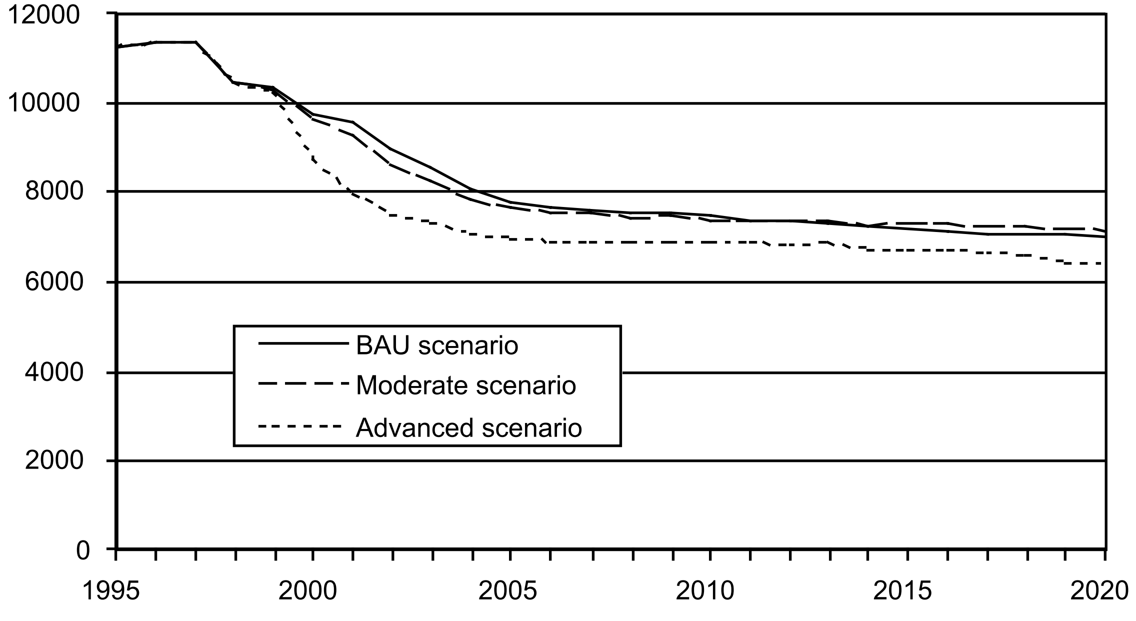


Fig. 7.6 Biomass Cofired Generation (% of Coal Generation)

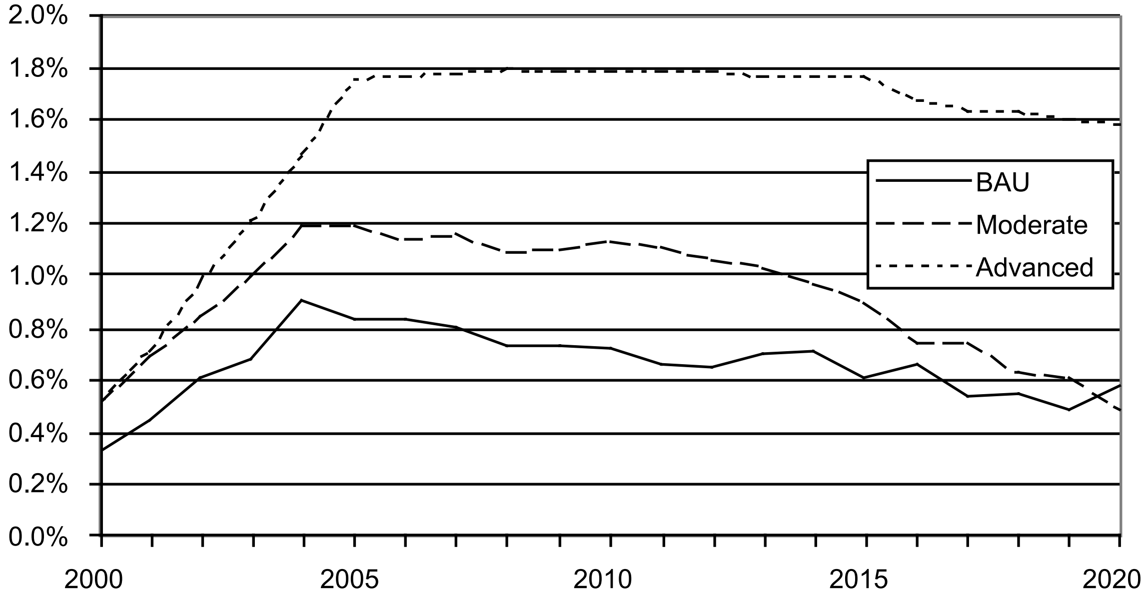


Fig. 7.7 Wind Capacity (GW)

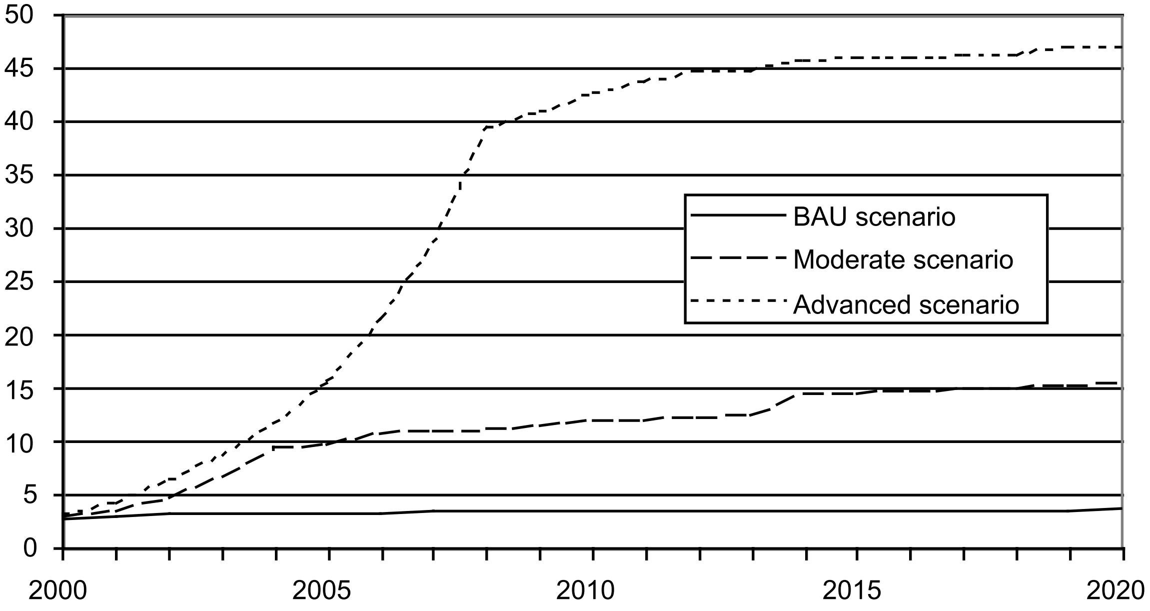


Fig. 7.8 Dedicated Biomass Capacity (GW)

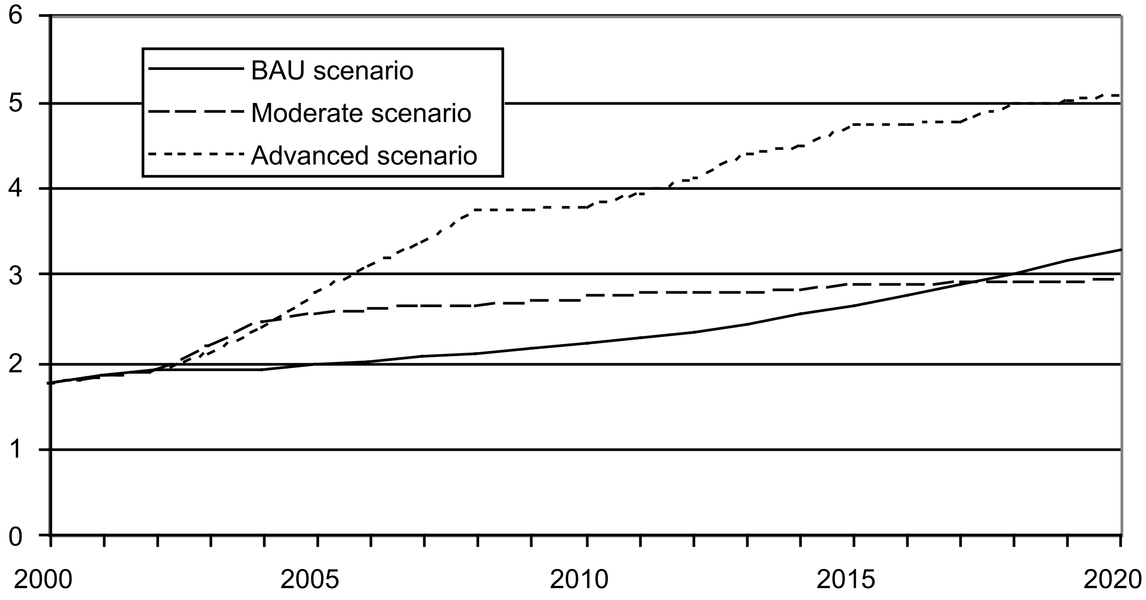
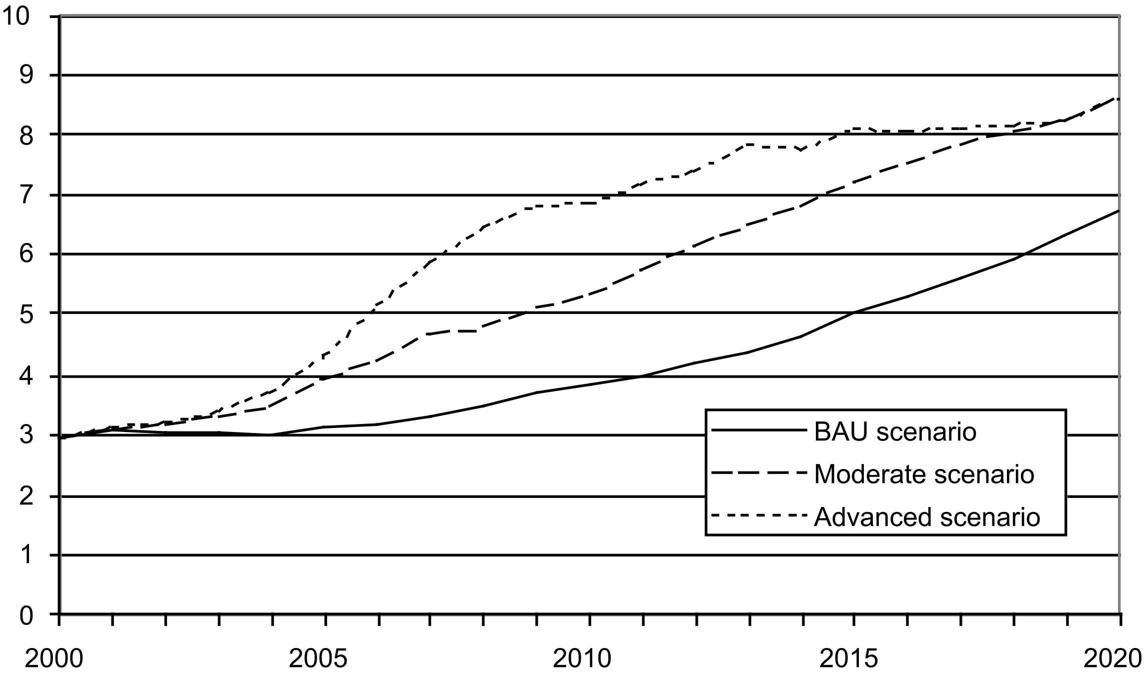


Fig. 7.9 Geothermal Capacity (GW)



7.4.2 BAU Scenario

The BAU scenario, as described above, has similar results to the AEO99 in total generation, but lower carbon emissions. Total generation by 2020 is 26 TWh lower and total generation capacity is 3 GW lower in the BAU scenario. These are less than 0.7% different from the AEO99 results. However, the mix of generation changed because of the change in the nuclear relicensing cost, biomass cofiring, and geothermal expansion described in section 7.3.1. Nuclear capacity in the BAU case in 2020 totaled 72 GW instead of the 49 GW in the AEO99 Reference case. Geothermal capacity increased from 3.5 GW to 6.7 GW. As a result, fossil and biomass capacities were reduced by 29 GW and total carbon emissions dropped 5.1%, from 745 MtC to 709 MtC.

Within the electric sector, no changes were made to the policies implemented within the AEO99. The major policies in AEO99 with regard to the electric sector are the Clean Air Act Amendments of 1990, the Energy Policy Act of 1992, EPA’s Ozone Transport Rule for 22 Northeast and Midwest states, and electricity restructuring in five regions. These five regions are California, New York, New England, the Mid-Atlantic Area Council (consisting of Pennsylvania, Delaware, New Jersey, and Maryland), and the Mid-America Interconnected Network (consisting of Illinois and parts of Wisconsin and Missouri).

Besides nuclear relicensing costs, the main changes to the electric sector BAU scenario are in the modeling of wind, biomass cofiring, and geothermal as described above. The changes to wind had very little impact on the BAU scenario, because the changes mainly loosened constraints on the amount wind could grow. These constraints were not the limiting factor for wind in the BAU scenario. Biomass cofiring was not included in the AEO99 reference case, but is allowed in the BAU scenario of this study. While biomass use was higher in the years 1998-2017, by 2020 biomass use was higher in the AEO99 than in the BAU scenario. This is largely due to the increase in generation from nuclear power.

7.4.3 Moderate Scenario

The inputs for the Moderate scenario were altered to model the policies defined in section 7.2. The 1.5¢/kWh Production Tax Credit for wind and biomass through 2004, 1¢/kWh for biomass cofiring through 2004, complete restructuring of the national electricity market by 2008, and enhanced R&D programs were all included.

The Moderate scenario shows a 5% decline in primary fuel consumption by 2010 and 10% by 2020 as compared to the BAU scenario (Table 7.10). These are mainly due to the decrease in demand from the end-use sectors. (In this discussion, declines are relative to what the values are in the BAU scenario, not in absolute terms.) Total end-use demand declined by 6% and 12% in the two years, respectively (Table 7.9). Total carbon emissions declined 7% and 12% compared to the BAU scenario (Table 7.12). Overall capacity declined in response to the lower demand (Table 7.13), but most of the decline was in the combined cycle (down 65 GW in 2020) and combustion turbine (down 39 GW) capacities. Coal capacity only declined 5% or 15 GW, while nuclear capacity declined by 8 GW from the BAU amount. On the other hand, wind increased by 11 GW over the BAU case by 2020, to 15 GW because of the incentives and improved technologies.

SO_2 emissions remain at the cap in the Moderate scenario but the allowance price needed to keep emissions at the cap drops between 6% and 16% (Table 7.14). With lower demands and improved new technologies, it is easier to meet the limits so the market price of allowances declines. NO_x levels decline as well.

Fuel prices decline in the Moderate scenario versus the BAU scenario because of the lower demands (Tables 7.10 and 7.15). Similarly, electricity prices are down by 8% in 2010 and 4% in 2020.

7.4.4 Advanced Scenario

The Advanced scenario's inputs were modified to incorporate the additional changes described in section 7.2. In the Advanced scenario, demand for generation (not including cogeneration) is lower than the BAU scenario by 14% and 22% in 2010 and 2020, respectively (Table 7.9). As a consequence, primary fuel consumption declines 11% and 24% (Table 7.10), while carbon emissions decline 29% and 46% (Table 7.12). (In this discussion, declines are relative to what the values are in the BAU scenario, not in absolute terms.) These declines show the large impact of carbon allowances, improved technologies, and the renewable production tax credits. Coal-fired generation declines 51% by 2020 with capacity declining from 320 GW in the BAU scenario to 225 GW in the Advanced scenario (Tables 7.11 and 7.13). The average capacity factor of coal also drops from 77% (base load) to 54% (intermediate load) as carbon allowances raise the variable cost of coal production. Oil and gas average capacity factors increase from 32% to 42% since they are less affected by the carbon-related costs. This capacity factor would be higher, but with the increase in wind capacity, some of the gas capacity is used to firm the wind power and so might have a lower capacity factor.

The Advanced scenario has a more rapid advance in the average efficiency of gas-fired generation (Fig. 7.5). The average heat rate declines more quickly as 25 GW more combined cycle capacity is brought on in the years 2000-2005 than in the BAU scenario, while 6 GW of less-efficient combustion turbines are not built. An additional 10 GW of inefficient gas and oil-fired steam capacity is retired. Furthermore, the additions are more heavily weighted towards the advanced gas technologies. While in reality, some of the improvements in the advanced technologies would be incorporated into the conventional technologies, in these scenarios only the advanced technologies were improved. If the conventional technologies were changed as well, overall efficiency could be higher or lower than these results. Efficiency could be higher because more technologies would be improved, but lower because the improved conventional technologies may be more economic and displace some of the advanced technology that was added in this scenario.

The heat rate is further improved because of changes in the use of inefficient plants. With the advent of the carbon allowances requirement, inefficient gas and oil steam plants are used more infrequently and 10 GW are retired by 2005. By 2020, 47 GW more of these plants are retired than in the BAU scenario. Heat rates for new gas technologies decline further (approaching 70% efficient, or 4875 Btu/kWh, for combined cycle plants with fuel cells as a ternary cycle), but the average heat rate does not decline as much, reaching only 54% efficient by 2020.

Other air emissions (SO_2 and NO_x) are reduced in the Advanced scenario, compared to the BAU scenario (Table 7.14). SO_2 emissions (as a surrogate for PM emissions) were further restricted over the years 2011-2020, culminating in a 50% reduction from the BAU ceiling in the final year. Because of the lower demands and new technologies, the new ceiling was met with little increase in the permit price. Its highest value was $185/ton in 2016. An Advanced scenario sensitivity without the lowered ceiling had the permit price dropping to zero because emissions were below the existing ceiling by 2020.

Wind capacity grows to 16 GW installed by 2005, due in part to the PTC, carbon limits, and improving economics of wind. To conform with the requirements of the RPS, it continues to grow after the PTC expires, rising to 43 GW in 2010 and 47 GW in 2020. This growth represents over 34% of all new capacity built between 2005 and 2020 and 10% of capacity built post-2010.

Biomass use grows as well, both dedicated capacity and cofiring. Cofiring grows rapidly between 2000 and 2005, displacing approximately 1.8% of coal generation (Fig. 7.6). The 1¢/kWh cofiring production tax credit improves the cost-effectiveness of biomass between 2000 and 2014. Starting around 2005, the carbon allowance provides a similar inducement, especially since biomass directly displaces coal. Dedicated biomass generation grows slowly, but cofiring remains at relatively the same percentage of coal production. Consequently, as coal production declines, so does cofiring. Total non-cogeneration biomass production peaks in 2015 at 52 TWh, then declines to 48 TWh in 2020 (Table 7.11).

As shown by the demand sensitivity analysis of section 7.5.3, the generation from clean sources like renewables can be sensitive to the overall growth in electricity capacity. If the end-use demand policies of the Advanced scenario are not implemented or are not as effective as estimated here, larger electricity demand will spur additional electric capacity growth and more opportunities for clean energy supply technologies. Similarly, if advances in fossil generation technologies are not as much as expected in the two scenarios, wind capacity increases (Table 7.17).

7.5 DISCUSSION OF RESULTS

While electric sector-specific technologies and policies (discussed below) are important to the results, a critical factor is the change in non-cogenerating electricity demands by the buildings and industry sectors under the various scenarios (Fig. 7.1.) (Industrial cogeneration and district energy systems can play a large role in the reduction of electricity demand growth for this sector, providing from 70 to 120 GW of capacity that would otherwise need to be provided by this sector.) The electric sector is only a middleman in that it transforms energy from one form to another for use by others. While it may control the types of primary energy used to make electricity, the growth or lack of growth in demand plays an important role in the amount of primary energy and type of technologies used. Advanced technologies are limited to the relatively fixed amount of capacity expansion needed to meet demand over a given scenario plus any retirements. Incentives to accelerate their deployment have less success if demand growth is low, unless other incentives for accelerated retirement of existing capacity are also used.

Another critical factor that is external to the sector is the price of fuels (Table 7.15.) Coal prices stay relatively the same between the BAU and Moderate scenarios. In the Advanced scenario, the carbon permit value of $50/tC increases the price of coal by $1.30/MBtu. This raises the price by 120% to 145% and is a major cause in the lowering of coal use. Natural gas prices decline by 11% to 16% in the Moderate scenario because of a lowering of demand for gas in all sectors (12% by 2020). Even in the Advanced scenario including carbon allowances, prices rise only 13% in 2010 and by 2% in 2020 over the BAU scenario. Subtracting the carbon permit costs, the raw prices for gas drop significantly from the BAU prices.

7.5.1 Key Technologies

A number of changes were made to each of the production technologies. In the BAU scenario, wind, biomass cofiring, geothermal and nuclear plant modeling fundamentals were changed. In the Moderate scenario the most significant change happened to the renewable technologies. Capital and operating costs, and capacity factors were adjusted based on EIA's estimates of the High Technology scenarios of the AEO99. EIA's High Technology for fossil plants are largely devoted to lowering the cost of the technology rather than improving the efficiency. Capital costs in the Moderate scenario were lower based on EIA estimates of the impact of enhanced R&D. Values for renewables were largely unchanged between the Moderate and Advanced scenarios. Fossil technologies in the Advanced scenario includes more radical advances in fossil technologies such as ternary cycles for coal and gas combined-cycle plants. These raise the efficiency greatly by using a fuel cell as a front-end cycle before the other components. Carbon sequestration was also allowed within the model in conjunction with advanced fossil technologies after 2010 (through a $50/tC increase in operating cost.) However, the parameters for the advanced technologies differ most greatly from the Moderate scenario in the latter part of the study period. With overall demand relatively flat post-2010, there is less call for new capacity and less opportunity for these advances to make a significant impact (Fig. 7.1 and Table 7.13).

The importance of advanced coal technologies such as IGCC are largely dependent on the cost of fuel (including any carbon allowance cost) and overall demand. In the BAU scenario, 15 GW of IGCC is brought on-line by 2020, along with 5 GW of conventional coal. In the Moderate scenario, however, gas prices in 2020 are 13% lower than in the BAU scenario (due to lower gas demands); only 5 GW of IGCC and 1.6 GW of conventional coal are added. In the Advanced scenario demand is lower still and coal prices more than double due to the carbon allowance cost. No IGCC capacity is brought online and just the 1.4 GW of conventional coal that is already planned.

Of the renewable technologies, wind received the most benefit from improvements in technology and other policies. Its capacity in 2020 grows from 4 GW in the BAU scenario to 15 GW in the Moderate scenario to 47 GW in the Advanced scenario (Fig. 7.7). There is a large growth of wind through 2008 because of the PTC and the RPS (to 11 GW in the Moderate and 39 GW in the Advanced scenarios). In the Advanced scenario, economics (and the carbon permit costs) cause wind to continue to grow beyond these levels in later years. In the Moderate scenario additional growth is more modest.

PV also plays a role with penetration in buildings spurred by the Million Solar Roofs (MSR) Program at DOE and the adoption of net metering policies. The MSR has collected commitments for over 900,000 roof-top photovoltaics and active solar hot water units by 2010. These commitments are also a reflection of the public's interest in green power, a range of benefits associated with distributed generation, and the continuing improvement in the economics of solar technologies. In the CEF Advanced scenario, the economics of PV are improved by 2020 to the point that over 2.6 million PV rooftop systems are estimated to generate approximately 17 TWh/year. This trend could became a signficant factor in U.S. carbon reductions after 2020 as the technology continues to improve.

Geothermal capacity showed more rapid growth in the two policy scenarios, with capacity 38% to 77% higher by 2010 for the Moderate and Advanced scenarios, respectively (Fig. 7.9). However, growth in the BAU scenario continues at a steady pace such that the ratios of capacity between the three scenarios narrow.

7.5.2 Key Policies

The key policy driving the changes within the electric sector is the carbon allowance in the Advanced scenario. The carbon allowance plays a role in two ways. First, because of its larger impact on carbon-intensive fuels such as coal and inefficient oil and gas plants, no unplanned coal plants were added and 83 GW of coal capacity was retired by 2020 in the Advanced scenario. In addition, 112 GW of other fossil steam (oil and gas) were retired. (These compare to 20 GW of coal added and 6 GW coal and 68 GW of other fossil steam capacity retired in the BAU scenario.) Second, the carbon allowance directly impacts the variable cost of production, thereby causing the remaining carbon-intensive technologies to lower their capacity factor. Nuclear power better maintained its cost-effectiveness. Even without changes in the relicensing cost of nuclear power beyond that in the BAU scenario, the Advanced scenario had 11 GW more of nuclear power in 2020, with generation up 15%.

Sensitivity cases run for the Advanced scenario without the carbon allowance show 62% more generation from coal in 2020 than in the Advanced scenario, 22% less generation from gas, and 41% less generation from non-hydro renewables. Wind is the renewable energy form most impacted by the carbon cap, with capacity in 2020 lower by 55% (or 26 GW) without the cap.

Restructuring also plays a significant role but with potentially contrary impacts. By removing incentives for regulated utilities to retain capital investments that are no longer cost effective, deregulation creates incentives for inefficient coal or other plants to retire when carbon emissions are constrained and/or gas plants represent a more cost-effective option. (Economic retirements were allowed in all three scenarios.) At the same time, however, real-time pricing becomes a more important factor in the market, and the system load factor increases. This means that less-utilized plants (i.e. peakers and intermediate plants) may be called upon for a higher percentage of time and be more profitable. If coal plants are on the margin for a region, they will be used more. Less new capacity is needed to meet peak demands because of customer shifts in peak load requirements. In the Advanced scenario, while generation dropped 2.3% between 2010 and 2020, generation capacity declined by 3.7% (Table 7.11and Table 7.13).

As mentioned in the section above, the PTC (either as a policy in and of itself or as a surrogate for the RPS) plays an important role in the growth of renewable capacity. By creating growth in wind through 2004 or 2008, a strong base of capacity is developed that leads to further growth but at a slower pace after the PTC and RPS expire. In the Advanced scenario, wind generation grows by over 1700% between 2000 and 2008. Wind capacity represents 23% of all additions in that period, but accounts for a smaller 14% of the new capacity additions between 2008 and 2020. Since all capacity additions decline in this latter period, there is only a 20% growth of wind capacity post 2008 (Fig. 7.7). Geothermal and dedicated biomass capacity also see an impact from the PTC and RPS, but not as pronounced (Fig. 7.8 and 7.9). In the Advanced scenario they both roughly double through 2008 and then grow another 35% through 2020. In the Moderate scenario, where the PTC stops in 2004 and there is no carbon allowance nor RPS, growth is more modest. Wind roughly triples in that time. Biomass grows 40% during the PTC but only 20% from 2005 to2020. Geothermal, on the other hand, shows a more steady growth: 18% through 2004 and 150% more by 2020.

7.5.3 Uncertainties and Sensitivity Analyses

Sensitivity analyses are used to determine the impact of specific policies in connection with the basket of policies that define each scenario. The relative importance of the renewable portfolio standard, technology advances, and carbon allowances have been examined.

RPS Sensitivity. The RPS can have a significant impact. When we removed the surrogate RPS from the Advanced scenario (by not extending the PTC to from 2004 to 2008), generation by non-hydro renewables was only 5.3% of the total in 2010 (versus the prescribed 7.5%) and 6.9% in 2020 (versus 8.9% in the Advanced with RPS). Most of the reduction occurred in wind generation, which fell 39% from 159 TWh in 2020 to 97 TWh. The difference was even more dramatic in 2010 with generation down 54% between the two cases. However, this gives wind a smoother growth trajectory over the study period. Removing the RPS also decreased geothermal generation 9% in 2020 from 67 TWh to 61 TWh, and biomass (both biomass cofiring and biomass gasification) 4% from 48 TWh to 46 TWh. Without the RPS, both gas and coal generation increase, with coal showing a 7% increase in generation in 2020 compared to the Advanced scenario with the RPS. While significant renewables are still present without the RPS, it certainly increases generation from renewables, even beyond the RPS expiration date.

Fossil-fuel Technology Sensitivities. The technology advances used in these scenarios are based on projections by various experts of the potential cost and efficiency improvements. However, they are not necessarily what will occur; other experts have been more or less optimistic. Sensitivity analyses has been conducted to examine a less optimistic future for the cost and performance of IGCC and Gas CC plants. The parameters that were changed are listed in Table 7.16. Further explanation of the values is in Appendix C-4. Renewables were not modified in this sensitivity so are not included in the table. Table 7.17 shows the capacity, generation, and carbon emission changes for 2020 in the Moderate and Advanced scenarios that result when future improvements in these technologies are reduced.

Table 7.16 Fossil Technology Capital Cost and Heat Rate Sensitivities

	5th Plant Capital Cost (1997 $/kW)		Heat Rate (Btu/kWh)		
	Base	Sensitivity	Base	Sensitivity	Year for Heat Rate
IGCC Moderate	942	1000	8333-6968	8400-7500	2000-2010
IGCC Advanced	942	900	6440-5690	7449-6800	2010-2020
Gas CC BAU	405	475	6927-6350	7200-6800	2000-2015
Gas CC Moderate	348	450	6919-6255	6749-6200	2000-2015
Gas CC Advanced	348	425	5539-4874	6199-5700	2010-2020

As expected, gas combined cycle capacity shows the largest decrease in capacity and generation due to lower optimism with respect to the future improvements in gas combined cycle cost and performance improvements. Also as expected, competing technologies such as nuclear and renewables benefit when their competition costs more. Somewhat unexpectedly, carbon emissions are lower in 2020 as more nuclear remains on line and additional renewable capacity is built. Also, end-use demand for generation is reduced due to the slightly higher electricity prices. In the Moderate sensitivity, coal capacity declines slightly as less new capacity is added, while the Advanced sensitivity has higher coal production due to fewer retirements. With higher cost advanced technologies, the market price for SO_2 credits increases from $160/ton in the regular Advanced scenario to $173/ton in the Advanced sensitivity scenario in 2020. Electricity prices also increase over the regular scenarios by about 0.1-0.2¢/kWh in the Moderate and Advanced sensitivities. Because of the availability of advanced technologies for renewables and combustion turbines and the continued availability of relicensed nuclear plants as backstops, less R&D success for combined cycle and IGCC technologies does not have a major impact on the overall results.

Table 7.17 Changes in 2020 Capacity (GW), Generation (TWh), and Carbon Emissions (MtC) with Less Optimistic Projections of Future IGCC and Gas Combined Cycle Cost and Performance

Technology	Moderate Scenario		Advanced Scenario	
	GW	TWh	GW	TWh
Coal Steam	-2 (-1%)	-4 (0%)	+5 (2%)	+41 (0%)
Other Fossil Steam	+4 (7%)	Oil +1 (7%) Gas -90 (-11%)	-7 (-20%)	Oil 0 (0%) Gas -122 (-11%)
Gas Combined Cycle	-26 (-19%)		-36 (-24%)	
Combustion Turbine	+9 (6%)		+7 (5%)	
Nuclear	+8 (12%)	+56 (12%)	+2 (3%)	+16 (3%)
Wind	+3 (20%)	+11 (21%)	+10 (21%)	+29 (18%)
Biomass	+0.4 (15%)	+6 (21%)	+1 (24%)	+9 (18%)
Geothermal	+1 (12%)	+9 (13%)	+1 (11%)	+8 (12%)
End-Use Demand		-12 (0%)		-20 (-1%)
Carbon emissions (MtC)		-6 (-1%)		-3 (-1%)

Numbers in parentheses represent the percentage change compared to the basic Moderate and Advanced scenarios.

Renewable Technology Sensitivities. Another set of sensitivities was performed with higher renewable energy technology costs. Wind capital cost was raised 20% and biomass capital cost was raised 25%, based on the uncertainty range listed in the EPRI study *Renewable Energy Technology Characterizations*

(EPRI, 1997). As a consequence, wind capacity in the Advanced scenario declined 46% from 47 GW to 25 GW in 2020. Dedicated biomass declined 25%, from 5.1 GW to 3.8 GW (not including cogeneration.) Biomass cofiring remains slightly higher over time because of the increased availability of biomass and coal capacity, but overall biomass generation declined 15%, or 7 TWh. Coal-fired generation increased by 6%, or 69 TWh while gas generation increased 9 TWh. Because of the reduction in renewables and concomitant increase in fossil generation, carbon emissions were 20 MtC (5%) higher. Whereas in the fossil technology sensitivity above, non-fossil technologies buffered the carbon impact of less R&D success, the lack of R&D success for non-carbon renewables had a more pronounced impact on carbon emissions.

Carbon Trading Policy Sensitivity. Although the impact of carbon allowances was described in section 7.5.2 above, to further examine their importance we ran the Advanced scenario but without any carbon trading system, still keeping the other supply and demand policies. This makes a large impact on the use of coal; generation is 62% higher than in the Advanced scenario in 2020. Coal capacity is 29% higher, at 291 GW. This is still below the capacity in 1997, with only 3 GW added but 17 GW retired over the time period.

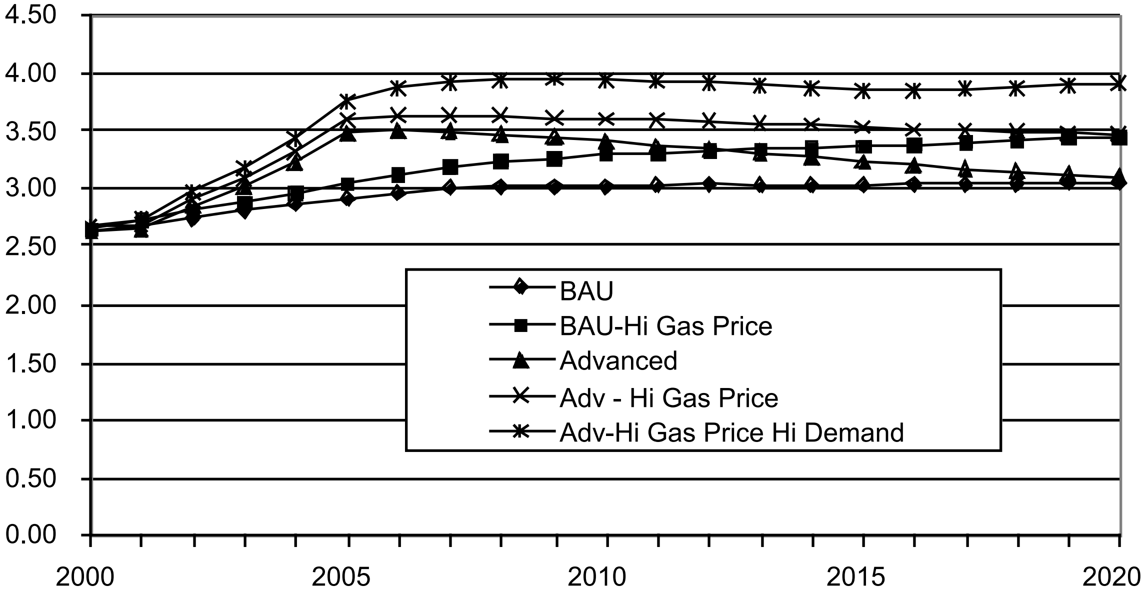
Natural gas, nuclear, and non-hydro renewables all have reductions in their generation by 20% to 30% as they are displaced by coal. Wind is hardest hit, with capacity reduced by 55% down to 21 GW. The 1.5¢/kWh PTC does not have the impact on renewable generation in that total generation by 2010 represents only 5.0% of generation, rather than 7.6%. This means that a RPS of 7.5% with a cap of 1.5¢/kWh would not reach the full portfolio standard level. Carbon emissions from the electric sector increase by 45% to 553 MtC. Overall demand increased by only 4% in 2010 and 3% in 2020 over the Advanced scenario, so the large increase in coal and carbon output are mainly due to the change in the relative price of fuels.

The SO_2 emissions cap policy is still in place so that emissions in 2020 are at 4.6 Mt SO_2, (SO_2 caps have been halved from the Phase II Clean Air Act Amendment requirements to reduce particulate matter emissions) This is 0.4Mt higher than in the Advanced scenario. In addition, the price of an SO_2 emissions allowance almost triples to $445/ton without the carbon trading system. The price of coal is $0.92/MBtu, $1.27/MBtu below the price in the Advanced scenario. However, this price is slightly above the Advanced scenario's price with the $50/tC carbon allowance fee removed. Electricity prices are lower, being only 5.2¢/kWh by 2020. This is lower by 0.9¢/kWh from the Advanced scenario, and is 0.4¢/kWh lower than the Advanced scenario even with the carbon fee removed from the fuel component (Table 7.15). One reason for this is the Advanced scenario had much more new construction, which increased the capital component of the electricity price by 0.3¢/kWh.

Gas Price Sensitivity. Because natural gas plays such an important role for new capacity, a set of sensitivities to modify the gas price were run on the BAU and the Advanced scenarios. CEF-NEMS does not allow the direct input of gas prices, so instead we reduced the technological progress to zero for oil/gas drilling/exploration and reduced technological progress rates by 50% for unconventional gas recovery and enhanced oil recovery. As a result, gas prices increase gradually till by 2020 they are about 12% or 38¢/MBtu higher (Fig. 7.10).

The most dramatic impact is on the amount of gas consumed, as expected. Gas consumption for electric generation is down by 12% to 13% by 2020 in the two sensitivities. In both cases, coal is used to make up most of the reduction in generation, 81% in the BAU and 72% in the Advanced sensitivity. Demand reduction is next and equals 10% of the reduction in gas generation in the BAU and 16% in the Advanced scenario sensitivity. Renewables have a larger impact in the Advanced sensitivity, replacing 12% of the lost gas generation, with 9% of that from added wind capacity (4 GW). In the BAU sensitivity, an additional 1.1 GW of nuclear is relicensed over the BAU scenario (making up 5% of the lost generation), but no new nuclear plants are built. The Advanced sensitivity sees no change in nuclear generation. Apparently, existing coal plants (non-retirement), energy efficiency, and renewable resources are the marginal supplies that are brought on if gas prices rise.

Fig. 7.10 Gas Prices to Electric Generators With and Without Restrictions on Technological Progress ($/MBtu)



An additional sensitivity was run to determine the impact if gas prices were raised as above and the end-use demand reduction policies were not put in place (as in the next sensitivity). These two factors combined raised the price of gas by 81¢/MBtu over the Advanced scenario, as shown in Fig. 7.10. Because of the increased demand, gas generation is 108 TWh higher than in the Advanced scenario, but this is 181 TWh (13%) lower than if gas prices are not adjusted (Table 7.18). As before, coal increases made up most (66%) of the gas reduction compared to the high demand scenario. Wind only increased to make up 4% of the lost gas generation, while biomass and geothermal made up 8% and 5% respectively. Since wind capacity was already very high at 63 GW due to the increase in demand, there was more opportunity for biomass (including cofiring) and geothermal to increase. Demand was higher by 524 TWh from the Advanced scenario but this is 30 TWh less than the scenario without demand reduction policies. Nuclear generation still did not change, since other technologies besides gas have lower costs and new nuclear still has a “lock-out” problem of high first plant costs due to the learning curve.

Demand Sensitivity. With the relatively flat electricity demand growth of the Advanced scenario, there is little demand for new electric capacity. This reduces the opportunities for clean energy supply technologies to enter the generation mix. We examined the impact of removing all the demand-side policies in the Advanced scenario. In this case, electricity demand is 16% greater in 2020 than in the Advanced scenario and, as shown by the percentage changes, non-hydro renewables and natural gas generation are impacted proportionately more than coal. However because the other clean sources, nuclear and hydro, are not impacted, the overall carbon impact is almost directly proportional to the energy impact.

Table 7.18 2020 Demand Reduction and High Gas Impacts in the Advanced Scenario (TWh) (w/o cogeneration)

	Advanced scenario	Advanced minus demand policies	Advanced minus demand policies plus hi gas prices
Electricity Demand	3442	3996 (+16%)[a]	3966 (+15%)[a]
Coal Generation	1065	1213 (+14%)	1333 (+36%)
Gas Combined Cycle Generation	1134	1428 (+25%)	1247 (+9%)
Non-hydro Renewables Generation	306	420 (+37%)	449 (+47%)
Nuclear and Hydro generation	923	924 (0%)	923 (0%)
Electric Sector Carbon (MtC)	382	440 (+15%)	460 (+20%)

[a] Percentage change from the Advanced scenario

Nuclear Sensitivities. One reason for the lack of penetration of new nuclear capacity is the capital cost of new technology. Learning from experience may eventually make plants cost-competitive, but the cost of the first plant precludes their development. This has been called "lock-out" (EIA, 1999). In CEF-NEMS there are two factors that raise the capital cost of the first plants, as compared to the fifth-of-a-kind plant that is entered. One is the Technical Optimism factor, a parameter in CEF-NEMS that raises the cost of the first nuclear plant by 19% above the input fifth-of-a-kind plant cost, decreasing with subsequent plants. For the Moderate and Advanced scenarios we removed this factor, justifying the removal by assuming a policy of joint development with other nations so that plants elsewhere in the world provided the technical knowledge to avoid the increase. The second factor is the Learning Curve factor, which raises the first plant's capital cost by an additional 28% with subsequent plants having a lower factor. The Learning Curve factor continues to lower the cost of plants beyond the fifth as capacity grows. Combined, the two factors in the BAU scenario make the first plant 52% higher in cost than the fifth one built. The Moderate scenario still had a first plant's cost 28% higher than the fifth. Even the Advanced scenario had the first plant 28% higher than the fifth one, but all had a 10% cut in the capital cost compared to the BAU. In none of these scenarios were nuclear plants built.

As a sensitivity to the Advanced scenario, we removed the Learning Curve factor for the first four advanced nuclear plants (in addition to the Advanced scenario's 10% reduction in capital cost and removal of the 19% technical optimism factor.) This removal could be reflective of a policy of subsidizing the construction cost of the first four plants to make them have the same cost as the fifth one. We also slightly modified the construction schedule so that costs are spread more evenly over the plant's construction period. These changes succeeded in lowering the average capital cost of the first plant from $1822/kW to $1427/kW in 1997$. However, this still did not make nuclear cost-competitive with advanced gas combined cycle plants or wind capacity (with the production credit). The national average levelized cost for nuclear capacity in the 2005-2010 time-frame was $39/MWh, while advanced gas CC plants had a peak cost of around $35/MWh in 2006 that then declined over time. In three regions of the country (California/Nevada, Rocky Mountains, and Florida) nuclear capacity had lower costs than gas CC for one or more years between 2004 and 2008. However, during those years renewable incentives were in place and in these regions wind or geothermal capacity were the lowest cost options. Consequently, the renewable technologies were selected instead of gas or nuclear.

A further sensitivity was run with the same nuclear costs as above but with higher end-use demands and gas prices (as described in the previous two sensitivities.) While gas CC plants did increase in cost, the change was not as high as expected. (Total cost rose 5%-15% by 2020 depending on region, despite a 25% increase in gas price.) Gas capacity expansion was lower than before, but other technologies (wind, biomass, geothermal, and non-retirement of existing coal plants) were still used instead of new nuclear plant construction.

As a further analysis of the cost of new nuclear technologies in comparison to gas-fired combined cycle, the two were compared in a series of cases outside of the CEF-NEMS model by varying their fuel price, capital costs, and efficiencies for the year 2020. A cost model comparing the life-cycle cost was used that has previously been used in analyses of future technology cost comparisons (Delene, et al., 1999). A reference nuclear plant was defined with values similar to those of the CEF-NEMS runs, and a consequent levelized cost of $44.6/MWh. (The levelized costs in 2020 for a fifth-of-a-kind plant from the BAU, Moderate, and Advanced scenarios were around $46, $45, and $41/MWh, respectively.) A reference gas combined cycle plant was defined that had a lower efficiency (50%) and higher capital cost ($615/kW) than that used in the Advanced scenario, resulting in a levelized cost of $36.6/MWh. In addition to calculating the levelized costs for comparison of the two technologies, the cost model was used to estimate a breakeven carbon allowance cost. For the reference cases, a carbon allowance charge of $80.4/tC will equalize the cost of the nuclear and gas combined cycle plants. Table 7.19 shows the results for the various cases.

The reference case uses a gas price of $3.24/MBtu, as in the 1999 AEO. Case 3 uses a gas price of $3.63/MBtu, from the High Economic Growth case in the 1999 AEO. Cases 2 and 4 are similar to Cases 1 and 3 except the price of gas was assumed to escalate at 0.8% and 1.3% above inflation for the subsequent years. Case 5 shows the impact of reducing the capital cost of the nuclear plant by 10%, as in the Advanced scenario. Case 6 represents the gas technology for 2020 as in the Advanced scenario, with a heat rate of 4874Btu/kWh (70% efficient). Gas prices match the Advanced scenario price of $2.36/MBtu (not including the carbon charge.) The final case shows the levelized cost of an advanced pressurized fluidized bed combustor using coal. More details on the parameters and results can be found in Appendix E-8.

Table 7.19 Sensitivity Analysis of Nuclear and Gas Levelized Costs

	Levelized Cost ($/MWH)		Breakeven Carbon Charge ($/tC)
	Nuclear	Gas CC (or Coal PFBC) [a]	
1. Reference	44.6	36.6	80.4
2. Gas price escalated post-2020 at 0.8%	44.6	38.9	56.9
3. EIA AEO99 high economic growth gas price	44.6	39.3	52.8
4. EIA AEO99 high growth plus 1.3%/yr gas escalation	44.6	43.8	8.0
5. Case 4 plus 10% reduction in nuclear capital cost	41.6	43.8	-21.8
6. CEF Advanced scenario gas price and CC technology	44.6	25.4	272
7. Coal-fired PFBC instead of Gas CC	44.6	37.5	33.8

[a] The levelized price for the fossil technologies do not include any cost for a carbon charge.

The results show the sensitivity to gas prices, capital costs, plant efficiencies, and escalation rates, at the same time showing that there are a combination of factors that would make nuclear power more economic than gas CC. If gas prices rise (due either to supply and demand and/or carbon charges), and technology advances for combined cycle plants don't occur, then an advanced nuclear plant can be competitive. However, if gas CC can reach its efficiency targets, then nuclear power may find it difficult to compete.

Also, other supply sources such as renewables and demand reductions through efficiency provide additional competition in the energy marketplace.

7.5.4 Policy Costs

Estimating the costs of policies in the electric sector is complicated by the fact that the electricity demand varies considerably between the different scenarios. The total electricity bill in the Moderate scenario is considerably less than that of either the BAU or the Advanced scenarios, as shown in Table 7.20. This is due to a reduction in demand and the absence of a cost for carbon allowances. The cost per kWh is also less in the Moderate scenario than in the BAU scenario due largely to the decrease in the cost of natural gas to the electric sector that results from lower gas demand in the end-use sectors. Similarly, the total national electric bill is less in the Advanced scenario than in the BAU scenario because of the lower electricity demand. However the cost per kWh in the Advanced scenario is higher than that of either of the other scenarios largely because of the cost of carbon allowances, which are $50/tonne from 2005 through 2020.

We have also approximated the direct energy costs of the more significant individual policies. The cost of carbon allowances to electric generators in the Advanced scenario is $23 billion per year in 2010 and falls slightly to $19 billion/year in 2020 with reductions in carbon emissions. These carbon allowance costs are also reflected in the total national electricity bill and represent about 10% of that bill. The cumulative undiscounted cost over the years 2005 through 2020 is $352 billion. There is no carbon allowance cost in the BAU or Moderate scenario because there is no assumed carbon trading system in those scenarios. Clearly, the carbon allowance cost is the highest cost policy for the electric sector. However, much of these costs would be recycled back into the economy depending on the design of the carbon trading mechanism. This is further discussed in Section 1.4.5.

The cumulative undiscounted cost over the years 2000 through 2018 of the renewable energy PTC was estimated to be $5 billion and $30 billion in the Moderate and Advanced scenarios, respectively. (The Advanced scenario extended the PTC as a surrogate of an RPS.) The cost in the Advanced scenario is appreciably larger because the credit is assumed to apply to all non-hydro renewables (not just wind and biomass as in the Moderate case), because the credit applies to capacity built through 2008 and cofiring through 2014, and because the carbon trading program in the Advanced scenario encourages more renewable energy. Table 7.20 shows the cost for the specific years of 2010 and 2020. While the credit is assumed to be available only to renewable energy generators constructed between 2000 and 2008 (2004 in the Moderate scenario), those plants are assumed to receive a credit for the first 10 years of production. Thus the annual costs shown in Table 7.20 for the year 2010 are non-zero. All plants receiving the credit have completed their first 10 years of production by 2020, so Table 7.20 shows no annual cost for that year.

The electricity-specific incremental cost of R&D programs has not been estimated in this chapter. The R&D expenditure increases are consolidated in the overall analyses (chapters 1 and 2) and are not broken out by sector. Clearly, some R&D investments would only help the electricity sector (e.g., nuclear, wind), but others (e.g., biomass, fuel cells, microturbines) would help more than one.

Use of a PTC as a surrogate for the RPS gives higher costs than the RPS as proposed by the administration. It matches the ceiling cost that the administration proposal includes, but effectively costs out all renewables at that ceiling price. In reality, some of the renewables will cost less, incrementally, than 1.5¢/kWh above the marginal cost of production. Some are economical without any credit, which is often described as the “free rider” problem; production that is economic without any subsidies receives them anyway. Another reason that the costs shown in Table 7.20 are slightly higher than an RPS is that the percentage of production from renewables in 2010 is 7.6% of total non-cogeneration production, which is higher than the proposed 7.5%.

These costs do not include a systems benefit charge that may be added to all electrical sales. This charge is collected by state organizations to assist in funding energy efficiency or other energy-related public benefits programs.

Additional administrative and macroeconomic costs to the economy as a whole associated with the policies evaluated in the electric sector are addressed in Chapter 8.

Table 7.20 Annual Cost of Policies in the Electric Sector (1997$)

		2010			2020		
	1997	BAU	Mod.	Adv.	BAU	Mod.	Adv.
Total electricity bill ($B/yr)	216	234	202	227	238	198	207
Cost per kWh (cents/kWh)	6.9	6.1	5.6	6.6	5.5	5.3	6.1
Carbon allowance payments $B/yr)	0	0	0	23	0	0	19
Production tax credit cost ($B/yr)	0	0	0.4	0.6	0	0	0
Renew Portfolio Standard ($B/yr)[a]	0	0	0.0	2.2	0	0	0

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

[a] Cost shown is the incremental cost for extension of the PTC to 2008 and the biomass cofiring credit to 2014.

7.6 CONCLUSIONS

In the Advanced scenario carbon emissions from the electric sector are substantially reduced from those of the BAU scenario – 29% in 2010 and 46% in 2020. Just under half of this reduction is due to lower demand for electricity as a result of efficiency improvements in the end-use sectors. While in the Advanced scenario demand fell 22% by 2020, fossil fuel use declined 42%, mostly (37% points) due to reductions in coal use. The difference is made up by nuclear and non-hydro renewables, which were 15% and 40%, respectively, larger than in the BAU scenario

The carbon reductions (relative to the BAU) in the electric sector in the Moderate scenario are considerably more modest – 7% in 2010 and 12% in 2020. Without a carbon trading policy in the Moderate scenario, the reduction in demand for electricity relative to the BAU was met almost entirely by not building new gas-fired generators. Consequently, in 2020 there is slightly more carbon produced per kWh in this scenario than in the BAU. The reduction in new gas generation more than offset the impact on carbon from using 8% less coal and 41% more generation from non-hydro renewables.

These results highlight the importance of the carbon trading policy. Without it we don't see the reductions in coal usage, nor the construction of new gas fired plants. The carbon trading policy works together with the R&D-driven technology improvements, RPS and the production tax credit for renewables to significantly increase renewable generation, primarily wind, in the Advanced scenario. While the carbon trading policy does increase the average price per kWh of electricity, the electricity bill is actually smaller in both the Moderate and Advanced scenarios than in the BAU due to reductions in the demand for electricity.

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Chapter 8

THE LONGER-TERM AND GLOBAL CONTEXT[1]

8.1 INTRODUCTION

This report has addressed the policies and costs of reducing the growth of energy consumption and associated environmental pollutants in a single nation – the United States. In addition to the report's restricted geographic focus, the time scale of the quantitative analysis is limited to the period between the present and 2020. The issues raised by the report, however, exist in a global context and are shaped by events throughout the world. They also are affected by long-term trends and the long-lasting impacts of near-term investments.

In the near term, the greatest opportunities for cleaner energy lie in energy efficiency on the demand side and switching to less polluting fuels and energy conversion technologies on the supply side. Although this conclusion is apparent from the CEF analysis of the United States, it is equally true for other countries throughout the world. The remarkable achievement of China in reducing coal production by 250 million tonnes per year in the past two years is an example of the ability of international capabilities to reduce local pollutant and greenhouse gas emissions in the near term (Sinton and Fridley, 2000).

In the longer term, however, the opportunities for a clean energy future depend critically on technologies that do not presently exist in the marketplace or are in early stages of commercial trial. The commercial success of these technologies – which range from technologies that produce energy with low or zero pollutant emissions (renewable, hydrogen, and advanced nuclear power systems) to those that dramatically reduce energy use per activity or output (e.g., 100 mile per gallon automobiles and 200 lumen per watt lighting systems) to systems for the sequestration of carbon – will make the difference between energy futures with high or low economic, social, and environmental impacts.

To address these long-term and global issues, this chapter covers the following topcis. Section 8.2 describes the longer term and global context. Section 8.3 explains the importance of R&D for the long term. Sections 8.4 through 8.7 describe new technologies for energy efficiency, clean energy supply, carbon sequestration, and multi-purpose or crosscutting applications, respectively. In Section 8.8, we provide conclusions relating to energy technologies for global markets in the long-term.

8.2 THE GLOBAL CONTEXT TO 2050

Many of the issues addressed in this CEF report at the national level are at least as prominent at the international level. As the recent PCAST report on international energy innovation states, "The problems and opportunities related to oil, energy-technology markets, nuclear proliferation, climate change, and development/security interactions are all inherently global" (PCAST, 1999).

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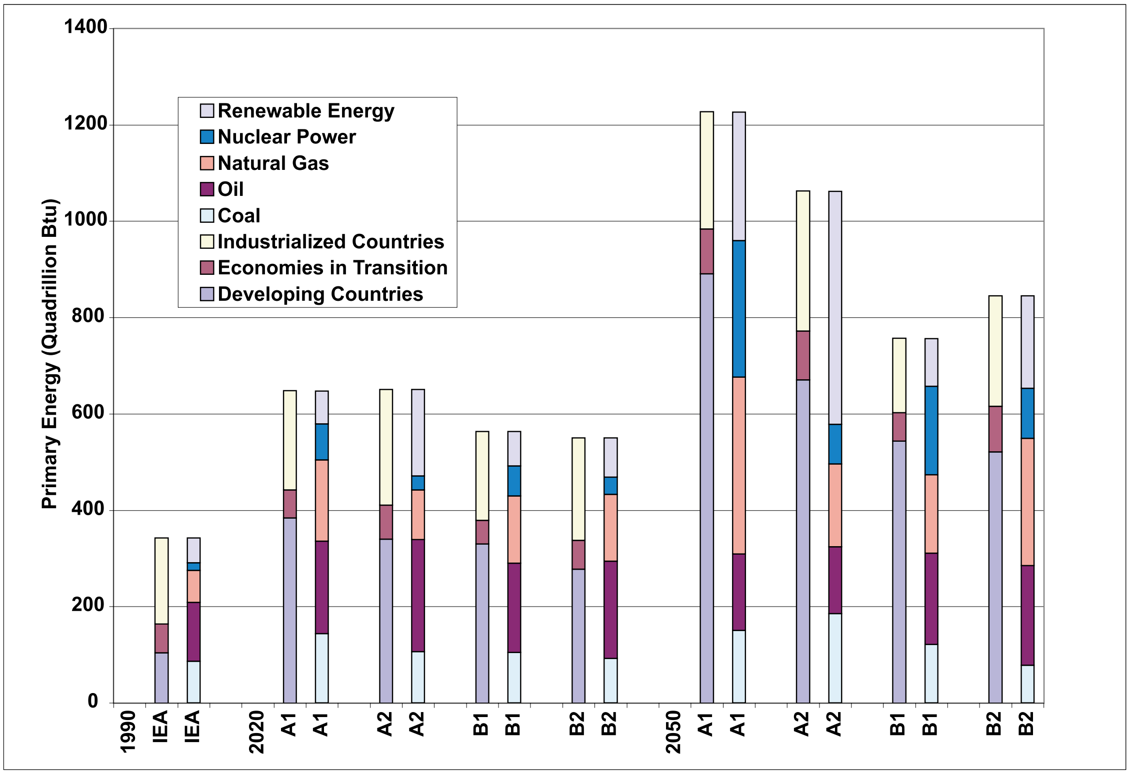
While the U.S. has made huge strides towards reducing its local air pollution problems, internationally the health impacts of local air pollution are staggering and growing as urban populations swell. Many countries do not have access to or cannot afford the SO_x and NO_x control technologies, cleaner natural gas fuels, and low-sulfur coal available to the U.S. The same PCAST study states, "acceptable outcomes all require major innovations in energy technology in order to … lower the emissions intensity of energy supply with respect to greenhouse gases, particulate matter, and gaseous precursors of regional smogs, hazes, and acid deposition (SO_x, NO_x, hydrocarbons)" (PCAST, 1999).

These local pollution problems prevalent around the globe will only worsen as the third of the world's population currently without commercial energy services increase their demand for electricity and access to fossil fuels for heating, transportation, and industrial processes. This growing demand on international fossil fuel supplies will produce higher prices if not outright conflict over access to oil and gas resources.

Figure 8.1 provides a snapshot of results of the major scenario construction and modeling efforts underway in many nations aimed at describing and understanding plausible global energy futures. These four scenarios are the four cases that the Intergovernmental Panel on Climate Change is using to depict a range of likely energy futures (IPCC, 2000). They are the four "marker" scenarios that typify outcomes of the following cases: high world economic growth, low population projections (A1), low economic growth, high population projections (A2), mid-range economic growth, low population growth (B1), similar to B1 but with somewhat lower economic and higher population growth (B2). The income disparity between the wealthy and poor nations was assumed to be considerably reduced from today's levels in all cases except B2.

Fig. 8.1 Four "Marker" Scenarios of Global Energy



The most striking observation from Fig. 8.1 is the tremendous growth of energy demand in the developing world *in all four cases.* The fraction of energy use in developing countries increases from about 30% at present to 50-59% in 2020 and to 62-73% in 2050. (A1 and B1 are at the high end of the range; A2 and B2, at the low.) More remarkably, for three of the four scenarios (A1, B1, and B2) more than 90% of energy demand growth between the present and 2050 occurs in the developing world. For A2, more than 75% of energy demand growth is in the developing world during this time period to 2050. In short, if one is to address the global problems of increasing energy demand, it is clear that the developing world is of the highest priority. From a business perspective, this is where the markets for energy will be. From an environmental perspective, it is where the greatest challenges to preserve and protect the environment from energy-related environmental insults will occur. From a social perspective, it is where low-cost, low-polluting efficient energy technologies will produce the greatest benefits to the largest populations.

These observations should not cause one to underestimate the enormous needs for the industrialized world to place great emphasis on clean energy including implementation of near-term technologies and R&D for the longer term. As will be clear in later section of this chapter, many of the best technologies will be developed and applied in industrialized countries. Developing nations will be reluctant to apply clean energy technologies on a large scale until the technologies have been clearly demonstrated to be technically successful and cost-effective. Such demonstrations will depend on widespread adoption of the technologies in the industrialized countries.

A second observation from Fig. 8.1 is that in all of these scenarios energy demand continues to grow. By 2050, energy demand is 2.2 (scenario B1) to 3.6 (scenario A1) times current levels. A major reason for the increasing energy demand in all cases is that none of these cases involve policies designed to expand energy technology R&D or to alter the choice of energy technology. The four scenarios involve different assumptions about economic and population growth and income distribution.

In Fig. 8.2, we present results for the North American region for six scenarios developed by Nakicenovic, Grubler, and McDonald (1998) for the World Energy Council (WEC). On a global basis, the first four of the scenarios are similar to the four IPCC scenarios discussed above. Importantly, Fig. 8.2 illustrates two cases (C1 and C2) in which demand growth is much reduced. These six scenarios portray a wide array of global economic conditions and energy developments over the next half-century. They range from a tremendous expansion of coal production to strict limits; from a phase-out of nuclear energy to a substantial increase; and from carbon emissions in 2100 that are only one-third of today's levels to increases by more than a factor of three. Primary energy use and carbon emissions vary tremendously across the six scenarios and across each of the 11 world regions that are modeled, as exemplified below (and in Fig. 8.2) for the North American region (which includes the United States, Canada, Puerto Rico, Virgin Islands, and Guam).

- Carbon emissions grow the fastest in Case A2, with its stepped-up exports of unconventional hydrocarbons and coal-based synfuels. Scenario A3's combination of comparatively high economic growth (1.6% annually, as in all of the "A" cases) and a focus on renewables and nuclear power results in North American carbon emissions dropping back to approximately 1990 levels by 2050. Case A1 has rates of growth of carbon emissions that are in between those of Cases A2 and A3. Its intermediate performance is driven by a strong growth in nuclear power but only modest increases in renewable energy[2].

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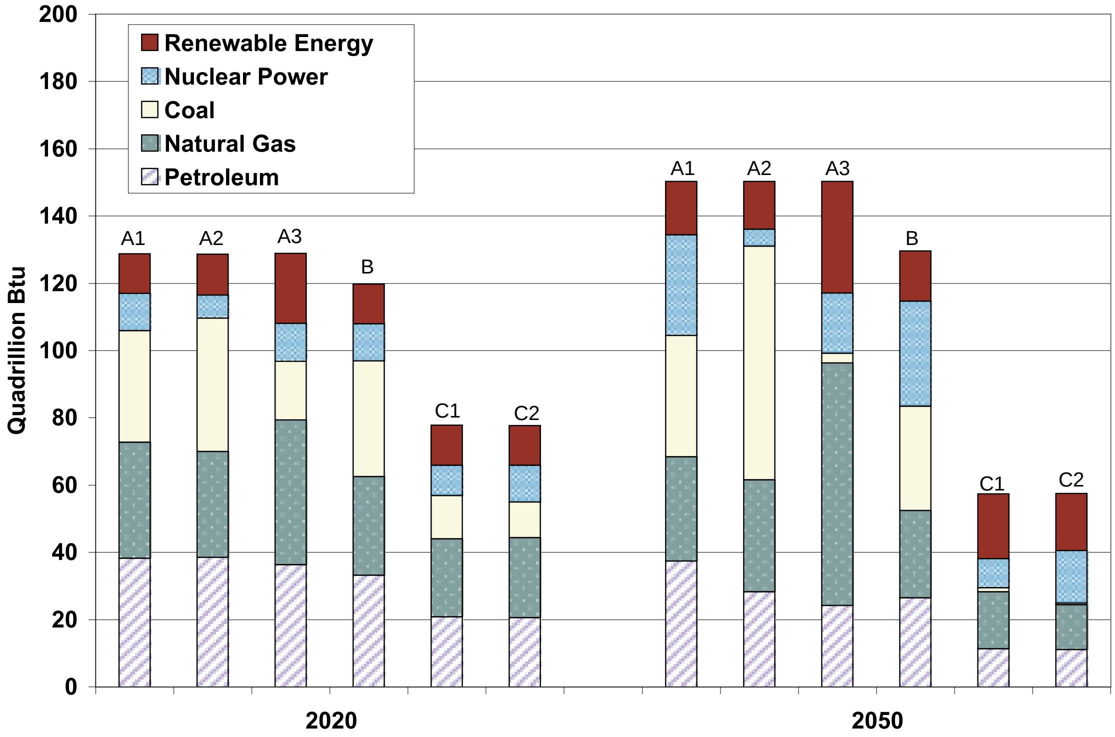
[2] Primary energy use in North America in all three of the "A" Cases for 2020 is only slightly greater than in the Clean Energy Future Study's BAU forecast. One would expect the "A" Cases to have much higher levels of energy use, since they include Canada while the CEF Study does not. The fact that the "A" Cases are not markedly higher can be explained largely by their assumption of a 1.6% annual economic growth rate, compared with the assumption of a 2.1% GDP growth rate in the CEF scenarios.

- Case B is characterized by more cautious forecasts of economic growth, rates of technological change, and energy availability. This results in carbon emissions in 2020 and 2050 that are somewhat lower than any of the “A” cases.

Fig. 8.2 Primary Energy Use in North America for Six Global Energy Scenarios



- Only in Case C are there substantial reductions in primary energy use and carbon emissions. In this case, ambitious policy measures accelerate energy efficiency improvements and develop and promote environmentally benign, decentralized energy technologies. This case describes a challenging pathway of transition away from the current dominance of fossil sources. In scenario C1, nuclear power proves a transient technology that is eventually phased out entirely by the end of the 21st century. In scenario C2, a new generation of nuclear reactors is developed that is inherently safe and small scale—100 to 300 MWe—and finds widespread social acceptability. By 2020, the primary energy use and carbon emission levels in Case C are well below those of the Advanced scenario, and they continue to decline in subsequent decades. To some extent the lower levels of energy use and carbon emissions in the “C” Cases are due to the assumption of a modest annual economic growth rate (1.1%).

In contrast to the vast differences in primary energy use and carbon emissions across the IIASA/WEC scenarios in 2050, the 2020 Cases retain vestiges of the current system that result in a number of common characteristics and similarities with one another and with the CEF scenarios. For instance, all of the IIASA/WEC scenarios include consistent trends for North America toward increasing reliance on natural gas and significant declines in traditional environmental pollutants. SO_2 emissions decline even in those cases where coal use increases, as a result of increased investments in environmental control technologies. One notable difference in 2020 is the high level of efficiency assumed in the C1 and C2 scenarios, which far surpasses the energy reductions of the other cases and the CEF scenarios. These “C” Cases and the CEF Advanced scenario differ in particular by their reliance on petroleum fuels in 2020. The IIASA analysts assumed that the existence in Case C of explicit policies to support public transportation and the diffusion of new transport technologies including high-speed trains, fuel cells, and electric vehicles (Nakicenovic, Grubler, and McDonald, 1998, pp. 158-159). The result is a significant reduction in petroleum use. Fuel cells also play a major role in the Advanced scenario, but large increases in public transportation and high-speed rail do not. The result is a smaller, but still sizeable reduction in petroleum use in the Advanced scenario.

8.3 R&D OPPORTUNITIES FOR THE LONG TERM

Given the uncertainties associated with long-term global conditions, it is important, as PCAST (1997) argues, for the United States to maintain a mix of clean energy sources and its leadership in the science and technology of energy supply and use. (See the following box.)

PCAST Conclusion

The United States faces major energy-related challenges as it enters the twenty-first century. Our economic well-being depends on reliable, affordable supplies of energy. Our environmental well-being—from improving urban air quality to abating the risk of global warming—requires a mix of energy sources that emits less carbon dioxide and other pollutants than today's mix does. Our national security requires secure supplies of oil or alternatives to it, as well as prevention of nuclear proliferation. And for reasons of economy, environment, security, and stature as a world power alike, *the United States must maintain its leadership in the science and technology of energy supply and use.*

— *Federal Energy Research and Development for the Challenges of the Twenty-first Century* by the President's Committee of Advisors on Science and Technology (PCAST, 1997) Italics added for emphasis.

To effect a technology-based solution to the nation's energy-related challenges, many promising efficient and clean energy technologies require considerable applied R&D before they are commercially feasible. Still other technologies are only at the conceptual stage but can be developed with further research. The importance of these long-term efforts is highlighted by key emerging technologies that largely fall outside the time frame of the CEF-NEMs analysis. While the specifics of these long-term advancements are not now known, we can nevertheless see trends that will continue to yield energy advancements after 2020. We describe these in three general areas below:

- energy efficiency (Section 8.4)
- clean energy (Section 8.5)
- carbon sequestration (Section 8.6)

The potential long-term contribution of four cross-cutting technologies is also described (Section 8.7) These sections describe a wide array of energy solutions and climate change mitigation options. Omitted from this inventory are numerous potential approaches to climate change adaptation. These range from geoengineering methods that reduce the sunlight reaching the earth's surface to fortification of our physical, informational, and institutional infrastructures. Such approaches deserve consideration and R&D alongside the energy opportunities outlined below. This is well beyond the scope of this study, but for a discussion of these options see Wilbanks and Kates (1999).

8.4 ENERGY-EFFICIENCY R&D OPPORTUNITIES

This section provides a sampling of some of the major advances that could occur with a sustained commitment to energy efficiency R&D. Many of these examples are drawn from the "11-lab study" by DOE National Laboratory Directors (1997) and a report by the International Energy Agency (1999).

8.4.1 Buildings

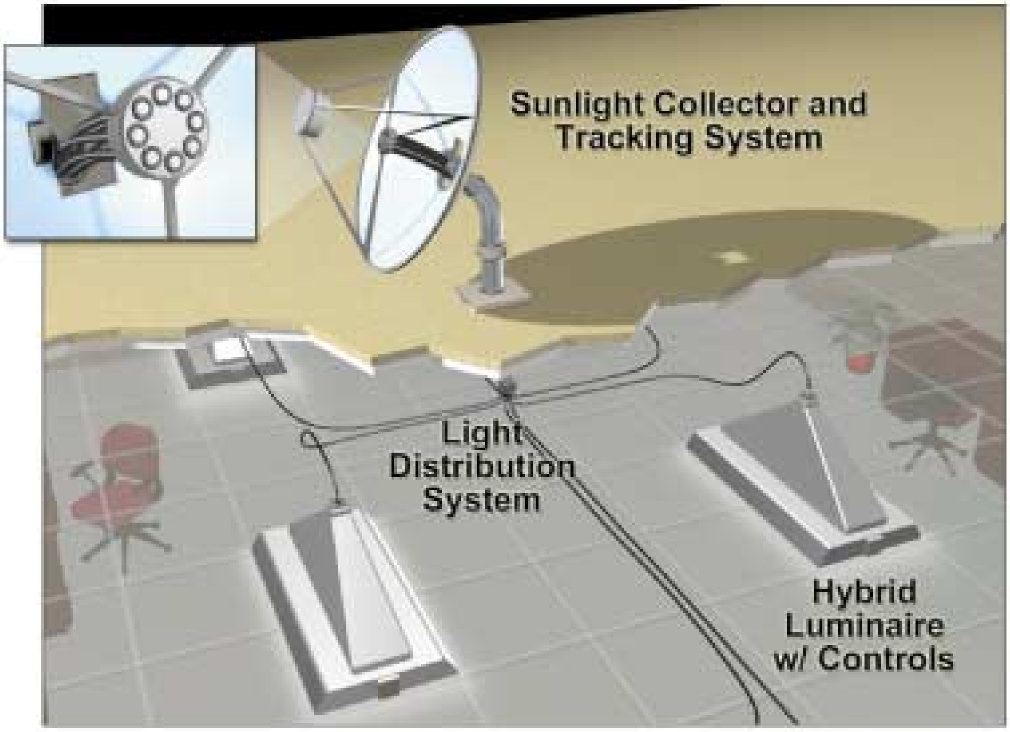
Major transformations are possible in the energy features of buildings as the result of applied technology R&D and in the underlying basic sciences. Inasmuch as most of these are best applied to new construction, their ultimate market penetration will occur well after the 2020 time frame of the CEF scenarios.

Equipment and Appliances. By definition, the energy used in buildings is consumed by equipment that transforms fuel or electricity into end-uses, such as delivered heat or cooling, light, fresh air, vertical transport, cleaning of clothes or dishes, information management, or entertainment. The overall efficiency of this transformation depends largely on the efficiency of the equipment itself.

Numerous opportunities exist to develop equipment that is much more efficient than that currently available.

- It may be possible to virtually eliminate space heating in many climates by means of building shells with very high resistance to heat loss or gain involving high insulation walls, ceilings, and floors and triple pane windows with transparent heat-reflecting films; wide use of passive designs; and mass-produced components (walls, ceilings) with very low infiltration rates.
- Microtechnology could greatly increase heat and mass transfer rates, with highly efficient applications to chemical and thermal systems. One potential buildings application, microheat pumps, could be distributed throughout the building as part of the walls or window. This distributed approach would allow selected rooms or even parts of rooms to be heated or cooled as needed.
- Multi-functional equipment and integrated systems offer the opportunity for a significant increase in efficiency improvement. For example, an integrated water heating/space cooling system that uses heat pumping to meet space heating, air conditioning, and water heating needs could be 70% more efficient than the combined efficiencies of systems in use today.
- Advanced lamp technology integrated with sunlight collectors and daylight distribution systems could be combined with control technologies to reduce lighting energy requirements to a fraction of today's levels. Figure 8.3 portrays a solar lighting and power system of the future. The concept separates and uses different portions of sunlight for two different uses, interior lighting and distributed power generation. The design takes advantage of two facts. First, the luminous efficacy of the visible part of the spectrum is more than double that of electric lamps. Second, photovoltaic cells, especially thermo-photovoltaic cells, are very efficient in converting the infrared portion of the spectrum to electricity.

Fig. 8.3 A Solar Lighting and Power System



- Dramatic declines in the energy consumed by supermarket refrigeration systems could be achieved with distributed system designs. Such systems of the future would locate compressors close to display cabinets thereby avoiding the loss of refrigerant charge. Use of the waste heat by heat pumps for space conditioning would lead to further efficiency gains.
- As energy conversion technologies evolve, many buildings could become net producers of energy as roofs incorporate photovoltaic panels and fuel cells and microturbines generate more power than is required on site. In addition, fuel cells and microturbines produce waste heat that can be employed to serve building thermal loads. These power technologies could transform the entire demand and supply chain in terms of energy generation, distribution, and end-use.
- Building control systems of the future will likely incorporate smart technology to closely match energy and water supply and ambient conditions with the needs of building occupants. Building loads and central plants supplying the loads will be more integrated and optimized to enhance the efficient use the energy streams into and out of the building.

The Building Envelope. The building envelope provides fundamental thermal load control for a building. Walls, roofs, and floors block or delay the flow of heat between a building's interior and exterior. Windows can also block heat flow, provide daylight, transmit solar energy, and provide a view of the outside. High-capacitance internal walls, ceilings, and floors can provide thermal storage that reduces energy use by storing solar energy and reduces peak loads by balancing energy use over a 24-hour period. Improvements in the energy performance of these building elements reduce energy use in buildings and thereby reduce GHG emissions.

Decreasing the building thermal load reduces the need for heating and cooling energy. These emerging building envelope technologies will significantly reduce building energy use:

- super insulation, based on vacuum principles
- new-formula high-efficiency foam insulation that uses no CFCs or hydrochlorofluorocarbons
- advanced gas-filled, multiple-glazing, low-emittance windows and electrochromic glazing
- roof systems that promote self drying, thereby preventing moisture from degrading its insulation
- passive solar components
- durable high-reflectance coatings
- advanced thermal storage materials

Intelligent Building Systems. The process of designing, constructing, starting up, controlling, and maintaining building systems is very complex. If it is done properly, the final product delivers comfort, safety, and a healthy environment and operates efficiently at reasonable cost. If any part of this process breaks down, the product fails to deliver these benefits. The lost health and productivity in office environments alone costs U.S. businesses hundreds of billions of dollars each year. In addition, operating these "broken" systems is estimated to cost at least 30% of commercial building energy use (more than $45 billion). The key to designing and operating buildings efficiently is the ability to manage information, deliver it in a timely manner to the proper audience, and use it effectively for building design and operation. More intelligently designed and operated buildings use energy more efficiently and thus reduce GHG emissions.

In the intelligent building systems concept, data from the design of the building, together with sensed data, will be used to automatically configure controls and commission (i.e., start up and check out) and operate buildings. Control systems will use advanced, robust techniques based on smaller, cheaper, and more abundant sensors than are in use today. Intelligent devices will use this wealth of data to ensure optimal building performance by continuously controlling and recommissioning building systems using automated tools that detect and diagnose performance anomalies and degradation. Such systems will optimize operation across building systems, inform and implement energy purchasing, guide maintenance activities, and report building performance while ensuring that occupant needs for comfort, health, and safety are met at the lowest possible cost.

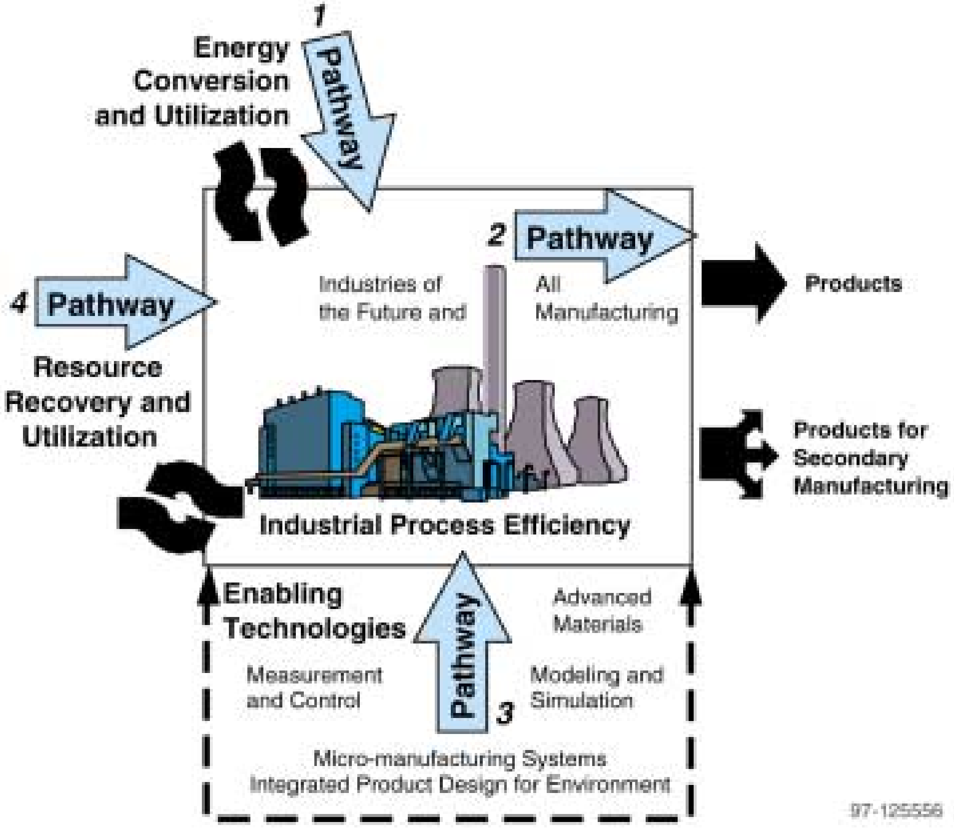
8.4.2 Industry

There is, and will long continue to be, opportunities to improve the energy efficiency of specific devices used in industrial applications. There are countless examples: more efficient chemical separations, highly efficient motors, and efficient processes for energy-intensive industries such as iron and steel, aluminum, and cement production. R&D will yield improvements in these areas for years and decades to come.

These are not, however, the ways in which major gains in energy efficiency will come about in industry in the longer term. It has long been recognized that the very substantial gains in energy efficiency result from changes in systems rather than individual devices (Fig. 8.4). The development of advanced control technology – and the application of control technology to industrial systems – has the potential to dramatically reduce industrial energy use.

Fig. 8.4 Four Technology Pathways to Increased Industrial Efficiency

Source: DOE National Laboratory Directors, 1997, p. 2-14



For example, improvements in individual motors can yield efficiency gains of a few percent. In contrast, the redesign of motor systems can produce savings of 20 to 60% (and higher). The addition of variable speed drives for many motor applications can yield further savings. Finally, the integration of advanced sensors and controls enable optimization of the entire system including the motors and the systems that the motors drive (fans, pumps, compressors, etc.). This will make possible the widespread transformation of motor systems. As motors presently consume more than 50% of U.S. electricity, advances in this area have the potential to yield dramatic impacts on industrial energy use.

Reviewing the industrial needs and opportunities that lie ahead, four major technological pathways have been identified. Figure 8.3 illustrates the relationship among them for the industrial sector.

Energy Conversion and Utilization. Energy efficiency could be improved through incorporating the best technologies in a systems approach. Technologies include advanced turbine systems, fuel cells, higher combustion efficiencies, and using thermal energy in a systems approach to mill/plant design. In the longer term, noncombustion technologies are likely to have a significant impact, such as fuel cells and gasification of biomass and in-plant residues. Integrated systems can offer further advantages. Heat cascading, in which the heat output of one process is used as the input to another process (that requires the heat at a lower temperature than the first process), can be shown in principle to yield significant energy savings. Such an approach in practice would mean the co-locating of different industrial processes, equipment design and sizing to permit new types of integration among industrial processes, and the very precise control of liquid and fluid transfers among different industrial processes.

Industrial Process Efficiency. Energy use in industrial processes can be substantially reduced by developing new, more efficient processes as well as by the energy conversion improvements mentioned earlier. These more efficient processes can encourage new, higher-quality products, while generating less waste and fewer undesirable by-products; they also offer the potential for increased economic growth. Technology opportunities for improving process efficiency include more selective catalysts, advanced separations, improved measurement and control systems, improved materials, and improved electric motor systems, such as large motors with superconducting wires. A particularly attractive longer-term opportunity is the use of biotechnology and bioderived materials. Technologies that employ crop and forest materials in the production of chemicals and materials are under development and being pilot tested.

Enabling Technologies. Increased fundamental understanding in chemistry, metallurgy, and biotechnology will allow the development of novel manufacturing processes. This knowledge, along with advanced modeling and simulation, improved industrial materials, and measurements (sensors) and intelligent control systems, will result in major incremental improvements and lead to fundamental breakthroughs. Likewise, developing and demonstrating micromanufacturing systems (i.e., mini-mills and micro-chemical reactors) for flexible process configuration and on-site/just-in-place (similar to just-in time) manufacturing can increase energy efficiencies and reduce GHG emissions in the long term. Decentralized manufacturing using locally distributed resources offers the advantage of reduced transport of raw materials and finished goods.

Resource Recovery and Utilization. This technology pathway is built upon the idea of an industrial ecology, wherein a community of producers and consumers perform in a closed system. Fossil energy is conserved and/or energy is obtained from non-GHG sources; in addition, materials are reused or recycled. Through technological advances, the raw materials and resources needed for manufacturing can be obtained by designing products for ease of disassembly and reuse, using more recycled materials in finished goods, and selecting raw materials to eliminate waste discharge or undesirable by-products. Some examples are developing new advanced polymers, composites, fibers, and ceramics engineering through advances in surface techniques and molecular structures. Another approach is to substitute materials such as biomass feedstocks for petroleum feedstocks in producing chemicals. Some longer-term technological approaches will seek to use CO_2 as a feedstock and non-GHG reductants as substitutes for carbon. Such fundamental changes in the way raw materials are obtained, the properties they exhibit, and the way they are used in the design process are likely to yield energy and greenhouse gas savings. Economic success will depend upon industry's using new design approaches and involving the entire supply chain in thinking about energy reduction in the materials life cycle.

Numerous environmental benefits would result from improved industrial process efficiency and waste minimization. In addition to reduced carbon emissions, these collateral benefits include reduced ground-level ozone, less demand for landfill space, and decreased emissions from incinerators and hazardous waste sites. U.S. industries would also be better prepared to compete in the $400 billion international market for environmental technologies.

8.4.3 Transportation

In the long term, additional advances hold the promise of spectacular reductions in energy use, greenhouse gas emissions, and air pollution from the transportation sector. Opportunities lie in the promise of new, revolutionary propulsion systems and alternative fuels and in the application of information technologies to manage and integrate intermodal transport systems in innovative and more efficient ways. Advances in information technology create new opportunities to increase system-wide efficiency and substitute communication for transportation to enhance economic well being and the overall quality of life.

Hybrid, Electric, and Fuel Cell Vehicles. Developing commercially viable, mass-market electric-drive vehicles (EVs) would free the automobile from dependence on carbon-based liquid fuels while simultaneously reducing vehicular emissions. Hybrid electric vehicles (HEVs) combine an electric drive with an auxiliary power unit and energy storage device (e.g., battery). A heat engine could be used as the auxiliary power source, but if fuel cell technology could be sufficiently advanced and the infrastructure for supplying hydrogen fuel developed, a potentially pollution-free propulsion system would be available (depending upon how the hydrogen is produced).

While HEVs are already on the market, their incremental costs are too high to enable large-scale market penetration. HEVs, EVs, and fuel cell vehicles all face formidable technical hurdles, many of which they share. Developing low-cost, rapidly rechargeable batteries is a critical factor in the success of HEVs and EVs. Fuel cells will also require cost reductions (on the order of 95%) as well as improvements in energy density and reliability. Recent, dramatic progress in batteries and fuel cells suggests that commercially competitive EVs can eventually be developed.

Carbon savings from battery-electric vehicles depend directly on the primary energy sources used to generate electricity. Potential advances in electricity generation technology could make EVs very-low-carbon vehicles. The power plants for HEVs may be fossil-fuel-burning internal combustion engines that could run on alternative fuels or could someday be replaced by fuel cells. In any case, an HEV that is three times more efficient would cut carbon emissions by at least two-thirds. Fuel cells may initially run on gasoline or alcohol fuels (reformed to produce hydrogen) and ultimately could use hydrogen stored on board the vehicle. Which fuels are used and how they are produced will determine the extent of CO_2 reductions over those of conventional vehicles.

Freight Vehicles. Freight vehicles—heavy trucks, railroad locomotives, and ships—are the second largest energy consumers in the transport sector after light-duty vehicles. Heavy trucks and locomotives are almost universally powered by highly efficient (40–45%) diesel power plants. The efficiency of diesel engines could be further improved to 55% by use of such technologies as advanced thermal barrier coatings, high-pressure fuel injection, turbocharging, and reduced-friction and lightweight, high-strength materials. Fuel cells are an especially promising technology for locomotives, where problems of size, fuel storage and reforming are greatly reduced. Emissions of NO_x and particulates remain the greatest barriers to ultrahigh-efficiency diesels, while for fuel cells, cost and the state of development of mobile fuel cell systems present the biggest challenges. Because freight vehicles and their power plants have useful lives measured in decades, the transition to low-carbon technologies would require decades.

Alternative Fuel Vehicles. Alternative transportation fuels are those that require substantial changes in conventional infrastructure, whether in fuel production, distribution, and retailing or in vehicles. Most alternative fuels currently under consideration are being explored for their ability to reduce pollutant emissions or displace petroleum and would have modest GHG reduction potential. Fuels such as compressed natural gas and propane can reduce carbon emissions by 10 to 20%, on a full fuel-cycle basis, over conventional gasoline or diesel fuel.

Far more promising from a GHG reduction perspective are biofuels, such as biodiesel produced from soy or rapeseed oils or ethanol or methanol produced from cellulosic feedstocks. Ethanol from cellulosic feedstocks produce essentially zero carbon emissions over the full fuel cycle. Vehicle technology for using ethanol and biodiesel is at a relatively advanced stage of development. The chief barriers to widespread use of these fuels are cost and limitations on feedstock production.

Air and High-speed Ground Transport. Commercial air travel is the fastest growing energy-using mode of transport. It is also the mode that has achieved the greatest improvements in energy efficiency during the past three decades. Yet commercial air transport is also the most petroleum-dependent mode. Opportunities to replace kerosene jet fuel appear to be many decades away. In the meantime, petroleum displacement in high-speed intercity transport may be achievable by integrating high-speed rail systems with the commercial air network. Operating at 180 to 300 mph, magnetically levitated or steel wheel rail cars could substitute electricity for kerosene in short-distance intercity travel, at the same time relieving both air traffic and highway congestion.

Although air transport has already more than doubled its energy efficiency over the past quarter century, opportunities remain for at least another 50% improvement during the next 25 years. Propfan technology, improved thermodynamic efficiency of turbine engines, hybrid laminar flow control and other aerodynamic improvements, and greater use of lightweight materials could accomplish this 50% improvement, and they are currently under development by NASA and aircraft and engine manufacturers. A potentially important issue for civil aviation is the possible advent of a new generation of far more energy-intensive supersonic high-speed civil transports. The unique requirements of supersonic and hypersonic aircraft could eventually drive the development of alternative fuels for commercial transport.

Having the best and most efficient commercial aircraft technology not only would reduce carbon emissions and petroleum use, but also will be critical to the U.S. aircraft industry’s remaining competitive. The principal impediment to continued efficiency improvement and lower carbon emissions is likely to be the relatively low cost of jet fuel, providing an inadequate incentive to adopt new, more complex, and possibly more costly aircraft technology.

Land use and infrastructure investment options offer powerful strategies for reducing the energy- and carbon-intensity of today’s transportation sector. Advances in information technology and a variety of policy levers offer the potential to develop urban spatial structures that decrease the demand for travel while maintaining accessibility. The exploding growth of e-commerce and the Internet economy could fundamentally reshape the nation’s demand for energy services. On the one hand, Romm, Rosenfeld, and Herrmann (1999, p. 9) argue that e-commerce could lead to significant reductions in the demand for energy services: “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.” Others argue that the explosion of Internet usage and e-commerce could increase demand for energy services including the transportation of goods and the movement of people. Only time will tell.

8.4.4 Symbiosis of Demand and Supply

While significant energy-efficiency improvements are expected from advancements of energy end-use technology in the demand sectors, additional energy-efficiency improvements are likely to emerge as the delineation between the energy demand and supply sectors vanishes. New competitive market structures are likely to provide energy solutions that seek global optima, in which benefits for both the demand and supply sectors are maximized.

For instance, with the advancements of fuel cell vehicles and their likely market adoption within this decade, it is a possible that residential and small commercial building customers could use their vehicles to produce electricity for their own use or become a net supplier of electric power into the distribution grid. By generating electric power at the location of use transmission and distribution losses can be avoided.

With an advanced information technology infrastructure, distributed generation and load management technologies are likely to become part of the generation mix of the future supply sector. It will then be feasible to trade-off a megawatt hour (MWh) of electric generation with a megawatt hour of load reduction. With such an information technology infrastructure in place, optimal dispatch of generation capacity could be extended to include load management assets at many commercial and industrial customers' sites. Under such a scenario, it is likely that the utilization of less energy-efficient peak power plants could be significantly reduced.

Several other symbiotic energy relations between the supply and the demand sectors are viable. These include district heating and cooling networks and combined heating, cooling and power concepts. Using network concepts, commercial or industrial customers can withdraw energy from or inject energy into the network as needed to maximize their benefits. These flexible energy concepts generally provide much higher efficiencies due to economy of scales and greater controllability.

8.5 CLEAN ENERGY R&D OPPORTUNITIES

8.5.1 Advanced Renewable Energy Technologies

There is considerable opportunity for continued improvement and market penetration of renewable energy technologies after 2020. There are two overarching reasons to believe that renewable energy can continue to evolve and grow as a source of energy not only in the near term, but well through the middle of the next century. First, much of the emergence of renewables will require time as it depends on:

- basic as well as applied research
- learning through increased production over time
- infrastructure development
- technology developments outside of the renewables field itself and the translation of those developments to renewables.

Second, renewables contribute towards the solution of the long-term national issues of climate change mitigation and the economic exhaustion of domestic fossil fuel resources, and towards several nearer term issues like local air pollution, rural development and international economic competitiveness. As these needs become more pronounced, the interest in, commitment to, and development of renewables will accelerate. A level of 20% use in 2025 and greater than 50% use in 2050 is foreseen for the world in a number of energy scenarios from, for example, Shell Petroleum Limited (1996), the World Energy Council (Nakicenovic, Grubler, and McDonald, 1998), and the International Panel on Climate Change (1995). Such high renewables usage will require significant long-term advances, not only in the cost competitiveness of renewables, but also in accessing the renewable resources and identifying new applications of these energy forms.

We examine below the potential for long-term advances in each of the individual renewable energy technologies.

Wind. Due to continuous improvements over the last two decades, wind is one of the renewable energy technologies closest to being economically competitive today. As a result we are seeing significant learning-by-doing at the international level as installations increase and prices fall. In 1999 worldwide wind capacity increased by 36% to 13,400 MW with Germany, the U.S., and Spain contributing over 40% of the increase (EIA, 2000). In the next quarter century, up to 10 to 20% of the electrical capacity in some regions could be from wind power without any adverse operating or economic effects. Such market penetrations require addressing the impact of the intermittent output of wind through modification of systems operation, hybrids with other technologies, energy storage, transmission and infrastructure, and improved wind forecasting.

Fig. 8.5 An Advanced Wind Turbines Design from AWT, Inc.

Improvements will continue in the near term through R&D on higher towers, lightweight blades with advanced airfoil designs, direct drive systems, advanced power conversion devices and development of durable and lightweight structural components. Two major design approaches are being investigated:

- stiff, heavy machines that resist cyclic and extreme loads, typical of historic European technology; and
- lightweight flexible machines that bend and absorb loads.

These options will require some time to sort out and further refine. While these improvements may be refined in the longer term, wind will also benefit for some time from technology advances in other areas. For example, improvements in short-term weather forecasting increase dispatchers' ability to plan for wind generation. Wind will also benefit from a completely restructured electric power system that includes real-time pricing at the retail level. With real-time purchasing, dispatchers will not be as constrained by their day-ahead planning and the intermittency of wind will be less important. Intermittently-available technologies, like wind and photovoltaics, will also benefit from improvements in real-time information control systems for dispatching and metering. Wind at remote resource sites is also likely to benefit from long-term advances in high power electronics and superconducting transmission.

Photovoltaics. About 100 MW of PV modules were sold worldwide in 1997; annual growth has been 15 to 20%. Hundreds of U.S. applications are currently cost-effective for off-grid electric power needs, such as powering remote telecommunications installations and utility sectionalizing switches. International interest is also very high. These off-grid applications are yielding significant improvements in the technology through learning-by-doing. The current annual growth rate of 15 to 20% could easily continue beyond 2020, continually yielding cost and performance improvements.

Important RD&D challenges include improving the fundamental understanding of materials and processes to provide a technology base for advanced PV options, optimizing cell and module materials and design, scaling up cells to product size, validating performance in outdoor and accelerated conditions, and improving manufacturing processes. At the same time, basic materials and film deposition research may lead to totally new approaches further out in the future. PV may also benefit over the long term from events as diverse as semiconductor industry advances, artificial photosynthesis breakthroughs, growing demand for personal vehicle transportation in developing countries, and electricity storage advances.

There are also deployment issues that will continue to resolve after 2020. For example, if PV becomes competitive with retail electric rates in the next two decades, we will see substantial installations on buildings. These deployments will be more economic for new buildings where the PV may substitute for roofing or other materials. New buildings also have the advantage that they can be designed and oriented to ensure solar access. Such new-building deployment opportunities could take a century to be fully realized as replacement of the current building stock will extend over the next 100 years.

Electric sector restructuring may also present deployment opportunities that extend well beyond 2020. First, restructuring itself is likely to require some time to be accepted by all the states. Second, aspects of restructuring like retail real-time pricing and net metering that could benefit PV will require some time to be widely accepted. Finally, many consumers will delay investing in distributed technologies like PV until they see clear sustained benefits from all the above factors working together.

In the longer term, PV may also be used to meet the needs of other energy markets. One tantalizing possibility is the light-duty vehicle transportation market (Fig. 8.6). There are several conceivable routes for PV to play a role in this rapidly evolving international market. The most direct possibility is the use of PV either mounted on the surface of a “world car” or stationary applications used to charge the batteries of an electric vehicle. In the long term, PV may also become the major energy source for hydrogen to power fuel cell vehicles. Either electrolysis or some form of direct photoconversion might be used. These concepts are attractive in that they address the long-term issue of petroleum resource availability and because they inherently include storage. They are not hindered by the issue of the intermittent availability of the solar resource.

Fig. 8.6 University of Missouri Entrant in Sunrayce 95

Solar Advanced Photoconversion. This suite of technologies uses the energy of sunlight to directly produce fuels, materials, chemicals, and electricity from renewable sources such as water, CO_2, and nitrogen. Examples of these natural and artificial photosynthesis processes include producing hydrogen from water or biomass and producing biodiesel, methane, and methanol from water, waste, and CO_2. Fundamental advances will be required in multidiscplinary areas involving biological pathways, molecular genetics, natural and artificial photosynthesis, catalysts and catalytic cycles, electron transfer, nanostructures, and materials. Advancements in these areas may yield spin-offs in or benefit from advances in opto-electronics, biosensors, biocomputers, bioelectronics and nano-scale devices.

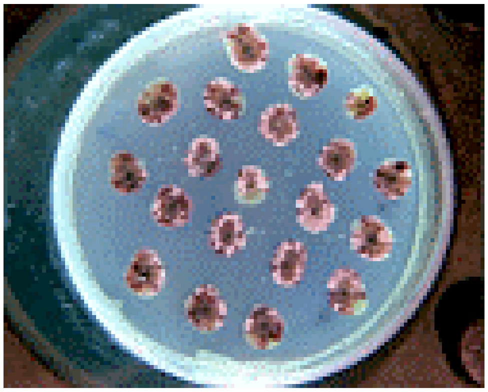
Most of these technologies – involving photobiological, photochemical, and photoelectrochemical approaches – are in the fundamental research stage where technical feasibility must be demonstrated. The pathway to full commercialization will easily extend well beyond the 2020 time frame of our scenarios' quantified results.

Bioenergy. Long-term improvements can be expected in the development of both biomass resources and the conversion technologies required to produce power, fuels and other bio-based products. As molecular genetics matures over the next several decades, its application to biomass energy resources can be expected to significantly improve the economics of all forms of bioenergy. Improvements in economics, in turn, will likely lead to increased efforts to develop new technologies for the integrated production of ethanol, electricity, and chemical products from specialized biomass resources. Similarly, improvements in fuel cells can be expected to increase the value and demand for biogas. At the same time, near-term biomass markets in corn-ethanol and the cofiring of coal-fired power plants are paving the way for the basic infrastructure required for the long-term, and providing opportunities for learning-by-doing.

Biomass gasification has the potential to have a major impact in the forest products industry as existing boilers are replaced. RD&D challenges include resolving issues around ash chemistry and NO_x reduction, demonstrating long-term operation of gas turbines on synthesis gas, improving materials, developing sufficient energy crops for feedstocks, and demonstrating advanced technologies. In the longer-term as fuel cells mature, biomass gasification for use in fuel cells will be demonstrated and will advance in the marketplace.

R&D challenges in the production of biofuels include low-cost production of enzymes, development of microorganisms for consolidated processes, improved performance of thermochemical processing, and advances in producing low-cost energy crops and controlling their composition. Many of these areas will benefit from advances in genetics and biochemistry. One of the most promising approaches today is the hydrolysis of fibrous biomass and subsequent microbial conversion of sugars to ethanol. However, there are other routes that could show future promise (Fig. 8.7). For example, oils can be produced from microalgae by both biological and thermochemical routes. Using the concentrated CO_2 from fossil fuel combustion is one potential route for reducing the cost of producing algae.

Fig. 8.7 Recombinant Streptomyces Bacteria:
A Potential Producer of Cellulase



Hydropower. Advanced hydropower technology improves on available techniques for producing hydroelectricity by eliminating adverse environmental impacts and increasing generation and other operational efficiencies. Current technology often has adverse environmental effects, such as fish entrainment and the alteration of downstream water quality and quantity. The goal of advanced hydropower technology is to maximize the use of water for hydroelectric generation while eliminating these adverse effects.

R&D challenges include quantifying the biological response of fish affected by hydropower projects and modeling the forces inside turbines to predict stress levels on fish. Better computational fluid dynamics models may enable the design of "fish friendlier" turbines. The development and demonstration of retrofits technologies is also needed, so that the large number of hydropower plant licenses that are currently scheduled to expire after 2020 are able to take advantage of these advances during the relicensing process. Other long-term opportunities include the integration of hydropower as a storage technology with intermittent renewables. As wind and photovoltaics penetrate the electric markets, hydroelectricity will offer the opportunity to firm up the power provided by these intermittent sources. The energy provided by intermittent renewables can also benefit those hydro sources that are constrained by limited water resources.

Geothermal. Geothermal energy is currently being used to produce power from hydrothermal resources as well as in direct use applications for geothermal heat pumps, greenhouses, and aquaculture. The geothermal resource in the U.S. is huge with over 40,000 Quads of energy potential. However, ninety percent of this potential is at low temperatures (<300˚ F) and much of that is inaccessible for any one of a number of reasons including lack of water, low permeability soils, and environmental concerns. To access these vast, but less attractive resources, basic research is needed in exploration technologies, drilling, reservoir engineering, and conversion technologies. While much technology has been borrowed from the petroleum industry, geothermal resources require new technology for higher temperatures, hard rock drilling, reservoir estimation, fracturing and other geothermal-specific requirements.

By 2020 these efforts could begin to stimulate active interest in enhanced geothermal systems. The use of hot dry rock resources appears particularly promising, where cool water is injected into dry hot rock formations through one well, travels through fractures to another production well, and is pumped out to run a steam turbine and produce electricity. Advances in offshore drilling technology by 2020 may also lead to the development of geopressurized brines in the Gulf of Mexico which provide not only thermal energy, but also associated methane resources and mechanical energy from the great pressures in the resource.

8.5.2 Inherently Safe Nuclear Power

There is strong potential for nuclear power to be a growing contributor to the energy mix of the United States, and the rest of the world, this century. In its 1997 report (PCAST, 1997), the PCAST Energy Research and Development Panel concluded that restoring a viable nuclear energy option to help meet our future energy needs is important. The PCAST Panel further determined that a properly focused R&D effort should be implemented by DOE to address the principal obstacles to achieving this option. These obstacles include issues involving proliferation, economics, nuclear waste, and safety.

In response, the DOE has established several initiatives including the Generation IV Program (to develop advanced nuclear reactor designs) and the Nuclear Energy Research Initiative (NERI, 1999) (to accelerate the long-term advancement of nuclear energy science). These R&D initiatives address both innovative technologies that can be developed and implemented over the next 10 years and revolutionary technologies that can be implemented over the next 30 years. Primary areas of needed research are described below.

Proliferation-Resistant Reactor and Fuel Technologies. Research to reduce or eliminate the potential for proliferation of nuclear fuel materials is critical to the success of nuclear energy systems. The development of new fuel cycles that reduce plutonium buildup, produce less waste, and have the least proliferation potential could significantly strengthen the future viability of nuclear power. New reactor concepts and plant configurations, large and small, that eliminate access to the nuclear fuel also hold great promise.

New High-Efficiency Reactor Designs. Scientific and engineering R&D of new and more efficient nuclear reactor concepts to achieve significant increases in performance and economics are required. Innovative reactor and power conversion concepts are needed that offer the prospects of higher efficiency, improved performance, design simplification, enhanced safety, and low cost. Promising future advances as envisioned in the Generation IV Program include:

- the development of reactor design advancements and alternative reactor core concepts;
- passive safety systems and components;
- innovative reactor concepts for electrical, nonelectrical or cogeneration purposes;
- technologies and design concepts incorporating construction and operations simplicity and cost reduction features; and
- specialized new applications such as process heat and electricity systems to compete in the global market.

Advanced Low Power Reactor Designs and Applications. Accelerated nuclear reactor R&D could produce innovative, small, compact, and easily deployable power reactor designs employing passive safety systems and long life cores for use in developing countries or for specialized applications. Potential applications include electricity generation, process heat, medical isotope production, and nuclear research. The ultimate objective is to develop small reactor systems, primarily for export, that need no on-site refueling for the life of the reactor, employ high safety margins and passive safety features, automated operation, minimized waste production, and high cost effectiveness.

Advanced Nuclear Fuel and New Technologies for Storage of Nuclear Waste. The first half of the next century could see the emergence of innovative technologies and techniques for the on-site and surface storage of commercial spent fuel and high level waste, and implementation of strategies for reductions in high-level waste generation. To achieve this, research is needed in the areas of interim storage and transport, transmutation, separation science, and waste form characteristics and integrity. New and innovative scientific and engineering R&D in advanced nuclear fuels is also necessary to realize measurable improvements in the performance of nuclear fuel with respect to safety, waste production, and economics to enhance the viability of nuclear reactor systems.

Fusion energy is also an important, albeit long-range element of the nation's energy strategy because of its many potential advantages as an energy resource. These benefits include: an almost limitless supply of fuel (primarily isotopes of hydrogen); greatly reduced radioactivity compared with fission (there are no long-lived gaseous radioactive products); and negligible atmospheric pollution (as with current nuclear generation) compared with fossil fuels. The successful application of practical fusion energy technologies at some point in the 21st century could help to enhance the Nation's energy, provide an environmentally acceptable alternative to fossil-fuel combustion, and help ensure continued economic growth through reliable electricity supply. Nuclear power can play a major role in the future electricity supply if issues described above are successfully addressed.

8.5.3 Fossil Energy Supply

In spite of the heavy dependence on fossil fuels in most parts of the world, the remaining fossil resource is still vast. One of these fuels, natural gas, is becoming increasingly popular because of its clean burning characteristics and relatively low greenhouse gas emissions compared to other fossil fuels. Finding ways to tap less conventional gas resources could extend the world's gas supplies for hundreds of years, as suggested by Fig. 8.8. Unfortunately, a fundamental characteristic of the world's hydrocarbon resources is that the larger the resource, the more challenging and difficult it is to exploit. Long-range targets of particular interest include deep gas and methane hydrates.

Deep Gas. A significant amount of undiscovered domestic gas is in accumulations deeper than 15,000 feet. They are in widely differing geologic settings, including ones shown as unconventional in Fig. 8.8. A number of technology challenges must be overcome to exploit deep resources, including better ways to detect commercial volumes of gas using surface-based sensing, and advanced materials for drilling at high temperatures and pressures at extreme depths.

Fig. 8.8 U. S. Natural Gas Resource Base

*Technically recoverable domestic resource base
**Mean estimate of U.S. hydrate resource base

Source: U.S. Department of Energy and U.S. Geological Survey

Methane Hydrates. Domestic methane hydrates are found on land in permafrost regions (such as much of Alaska) and within ocean floor sediments. To achieve safe and environmentally acceptable production by 2015, it would be necessary to determine the location, sedimentary relationships, and physical characteristics of methane hydrates, and develop production approaches for disassociating the methane from the cage of water ice molecules in the hydrates.

Fig. 8.9 Burning Gas from Methane Hydrate Ice

Source: ORNL Review, 2000, p. 4

8.5.4 Fossil Energy Conversion

Continued improvements in efficiency and environmental acceptability could enable fossil energy to play a growing role in the U.S. and world's energy mix while pursuing the goals of a clean energy future. The DOE has developed a new approach to 21st century energy production from fossil fuel-based systems called the "Vision 21 EnergyPlex, (FETC, 1999)." This vision integrates advanced concepts for high-efficiency power generation and pollution control into a new class of fuel-flexible facilities capable of co-producing electric power, industrial-grade heat, high value fuels, chemicals and hydrogen, with virtually no emissions of air pollutants. This multi-product approach, if successful, will squeeze every useable amount of energy out of a fuel source, achieving efficiencies in the post-2015 period that could approach 60 to 80 percent, well above the typical 33 to 35 percent efficiencies of today's conventional coal-fired power plants.

A *Vision 21* power plant would also have remarkable fuel flexibility. It could be fed by coal, natural gas, biomass, municipal waste, or perhaps a combination of these fuels. Made up of modules that could be interchanged to meet different fuel and product needs, *Vision 21* plants could be tailored for a variety of geographic regions and different energy markets. Advanced technology could permit CO_2, to be captured, and ultimately eliminated when viable sequestration approaches emerge in the next several decades. The Vision 21 plant depicted could be extremely compact and efficient. With near-zero emissions, the plant could have no stack, and in some cases be sited near urban and industrial centers, thereby relieving the need for additional transmission lines.

Many of the initial building blocks for "Vision 21" are already under development. In the future these could be integrated with further advances such as described below.

Fuel-Flexible Gasification. Coal gasification is an ideal core technology for "Vision 21" because it produces a gas stream that can be combusted for electric power, used as a source of hydrogen for a fuel cell or chemical process, or processed as a fuel gas for industrial plants. To enhance fuel flexibility, R&D is needed to determine how best to gasify fuel mixtures, such as coal and biomass or fuel-rich wastes.

Fig. 8.10 Conceptual Drawing of a Vision 21 Energy Plex

Gas Separation Technologies. To make a future "Vision 21" plant as cost-effective and efficient as possible, lower-cost means would be needed to produce oxygen for the gasification process. This need could be met by developing innovative membranes to replace the costly cryogenic air separation used today. Similarly, advanced membranes could offer a better way to separate a pure stream of hydrogen from the gasified hydrocarbon fuel that could then be used by a fuel cell or converted to high value fuels and chemicals. Gas separation technologies could provide an effective future means for separating CO_2 effluents from combustion streams for sequestration in deep aquifers, depleted oil and gas wells, or ocean depths and sediments.

Fuel Cell/Turbine Hybrids. To date, R&D has focused largely on fuel cells and turbines as separate power generating devices, but in the future, combining the two may offer significant efficiency and economic benefits. A key challenge that could be met over the next two decades is the integration of fuel cell and turbine technologies and the adaptation of them to run on multiple types of fuel feedstocks.

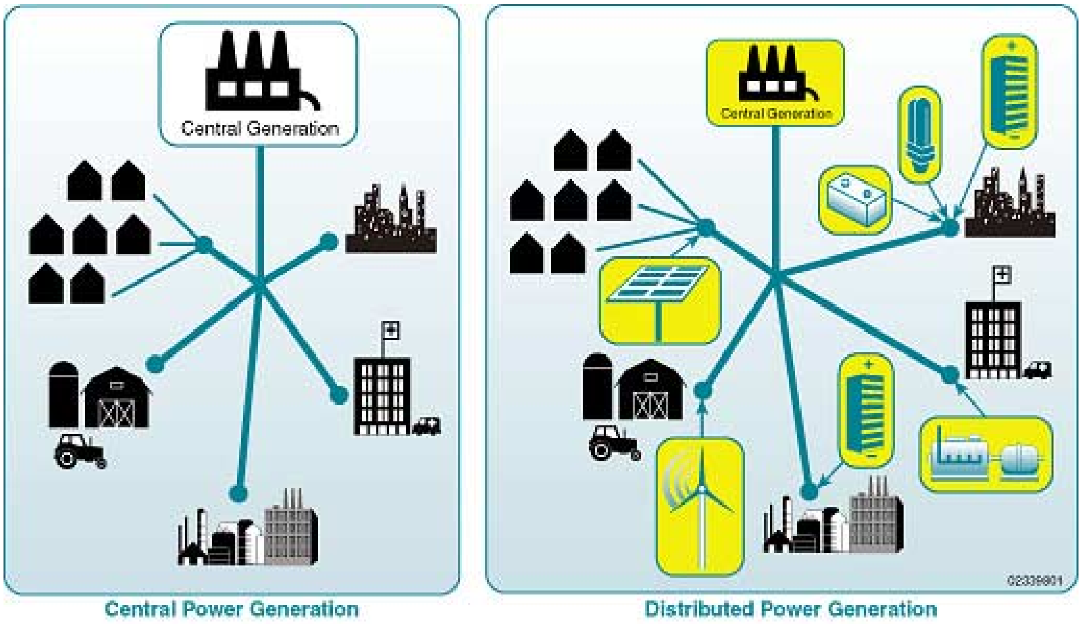
High-Performance Combustion. An alternative "Vision 21" configuration would rely on combustion rather than gasification. In this design, advanced technologies such as pressurized fluidized bed combustion and high-temperature heat exchangers will need to be improved through expanded R&D.

If the "Vision 21" concept can be successfully coupled with low-cost carbon sequestration, the result will be a future energy facility with virtually no environmental impacts outside of its "footprint."

8.5.5 Distributed Energy Resources

Distributed energy resources are small power generation or storage systems located close to the point of use. They offer significant potential for reduced transmission and distribution costs, higher efficiencies through cogeneration, fuel flexibility, reduced emissions of carbon and local air pollutants, enhanced power quality and reliability, and more end user control. Many believe that these potential advantages will bring about a "paradigm shift" in the energy industry, away from central power generation to distributed generation (Fig. 8.11).

Fig. 8.11 The Transition to Distributed Energy Resources



With generation located near loads, transmission and distribution costs could be reduced by (1) deferring upgrades to substations and other transmission and distribution facilities; (2) providing black start capability, spinning reserves, and voltage support; and (3) reducing reactive power losses. Some distributed generation technologies, like renewable energy and fuel cells, can generate electricity with no, or at least fewer, emissions than central station fossil-fired power plants. Total emissions can also be reduced through distributed generation using fuel cells, microturbines and internal combustion engines if the waste heat generated is usefully employed on site to improve overall system efficiency. Finally, as the electric industry restructures, distributed generation could also provide increased reliability as reserve margins shrink, independent system operators become effective in their operation, and market volatility is tamed (NRECA, 2000).

Today's distributed generation market in the United States is largely limited to backup generation. Customers are hospitals, industrial plants, Internet server hubs, and other businesses that have high costs associated with power outages. Smaller niche markets are growing, where distributed energy resources are used as a stand-alone power source for remote sites, to reduce costs associated with on-peak electricity charges and price spikes, and to take advantage of cogeneration efficiencies. Distributed generation could be particularly advantageous in developing countries by requiring less infrastructure investment, reducing transmission line requirements, and being more responsive to rapidly growing demand for power. It is likely that this increased demand will continue, and possibly accelerate, well into the future as small-scale modular units improve in performance and decrease in cost, interconnection and other barriers are tackled, the demand for electricity continues to grow, and the worldwide digital economy explodes.

A recent report commissioned by E Source describes a visioning process based on the assumption that the demand for ultra-reliable power service will increase far more rapidly than the demand for electricity itself (Geraghty, 1999). Many futurists foresee more and more digital information being created, processed, and transported faster and faster by power-sensitive equipment. Power densities of microprocessors and routers are increasing, as are the requirements for heat dissipation associated with this equipment. This growth could mean an increase in the cost of power outages and a growing demand for power reliability. This indicates a rapidly growing demand for ultra-reliable power services, which could be met by distributed energy resources.

Research is ongoing now on distributed generation technologies and their interconnection to the grid. For distributed generation to enhance system-level efficiency, improvements would be needed in the performance of power-producing equipment such as advanced turbines and microturbines, natural gas engines, fuel cells, cooling heating and power systems, and renewable and hybrid systems. A next generation of power electronics, energy storage, and sensors and controls would also be required. With successful RD&D, the United States (and much of the rest of the world) could realize a paradigm shift to ultra-high efficiency, ultra-low emission, fuel-flexible, and cost-competitive distributed generation technologies easily interconnected into the Nation's energy infrastructure and operated in an optimized manner to maximize value to users and energy suppliers, while protecting the environment.

8.6 CARBON SEQUESTRATION R&D OPPORTUNITIES

There are numerous ways of removing CO_2 from the atmosphere and storing it or keeping anthropogenic carbon emissions from reaching the atmosphere. Six of these carbon sequestration methods are described in a recent report (DOE, 1999):

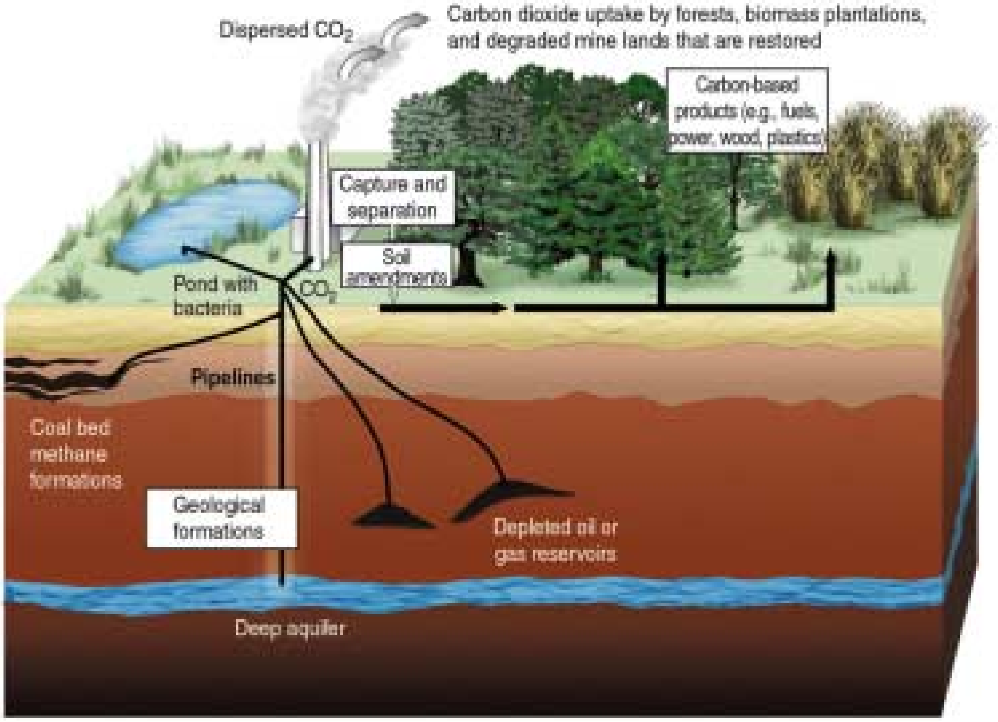
- Separation and capture of CO_2 from the energy system
- Sequestration in the oceans
- Sequestration in terrestrial ecosystems
- Sequestration in geological formations
- Advanced biological processes
- Advanced chemical approaches

Some of these options are available today – such as improved agricultural practices and wetlands protection. Others are available in the near-term because they can provide important secondary benefits, such as improving ecosystems during reforestation and enhancing oil recovery through CO_2 injection. Most, however, are long-term carbon management options that require considerable research to ensure their successful development and acceptance. Ultimately, one can envision a systems approach to carbon management, involving a combination of carbon capture, separation, and sequestration (Fig. 8.12).

Separation and Capture of CO_2 from the Energy System

Several currently available technologies could be used to separate and capture CO_2 from fossil-fueled power plant flue gases; from the effluents of industrial processes such as iron, steel, and cement production; and from hydrogen production by reforming of natural gas. CO_2 could be absorbed from gas streams by contact with amine-based solvents or cold methanol. It could be removed by adsorption on activated carbon or other materials or by passing the gas stream through special membranes. Commercial hydrogen production via reforming of natural gas involves separating H_2 from the reformate gases (a mixture of unreacted methane and other hydrocarbons, CO, CO_2, and water) by adsorption processes such as pressure swing adsorption (PSA). Should fuels decarbonization (e.g., reforming of natural gas to produce H_2) become part of a CO_2 mitigation strategy, the PSA technology could logically be extended to CO_2 separation and capture.

Fig. 8.12 Schematic of an Integrated System with Carbon Capture, Separation, and Sequestration



Source: ORNL Review, 2000, p.13.

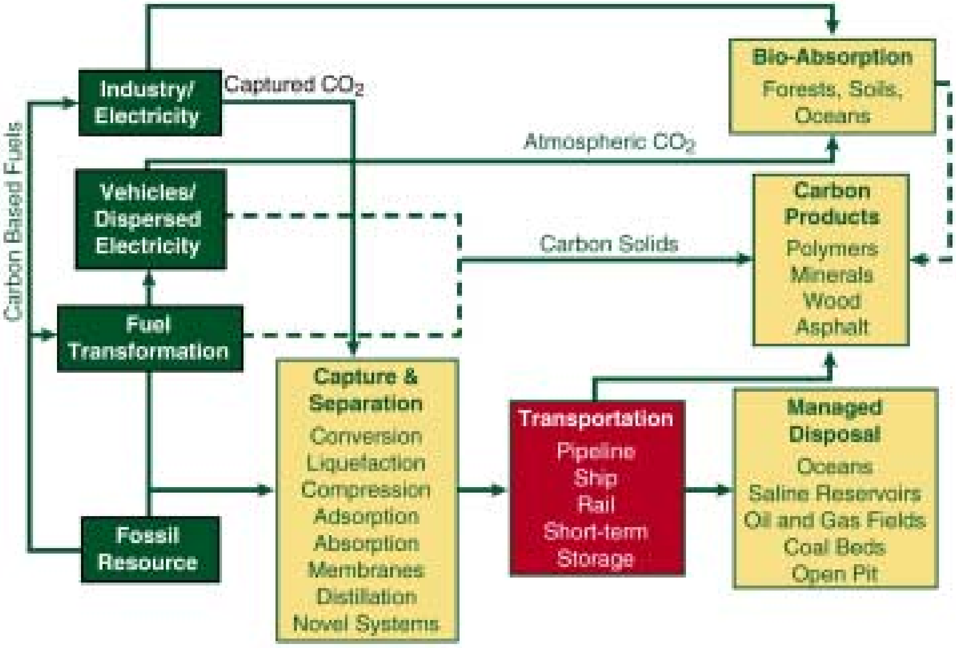
Advanced methods might include adsorbing CO_2 on zeolites or carbon-bonded activated carbon fibers and separating it from flue gases or process gases from industrial operations using inorganic membranes. The use of commercial CO_2-removing processes that scrub gases with amine-based solvents is projected to raise substantially the cost of producing electrical power from coal-fired power plants using existing technology. Thus although CO_2 is separated routinely, dramatic improvements would be necessary to make the process economical. Techniques would be needed to transform the captured CO_2 into materials that (1) could be economically and safely transported and sequestered for a long time or (2) could be used to make commercial products (e.g., construction materials) that could offset the costs of separation and capture.

There are numerous options for the separation and capture of CO_2, and many of these are commercially available. However, none has been applied at the scale required as part of a CO_2 emissions mitigation strategy, nor has any method been demonstrated for all the major anthropogenic sources. Many issues remain regarding the ability to separate and capture CO_2 from anthropogenic sources on the scale required, and to meet the cost, safety, and environmental requirements for separation and capture.

Geologic or ocean storage sequestration options that use a concentrated source of CO_2 require low-cost carbon separation and capture techniques to be viable options. The scale of the industrial system required to process gigatonnes of carbon warrants investigation into new solvents, adsorbents, and membrane separation devices for either pre- or post-combustion separation.

Figure 8.13 gives a top-level picture of a carbon capture and sequestration system and its linkages to the energy system. Within the current fossil energy system, carbon is processed in several forms by different fossil fuel technologies in many different parts of the energy system. To keep it from being emitted to the atmosphere, this carbon must be captured, processed in some way to separate or purify it, and changed to a solid, liquid, or gaseous form that is convenient for transport. It can then be transported in an engineered system to a site for sequestration or for transformation into a long-lived end product. Alternatively, the carbon could be emitted as CO_2 and transmitted through the atmosphere if sequestration by bio-absorption could be assured in some part of the natural carbon cycle.

Fig. 8.13 A Carbon Capture and Sequestration Technology System



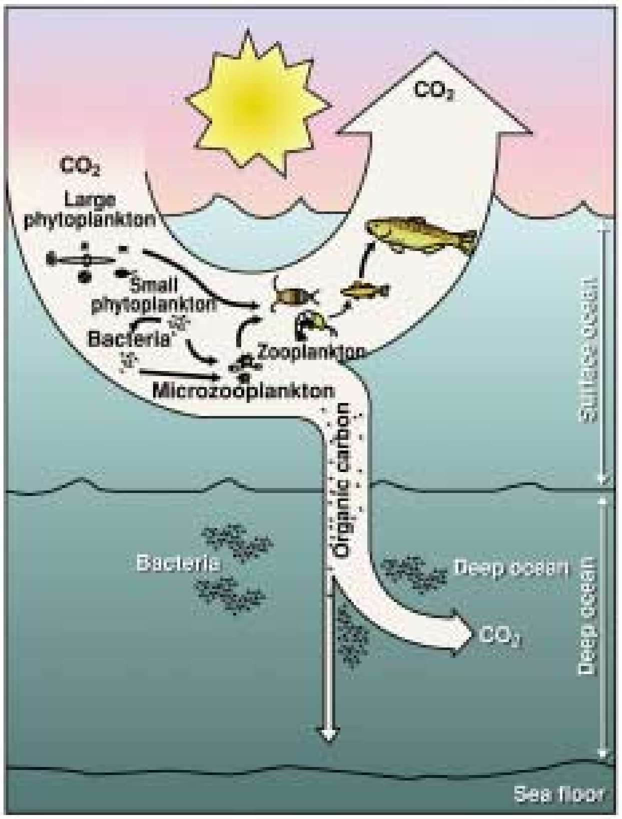
Source: DOE, 1999, p. 8-3

8.6.1 Sequestration in the Oceans

Ocean sequestration represents a large potential sink for CO_2. Although the ocean's biomass represents about 0.05% of the terrestrial ecosystem, it converts about as much inorganic carbon to organic matter (about 50 GtC/year) as do processes on land. The photosynthetic fixation of CO_2 by ocean organisms, followed by the sinking and slow remineralization (conversion to CO_2) of organic carbon, is a natural process for sequestering CO_2 in the deep sea. This process is often referred to as the "biological pump" (see Fig. 8.14). Eventually (over 1000 years), about 85% of today's anthropogenic emissions of CO_2 will be transferred to the ocean. Ocean sequestration strategies would attempt to speed up this ongoing process.

Iron fertilization is one promising method for accelerating the net oceanic uptake from the atmosphere. There is evidence that natural iron fertilization of the Southern Ocean was responsible for significant reductions in atmospheric concentrations of CO_2 following the onset of past ice ages. Iron fertilization is believed to enhance biological productivity of certain ocean regions, effectively transporting atmospheric CO_2 as biomass to lower regions of the ocean which have limited interaction with the atmosphere. Active experiments are already under way in iron fertilization and other tests of enhanced marine biological sequestration. Improvements in understanding marine systems would be needed before implementation of major marine sequestration campaigns, to enhance the effectiveness of applications and avoid undesirable consequences.

Fig. 8.14 A Schematic Diagram of the Biological Pump

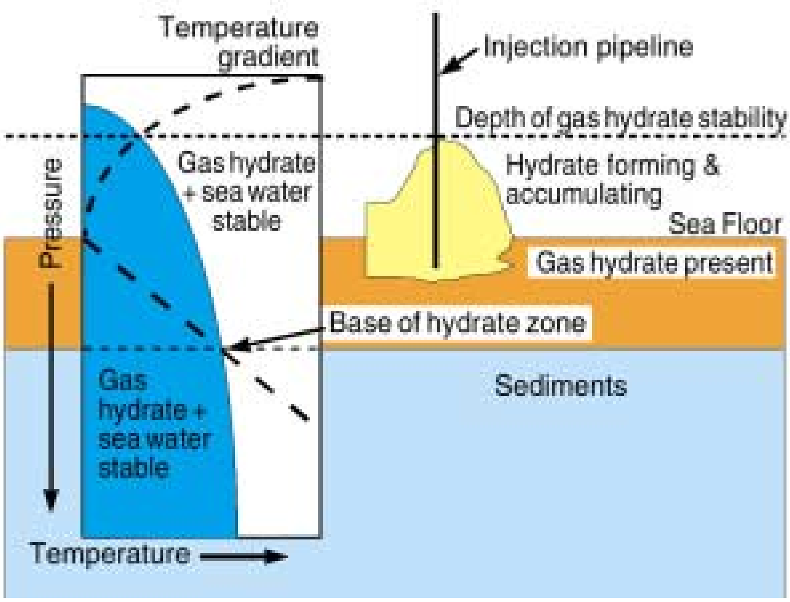


Source: DOE, 1999, p. 3.3

Another promising approach involves injecting relatively pure CO_2 streams that have been generated by a power plant or industrial facility directly into the ocean to be trapped in ice-like solids called gas hydrates. Gas hydrates are nonstoichiometric compounds in which the gas molecules are engaged within a host crystal lattice of water molecules. CO_2 could be pumped into regions such as deep oceans where hydrate is stable and sequestered as accumulated gas hydrate.

The drawing in Fig. 8.15 shows a conceptual cross-section of CO_2 introduced to a deep seafloor or within seafloor sediments. In arctic oceans, permafrost regions, and deep oceans, the pressure and temperature conditions favor gas hydrate stability. At deep ocean depths, CO_2 hydrates form below temperatures of 10°C. As a result of these same in situ processes, CH_4 hydrates form on the ocean floor and within ocean sediments. The sequestration process is the opposite of systems envisioned to extract CH_4 hydrates from the seafloor as an energy source. CO_2 could be piped into regions where hydrates are stable, to be sequestered as accumulated gas hydrates at the seafloor-ocean interface or within the accumulating sediments (the possible reservoir is basically unlimited because of the areal extent of ocean and permafrost regions where hydrates are stable). The advantages of the gas hydrate sequestration pathway are that hydrate formation results in a significant reduction in volume for equivalent mass and that the process may be less rate dependent than relying on CO_2 mixing with sea water.

Fig. 8.15 Conceptual Cross-Section of CO_2 Introduced to a Deep Seafloor



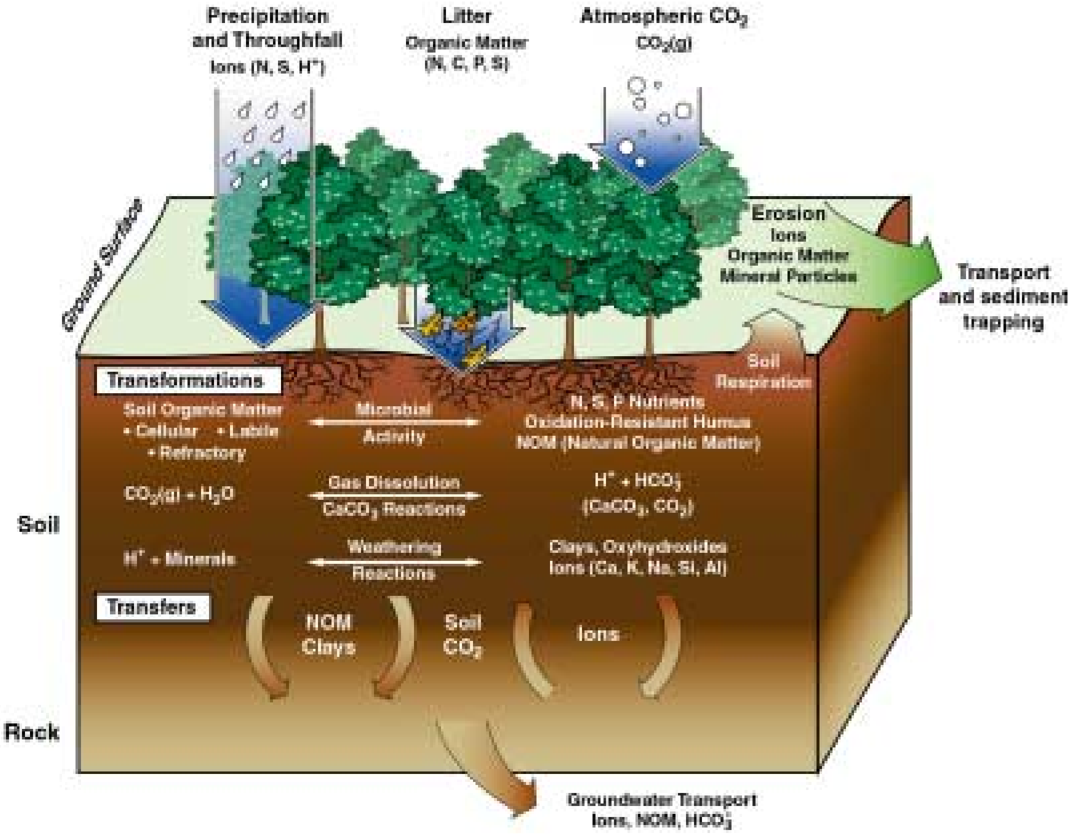
Source: DOE National Laboratory Directors, 1997, p. B-96

8.6.2 Sequestration in Terrestrial Ecosystems

The terrestrial biosphere is a large and accessible reservoir for sequestering CO_2 that is already present in the atmosphere. Terrestrial ecosystems, including forests, vegetation, soils, farm crops, pastures, tundra, and wetlands, act as huge natural biological scrubbers for CO_2. Computer models estimate that terrestrial ecosystems have a net carbon accumulation of about one-fourth (1.5 to 2 GtC) of the 7.4 GtC emitted annually into the atmosphere by fossil fuel combustion and land use changes. Their carbon sequestration potential could be significantly increased by careful manipulation to enhance the natural carbon cycle. Because natural carbon fluxes are huge, even small forced changes resulting from R&D advances would be very significant.

The potential for terrestrial ecosystems to remove and sequester more carbon from the atmosphere could be increased by reducing oxidation of soil carbon, enhancing soil texture to trap more carbon, and protecting wetlands. The dynamics of carbon transformations and transport in soil are complex and could result in either carbon sequestration or increased emissions of CO_2 (Fig. 8.16). Bicarbonate (HCO_3) ions dissolved in water could be sequestered if the dissolved carbonate enters a deep groundwater system that has a residence time of hundreds to thousands of years. Natural organic matter is another type of soil carbon that could be transported to deep groundwater systems. Natural organic matter could be mobilized during intense precipitation following prolonged dry periods. This carbon-rich material may be sequestered if it is transported to deeper groundwater systems or deposited deeper in soil. Thus, there may be opportunities to encourage geohydrologic systems to promote the deep transport of carbon into groundwater systems.

Fig. 8.16 The Dynamics of Carbon Transformations and Transport in Soil



Source: DOE, 1999, p. 4-9

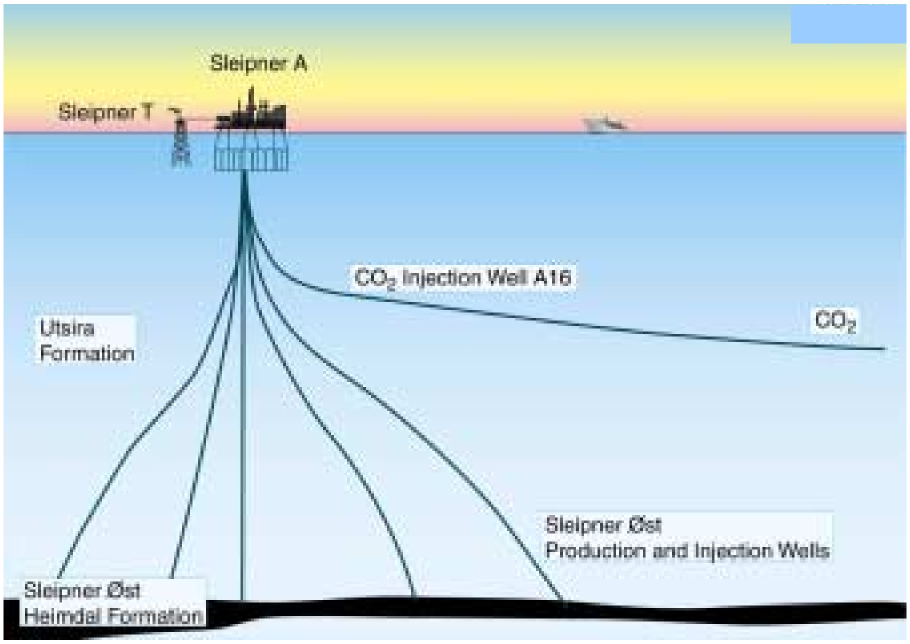
8.6.3 Sequestration in Geological Formations

CO_2 could be sequestered in geological formations by three principal mechanisms. First, CO_2 could be trapped as a gas or supercritical fluid under a low-permeability caprock, similar to the way that natural gas is trapped in gas reservoirs or stored in aquifers. This mechanism, commonly called hydrodynamic trapping will likely be, in the short term, the most important for sequestration. Finding better methods to increase the fraction of pore space occupied by trapped gas would enable maximum use of the sequestration capacity of a geologic formation. Second, CO_2 could dissolve into the fluid phase. This mechanism of dissolving the gas in a liquid such as petroleum is called solubility trapping. In oil reservoirs, dissolved CO_2 lowers the viscosity of the residual oil so it swells and flows more readily, providing the basis for one of the more common techniques for enhancing oil recovery.

Finally, CO_2 could react either directly or indirectly with the minerals and organic matter in the geologic formations to be come part of the solid mineral matrix. In most geologic formations, formation of calcium, magnesium, and iron carbonates could be the primary mineral-trapping processes. However, precipitation of these stable mineral phases is a relatively slow process with poorly understood kinetics. Developing methods for increasing the rate and capacity for mineral trapping could create stable repositories of carbon that are unlikely to return to the biosphere and could decrease unexpected leakage of CO_2 to the surface

About 70 oil fields worldwide use injected CO_2 for enhanced oil recovery. CO_2 sequestration is already being practiced in a sub-seabed reservoir in the North Sea of Norway (Fig. 8.17). The United States appears to have sufficient capacity, diversity, and broad geographical distribution of potential reservoirs to enable widespread usage of geologic sequestration.

Fig. 8.17 A Norwegian CO_2 Injection System



The primary uncertainty is the effectiveness of storing CO_2 in geological formations—how easily CO_2 can be injected and how long it will remain. It is not yet possible to predict with confidence storage volumes and integrity over long time periods. Many important issues would need to be addressed to reduce costs, ensure safety, and gain public acceptance.

8.6.4 Advanced Biological Processes

Advanced biological processes could be developed and implemented to limit emissions and capture and sequester carbon. Bacteria and other organisms could be used to remove carbon from fuels and to recycle carbon from man-made waste streams. Crop wastes and dedicated crops could be used as feedstocks for biological and chemical conversion processes to manufacture fuels and chemicals. In addition, advanced crop species and cultivation practices could be designed to increase the uptake of atmospheric CO_2 by terrestrial and aquatic biomass while at the same time decreasing CO_2 emissions to the atmosphere from soils and terrestrial and aquatic biomass.

The 21st Century has been referred to as the "Century for Biology." Indeed, many new molecular tools have been developed that could aid in new discoveries and assist in providing solutions to key problems facing humankind and the planet. The difference that advanced biological techniques could make will be evident when they are integrated with land, subsurface, and ocean management practices.

8.6.5 Advanced Chemical Approaches

Improved methods of separation, transport, and storage of CO_2 could benefit from research on and development of advanced chemical techniques to address sequestration via chemical transformations. Any viable sequestration technique must store vast amounts of carbon-rich materials. Thus, environmental chemistry could be valuable to determine whether these materials would be stable when sequestered. Many issues pertaining to aqueous carbonate/bicarbonate chemistry are relevant to sequestration of carbon in oceans, geological formations, and groundwater. Carbonate chemistry in very basic solutions could lead to a method for extracting CO_2 from air. Clathrates, compounds that can enclose molecules such as CO_2 within their crystal structure, could be used to separate CO_2 from high-pressure systems. Learning clathrate properties may be important to understanding chemical approaches to ocean storage of carbon. Subsurface arctic and marine hydrate formations could also be viable as geologic sequestration options.

The proper focus of R&D into advanced chemical sciences and technologies is on transforming gaseous CO_2 or its constituent carbon into materials that either have commercial value or are benign, inert, and contained in the earth or water of our planet.

In the long-term, carbon sequestration could play a significant role. In fact, low-cost carbon sequestration techniques could enable the nation's continued reliance on its vast fossil fuels resources for large-scale energy production. It could allow greater flexibility in the future primary energy supply. In addition, it could offer other benefits such as the manufacture of commercial products (e.g., construction materials and plastics); improved agricultural practices that could reduce soil erosion, conserve water and increase the sustainability of food production; the restoration of wetlands, which would help preserve wildlife and protect estuaries; increased biodiversity; enhanced recovery of oil and methane (from coal beds); and the development of exportable technologies to help the U.S. economy.

8.7 CROSSCUTTING TECHNOLOGIES

A number of technologies crosscut a wide range of applications that could enable significant energy efficiency gains, facilitate increased use of clean energy, and reduce the costs of sequestering carbon. Advancing these crosscutting technologies integrates the pull of technology with the push of basic science.

This subsection describes four crosscutting technology areas: hydrogen and fuel cells; electrical transmission, distribution, and components; sensors and controls; and energy storage. Further details about the RD&D required to advance these technologies are presented in Appendix B of the DOE National Laboratory Directors (1997) report.

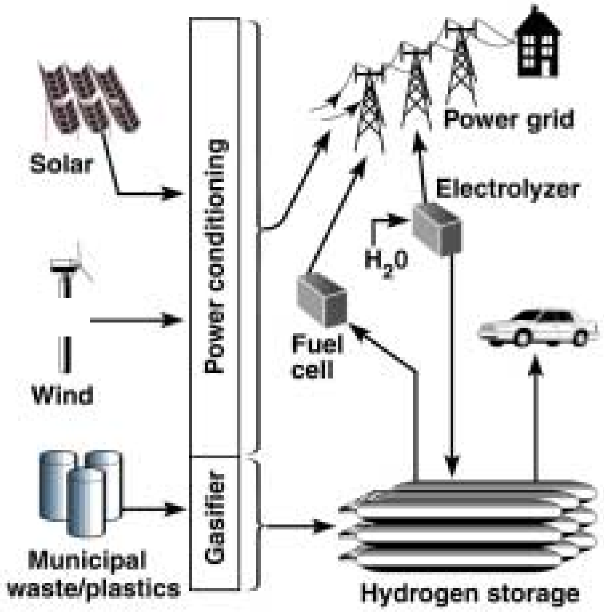
8.7.1 Hydrogen and Fuel Cells

Hydrogen is a carbon-free energy carrier that could be used to energize every aspect of society. For example, it could fuel transportation vehicles (air and ground), provide heat for industrial processes, supply domestic heating needs through cogeneration or heat recovery systems, and fuel power plants for centralized or distributed electrical generation. Integrated systems that combine electricity generation with a hydrogen transportation fuel system could offer significant economies of scale and could accelerate the penetration of renewables into the marketplace (Fig. 8.18).

Hydrogen is an energy carrier that must be produced efficiently from a primary energy source. Depending on the source, its production may or may not involve CO_2 emissions. When hydrogen is produced from carbon-containing primary energy sources, CO_2 appears as a concentrated byproduct; subsequent sequestration could result in low emissions of CO_2 depending on the amount of fossil energy used in the hydrogen production process. Hydrogen from biomass or solid wastes could result in very low CO_2 emissions, depending on the amount of fossil fuel used for fertilization, cultivation, and transportation of the bioenergy feedstock. Zero-carbon dioxide hydrogen production concepts include:

- electricity converted to hydrogen by electrolysis of water, and
- photoelectrochemical and photosynthesis-based processes for producing hydrogen from water.

Fig. 8.18 An Integrated Hydrogen Fuel Cell System



Source: DOE National Laboratory Directors, 1997, p.3-10.

Before hydrogen can be a major energy carrier, infrastructure must be greatly improved (e.g., storage technologies and distribution systems). Advanced storage concepts include metal hydrides, carbon adsorption, and carbon nano-tube encapsulation. Many of the more promising concepts are still in the basic research stage. Distribution systems would also have to be deployed that are capable of containing and pumping the low molecular weight fuel, and resisting embrittlement.

Hydrogen could be used in modified conventional combustion energy conversion devices (e.g., engines) to ease the transition to a completely new energy infrastructure where hydrogen would be used in fuel cells for energy conversion. Fuel cells promise potentially higher system efficiency and solid-state operation with water as the only effluent.

Fuel cells convert chemical energy directly into electrical energy; no combustion is involved. Operating on hydrogen, a fuel cell does not emit CO_2 and is projected to be up to two times as efficient as other advanced power generation technologies. A highly efficient end-use/conversion device such as a fuel cell would be necessary to offset the energy penalty associated with producing hydrogen and to achieve the full benefits of a transition to a hydrogen economy.

A fuel cell power plant typically consists of three main parts:

- a fuel processor that converts a fuel (e.g., natural gas, diesel fuel, ethanol, methanol, gasoline) to a hydrogen-rich gas,
- the fuel cell stack system that converts hydrogen into direct-current (dc) electricity, and
- a power conditioner that converts the dc electricity to regulated alternating-current (ac) electricity.

Fuel cells span all important energy use sectors. They are commonly classified according to the type of electrolyte employed. Molten carbonate and phosphoric acid fuel cells target power generation, both large-scale and distributed power production. Solid-oxide fuel cells are mostly considered for stationary application. Proton exchange membrane fuel cells target transportation as well as distributed power applications. Along with electricity, fuel cells produce heat, which could be used directly or, if the temperature is high enough, as input to a bottoming cycle to produce additional electricity. In the long run, hydrogen could become the world's principal energy carrier. It provides energy security because it could be produced efficiently from numerous domestic sources. It can be stored, thereby eliminating the drawbacks of intermittent renewable electric technologies. In addition, it could be transported by pipeline from remote renewable resource locations to load centers.

A hydrogen energy system would allow a gradual transition from fossil fuels to non-carbon primary energy sources while reducing CO_2 and other emissions. At full market penetration, all conventional use of fossil fuels would be replaced by hydrogen derived from renewable or carbon-sequestered fossil-fuel sources. Before hydrogen could achieve this premiere status in the energy economy, however, significant advances would be required in hydrogen production, storage and distribution technologies, and in the performance and cost of fuel cells and carbon sequestration.

8.7.2 Transmission and Distribution Technologies

Many proposed clean energy technologies involve alternative ways of producing electricity. In most cases, the U.S. electric transmission and distribution system is the means by which these alternative approaches could be made available to energy users. Almost 40% of the capital investment currently required to produce and deliver electricity goes to construct transmission and distribution facilities. The availability of reasonably priced transmission capacity will be crucial to the commercial success of alternative generation strategies. This is particularly a concern for large-scale development of remote renewable resources such as geothermal and wind power, which often require significant investments in new transmission capacity because of the distances between the best resource areas and load centers. At the same time, public opposition to the construction of conventional transmission lines for environmental reasons has focused attention on opportunities for increasing the capacity of existing corridors, as well as on development of transmission technologies that are compatible with public concerns and therefore present a minimum of permitting risk. In addition, the importance of other collateral benefits of these technologies cannot be overlooked, especially their contribution to improving power quality and reliability.

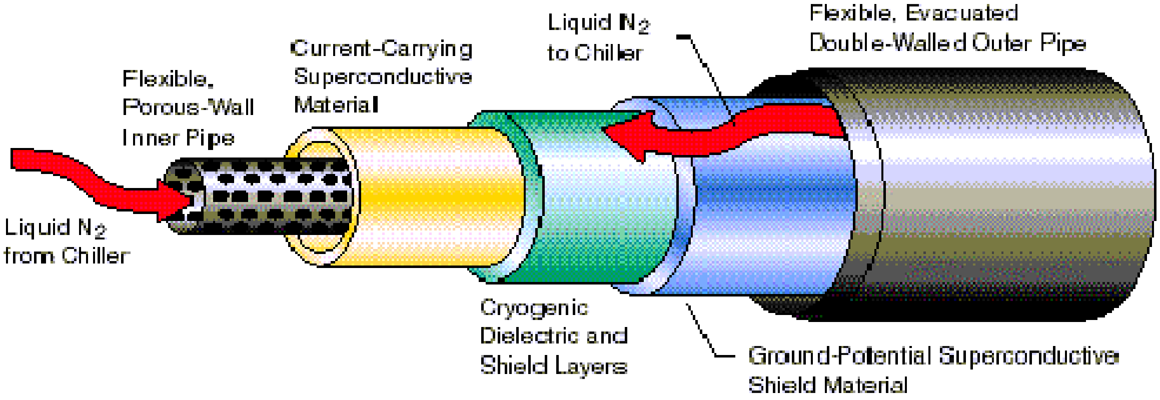
R&D would be needed on automated system control technologies that better use the capacity of existing systems, as well as advanced composite-reinforced high-strength overhead line conductors to increase the capacity of individual lines. Developments in power electronics – including wide-bandgap semiconductors for high-power switching devices and advanced converter designs – would be needed to improve power management on existing systems and to enable high-voltage DC transmission for long-distance power transfers.

Electric power has two characteristics that make it a unique commodity. First, because there are essentially no commercially viable, large-scale and inexpensive energy storage options (although this gap may be filled in the future – see Section 8.7.4), aggregate production and consumption must be balanced essentially instantaneously. Second, it is inordinately expensive to control the power flow over individual lines, power flows are dictated by generator and load locations and the impedances of the interconnecting lines. Power electronics hold the promise of dramatically changing the nature of the electric power industry if they can lower the cost of line flow control. This would greatly increase the transmission system utilization and reduce the need for additional transmission lines.

Seven and one-half percent of electricity generated in the United States each year is currently lost due to the resistance of copper and aluminum wire. By the middle of the 21st century, the electricity superhighway could be dominated by high-temperature superconducting (HTS) wires in cables (Fig.

8.19), transformers, and current controllers. Superconductors, which have nearly zero resistance, could make available most of the energy that is currently lost in distribution, without requiring any additional fossil fuel use or generating capacity. In addition to reducing electricity losses, HTS materials could strengthen the reliability of the U.S. electricity infrastructure, eliminate hazardous materials from electrical systems, and create thousands of new high-technology domestic jobs. Research is needed to scale up second-generation HTS "coated conductors" to lengths for use in power equipment.

Fig. 8.19 Cross-Sectional View of Cold Dielectric Design of High-Temperature Superconducting Cable



8.7.3 Sensors and Controls

Sensors and controls could play a significant role in enabling many technological pathways to a clean energy future. By maximizing system efficiencies at minimal cost, sensors and controls have a broad range of potential applications.

Some of the key attributes of future sensor technologies will likely be the integration of transduction, signal conversion, information abstraction and telecommunication on a single chip and an ability to adapt to changing system requirements. The combination of scalability and decreasing cost with increasing functionality that has been evidenced in semiconductor devices will likely prevail in sensor technologies as well. Revolutionary advances could take place in materials for sensors and integrated circuits that would allow devices to become more robust in harsh operating conditions and facilitate a paradigm shift in how sensors are employed (measuring from the inside and communicating out, rather than attached to the outside looking in). The integration of biological molecules and systems with emerging solid state device technologies foretells of the advent of molecular electronics and nano-technology systems with practical use. All types of sensors and sensor/actuator systems could have the potential for integration in systems where the sensor itself becomes a node on a potentially vast distributed network. In such systems, the sensors would be essentially free, and the information would become the commodity for sale.

Many of these technologies are emerging now and engender the excitement that micro-electro-mechanical systems (MEMs) produced some 20 years ago. As MEMs evolve they could play an important role as the transducer or actuator in many integrated systems. In addition to electro-mechanical integration on a miniature scale, chemo-electro-mechanical and bio-electro-mechanical devices could emerge and play a key role in many process and environmental measurement applications.

With the advent of carbon-fullerene micro-spheres and now carbon nano-tubes, we see the never-ending push toward assembling system atom-by-atom or certainly molecule-by-molecule. Tailored materials, at the atomic scale, are a critical element of the ultimate sensor system construct wherein machines become self-aware through the use of massively-distributed sensor networks that possess sufficient embedded intelligence to perform cognitive tasks in relation to mission requirements, their operating environment, and their own ability to perform within the mission context.

Numerous specific energy applications for advanced sensors and controls are already becoming a reality, while many others are envisioned for the future. For example, chemical sensors capable of operation in boreholes could improve fossil fuel recovery. Both refining processes and fossil fuel reforming for CO_2 sequestration at the wellhead require substantial chemical processing that could be enhanced through real-time process sensors and controls. Sensors and controls that more accurately measure operational parameters could also be used to increase the output of nuclear power plants. Improved sensors and controls also allow operation closer to theoretical materials and process limits, which improves efficiency in processes such as fossil-fired power generation.

In the area of energy efficiency, novel sensors would be needed in the transportation sector to enable the use of more efficient engine technologies. Oxygen, NO_x, and knock sensors and engine control technologies would be necessary to optimize the various lean-burn internal combustion engines, compression-ignited/direct-injection engines, and diesel engines being developed. Pattern recognition, artificial intelligence, fuzzy logic, and other enabling technologies for real time data analysis and “sensor fusion” would also be needed. Almost all industrial processes depend on sensors and controls to ensure the quality of goods produced, and advanced sensors could help to reduce wasted energy, CO_2 emissions, and other pollutants. Across the industrial arena, sensors would be needed that could be used in harsh environments and that would measure such on-line process parameters as viscosity, moisture, chemical composition, density, flow, temperature, and pressure. The next half century could witness the close integration of sensors and microtechnologies that could use “smart controllers” to provide real-time on-line process control to improve productivity and decrease energy requirements.

In carbon sequestration, innovative sensors for analyzing photochemical processes and carbon fixation would be needed. The same family of sensors could be used to increase the production of energy crops.

Often a single fundamental sensor technology would meet the needs of different applications, so sensors are a true crosscutting technology. An excellent example of this is the solid-state oxygen sensor developed for the space program in the 1960s. This sensor is now universally used in gasoline engine control and is common in industrial combustion control, touching virtually every major energy-consuming industry. A large variety of novel sensor technologies that are robust, fast, inexpensive, wireless, miniature, and capable of supporting real-time control could be available and widely used by 2050. It is possible that the next half-century would produce a new generation of techniques for fabricating electronic devices that would allow unprecedented miniaturization of sensors and associated electronic controls.

8.7.4 Energy Storage

Stationary energy storage is now primarily in the form of bulk storage of fossil fuels (piles of coal, oil in tanks, gas in pipelines) and water in reservoirs. Reversible energy storage technologies in use today include pumped hydropower, compressed air, and chemical batteries for small uninterruptible power. Advanced storage technologies under active development include processes that are mechanical (flywheels, pneumatic), electrochemical (advanced batteries, reversible fuel cells, hydrogen), and purely electrical (ultracapacitors, superconducting magnetic storage). The major hurdle for all storage technologies is cost reduction.

Advanced energy storage concepts could improve system efficiencies and reduce carbon emissions in most sectors of the economy.

- **Power:** The efficiency of a typical steam plant falls from about 38% at peak load to 28–31% range at night. In the future, utilities could store electrical energy at off-peak times, allowing power plants to operate near peak efficiency. The stored energy would be used during peak demand times. CO_2 emissions would be reduced if the efficiency of the energy storage were greater than 85%. Battery use for peaking could also lessen the need for lower-efficiency peaking units by charging with higher efficiency units during low demand, but the net emissions depend on the relative cleanliness of the two. Battery-powered electric vehicles could serve as a distributed off-peak energy storage system, but higher turn-around efficiency than the 70% of lead-acid batteries is needed. In the long term, as demand grows, renewable sources could be added to the grid that could use storage to achieve dispatchable power for peaking, to improve power quality, and to more fully utilize the connecting transmission system.
- **Vehicles:** Energy storage in automotive electric and hybrid drive trains allows regenerative braking, which can reduce fuel consumption by 25% on the urban driving cycle. Additional optimization of engine size in hybrids to allow better average-power matching could improve total powertrain efficiency by a factor of 2 over existing automobiles. Energy storage and power density for automotive applications must be lightweight and have high cycle life (100,000s of cycles). Bus and delivery heavy-duty vehicles could also benefit from hybrid powertrains, although the improvement is not likely to be as great as for automobiles.
- **Home cogeneration:** Small amounts of energy storage could be a pathway to commercially viable home cogeneration using solid oxide fuel cells or optimized engines coupled to small generators that are fueled with natural gas. Storage of a few kilowatt-hours with power output of 5–10 kW would reduce the start-stop cycles on the fuel-to-electricity converter, lower the size of generator needed, and improve the efficiency of the overall system. Waste heat from the converter would be used for space heating and domestic hot water. Such systems could use 70–90% of the fuel energy, depending on seasonal heating requirements. If the fuel converter had greater efficiency than central power plants along with their transmission losses, these systems could be connected to the grid to carry out distributed power peaking.

In transportation, hybrid powertrains that use batteries, flywheels, or ultracapacitors in conjunction with engines allow the reduction of engine size. A hybrid powertrain could increase overall efficiency by up to 100% without a loss in vehicle performance (acceleration, range, and passenger capacity). Advanced energy storage could enable electric utilities to shift generation to off-peak periods and to better use intermittent renewable energy sources, such as solar PVs and wind, that produce no direct CO_2.

8.8 CONCLUSIONS

A consideration of the longer term makes clear the tremendous variety of possibilities that exist for energy futures. The discussion of energy technologies under development in this chapter gives a sense of the many different technological opportunities that could alter these futures. It is of course not possible to know which of the infinite number of possible energy futures will happen.

In spite of the many uncertainties about the future and the richness of choice that will exist over time, there are several observations that appear highly likely. The first, and probably most important, is the increasingly dominant role that developing nations will play in world energy markets. In all of the IPCC "marker" scenarios – and indeed in all the major energy scenarios developed by international energy analysts (Nakicenovic, et al, 2000) – a very high percentage of energy demand growth takes place in the developing world. As we noted earlier, three of the four IPCC "marker" scenarios showed that 90% or more of the increase in energy demand will occur in developing countries between the present and 2050, and the fourth showed more than 75%.

This does not mean that the industrialized world need not be concerned about energy demand, since such a large portion of the growth will be in developing countries. Quite the contrary: most opportunities for developing and applying clean energy technologies will likely occur first in industrialized countries.

A second important observation from this chapter is the tremendous richness of opportunities to improve the global energy future over the longer term. There are numerous technologies that could make a huge difference in the environmental impacts of energy production, transmission, and distribution; avoiding future stresses on the energy system by much higher efficiency of energy end-use; and in reducing direct economic as well as environmental and social costs of energy use.

Thus, there appear to be two important lessons from this chapter that provide a broader perspective to the CEF results for the United States:

- R&D on advanced energy systems has the potential to lead to important new technologies; such technologies can provide enormous benefits to society, especially in the longer term, and
- This R&D should be done with an eye to applications in the developing world, since a very large portion of energy demand growth is highly likely to occur in these developing regions.

Given the uncertainties in global economic trends, demographics and lifestyles, air quality, and climates, an expanded R&D effort in most energy technology arenas would appear to be warranted. There is a broad range of longer-term technology options which, with successful research, could provide additional solutions to the energy-related problems facing the nation and the world.

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