

Chapter 2

INTRODUCTION AND BACKGROUND¹

This chapter begins by describing the climate change rationale for the Clean Energy Future Study. It then describes recent energy and CO₂ emission trends in the United States (Section 2.2), so that the CEF scenarios can be placed into an historical context. Section 2.3 characterizes and explains the nation's energy efficiency gap. The market and institutional barriers that cause this gap, along with the existence of external costs and benefits, provide the rationale for the public policies and programs that are modeled in subsequent chapters. This rationale is explained in Section 2.4. The organization of the full report is then summarized (Section 2.5).

2.1 THE STUDY'S CLIMATE CHANGE RATIONALE

The principal goal of this study is to produce fully documented scenarios that assess how well public policies and programs can foster and promote efficient and clean energy technologies to meet the energy-related challenges facing the nation while also enabling economic growth. While multiple challenges are addressed, *Scenarios for a Clean Energy Future* concentrates primarily upon the challenge of global warming.

According to a recent report of the Intergovernmental Panel on Climate Change (IPCC), the earth's surface temperature has increased about 0.2°C per decade since 1975. Further, "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 Box 2.1). 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 (CO₂), methane (CH₄), ozone (O₃), nitrous oxide (N₂O), water vapor (H₂O), and a host of engineered chemicals such as chlorofluorocarbons (CFCs). 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 1998, Table ES2, p. x) (Fig. 2.1).

2.1.1 The Role of Carbon Dioxide

CO₂ accounts for a majority of recent increases in the heat-trapping capacity of the atmosphere, with worldwide atmospheric concentrations of CO₂ increasing at about 0.5% annually. Anthropogenic CO₂ has resulted in atmospheric CO₂ concentrations that exceed preindustrial levels by 30%.

Energy-efficient, renewable-energy, and other low-carbon technologies reduce CO₂ emissions by

Box 2.1

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 pattern 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.*"

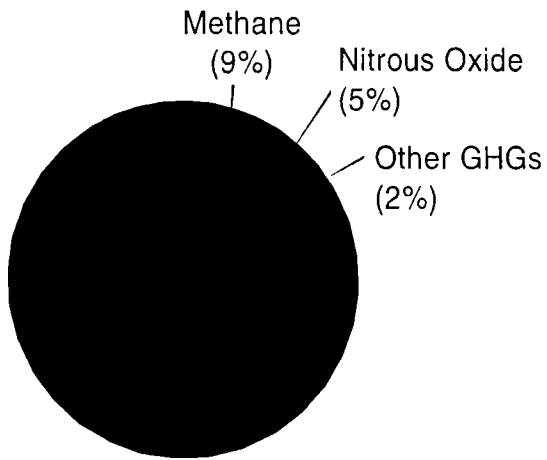
— From the Intergovernmental Panel on Climate Change (IPCC, 1996, p. 5). *Italics added for emphasis.*

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displacing the need for fossil fuel combustion. As a result, this report describes the greenhouse gas reduction benefits of its scenarios principally in terms of carbon emission reductions.

Fig. 2.1 Greenhouse Gas Emissions in the United States in 1997

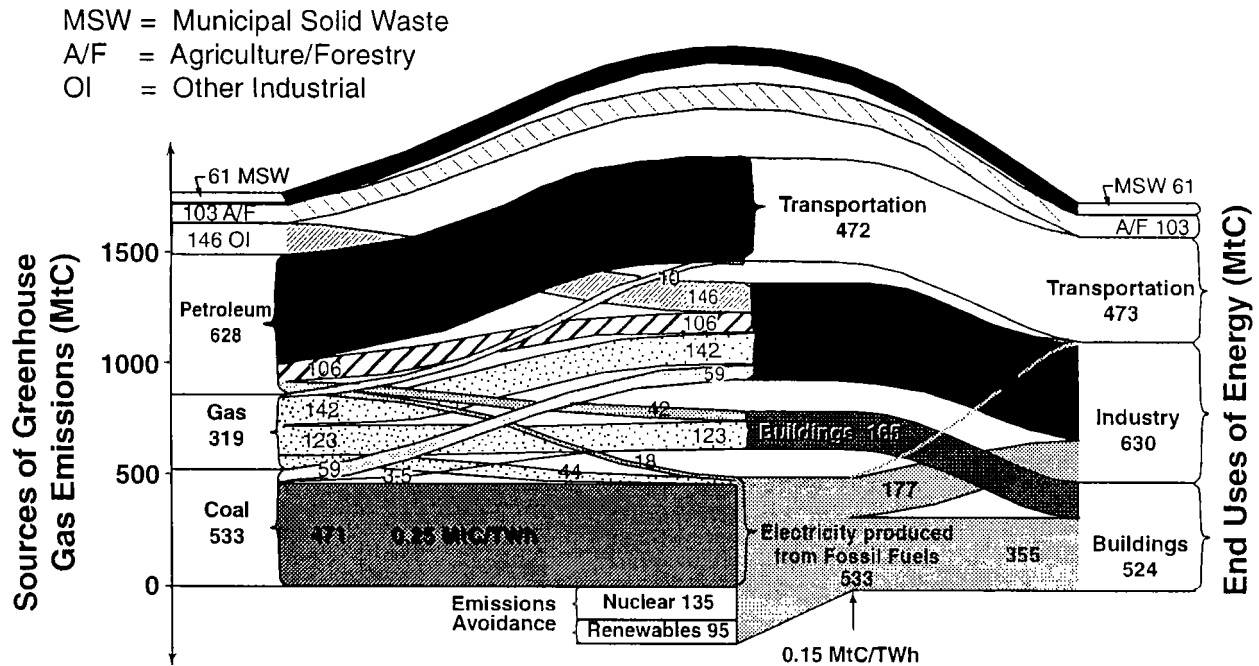
(Source: EIA, 1998b, Table ES2, p. x)



In 1997, human activities in the United States resulted in CO₂ emissions totaling about 1480 million metric tons of carbon (MtC). Emissions of other greenhouse gases in that year were equivalent to another 290 MtC, bringing total emissions in 1997 to 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.

The stimulus for this study derives from a growing recognition that the nation's ability to respond to international calls to reduce the growth of greenhouse gas emissions is dependent on its ability to transform its sources and uses of energy. 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. Carbon sequestration could also be an important tool for reducing atmospheric concentrations of CO₂.

Figure 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)



Such changes have the potential to affect the very fabric of society through their impacts on key sectors—including buildings, industry, transportation, and electricity production (Fig. 2.3).

2.1.2 Carbon Sequestration and Adaptation Options

Given the magnitude of carbon emission reductions needed to stabilize atmospheric CO₂ concentrations, multiple approaches to carbon management will be needed (see Box 2.2). Energy efficiency improvements and the use of lower-carbon (i.e., “clean”) energy are the principal approaches assessed in this report. There are also various ways of removing CO₂ from the atmosphere and storing it or keeping anthropogenic carbon emissions from reaching the atmosphere by capturing and diverting them to secure storage.

Most approaches to “carbon sequestration” will require considerable research to ensure their successful development and acceptance. However, in the long-term, they could play significant roles. In fact, if the demand for energy continues to increase, it is possible that the only way fossil fuels can be used for large-scale energy production will be in conjunction with methods to capture and sequester carbon. We describe carbon sequestration options in more detail in the discussion of future energy R&D in Chapter 8.

Adaptation pathways are also available. 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.

As with most approaches to carbon sequestration, adaptation approaches will require significant R&D. Some of the adaptation pathways that have been discussed to date include:

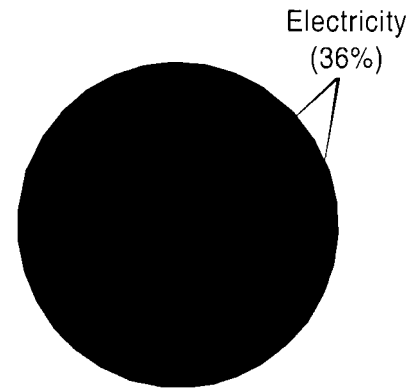
- geoengineering to reduce climate change without reducing emissions (e.g., orbiting reflecting panels, changing the path of the Gulf Stream),
- geoengineering to mitigate climate change impacts (e.g., accelerating the adaptation of natural biosystems, genetic engineering of crops and forests, long-distance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

Further evaluation of these non-energy options is well beyond the scope of this study.

2.1.3 Other Greenhouse Gas Emissions

Although non-CO₂ industrial emissions of greenhouse gases are small by weight, they have 100-year global warming potentials (GWPs) that range from 21 for methane to 23,900 for sulfur hexafluoride

Figure 2.3 CO₂ Emissions in the United States, by Source, in 1997
(Source: EIA, 1998b)



Box 2.2 Options for Addressing Global Climate Change

Reducing Atmospheric Carbon

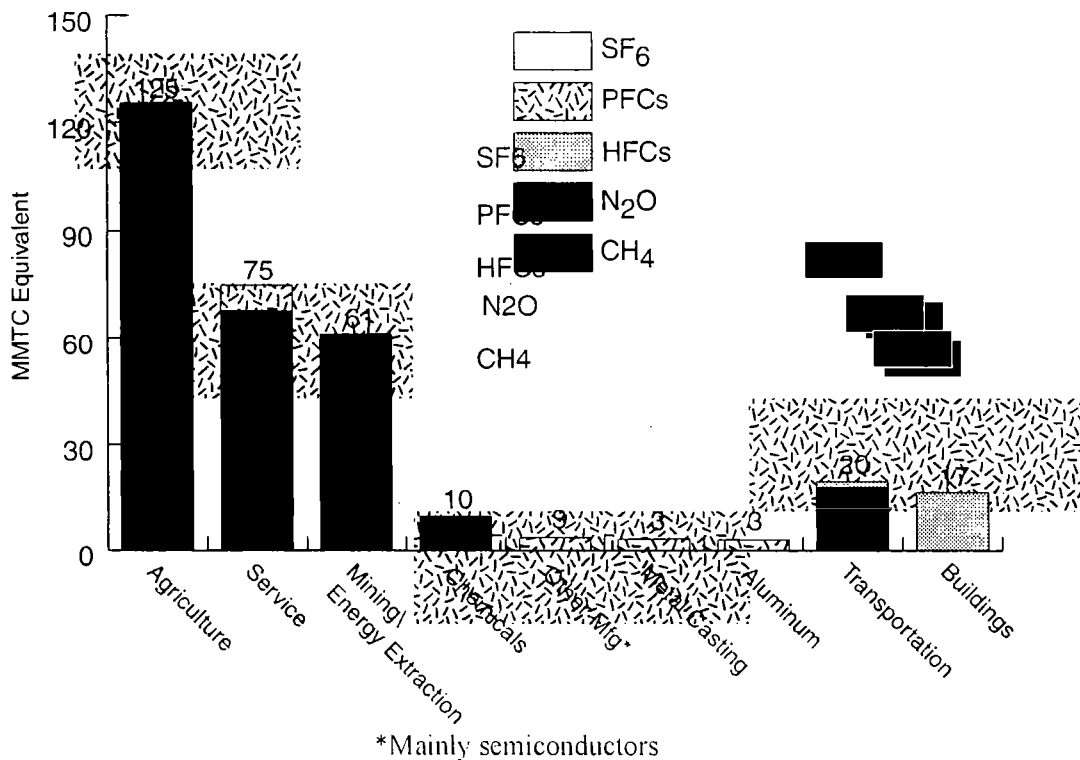
- Energy efficiency
- Clean energy
- Carbon sequestration
 - Sequestration of atmospheric carbon
 - Sequestration of separated carbon (pre- or post-combustion)

Adapting to Global Climate Change

- Geo-engineering approaches
- Strengthening physical, information, and institutional infrastructures

(SF₆). Carbon dioxide has a GWP of one by definition. Fig. 2.4 shows the relative contribution of these other gases in MtC equivalent. The largest non-CO₂ greenhouse gas contribution is from methane (CH₄), which is responsible for the equivalent of 179 MtC. Next is nitrous oxide (N₂O), which is responsible for 104 MtC equivalent and has a GWP of 310. Various halocarbons and other engineered chemicals (i.e., HFCs, PFCs, and SF₆) contributed 35 MtC equivalent in 1996. The rapidly growing emissions of these engineered chemicals is a source of concern. HFCs, PFCs, and SF₆ have increased from 22 in 1990 to 35 in 1996 (EPA, 1998b). Note also that many of these emissions are seen not only in energy-intensive industries but also in “high-tech” and service industries, as shown in Fig. 2.4.

Figure 2.4 Emissions of Non-CO₂ Greenhouse Gases by End-Use Sector and Industry
(Sources: EIA (1998b) Tables 15, 25, and 30, and pp. 54-56, and EPA (1998b) Table ES-9)



This report does not conduct original research on the potential for reducing non-CO₂ 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 the recent studies on the costs of reductions for both the U.S. and other countries. This review suggests that a reduction in non-CO₂ emissions of approximately 90 MMTCE 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. Hayhoe, et al. (1999) come to the same conclusion.

By documenting the benefits that efficient and clean energy technologies can deliver in the short term and by describing the additional potential of emerging technologies, this report informs a broad range of readers among the public and in government about policy-driven, technology-based approaches to reducing greenhouse gas emissions and addressing other fossil energy-related challenges.

2.1.4 The Kyoto Protocol

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 baseline levels (1990 and 1995, depending on the gas). The time frame for meeting the agreement's goals was set at 2008-2012. The U.S. agreed to a 7% reduction, which must be ratified by the U.S. Senate prior to implementation. However, 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. is at most 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. Assessments of such "off shore" sources of greenhouse gas reductions are not examined in this study, although a sidebar provides a discussion of this option, for context. Instead, this report focuses strictly on domestic opportunities for carbon reductions. It 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.

Reducing domestic CO₂ emissions back to 1990 levels over the next decade would require a major national effort. Between 1990 and 2010, the U.S. is forecast to increase its CO₂ emissions by more than 30%, reflecting the projected strong growth in GDP and the expectation of only a modest rise in energy prices. Within this context, a "full court press" would be needed to improve the performance of low-carbon and efficient technologies, and various incentives, codes, standards, and information programs would be needed to motivate Americans to purchase them. Thus, this report's analysis of alternative policies and programs is timely. A great deal of research is required to identify "smart" policies – policies that are flexible, efficient, and feasible. These policies also should be mindful of the longer-term goal of stabilizing atmospheric concentrations of greenhouse gases and the need to simultaneously contribute to solving the many other energy and environmental challenges facing the nation.

2.1.5 Stabilizing Atmospheric Concentrations

A global effort will be needed 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 (CO₂) 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) predicts in its 1995 "business-as-usual" energy scenario that future global emissions of CO₂ to the atmosphere will increase from 7.4 billion tonnes of carbon (GtC) per year in 1997 to approximately 26 GtC/year by 2100. IPCC also projects a doubling of atmospheric CO₂ concentration by the middle of next century and growing rates of increase beyond. Although the effects of increased CO₂ levels on global climate are uncertain, many scientists agree that a doubling of atmospheric CO₂ concentrations could have a variety of serious environmental consequences.

2.2 HISTORICAL ENERGY AND CO₂ 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% increase in GDP meant a 3% 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 quads.

The inextricable connection between energy and economic growth came to an abrupt end with the Arab 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 and other fluctuations, but it averaged about 74 quads.² Relative to previous decades, it was an 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. 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.

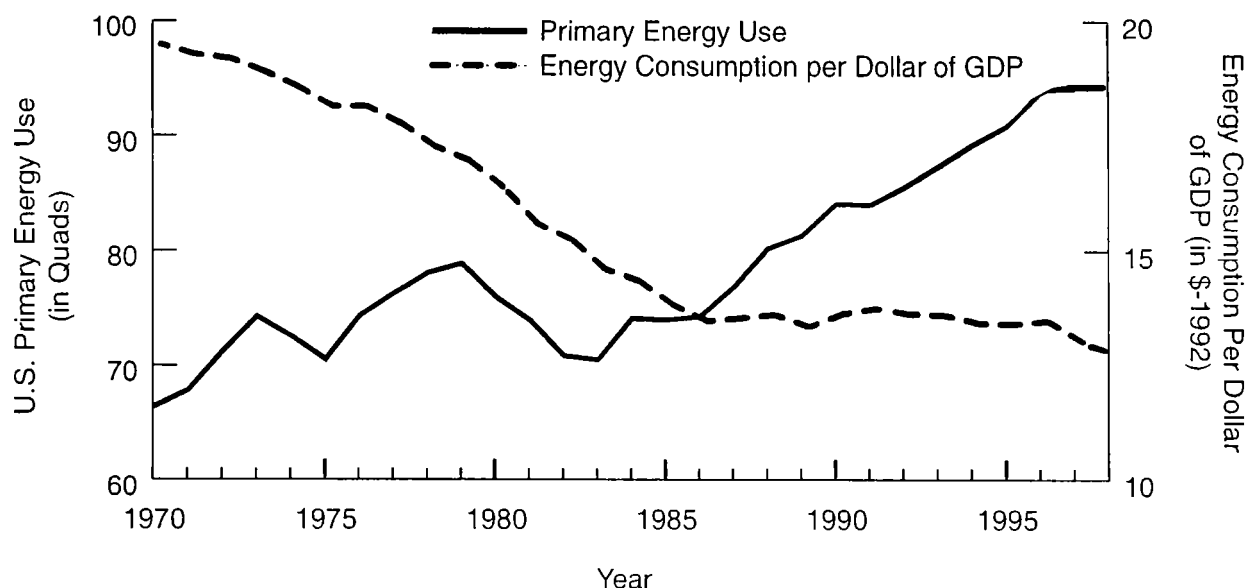
Fully two-thirds of the freeze in energy use during this period was due to increases in energy efficiency while one-third was due to structural changes such as declines in energy-intensive industry and increases in the service sector (U.S. Department of Energy, 1995). These energy efficiency improvements 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 energy savings (Hirst, Marlay, Greene, and Barnes, 1983).

The gains in energy productivity achieved by the U.S. 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 for 13 years. A reversal of U.S. energy growth over a similar time frame will be required to meet the Kyoto Protocol's U.S. goals. Yet the inducement of high energy prices no longer exists, and government energy RD&D has been scaled back.

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

² Primary energy use is the chemical energy embodied in fossil fuels (coal, oil and natural gas) or biomass, the potential energy of a water reservoir, the electromagnetic energy of solar radiation, and other renewable resources, and the energy released in nuclear reactors. For the most part, primary energy is transformed into electricity or fuels such as gasoline, jet fuel, heating oil or charcoal-called secondary energy. The end-use sectors of the energy system provide energy services such as cooking, illumination, comfortable indoor climate, refrigerated storage, transportation and consumer goods using both primary and secondary energy (National Academy of Sciences, 1992, p. 3)



Starting in 1986, the nation has benefited from declining energy prices—a trend that has continued to the present. Some of this price decline has resulted from the deregulation of energy markets. It has also resulted from public- and private-sector R&D, which has led to steady improvements in energy exploration and production technologies.

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. Throughout the 1990s the EERE appropriations have averaged approximately \$800 million per year (in \$1995).

These declining energy prices and R&D expenditures have caused energy demand to grow in lockstep with the economy, increasing 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), energy demand is predicted to reach 111 quads in 2010 (EIA, 1999b, p. 148, Table B2). The challenge is to curb this increase in energy demand and reduce the carbon content of the fuels used, while enabling the economy to continue to grow. Such a possibility was illustrated during the 13 years following the Arab oil embargo of 1973-74.

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 and a slowdown in manufacturing output as well as 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	33.7
Industry	31.5	26.6	32.1	34.5	35.7
Transportation	18.6	20.8	22.5	24.1	24.8
Total	74.3	74.3	84.1	90.9	94.2
Total carbon emissions from energy (in MtC)	1260	1240	1346	1424	1480

Sources: EIA (1998a, Table 1.1, p. 5 and Table 2.1, p. 37).

Carbon emissions estimates for 1990 and 1997 are from EIA (1998b, p. 16), and for 1995 are from EIA (1996, Table A19, p. 120). Carbon emission estimates for 1973 and 1986 were derived using factors for carbon emissions from combustion of oil, natural gas, and coal for 1990.

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

Energy Use:	Change from 1973 to 1997:		Change from 1990 to 1997:	
	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

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 growth in buildings and transportation has been relatively steady, at 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 has been much more volatile during the period, showing substantial declines during the years of rising prices (a negative 1.3% annual growth from 1973 through 1986), an increase of 4.8% per year from 1986 to 1990, and relatively small annual increases since then, reflecting flat or falling prices.

Table 2.3 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 EFFICIENCY PARADOX

Numerous engineering-economic studies have identified a plethora of 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” analyses³ 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, then why doesn't more of it happen without policies? If individuals or businesses can make money from energy efficiency, then why don't they all just do so? Assuming the empirical data show that truly cost-effective and efficient technologies are not accepted, 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 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.

The following sections provide evidence that sizeable cost-effective opportunities for energy efficiency improvements permeate the economy. First we look at sector-specific evidence. Next we provide individual technology case studies that present compelling evidence of an efficiency gap. Then we describe a range of market and institutional barriers that explain the existence of this gap.

2.3.1 Sector-Specific Evidence

³ 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).

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 energy-efficiency is discouraged because investments that increase output are preferred to those that reduce operating costs (Ross, 1990). 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 accepted 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.

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 low initial cost. 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).

The end-use sectors also differ in terms of their ability to respond to changing energy prices. The transportation and residential sectors can respond relatively quickly to price spikes, because people can drive less and adjust thermostat settings. But transportation is relatively fuel-inflexible, being primarily dependent on petroleum, while portions of the buildings and industrial sectors have somewhat greater fuel flexibility.

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 greenhouse gas emissions, since most of the energy consumed in buildings comes from burning fossil fuels.

2.3.2 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). (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 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.

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.

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. 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.

2.3.3 What Accounts for Efficiency Gaps?

The existence of a range of market and institutional barriers helps to explain the efficiency gap. Some of these barriers are market failures, which occur when there is a flaw in the way markets operate, leading consumers and/or producers to respond to the wrong price signals. Such failures include situations where decision-makers have insufficient or incorrect information, where there is an asymmetry between the decision-maker and the person paying the energy bills, or where there are unpriced effects such as air pollution (Faffe and Stavins, 1994; Jacoby, 1998).

Other barriers to energy efficiency include a variety of non-market failures that 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 pollutants from fossil fuel combustion, it is important to understand the full range of barriers. The following generic barriers are discussed below: (1) incorrect price signals, (2) imperfect information, (3) capital market imperfections, (4) lack of availability of energy-efficient features or products, and (5) high transaction

costs. Many of these are discussed. These, and other sector-specific barriers are discussed in subsequent chapters.

Low energy prices mean long payback periods for many energy-efficient products. As a result, energy efficiency is not a high priority for most consumers, and producers have little interest in producing energy-efficient products for which there is limited demand. Because energy prices do not include the full cost of environmental externalities, they understate the societal cost of energy. There is little disagreement about these statements in principle; at the same time, there is considerable disagreement about the magnitude of external costs that should be incorporated into energy prices.

There are many different types of **information failures** that can account for misplaced incentives and suboptimal investments in energy efficiency. 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.

Decision-making difficulties often lead to purchases that minimize first costs rather than minimizing life cycle costs. 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. For this reason, 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. 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.

It can be argued that the lack of information and explicit consumer choices is a consequence of consumer disinterest in energy efficiency. This disinterest, in turn, is a function of low energy prices.

An example of an anomaly in capital markets that has a large effect on energy efficiency choice is that energy suppliers evaluate investments using a much lower discount rate than consumers (i.e., the **discount rate gap**). Electric and gas utilities are able to borrow money at a real cost of capital of about 6%. (This is an historical average for the electric utility industry; it is likely to rise with deregulation.) The market for energy efficiency, determined by the decisions of millions of individual investors, operates at much higher discount rates. Indeed, in most cases the decision on efficiency choice is made with a discount rate several multiples of the utility cost of capital (Hausman, 1979; Ruderman et al. 1987; Ross, 1990). This finding generally applies to residential, commercial, and industrial consumers. The height of these hurdle discount rates reflects past information gaps, institutional barriers, short time horizons, and non-separability of energy equipment, all of which are subject to policy intervention which could move the rates down towards normal auto-loan, mortgage, and opportunity costs.

Availability of energy efficiency is often a serious dilemma. Energy efficiency is generally purchased as an attribute of a product intended to provide some 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 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).

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. The 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. Appliance standards, by eliminating new refrigerators that are inefficient, removes these transaction costs. Similarly, for many years managers of commercial buildings were unwilling to pay the costs required to gain confidence in advanced lighting technologies that would save money and provide high-quality environment. Utility demand-side management programs in many regions demonstrated the value of these products and led to their widespread acceptance (Levine and Sonnenblick, 1994).

2.4 THE RATIONALE FOR PUBLIC POLICIES AND PROGRAMS

The existence of market failures that inhibit socially optimal levels of investment in energy efficiency is the primary reason for considering public policy interventions. If a feasible, low-cost policy can be implemented that address these failures, markets will operate more efficiently and society will benefit. Government promotion of clean energy supply technologies is based principally on the existence of external costs and benefits, a particular type of market imperfection. The following section describes this rationale. Examples of a range of successful government policies and programs are then provided.

2.4.1 Externalities and Public Goods

Many of the nation's energy and environmental challenges are related to the existence of externalities and public goods. These conditions lead to market imperfections that may justify public intervention.

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."

The consumption of fossil energy using today's conversion technologies produces a variety of negative externalities including greenhouse gas emissions from fossil fuel use; air, water, and land pollution associated with the discovery, extraction, processing, and distribution of fuels and power; and oil supply vulnerabilities associated with the uneven geographic distribution of petroleum resources. As a result, more negative byproducts of energy use are produced than is socially optimal. Public intervention is needed to correct these market imperfections.

An additional rationale for government support of R&D on efficient and clean energy alternatives is based on the public goods nature of research. R&D activities often result in benefits that cannot be captured by private entities. Although benefits might accrue to society at large, no single firm can realize enough economic gain to justify the costs. Further, companies that absorb the market risk of introducing

new technologies are generally unable to reap the full benefits of their trailblazing. 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 recent Council of Economic Advisers report (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.

As a result of this "public goods" problem and other trends, industry's priorities are shifting 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 more than \$100 billion per year on all types of RD&D. The top 20 companies in terms of these investments all have RD&D budgets exceeding \$1 billion per year. These expenditures dwarf the U.S. government's energy-related RD&D appropriations. If climate change mitigation policies reoriented even a tiny fraction of this private-sector expenditure and capability, 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.

2.4.2 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;
- market transformation and government procurement 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 a total of about \$8 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 has revised and updated the estimated benefits accruing from five technologies that were developed with DOE support. Altogether, these five public-private RD&D partnerships alone have resulted in annualized consumer cost savings of \$3 billion in 1996 (i.e., energy bill savings in 1996 minus the annualized cost premiums for better equipment) and annual greenhouse gas emissions reductions equivalent to 16 million metric tons of carbon (Table 2.4). Additional case studies and benefits of R&D and deployment programs are documented in Brown et al (1999), Geller and Thorne (1999), Geller and McGaraghan (1996), and DOE/SEAB (1995). The

accomplishments of the Energy Star and Green Lights programs of EPA's Climate Protection Division are described in EPA (1999).

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

^aSavings 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.

It is important to note that DOE does not take full credit for the entire stream of benefits produced by these successes. Most of these accomplishments have involved public-private 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.

Evidence of cost-effective public-private R&D collaborations in the industrial sector is provided in a recent publication (U.S. Department of Energy, 1999). For more than 15 years, DOE's Office of Industrial Technologies (OIT) has assessed the progress of the technologies supported by its research programs. Energy savings associated with specific technologies are estimated by the Pacific Northwest National Laboratory (PNNL) through a rigorous process of data tracking and management. Detailed results on each technology application are solicited from technology vendors or users to estimate total energy savings and emissions reductions. Cumulative federal costs for the R&D projects supported by OIT through fiscal year 1997 total \$1.46 billion. Cumulative energy savings from completed and tracked projects add up to approximately 1 quadrillion Btu, representing a cumulative production cost savings of over \$2.12 billion.⁴

Policy successes in the power sector have also been numerous, especially those involving cost-shared public-private RD&D partnerships. Improvements in photovoltaic (PV) manufacturing resulting from such partnerships have contributed to a near quadrupling of PV manufacturing capacity in the United States and have helped maintain U.S. world leadership in PV manufacturing. DOE's research partnerships with the domestic wind industry have led to wind turbine advances that are helping the United States be a leader in technology for one of the world's fastest growing energy source.

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, 1999). 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

⁴ These production cost savings represent the net total value of all energy saved by technologies developed with OIT support plus any non-energy production cost savings, minus the cost to industry of using the technologies (including capital costs and operating/maintenance costs).

Agency (EPA) launched its Energy Star Program. In 1992, manufacturers producing almost all computers and laser printers agreed 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 federal government's Corporate Auto Fuel Economy (CAFE) standards required a doubling of auto fuel economy from 14 to 28 miles per gallon over a decade. Greene (1998) shows that these gains were achieved with technology that appears to have been cost-effective and without sacrifice of auto features or amenities.

The promulgation of national appliance efficiency standards in the late 1980s is another example of government-stimulated efficiency gains. An in-depth analysis of the effects of these standards, as compared to a case in which market forces alone determined the energy efficiency of consumer products, shows a net benefit of standards enacted through 1994 of about \$45 billion evaluated at a 6% real discount rate (Levine et al., 1995). These standards alone have cut projected energy demand growth for residential buildings from 0.5% to 0.1% per year from 1991 to 2000. New standards for residential and commercial buildings now under consideration could yield greater savings yet. Estimates of the costs of the standards, completed prior to their being promulgated, showed them to be highly cost-effective. The one quantitative retrospective study—for refrigerators, the product for which the greatest savings were achieved—showed no measurable impact of the standards on the cost of this product (Greening et al., 1997).

Demand-side management programs operated by Bonneville Power Administration and California's investor-owned utilities in the late 1980's and early 1990's are compelling examples of effective **financing and investment-enabling policies** (Brown and Mihlmester, 1995a and b). Additional examples can be found in the proceedings of the biennial National Energy Program Evaluation Conferences.

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. They also noted that costs and benefits resulting from non-energy ramifications of energy-efficiency projects are often not included in cost/benefit analysis of energy-efficiency projects.

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.

2.5 OVERVIEW OF THE REPORT

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 year 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.
- 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 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, the 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.

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Chapter 3

STUDY METHODOLOGY¹

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 U.S. 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, values, regulation, etc.,
- 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 accuracy 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 meets these requirements by employing a combination of tools and analytical approaches. A scenario-based approach is used to allow an examination of a range of public perceptions of the severity of the global climate change problem. Each scenario includes a package of policies compatible with that public perception.

The central tool employed to analyze the policy set of each scenario is the CEF-NEMS model. This model was derived from the National Energy Modeling System (NEMS) as used by the DOE Energy Information Administration in their recently released *Annual Energy Outlook 1999*. For flexibility in addressing specific policies, additional sector and end-use specific assessment methods and tools have been exercised and their results integrated within the CEF-NEMS framework. Macro-economic impacts and feedbacks have also been incorporated through the use of scenarios and qualitative analysis of indirect costs associated with some of the policies and programs evaluated.

The use of CEF-NEMS to provide integrated results across individual sectors and the analysis of policy impacts are two methodological enhancements that distinguish this study from the Five-Lab Study. Additional methodological improvements to the individual sector analyses are 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 being 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

To address a range of possible climate change developments, we employ three 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. The scenarios of this study allow an examination of a range of public perceptions of the severity of the global climate change problem.

Each scenario consists of a set of policy implementation pathways, which are assessed as a package in terms of both benefits and costs out to 2020. The benefits include not only greenhouse gas emission reductions, but also reduced local air pollution, national security benefits of reduced energy imports, and greater efficiency of production. The costs include direct costs of the private-sector investment in efficiency and low-carbon technologies and of the federal programs designed to encourage such technologies, as well as any possible indirect costs due to production shifts.

3.2.1 Policy Implementation Pathways of the Scenarios

Each scenario is defined in terms of the public perception of the urgency of meeting significant goals relative to energy productivity, oil independence, air quality, and greenhouse gas mitigation. This perception defines the policy pathways that might be expected under the scenario. 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 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.

3.2.1.1 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). We start from the AEO99 Reference Case because it is widely available, frequently referenced, and a well-documented projection. 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 the sector results in the chapters that follow. In general, the BAU case assumes that no further 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. This ongoing investment, in combination with other private- and public-sector actions, is assumed to result in a steady pace of 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.”

3.2.1.2 Moderate Scenario. The Moderate Scenario reflects 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:

- they are not highly controversial today;
- Have generally no increased net direct cost to the customer
- Would not impose significant 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

Because of the first criterion, the pathways defining the Moderate Scenario do not include fiscal policies that involve taxing energy, directly or indirectly (such as a carbon emissions trading program). Instead, the Moderate Scenario will be 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.

3.2.1.3 Advanced Scenario. The Advanced Scenario reflects 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 would not be politically feasible in the Moderate Scenario.

In this Advanced Scenario, greater energy efficiency and low-carbon investments are pursued as the result of changing public preferences and more vigorous policy pathways. 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 cap and trade system

One key policy assumed in the Advanced Scenario is the establishment of a carbon emissions cap along with a system for the trading of carbon permits within the U.S. This domestic trading system is applied to all fuels and all sectors of the economy; it is assumed to be announced in the year 2000, initiated in 2002, and fully implemented by the year 2005.

The 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 can be allocated to existing carbon emitters, etc. In the competitive market scenario assumed for the Advanced Scenario, the means of allocation does not impact the energy results. Energy prices are based on marginal costs and therefore include the full carbon permit value, regardless of the allocation process³. However, the impact on the economy can vary significantly between different permit allocation schemes. Such macroeconomic impacts are discussed in more detail in sections 1.4.5 (costs), 3.6.2 (methodology), 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 U.S. to purchase allowances on the international markets, nor in the capability of the U.S. 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 Scenario's assumption of a "nationwide sense of urgency." Should an international permit trading system be established with prices lower than \$50/ton of carbon, then one should expect to see lower carbon permit prices in the U.S. as well, and less 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).

The scenarios also 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. Coal and natural gas prices vary between 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 long-term impacts of policies, we have extended the period of analysis to 2020. 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.

- 1990 is included because it is the reference point for the Kyoto accords on greenhouse gas emissions.
- 1997 is included as the last year for which we have historical data.
- 2010 is of interest because it is the midpoint of the first commitment period in the Kyoto Protocol.
- 2020 represents a reasonable long-term point for which we can still have some confidence with respect to technology improvements.

Results for additional intermediate years are reported in the appendices. 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.³

3.3 CEF-NEMS

The central model employed for this study was the CEF-NEMS.

3.3.1 General Characterization

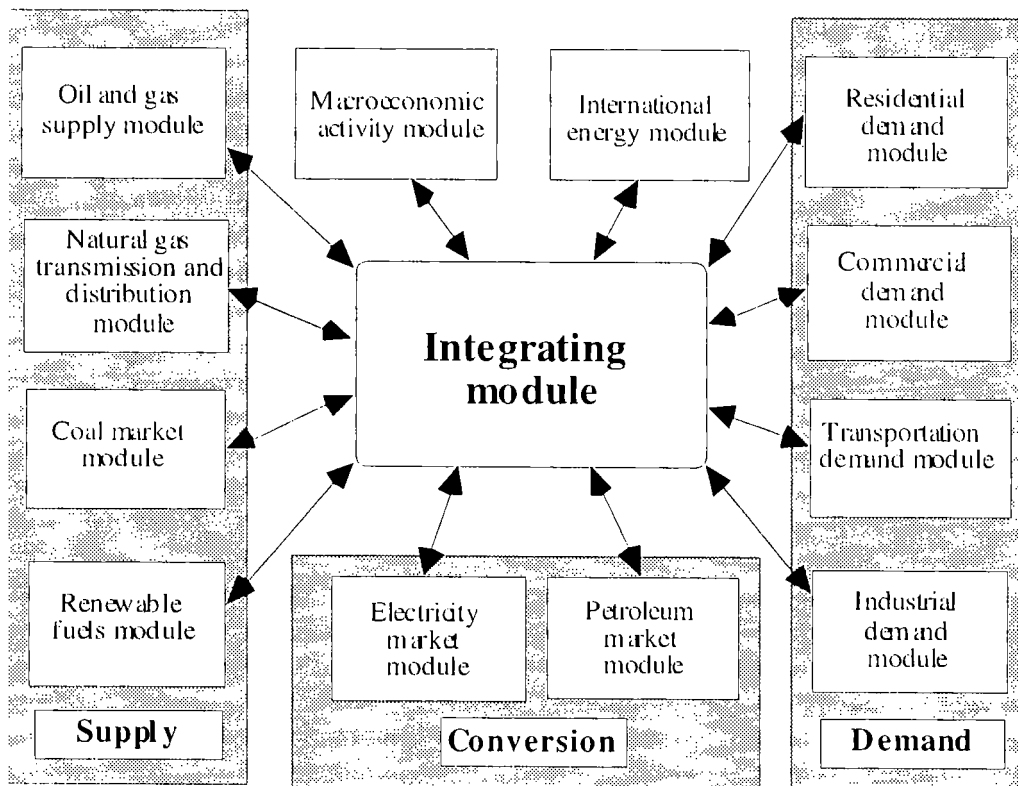
The CEF-NEMS model is derived from the National Energy Modeling System (NEMS) developed by the Energy Information Administration (EIA) for the analysis behind its 1999 Annual Energy Outlook (EIA, 1998a). At the EIA's request, we have appended the acronym CEF (Clean Energy Future) to the front of the name 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 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 Figure 3.1, CEF-NEMS consists of 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); one module to simulate world oil market (international energy activity); and one module that provides the mechanism to achieve a general market equilibrium among all the other modules. Figure 3.1 depicts the high-level structure of CEF-NEMS. 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.

Figure 3.1: Schematic representation of the CEF-NEMS



Source: Adapted from EIA, 1998b.

3.3.2 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).

3.3.3 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).

3.3.4 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 increases. 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).

3.3.5 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).

3.3.6 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. Cogeneration and other facilities whose primary business is not electricity generation are represented in the demand and fuel supply modules.

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.

3.3.7 Validation and Documentation of CEF-NEMS

Other than the changes documented in Appendix A of this report, CEF-NEMS is the same model as the EIA's NEMS model as used in their recently released AEO99 report (EIA, 1998a). This NEMS model has been developed over the last decade with probably more peer review than any other U.S. energy model. This peer review has taken many forms. The model has been directly reviewed in its initial development as well as over the last decade as it has been used extensively by the EIA. It has been reviewed indirectly through reviews of the projections published by the EIA in their *Annual Energy Outlook* reports, which are based on NEMS results. The model is documented both in hardcopy (EIA, 1999 a, b, c) and on the worldwide web at:

<ftp://ftp.eia.doe.gov/pub/pdf/multi.fuel/058198.pdf>

As with all useful energy models, NEMS is in continual development. Partially in response to the above reviews, the EIA is actively improving the model both in terms of the level of detail it can address and its ability to simulate different policies and programs. We believe the CEF-NEMS model takes this continuous development process to the next step with respect to efficiency and low-carbon technologies and the policies that promote them. In fact, we would expect that, consistent with past practice, the EIA will adopt some of the modeling changes made in this study.

3.3.8 Limitations of CEF-NEMS

While NEMS (and CEF-NEMS) is the best model available for forecasting U.S. energy use, it is limited in its ability to simulate the impact of non-fiscal policies like energy education initiatives, voluntary programs, enhanced R&D, technical assistance, feebates, etc. Where possible feasible adaptations have been made in CEF-NEMS to address the impact of such policies and programs. These adaptations are described in detail in Appendix A. However in some cases, the analysis and modeling of these programs had to be done outside of CEF-NEMS to capture specific attributes of the policies that are not easily represented in CEF-NEMS. For example, CEF-NEMS cannot endogenously represent the advantages of labeling programs like Energy Star Buildings and Green Lights.

For programs and policies that cannot be simulated in CEF-NEMS, other sector- or end-use-specific tools and methods were used. These are summarized in the next subsection and described in detail in the individual sector chapters and appendices. The results from these individual policy analyses were then integrated back into CEF-NEMS. In a limited number of cases, this meant simply "hardwiring" the results into CEF-NEMS. More frequently, the approach was to alter some of the parameters of CEF-NEMS to yield the same results while at the same time retaining some responsiveness to changes in fuel prices, etc. For example, after estimating the impact of the Green Lights program in the buildings sector using spreadsheet models based on recent Green Lights experience, the discount rates 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 Green Lights alters consumers' purchases by removing market barriers, providing information, etc. 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).

3.4 SECTOR APPROACHES

CEF-NEMS was used to analyze policies in each of the end-use demand sectors, as well as the electricity sector. All the sectors required some analysis outside of CEF-NEMS to generate the inputs to NEMS. 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 SO₂ ceilings to represent tighter particulate matter standards, to competitive pricing in all regions to capture deregulation of the sector. In the transportation sector, changes to NEMS included, among other things, a tax credit for high efficiency vehicles, accelerated RD&D-driven reductions in the cost of ethanol, voluntary agreements with vehicle manufacturers regarding fuel economy, and pay-at-the-pump insurance policies.

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, consumer preferences and additional 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 across all industrial subsectors were examined with a separate model 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 largely the discount rate in CEF-NEMS' building model. In the industrial sector, these included the discount rates, energy intensity, and stock turnover rates. Details on these analyses outside of NEMS can be found in the individual sector chapters of the report and the appendices.

3.5 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.

3.5.1 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.

3.5.2 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 proliferate over the next decade as turbine and fuel cell technologies improve. 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 provide 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 model⁴ (see Appendix A-2). The DISPERSE results have not been integrated into the CEF-NEMS model due to difficulties associated with replicating the results at the industrial subsector level in CEF-NEMS. The DISPERSE results are however presented separately in section 5.5.4.

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 (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, the DISPERSE model estimate of economic potential is used in estimating industrial production of electricity and steam, as well as the fuel consumption associated with the production.

3.5.3 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 generate electricity or to propel a vehicle. Some of the improvements to stationary power producing fuel cells can also be applied to mobile applications in vehicles, and vice versa. Thus a synergism exists between these two different forms of the technology in that extensive deployment (and consequent learning) of one could benefit the other in the form of reduced costs and improved efficiency. This synergism is accounted for outside of CEF-NEMS and reinserted into CEF-NEMS in the form of fuel cell cost and performance parameters over time.

3.6 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.

3.6.1 Benefits

Energy benefits: 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.

Local air pollution benefits: for the electric sector these are estimated in CEF-NEMS. Emissions from the end-use sectors will be estimated with the ERCAM model in conjunction with the EPA. These estimates are not available for this draft.

Greenhouse gas emission benefits: As stated earlier, the only greenhouse gas emissions analyzed are carbon emissions from fossil fuel use. Thus, as with the local air pollution benefits, there is a direct translation between reduced use of fossil fuels and carbon emissions using standard carbon emission coefficients.

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. See the section below on macroeconomic costs for a more complete discussion on the assessment of macroeconomic impacts.

3.6.2 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 made to that point in time. 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. (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 and the impact of the CEF policies on those barriers).

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 with the CCEs 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 preferences⁵. With these discount rates, 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.

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 3.1 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. This value of \$0.6/Mbtu is being reviewed and may be revised as the result of an ongoing analysis of policy and program implementation costs.

Table 3.1 A Review of Administrative Costs for Energy-Efficiency Programs

Policy/Program	Type of Policy/Program	Administrative Cost per MBtu of Primary Energy Saved	Buildings	Industry	Transportation
Residential Appliance and Commercial Equipment Program	Regulatory policies—Codes and Standards	\$0.095	√		
Building Standards and Guidelines Program	Regulatory policies—Codes and Standards	\$0.052	√		
Demand-Side Management Programs of the Bonneville Power Administration: Residential	Financing and investment enabling	\$0.543	√		
Demand-Side Management Programs of the Bonneville Power Administration: Commercial	Financing and investment enabling	\$0.323	√		
Weatherization Assistance Program	Financing and investment enabling	\$0.899	√		
Market Transformation Programs of the Southern California Edison: Residential	Financing and investment enabling	\$2.486	√		
Energy Star Programs	Voluntary, information and technical assistance	\$0.092	√	√	
Market Transformation Programs of the Southern California Edison: Non-Residential	Financing and investment enabling	\$0.515	√	√	
Industrial Assessment Centers	Voluntary, information and technical assistance	\$0.386		√	
Demand-Side Management Programs of the Bonneville Power Administration:	Financing and investment enabling	\$0.115		√	
Energy-Related Inventions Program	Public-private RD&D partnerships	\$0.697	√	√	√
Fuel Economy Guide	Voluntary, information and technical assistance	\$0.131			√

These estimates of administrative costs are quite consistent with the 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.

Macroeconomic Costs: The issue of macroeconomic costs and benefits devolves to almost a philosophical debate as to whether or not there is an “energy 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 will 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 cap and trade 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 don’t 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. In Chapter 8 we include different values from this range in our comparison of the costs and benefits of the policies in our Advanced Scenario.

We present a host of evidence in the end-use sectors of this report to buttress our claim that an efficiency gap does exist that can be closed 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 cap and trade) 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 the Federal government to react differently in the future
- 3) cannot model the substitution of information for energy that these policies affect.

Given the above modeling problems, we have included macroeconomic costs for only the carbon cap and trade policy, and that is done based on the literature. We have also included the direct investment costs for all policies as well as the program and administrative costs for administering those policies..

Net Direct Costs. Net Direct Costs are computed as the sum of the direct costs (annualized incremental technology investment cost plus the program implementation and administration costs) and macroeconomic costs minus the energy cost savings. The net direct costs remain preliminary because some cost elements are not fully included (e.g., the electric sector's policy implementation and administration costs), and other cost elements will be refined for the final report.

3.7 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 each individual sector. The discussion that follows focuses on analysis issues that impact all the sectors.

Probably the largest single issue is the modeling of the impact of policies that are non-fiscal in nature such as information programs, labeling, voluntary agreements, etc. Other major analysis need that cuts 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.

3.7.1 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.⁶ 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. 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 impacts 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 careful assessment could help avoid possible overcounting of impacts where multiple programs affect the same consumers.

3.7.2 Expanded Technology Representations

Due to time and resource limitations, a number of technologies have not been explicitly considered in this analysis. For example, our combined heat and power industrial analysis has not been integrated into the overall results yet. 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 (see section 4.7). 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. In the transportation sector, we have included only the more promising alternative fuel vehicles.

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.

3.7.3 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 cap and trade system assumed in the Advanced Scenario. Future efforts might include the refinement and use of macroeconomic models in conjunction with NEMS 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.

3.7.4 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. We are currently investigating possibilities for producing rough estimates in conjunction with the EPA. At the same time, it is our understanding that the EIA is modifying NEMS to estimate NO_x emissions in the transportation sector.

3.7.5 Non-Energy Emissions and GHG Reduction Opportunities

This study focuses on reductions in carbon dioxide emissions from the use of energy in the U.S. However, 16% of the global warming potential of the gases emitted in 1997 by the U.S. 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. These opportunities 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).

3.7.6 Time Frame and Geographic Disaggregation

The climate change problem is a long-term problem. It will require continuing attention throughout the next 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.

3.8 REFERENCES

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3.9 ENDNOTES

¹ Author: Walter Short (NREL) and Marilyn A. Brown (ORNL).

² 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.

³ In this report, 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, million tonnes of carbon (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).

⁴ Distributed Power Economic Rationale Selection (DISPERSE) model.

⁵ Hurdle rates may also include transaction costs. Insofar as transaction costs are actual monetary costs, they could also be included in a CCE calculation.

⁶ In the building sector, the NEMS module 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.

Chapter 4

BUILDINGS SECTOR¹

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 a stream of advanced building technologies and practices after 2010 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 \$237 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.

4.1.2 Buildings Sector Primary Energy Use in 1997

Figures 1a and 1b show 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 “all other uses” category contains a variety of smaller end-uses, including cooking, clothes washers, clothes dryers, dishwashers, home electronics, fans in fuel-fired furnaces, and all the other so-called “miscellaneous” energy end-uses (these are called “other uses” in NEMS terminology).

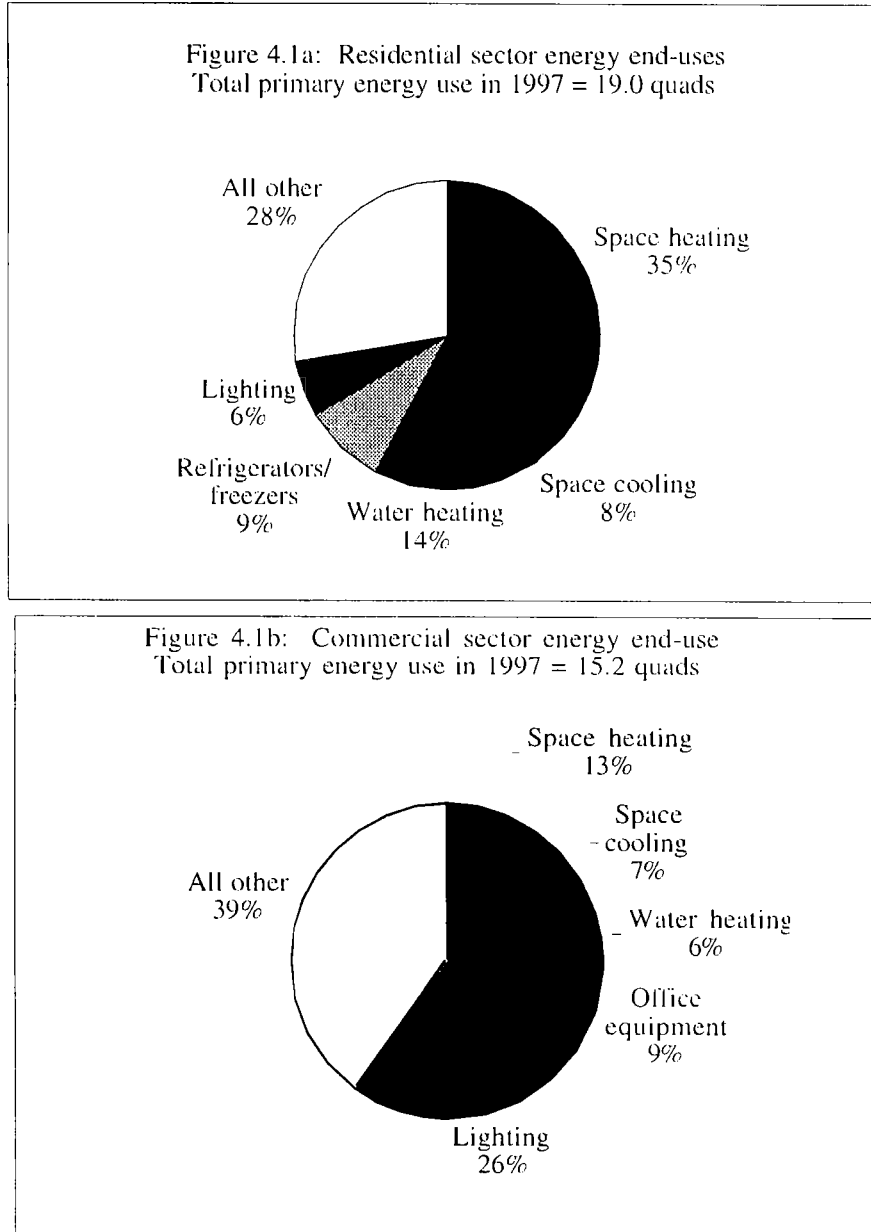
In the commercial sector, lighting accounts for about one quarter of total primary energy use, and is far and away the largest identified end-use in this sector. Space heating is next, followed by office equipment, cooling, and water heating. The “all other” category contains refrigeration, ventilation, cooking, district services, automated teller machines, telecommunications equipment, and medical equipment. 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.

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).

Fig. 4.1a and 4.1b: End-Use Breakdown of Residential and Commercial Sector Primary Energy in 1997



4.2 BUSINESS-AS-USUAL CASE

The building sector uses the AEO99 reference case 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, based on an assumption that the combination of Building America, ENERGY STAR homes, the Partnership for Advanced Technology in Housing (PATH), R&D, and building codes all have major effects. 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.² 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.

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.³ 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, *Consumer Reports*, or an electric utility).

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.

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 utility 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 sizing¹, 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 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 a carbon cap & trade system. 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.

Voluntary Programs. The major voluntary buildings-sector programs in the U.S. are 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 have also been effective in working with manufacturers to convince them to promote existing and develop new energy-efficient.

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 and home computers. Future product programs may include home audio equipment, 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.

Table 4.1 Carbon Mitigation Policies and Which Barriers They Can Affect

Barrier	Policy Type
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	Voluntary Programs	Building Codes	Equipment Standards	State Market Transformation Programs	Financing	Government Procurement	Tax Credits	Accelerated R&D	Carbon Cap & Trade
<i>SCENARIO</i>	B	B	B	B	B	B	B	B	A
<i>Barriers faced by users</i>									
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	X		X		X
Split incentives		X	X						
<i>Barriers faced by manufacturers, builders, designers, & product suppliers</i>									
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.

The DOE's Building America program is designed to improve the energy efficiency of new homes by applying innovative design and production techniques in the field. The goal is to achieve 30 to 50% energy savings relative to typical new construction, at an incremental first cost of no more than \$500 per house. DOE helps builders with design assistance and technology transfer.

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 25-30%.

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.

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

End-Use/Technology	Policy Type
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	Voluntary Programs	Building Codes	Equipment Standards	State Market Transformation Programs	Financing	Government Procurement	Tax Credits	Accelerated R&D	Carbon Cap & Trade
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-Comm Retrofits	X	X			X			X	X
Thermal Shell-Comm New	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
Commercial Ducts					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
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.

At the time of this writing, the latest officially-adopted commercial building code is ASHRAE 90.1-1989. This code, finalized in 1989, is a model that may be adopted by state or local governments as the basis for their building codes. The rate at which the code is adopted and enforced will determine the effect of the policy. This rate is strongly influenced by Federal and state actions mandated under the Energy Policy Act of 1992. This code affects the thermal shell, space conditioning, water heating, lighting and other aspects of commercial building operation. As of August 1999, ASHRAE seems poised to finalize a new and revised code for commercial

buildings. If this occurs, a new standard, ASHRAE 90.1-1999, will be available for adoption. As of this writing, however, we do not know for certain whether this standard will be finalized and adopted, thus our policy pathways focus on the ASHRAE standard currently available for adoption. While more advanced commercial codes have not yet been included in our scenarios, these codes will be added for the December 1999 public review draft.

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 addresses 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 product covered under NAECA, fluorescent lamp ballasts, currently has a standard that prevents sales of the lower efficiency core-coil magnetic ballasts (high-efficiency magnetic ballasts can still be sold). We expect that DOE will enact a revised standard for ballasts that takes effect in 2004.

State Market Transformation Programs Funded Through "Public Benefits (Lines) 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. 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.

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 the 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 R&D is not included in our scenarios.

We assessed roughly twenty different key R&D technologies for buildings (see annex at end of chapter), and of those chose four 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, 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 four 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 in the 2010-2020 time period, and assessed the additional market penetration associated with such cost reductions.

Carbon cap & trade 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)⁵ 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).

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.

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.	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 2010)	Higher Line charges for states implementing electricity restructuring (full national utility restructuring by 2005)
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.	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.
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 cap and trade 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.

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 many sources (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 1998, 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). 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	495	421	A
	Freezers	2010	kWh/year	455	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) SEER = Seasonal Energy Efficiency Ratio, HSPF = Heating Seasonal Performance Factor, EF = Energy Factor.

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

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

(4) The standard levels and timing of equipment efficiency standards shown in this table represent the author's 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 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

<i>Sector & fuel</i>	<i>Technoeconomic potential % savings relative to business as usual case</i>		<i>Achievable percentage of technoeconomic potential</i>		<i>Technology cost</i>	
	<i>2010</i>	<i>2020</i>	<i>2010</i>	<i>2020</i>	<i>\$/MBtu 2010</i>	<i>\$/MBtu 2020</i>
<i>Residential--Moderate</i>						
Electricity	28%	37%	28%	44%	6.13	5.67
Natural gas	5%	12%	21%	22%	2.11	2.27
Oil	6%	13%	0%	0%	1.92	1.87
LPG	6%	13%	0%	0%	N/A	N/A
Other	0%	0%	N/A	N/A	N/A	N/A
Total	14%	22%	25%	36%	5.34	5.04
<i>Residential--Advanced</i>						
Electricity	28%	37%	35%	63%	5.28	4.46
Natural gas	5%	12%	28%	36%	2.49	4.46
Oil	6%	13%	0%	18%	1.83	1.88
LPG	6%	13%	0%	0%	N/A	N/A
Other	0%	0%	N/A	N/A	N/A	N/A
Total	14%	22%	31%	54%	5.01	4.13
<i>Commercial--Moderate</i>						
Electricity	19%	26%	40%	59%	7.41	7.10
Natural gas	16%	26%	24%	30%	1.78	1.69
Oil	16%	26%	0%	0%	N/A	N/A
Other	0%	0%	N/A	N/A	N/A	N/A
Total	17%	25%	30%	42%	6.07	5.79
<i>Commercial--Advanced</i>						
Electricity	19%	26%	46%	69%	7.00	6.69
Natural gas	16%	26%	32%	48%	1.80	1.66
Oil	16%	26%	0%	0%	N/A	N/A
Other	0%	0%	N/A	N/A	N/A	N/A
Total	17%	25%	36%	55%	5.20	4.84

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) CCEs for electricity are expressed in terms of site energy at 3412 Btus/kWh.

3) All costs are in 1997 dollars.

4) Program implementation costs of \$0.6/MBtu of primary energy are used across the board, as described in Chapter 1.

4.4.2 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 change hurdle rates, technology costs, and growth trends for each end-use (as needed). 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 and percentage 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-third 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 equal to site energy savings in percentage terms, which means that the supply-side changes are neutral with regards to the overall efficiency of generating and delivering electric power.

We can also decompose the carbon savings in electricity in the Advanced Scenario in 2020. Fifty four percent of total buildings electricity-related carbon savings in 2020 in this scenario are attributable to fuel switching on the electricity supply-side, and forty six percent are attributable to demand-side efficiency improvements.

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.

Total bill savings in 2010 compared to the BAU case are about \$27B/year, and by 2020 these savings grow to \$38B/year. Total net savings after accounting for investment costs and program costs are \$21B and \$24B/year in 2010 and 2020, respectively.

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.

Total bill savings in 2010 compared to the BAU case are almost \$30B/year, and by 2020 these savings grow to more than \$50B/year. Total net savings after accounting for investment costs and program costs are \$17B and \$29B/year in 2010 and 2020, respectively.

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

Sector & fuel	1990	1997	2010				2020			
	Q	Q	BAU Q	Moderate Q	Advanced % Δ	Advanced Q	BAU Q	Moderate Q	Advanced % Δ	Advanced Q
<i>Residential</i>										
Primary Electricity	10.2	11.7	13.7	13.1	-4.4%	12.1	15.1	13.3	-11.4%	11.2
Natural gas	4.5	5.2	5.5	5.5	-0.4%	5.2	6.0	5.9	-0.8%	5.5
Oil	0.8	0.9	0.7	0.7	0.0%	0.7	0.7	0.7	0.0%	0.6
LPG	0.4	0.4	0.4	0.4	0.0%	0.4	0.4	0.4	0.0%	0.4
Other	0.7	0.8	0.7	0.7	0.0%	0.7	0.8	0.8	1.3%	0.8
Total primary	16.7	19.0	21.1	20.5	-2.9%	19.2	22.8	21.1	-7.7%	18.5
<i>Commercial</i>										
Primary Electricity	9.3	11.0	12.7	12.3	-3.5%	11.4	13.4	12.3	-8.1%	10.8
Natural gas	2.8	3.4	3.8	3.8	-2.3%	3.7	4.0	3.8	-6.0%	3.7
Oil	0.5	0.5	0.3	0.4	5.9%	0.3	0.3	0.3	9.7%	0.3
Other	0.4	0.3	0.3	0.3	0.0%	0.3	0.3	0.3	0.0%	0.3
Total primary	13.0	15.2	17.2	16.7	-3.0%	15.7	18.1	16.8	-7.2%	15.1
<i>Total Buildings</i>										
Primary Electricity	19.6	22.8	26.4	25.3	-3.9%	23.5	28.5	25.7	-9.9%	22.0
Natural gas	7.4	8.5	9.4	9.3	-1.2%	8.9	10.0	9.7	-2.9%	9.2
Oil	1.3	1.4	1.1	1.1	1.9%	1.0	1.0	1.0	3.1%	0.9
LPG	0.4	0.4	0.4	0.4	0.0%	0.4	0.4	0.4	0.0%	0.4
Other	1.1	1.1	1.1	1.1	0.0%	1.1	1.1	1.1	0.9%	1.1
Total primary	29.8	34.2	38.3	37.1	-3.0%	34.8	40.9	37.8	-7.5%	33.5
<i>Site Electricity</i>										
Residential	3.15	3.65	4.57	4.27	-6.6%	4.07	5.30	4.44	-16.2%	3.94
Commercial	2.88	3.45	4.25	4.02	-5.4%	3.84	4.74	4.10	-13.5%	3.80
Total	6.03	7.10	8.82	8.29	-6.0%	7.91	10.04	8.54	-14.9%	7.74

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.

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

Sector & fuel	1990 MtC	1997 MtC	2010						2020					
			BAU MtC	Moderate MtC	% Δ	Advanced MtC	% Δ	BAU MtC	Moderate MtC	% Δ	Advanced MtC	% Δ		
<i>Residential</i>														
Primary Electricity	162	182	228	203	-10.9%	159	-30.1%	267	212	-20.4%	128	-51.9%		
Natural gas	66	74	80	79	-0.4%	76	-4.8%	86	85	-0.7%	79	-7.4%		
Oil	17	20	15	15	0.0%	15	-3.3%	14	14	0.0%	13	-6.5%		
LPG	6	8	8	8	0.0%	7	-3.8%	7	7	0.0%	7	-1.4%		
Other	3	1	1	1	0.0%	1	0.0%	1	1	0.0%	1	0.0%		
Total primary	253	286	332	307	-7.6%	258	-22.1%	375	320	-14.7%	229	-38.9%		
<i>Commercial</i>														
Primary Electricity	148	172	212	191	-10.1%	150	-29.1%	237	196	-17.2%	123	-48.0%		
Natural gas	41	49	55	54	-2.2%	53	-4.3%	58	54	-5.9%	53	-7.8%		
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	281	259	-7.9%	216	-23.1%	308	264	-14.2%	189	-38.7%		
<i>Total Buildings</i>														
Primary Electricity	311	354	440	394	-10.5%	310	-29.6%	504	409	-18.9%	252	-50.1%		
Natural gas	107	123	135	133	-1.1%	129	-4.6%	143	139	-2.8%	132	-7.5%		
Oil	26	34	26	27	1.5%	25	-4.2%	25	25	2.0%	23	-7.3%		
LPG	6	8	8	8	0.0%	7	-3.8%	7	7	0.0%	7	-1.4%		
Other	10	4	4	4	0.0%	4	-2.6%	4	4	0.0%	4	-2.6%		
Total primary	460	522	613	565	-7.7%	475	-22.5%	683	584	-14.4%	418	-38.8%		

- 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.

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

Sector & fuel	1990	1997	2010				2020			
	Q	Q	BAU Q	Moderate Q	Advanced Q	% Δ	BAU Q	Moderate Q	Advanced Q	% Δ
<i>Residential</i>										
Space heating	5.1	6.9	6.9	7.0	1.4%	6.7	7.1	7.3	2.1%	6.7
Space cooling	1.7	1.5	1.6	1.6	-3.3%	1.4	1.7	1.5	-11.8%	1.3
Water heating	2.4	2.6	2.7	2.5	-4.4%	2.4	2.8	2.5	-9.1%	2.3
Refrigerators/ freezers	2.2	1.6	1.1	1.0	-3.4%	1.0	1.0	0.9	-6.3%	0.8
Lighting	1.0	1.1	1.2	1.2	-2.8%	1.0	1.3	1.2	-10.4%	0.9
All other	4.4	5.3	7.6	7.1	-6.2%	6.7	8.9	7.6	-14.2%	6.4
Total	16.7	19.0	21.1	20.5	-2.9%	19.2	22.8	21.1	-7.7%	18.5
<i>Commercial</i>										
Space heating	1.9	1.9	1.9	1.9	-0.1%	1.8	1.9	1.9	-2.5%	1.7
Space cooling	1.8	1.1	1.1	1.0	-9.3%	0.9	1.0	0.9	-13.1%	0.8
Water heating	1.1	0.9	0.9	0.9	-5.9%	0.9	0.9	0.9	-6.3%	0.9
Office equipment	0.6	1.3	1.9	1.9	3.7%	1.8	2.2	2.3	7.6%	2.2
Lighting	3.7	3.9	3.8	3.7	-2.7%	3.4	3.7	3.4	-9.9%	2.9
All other	3.8	6.1	7.6	7.3	-4.2%	6.9	8.2	7.4	-10.3%	6.6
Total	13.0	15.2	17.2	16.7	-3.0%	15.7	18.1	16.8	-7.2%	15.1

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.

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

Sector & Fuel	1990 MtC	1997 MtC	2010					2020				
			BAU MtC	Moderate MtC % Δ		Advanced MtC % Δ		BAU MtC	Moderate MtC % Δ		Advanced MtC % Δ	
Residential												
Space heating	79	99	98	98	-0.2%	90	-8.4%	103	102	-0.3%	88	-14.4%
Space cooling	27	23	27	25	-9.8%	18	-33.0%	30	24	-20.7%	15	-51.3%
Water heating	36	39	42	39	-7.2%	34	-18.9%	45	39	-13.2%	32	-29.7%
Refrigerators/ freezers	35	25	18	16	-9.9%	13	-25.9%	18	15	-15.8%	9	-46.4%
Lighting	15	17	20	18	-9.4%	14	-31.4%	23	19	-19.4%	11	-53.6%
All other	60	82	126	111	-12.3%	89	-29.5%	156	121	-22.6%	74	-52.3%
Total	253	285	332	307	-7.6%	258	-22.1%	375	320	-14.7%	229	-38.9%
Commercial												
Space heating	30	32	32	32	-0.5%	29	-9.8%	32	31	-3.6%	28	-15.0%
Space cooling	29	17	18	15	-15.4%	12	-31.9%	18	14	-21.5%	10	-47.6%
Water heating	17	14	15	14	-7.3%	13	-12.1%	15	14	-8.3%	13	-14.1%
Office equipment	10	20	31	30	-3.4%	24	-21.5%	39	37	-3.0%	25	-35.9%
Lighting	59	61	64	58	-9.4%	45	-29.5%	66	54	-18.7%	33	-49.8%
All other	61	93	121	110	-9.2%	92	-23.6%	138	114	-17.2%	81	-41.2%
Total	206	237	281	259	-7.9%	216	-23.1%	308	264	-14.2%	189	-38.7%

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.

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

<i>Sector & technology</i>	<i>Scenario</i>	<i>2000</i>	<i>2005</i>	<i>2010</i>	<i>2015</i>	<i>2020</i>
<i>% of New Shipments</i>						
<i>Residential</i>						
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%
<i>Commercial</i>						
Electronic ballasts	Moderate	53%	100%	100%	100%	100%
	Advanced	54%	100%	100%	100%	100%
High Efficiency Transformers	Moderate	9%	25%	40%	48%	55%
	Advanced	9%	100%	100%	100%	100%
<i>% of Equipment Stock</i>						
<i>Residential</i>						
Heat pump WH	Moderate	0%	1%	2%	5%	8%
	Advanced	0%	1%	5%	12%	21%
Dedicated CFL Lighting Fixtures	Moderate	0%	1%	3%	5%	7%
	Advanced	0%	2%	5%	9%	15%
Horizontal Axis Clothes Washer	Moderate	0%	4%	33%	66%	91%
	Advanced	0%	16%	51%	83%	98%
<i>Commercial</i>						
Electronic ballasts	Moderate	2%	21%	60%	92%	100%
	Advanced	3%	24%	62%	93%	100%
High Efficiency Transformers	Moderate	0%	3%	9%	16%	25%
	Advanced	0%	8%	25%	41%	58%

(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)

Sector & fuel	1997 B\$/yr	2010					2020				
		BAU B\$/yr	Moderate B\$/yr	% Δ	Advanced B\$/yr	% Δ	BAU B\$/yr	Moderate B\$/yr	% Δ	Advanced B\$/yr	% Δ
<i>Residential</i>											
Annual fuel cost	138	146	133	-9%	130	-11%	151	132	-13%	120	-20%
Annualized incremental technology cost of energy efficiency	0	0	3.5	N/A	6.5	N/A	0	9.0	N/A	16.0	N/A
Annual program costs to promote energy efficiency	0	0	0.5	N/A	1.0	N/A	0	0.7	N/A	1.4	N/A
Annual total cost of energy services	138	146	137	-6%	137	-6%	151	142	-6%	138	-9%
<i>Commercial</i>											
Annual fuel cost	99	103	89	-14%	91	-12%	103	84	-18%	82	-20%
Annualized incremental technology cost of energy efficiency	0	0	1.6	N/A	2.5	N/A	0	3.2	N/A	4.3	N/A
Annual program costs to promote energy efficiency	0	0	0.4	N/A	0.8	N/A	0	0.6	N/A	0.8	N/A
Annual total cost of energy services	99	103	91	-12%	95	-8%	103	88	-14%	87	-15%
<i>Total Buildings</i>											
Annual fuel cost	236	249	222	-11%	221	-11%	254	216	-15%	202	-20%
Annualized incremental technology cost of energy efficiency	0	0	5.1	N/A	9.1	N/A	0	12.1	N/A	20.3	N/A
Annual program costs to promote energy efficiency	0	0	1.0	N/A	1.8	N/A	0	1.4	N/A	2.2	N/A
Annual total cost of energy services	236	249	228	-8%	232	-7%	254	230	-10%	225	-11%

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.

3) % Δ (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.

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.

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. 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 2020, 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 four 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.

4.6.3 Key End-Uses

In residential buildings by 2020, the largest primary energy savings in percentage terms (relative to the BAU case) accrue in lighting, cooling, and in "all other" end-uses. In absolute terms, "all other" uses have by far the largest primary energy savings, followed by heating, water heating, and cooling. Recall that "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. The "All Other" category also contains the CEF-NEMS residential "other uses" category (consisting of unidentified uses), which is significant and growing rapidly.

In commercial buildings, lighting and "all other" end-uses dominate the energy savings in absolute terms, and lighting, cooling, and "all other" end-uses dominate the energy savings on a percentage basis. "All other" in commercial includes smaller end-uses that are explicitly represented in CEF-NEMS, including ventilation, cooking, and refrigeration. The "All Other" category also contains the CEF-NEMS commercial "other uses" category (consisting of unidentified uses and other miscellaneous energy use), which is also significant and growing rapidly.

Even among the end-uses that are not explicitly identified in the CEF-NEMS framework (e.g., "other 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 "other uses", and transformers and exit signs are particularly important in the commercial "other uses". The details of these calculations are contained in Appendices B-1 and C-1.

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

<i>Year</i>	<i>Scenario</i>	<i>Sector</i>	Equipment Standards	Building Codes	Voluntary Programs	State/Utility Programs	Tax Credits	R&D (Direct Effects Only)	Total
2010	Moderate	Residential	52%	2%	37%	1%	3%	5%	100%
		Commercial	31%	0%	52%	0%	0%	17%	100%
	Advanced	Residential	45%	3%	38%	1%	9%	4%	100%
		Commercial	29%	0%	50%	0%	0%	21%	100%
2020	Moderate	Residential	45%	4%	37%	1%	1%	12%	100%
		Commercial	29%	0%	35%	0%	0%	35%	100%
	Advanced	Residential	36%	4%	45%	1%	2%	12%	100%
		Commercial	36%	0%	26%	0%	0%	38%	100%

(1) Sector totals weighted by site energy.

(2) Tax credits were not considered for commercial buildings. Building codes for commercial buildings have not been included thus far, but will be added to the analysis in time for the public review draft in December 1999.

Box 4.1 Breakthrough Buildings Technologies

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, 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.

- **Fuel cells** produce electricity through electrochemical reactions between oxygen and fuels such as natural gas or hydrogen. Electrical conversion efficiency is about 40%, which increases to 70-80% in combined heat and power applications. 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 10-300 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.
- **Combined Heat and Power/District Energy Systems** 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. totals about 50 GW by 2020 (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/>

4.7 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 fuel cells and microturbines, 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 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 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.
- 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.

- 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.
- 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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4.10 ENDNOTES

¹ Authors: Jonathan G. Koomey, Carrie A. Webber, and Celina S. Atkinson LBNL, Andrew Nicholls and Brad Holloman, PNNL

² 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 .

³ 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".

⁴ 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.

⁵ 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.

ANNEX: 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
Improved compact fluorescent lighting
Improved lighting distribution systems
Building commissioning

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. Thus, they reflect our own judgment, based on extensive studies and the input by external reviewers. 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. 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 34.85 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 (energy and feedstocks), glass, cement, steel, primary aluminum, petroleum refining, metals-based durables, and other manufacturing.² Figure 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 494.1 MtC, accounting for 33% of total U.S. CO₂ emissions (U.S. DOE, EIA, 1998a). Figure 5.2 provides a breakdown of the share of CO₂ emissions by industrial subsector. The largest CO₂-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 CO₂ emissions than primary energy use due to the process emissions produced during calcination of limestone³ while producing clinker. Process CO₂ emissions from calcination are added to the cement sub-sector energy-related CO₂ 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 CO₂ 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 CO₂ 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

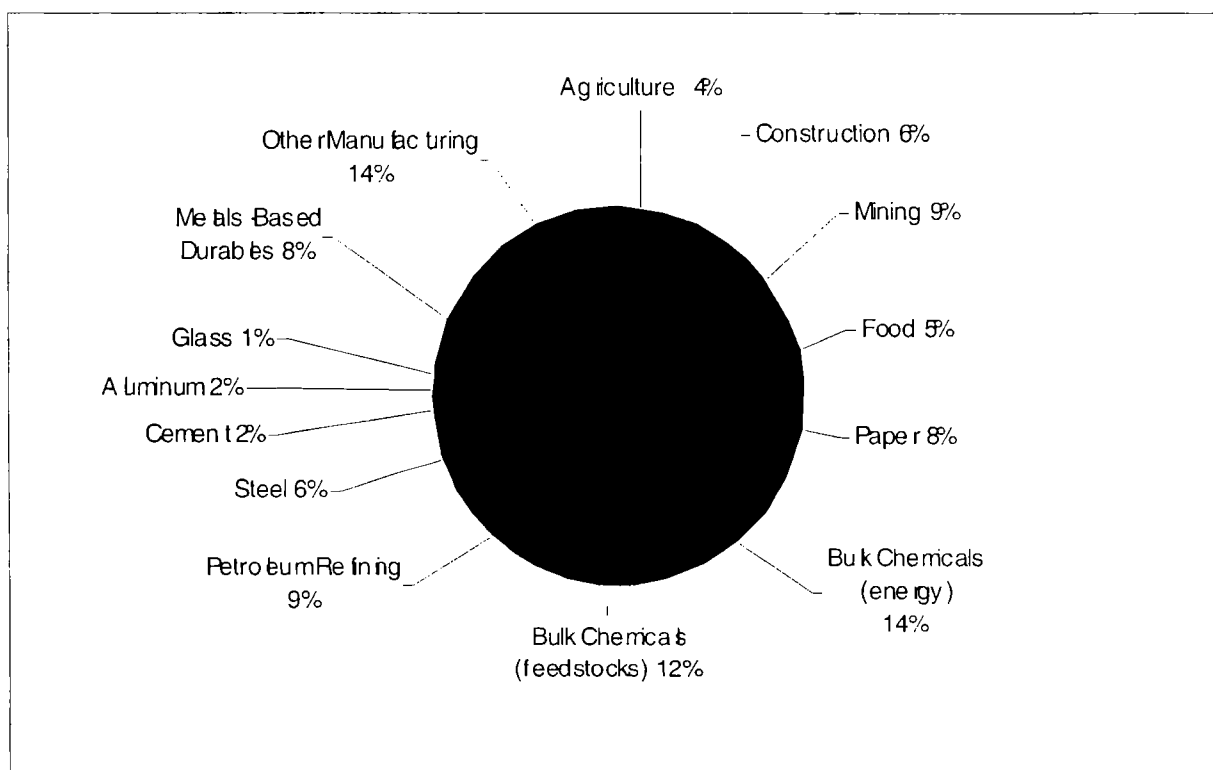
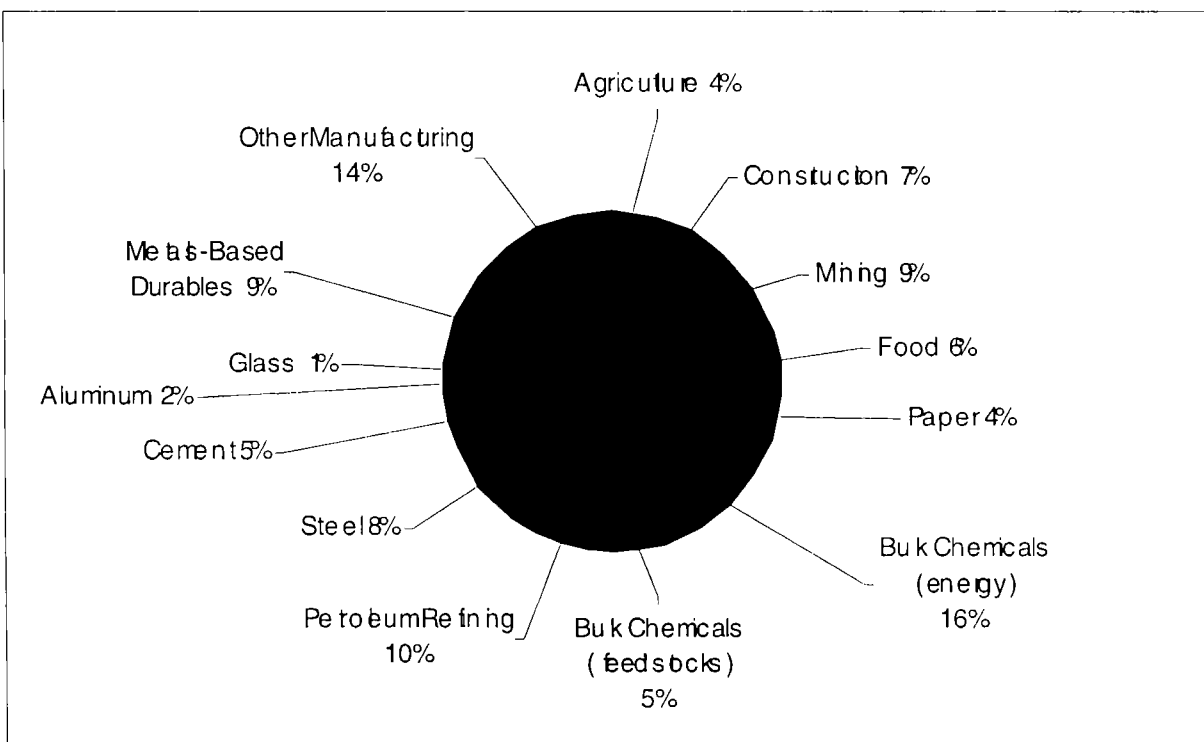


Fig. 5.2 Carbon Dioxide Emissions by Industrial Subsectors, 1997



5.1.3 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), and one cross-cutting measure (CHP). Barriers may limit the speed of adoption of these technologies (see section 5.3.2).

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) 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.⁴ Total CO₂ emissions from steelmaking in 1994 were 34.4 million metric tonnes C (MtC), with 80% of these emissions from integrated steelmaking. The CO₂ intensity of integrated steelmaking was 0.5 tC/ton of crude steel while the CO₂ intensity for secondary steelmaking was 0.2 tC/ton crude steel, resulting in a total sector CO₂ 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. 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 a 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).⁵ 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 Klessner, 1991; Hofer, 1997). The simple payback period of installing a scrap preheater is estimated at 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 Mu/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 (Khrushch et al., 1999). The pulp and paper industry's 1994 CO₂ 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 CO₂ emissions (Khrushch 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 (Khrushch 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; Miller Freeman, 1998; 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, Weyerhaeuser, and Champion) (McCubbin, 1996; Fincham, 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-calcliner 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-Calcliner 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-calcliners, 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 precalcliner 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 precalcliners 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 (Duploux 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 cement⁶ accounting for and the remaining 44% portland cement (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 (Khushch 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.⁷

5.2 BUSINESS-AS-USUAL SCENARIO

We adopt the values in 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 greater detail than the other sectors. 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, or UEC, values) and the annual rate of improvement in the UECs over time (referred to as Technology Possibility Curves, or TPCs).

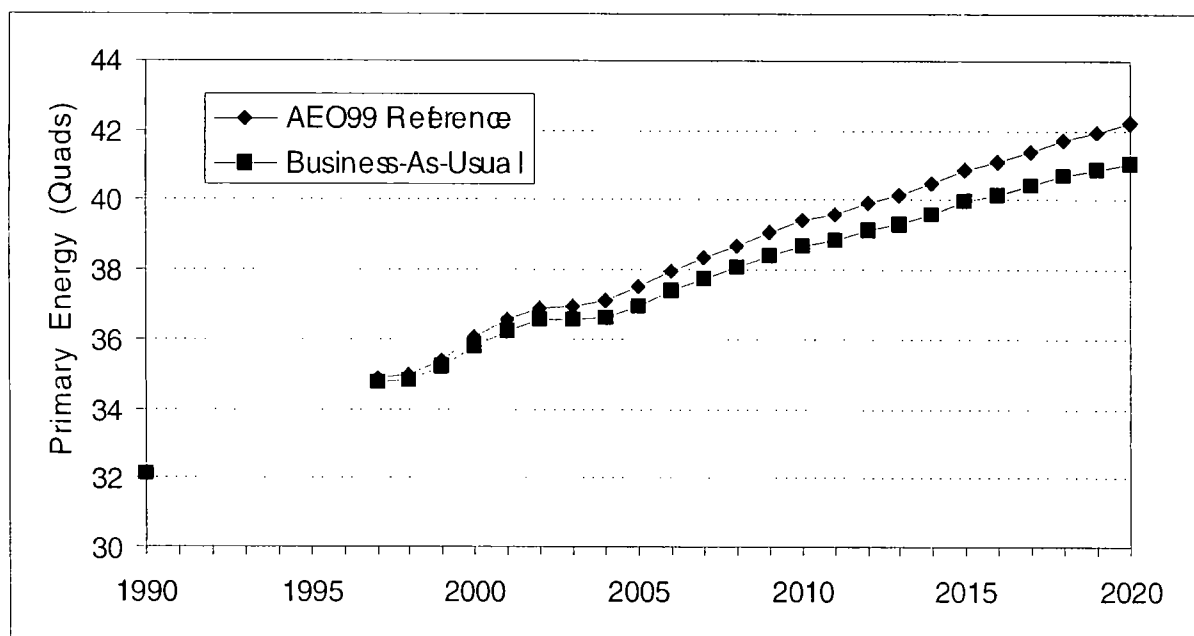
For the business-as-usual scenario for the paper, cement and steel sub-sectors, we modified the UECs and TPCs for both existing and new equipment based on a number of recent analyses (Worrell et al., 1999; Khrushch et al., 1999; Martin et al., 1999). A detailed description of these modifications is provided 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).⁸

Figure 5.2 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.

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

Sector	Retirement (%/yr)		Lifetime (year)	
	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

Fig. 5.2. 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.⁹ 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 support the 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 (CO ₂ and non-CO ₂) in energy-intensive and GHG-intensive industries, for specific industrial process or buildings.	Voluntary programs to reduce GHG emissions (CO ₂ and non-CO ₂) 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 clearinghouse 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 Act State Implementation Plans	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 is extended from 2003 to 2020, leading to increased expansion of CHP as well as third party producers at industrial sites.	Tax credit is extended from 2003 to 2020, leading to increased 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 motors and enforces 100% compliance. Promote national motor repair standard.	Extends standards to all motors and enforces 100% compliance. Mandates national motor repair standard.
Clean Air Act State Implementation Plans	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 and 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 Other OIT R&D programs	Increased R&D efforts in all industries currently in program. Program R&D efforts increased in all areas related to improving industrial sector energy efficiency.	Increased R&D efforts in all industries currently in program and expansion to a number of smaller "other manufacturing" industries. Industrial sector energy efficiency R&D efforts further increased.

Domestic Carbon Dioxide Emissions Cap and Trade System		
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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	Expanded State Programs	Expanded ESCO/utility Programs	Financial Incentives	Expanded R&D Programs	Expanded Demonstration Programs	Cap and Trade
SCENARIO	Both	Both	Both	Both	Both	Both	Both	Both	Both	Both	Both	Advanced
END USE SECTORS												
Agriculture		X	X	X	X		X		X	X	X	X
Mining	X	X	X		X		X		X	X	X	X
Construction		X	X	X	X		X		X		X	X
Food	X	X	X	X	X		X	X	X		X	X
Paper	X	X	X	X	X	X	X	X	X	X	X	X
Chemicals	X	X	X		X		X	X	X	X	X	X
Glass	X	X	X	X	X	X	X	X	X	X	X	X
Cement	X	X	X	X	X		X	X	X	X	X	X
Iron and Steel	X	X	X	X	X	X	X	X	X	X	X	X
Aluminum	X	X	X	X	X	X	X		X	X	X	X
Metals-Based Durables		X	X		X		X	X	X	X	X	X
Other Non-Intensive		X	X		X		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 et al. (1999).

Experience with industrial sector voluntary agreements exists in the U.S. for the abatement of CFC and non-CO₂ 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 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 Challenge.*¹⁰ 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 (especially important in light industries) of industrial energy use. 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 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.

→ **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, 1998; 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.¹¹ 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 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, Wisconsin. The Energy Center of Wisconsin focuses on demonstration projects. The NYSERDA 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 Act State Implementation Plans.* There are various ways to comply with the provisions of the Clean Air Act. Harmonized strategies to reduce air pollutant emissions and 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 so-called 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 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 dangers 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 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 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 motors 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 motors 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.

— Clear Air Act State Implementation Plans

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 (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 (NICE³), 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 NICE³ 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 ultra-high efficiency natural gas turbines 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 decrease the costs of new technologies as well as promote 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 Cap and Trade System

In the advanced scenario a cap and trade 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 (Velthuisen, 1995). The literature suggests that the fewest barriers to energy efficiency investment exist in the industrial

Box 5.1. 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

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 (Velthuisen, 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 5.1) (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; Velthuisen, 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 (Velthuisen, 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 (Velthuisen, 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	Expanded R&D Programs	Expanded ESCO/utility Programs	Expanded Climate Wise Program	Expanded Pollution Prevention	Financial Incentives	Cap and Trade
SCENARIO	Both	Both	Both	Both	Both	Both	Both	Both	Both	Both	Both	Advanced
BARRIERS												
Willingness to Invest	X	X	X	X				X		X	X	
Information / Transaction Costs	X	X	X	X	X	X		X	X	X		
Profitability		X		X			X	X			X	X
Lack of Skilled Personnel			X	X		X		X				
Pricing				X							X	X
Innovation		X		X		X	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; Khrushch 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) 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 cap and trade 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 cap and trade system will affect the price of energy and will likely influence all parameters of the CEF-NEMS model.

Table 5.5. Qualitative Representation of Policy and Program Impacts on CEF-NEMS Inputs by Industrial Subsector.

	Demonstration Programs	Assessment 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	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	Cap and Trade
Agriculture	1.2.8	1	1.2.8	3.6.9	6.9			1.2.3		2	2.6	1.6.9	1.2.8		1		6.9	1-6.8.9
Mining	1.2.8	1	1.2.8	3.6.9	6.9			1.2.3		2	2.6	1.6.9	1.2.8		1		6.9	1-6.8.9
Construction	1.2.8	1	1.2.8	3.6.9	6.9			1.2.3					1.2.8				6.9	1-6.8.9
Food	1.2.8	1	1.2.8	3.6.9	6.9	5		1.2.3.5	1.2.3.6.9		2.3.6	1.5.6.9	1.2.8		1.5	2	6.9	1-6.8.9
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	2	2.3.6	1.5.6.7.9	1.2.7.8	4	1.5.7	2	6.9	1--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	2	2.3.6	1.5.6.9	1.2.8		1.5	2	6.9	1-6.8.9
Glass	1.2.8	1	1.2.8	3.6.9	6.9	5		1.2.3.5	1.2.3.6.9	2	2.3.6	1.5.6.9	1.2.8	4	1.5	2	6.9	1-6.8.9
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	2	2.3.6	1.5.6.7.9	1.2.7.8		1.5.7	2	6.9	1--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	2	2.3.6	1.5.6.7.9	1.2.7.8	4	1.5.7	2	6.9	1--9
Aluminum	1.2.8	1	1.2.8	3.6.9	6.9	5		1.2.3.5	1.2.3.6.9	2	2.3.6		1.2.8	4	1.5	2	6.9	1-6.8.9
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	2	2.3.6	1.5.6.9	1.2.8		1.5	2	6.9	1-6.8.9
Other Manufacturing	1.2.8	1	1.2.8	3.6.9	6.9	5		1.2.3.5	1.2.3.6.9			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	n/a	n/a	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 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).¹² 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.

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, expanded other OIT R&D programs, expanded ENERGY STAR and Climate Wise, 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 (Khrushch 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, 1998) 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. In aluminum to simulate increased recycling (Plunkert, 1997) is simulated by reducing production growth of primary aluminum 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 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 (Khrushch et al., 1999) and steel industries (Worrell et al., 1999).

Combined Heat and Power Production (CHP) ¹³ 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 model¹⁴ (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 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.¹⁵ 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).

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 13.0% 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 37.8 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. Carbon emissions are increasing to approximately 518 MtC, or a reduction of 10% relative to the reference scenario. The changes in carbon intensity are a bit stronger 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. The other energy intensive industries show a relative strong improvement rate over the reference scenario, mostly due to increased energy efficiency improvement. This results in a 8% 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 5% 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 higher carbon dioxide emission reductions.

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 34.3 Quads in 2020 (excluding CHP). Total industrial energy use in 2020 under the advanced scenario is about 16% lower than the reference scenario. Under the conditions in the advanced scenario overall industry energy intensity falls by 1.8%/year, of which 1.0%/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 408 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%/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 CO₂ 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 cap and trade system. This will lead to a 27% 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.

**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)**

Sector & fuel			2010					2020				
	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	1.5%	0.04	-68.6%	0.10	0.10	-0.8%	0.02	-80.3%
natural gas		0.54	0.45	0.40	-9.5%	0.38	-15.6%	0.39	0.34	-13.8%	0.34	-14.3%
coal		0.87	0.80	0.81	1.2%	0.76	-4.4%	0.78	0.79	0.5%	0.76	-3.1%
primary electricity		0.56	0.53	0.50	-4.7%	0.44	-17.0%	0.50	0.45	-10.7%	0.40	-21.3%
Total primary		2.09	1.88	1.83	-3.0%	1.61	-14.4%	1.78	1.68	-5.9%	1.51	-15.1%
Paper												
petroleum		0.12	0.11	0.10	-8.1%	0.08	-31.3%	0.10	0.08	-13.4%	0.07	-29.1%
natural gas		0.67	0.50	0.52	3.9%	0.36	-27.2%	0.43	0.51	20.5%	0.43	0.6%
coal		0.39	0.31	0.28	-9.9%	0.12	-60.8%	0.27	0.23	-15.0%	0.11	-60.3%
renewables		1.48	1.81	1.78	-1.5%	1.93	6.9%	2.00	1.92	-3.7%	2.18	9.3%
primary electricity		0.83	0.80	0.78	-3.3%	0.66	-17.7%	0.79	0.73	-7.7%	0.57	-27.8%
Total primary		3.50	3.54	3.46	-2.1%	3.16	-10.7%	3.58	3.48	-2.8%	3.36	-6.2%
Cement												
petroleum		0.04	0.04	0.03	-3.9%	0.04	7.8%	0.03	0.03	-7.2%	0.03	3.3%
natural gas		0.02	0.02	0.02	16.3%	0.03	105.9%	0.01	0.02	25.0%	0.03	119.1%
coal		0.32	0.32	0.30	-4.0%	0.24	-22.8%	0.31	0.29	-7.8%	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	-0.8%	0.09	-2.9%	0.09	0.09	-3.3%	0.08	-11.2%
Total primary		0.47	0.46	0.45	-2.6%	0.40	-12.2%	0.45	0.42	-5.9%	0.36	-20.0%
Other Energy-Intensive												
Petroleum		5.1	5.8	5.5	-5.2%	5.2	-10.0%	5.9	5.3	-11.3%	4.7	-20.2%
Natural gas		4.7	5.1	5.1	0.0%	4.9	-5.1%	5.6	5.6	0.7%	5.3	-4.8%
coal		0.2	0.2	0.2	-18.7%	0.1	-49.7%	0.2	0.1	-36.6%	0.1	-65.2%
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	-5.4%	2.5	-19.8%	3.2	2.8	-13.4%	2.2	-33.0%
Total primary		13.1	14.3	13.8	-3.6%	12.7	-10.9%	15.0	13.8	-7.7%	12.3	-17.9%
Non-Energy-Intensive												
Petroleum		3.0	3.8	3.6	-5.9%	3.5	-7.9%	4.2	3.8	-10.4%	3.6	-14.8%
Natural gas		4.8	5.8	5.4	-6.4%	5.2	-9.7%	6.4	5.7	-11.8%	5.3	-17.4%
coal		0.6	0.7	0.7	-6.7%	0.5	-26.7%	0.8	0.7	-11.6%	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	0.4%
primary electricity		6.7	7.6	7.4	-2.8%	6.9	-10.0%	8.2	7.8	-5.5%	6.8	-17.3%
Total primary		15.6	18.4	17.6	-4.6%	16.6	-9.8%	20.2	18.5	-8.6%	16.8	-17.1%
Total Industrial												
Petroleum		8.4	9.8	9.3	-5.4%	8.9	-10.0%	10.4	9.2	-10.9%	8.4	-18.6%
Natural gas		10.7	11.9	11.5	-3.3%	10.9	-8.5%	12.8	12.1	-5.3%	11.4	-11.1%
coal		2.4	2.4	2.2	-5.1%	1.8	-25.1%	2.4	2.1	-9.9%	1.7	-30.0%
renewables		1.9	2.3	2.3	-1.1%	2.4	5.5%	2.6	2.5	-2.6%	2.8	7.4%
primary electricity		11.3	12.2	11.8	-3.6%	10.6	-13.3%	12.9	11.8	-7.8%	10.0	-22.0%
Total primary	32.1	34.7	38.6	37.1	-3.9%	34.5	-10.6%	41.0	37.8	-7.6%	34.3	-16.4%

(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)**

Sector & fuel			2010						2020				
	1990	1997	BAU	Moderate		Advanced		BAU	Moderate		Advanced		
	MtC	MtC	MtC	MtC	%	MtC	%		MtC	%	MtC	%	
Iron and Steel													
Petroleum		1.93	1.72	1.74	1.3%	0.53	-69.4%	1.52	1.49	-1.9%	0.29	-81.1%	
natural gas		7.40	6.08	5.50	-9.6%	5.12	-15.7%	5.33	4.59	-13.8%	4.57	-14.3%	
Coal		21.61	20.25	20.49	1.2%	19.37	-4.3%	19.83	19.96	0.6%	19.21	-3.1%	
Electricity		8.63	8.72	7.79	-10.6%	5.76	-33.9%	8.53	7.18	-15.9%	4.55	-46.7%	
Total		39.56	36.76	35.52	-3.4%	30.78	-16.3%	35.21	33.21	-5.7%	28.62	-18.7%	
Paper													
Petroleum		1.99	1.65	1.52	-8.2%	1.11	-32.9%	1.43	1.22	-14.4%	0.97	-32.0%	
natural gas		9.19	6.84	7.10	3.9%	4.97	-27.3%	5.83	7.02	20.5%	5.86	0.6%	
Coal		9.75	7.95	7.17	-9.9%	3.12	-60.8%	6.82	5.80	-14.9%	2.70	-60.4%	
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	12.12	-9.3%	8.75	-34.5%	13.34	11.59	-13.1%	6.53	-51.0%	
Total		33.80	29.79	27.90	-6.3%	17.94	-39.8%	27.41	25.64	-6.5%	16.06	-41.4%	
Cement													
petroleum		0.59	0.54	0.52	-4.1%	0.57	5.3%	0.49	0.45	-8.3%	0.49	-1.0%	
natural gas		0.25	0.21	0.24	16.3%	0.43	105.5%	0.19	0.23	25.0%	0.41	119.1%	
coal		7.80	8.02	7.71	-3.9%	6.19	-22.7%	7.92	7.31	-7.7%	5.47	-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	
electricity		1.49	1.52	1.41	-6.9%	1.17	-22.7%	1.49	1.36	-9.0%	0.90	-39.8%	
total energy emissions		10.13	10.28	9.88	-3.9%	8.36	-18.7%	10.10	9.35	-7.4%	7.26	-28.0%	
process emissions		10.98	11.83	11.72	-0.9%	11.32	-4.3%	12.20	11.60	-5.0%	10.56	-13.4%	
Total		21.11	22.11	21.60	-2.3%	19.68	-11.0%	22.30	20.95	-6.0%	17.83	-20.1%	
Other Energy-Intensive													
petroleum		50.8	53.7	50.5	-6.0%	45.8	-14.8%	51.5	44.1	-14.4%	36.4	-29.3%	
natural gas		59.6	65.2	65.3	0.3%	61.7	-5.2%	70.8	71.7	1.3%	67.8	-4.3%	
coal		4.4	5.0	4.1	-18.7%	2.5	-49.6%	5.7	3.6	-36.6%	2.0	-65.2%	
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	46.8	-11.2%	33.7	-36.1%	54.5	44.4	-18.5%	24.7	-54.6%	
Total		162.6	176.6	166.7	-5.6%	143.7	-18.6%	182.6	163.9	-10.2%	130.9	-28.3%	
Non-Energy-Intensive													
petroleum		50.5	58.2	54.6	-6.1%	52.2	-10.2%	63.1	55.8	-11.6%	51.4	-18.5%	
natural gas		65.8	79.0	73.9	-6.4%	71.2	-9.8%	87.4	77.1	-11.7%	72.1	-17.5%	
coal		14.9	18.4	17.2	-6.6%	13.5	-26.6%	20.0	17.7	-11.5%	12.8	-35.9%	
renewables		0.0	0.0	0.0	N/A	0.0	N/A	0.0	0.0	N/A	0.0	N/A	
electricity		104.7	126.7	115.5	-8.8%	90.8	-28.4%	139.5	124.0	-11.1%	78.2	-44.0%	
Total		236.0	282.3	261.2	-7.5%	227.7	-19.3%	310.0	274.7	-11.4%	214.5	-30.8%	
Total Industrial													
petroleum		105.8	115.8	108.9	-6.0%	100.2	-13.5%	118.1	103.1	-12.7%	89.6	-24.1%	
natural gas		142.2	157.3	152.1	-3.3%	143.5	-8.8%	169.5	160.7	-5.2%	150.7	-11.1%	
coal		58.5	59.6	56.6	-5.0%	44.7	-25.0%	60.3	54.4	-9.8%	42.2	-30.0%	
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	183.6	-9.6%	140.1	-31.0%	217.4	188.6	-13.2%	114.9	-47.1%	
total energy emissions		482.1	535.7	501.2	-6.4%	428.5	-20.0%	565.3	506.8	-10.3%	397.4	-29.7%	
total process emissions		11.0	11.8	11.7	-0.9%	11.3	-4.3%	12.2	11.6	-5.0%	10.6	-13.4%	
Total		493.1	547.5	512.9	-6.3%	439.8	-19.7%	577.5	518.4	-10.2%	408.0	-29.4%	

(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. Bulk chemicals excludes feedstocks. The increased contribution of CHP is excluded in this analysis (see section 5.5.4).

Economic Intensities (Mbtu/\$-output (1987-\$) on a primary energy basis							
Scenario Sector	1997	Business-as-Usual		Moderate		Advanced	
		2010	2020	2010	2020	2010	2020
Refining	23.6	26.7	25.3	26.3	23.7	24.3	18.6
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	21.3	21.1	20.6
Bulk Chemicals	32.2	28.9	27.6	27.4	25.1	24.4	22.1
Glass	13.1	11.5	10.6	11.5	10.4	9.9	9.0
Cement	97.7	89.4	84.5	86.8	79.1	79.9	68.7
Iron & Steel	30.1	24.0	21.9	23.2	20.5	20.6	18.8
Aluminum	23.3	19.2	17.3	18.3	16.3	15.8	14.2
Agriculture	5.2	5.0	4.9	4.8	4.4	4.5	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	20.1	20.3	19.1
Metal Durables	2.0	1.8	1.6	1.7	1.4	1.5	1.2
Other Manufacturing	5.5	5.1	4.8	4.9	4.4	4.5	3.8
Total	8.7	7.4	6.7	7.1	6.2	6.6	5.5
Physical Intensities (MBtu/ton) on a primary energy basis							
Pulp & paper	33.9	28.4	26.4	27.7	25.5	25.3	24.7
Glass	17.2	15.2	14.1	15.2	13.9	13.1	12.0
Cement	4.7	4.6	4.0	4.1	3.8	3.8	3.3
Iron & Steel	20.2	18.2	14.5	15.5	14.2	13.7	12.4
Aluminum	125.3	105.7	93.1	98.1	85.8	84.9	76.5

Table 5.9 Annual Total Costs of Energy Services by Scenario in the Industrial Sector (B1997\$/year)

	1997	2010						2020					
		BAU		Moderate		Advanced		BAU		Moderate		Advanced	
		B\$/yr	B\$/yr	%	B\$/yr	%	B\$/yr	B\$/yr	%	B\$/yr	%	B\$/yr	%
<i>Total - Industry</i>													
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	99	-9%	101	-8%	115	103	-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 the industrial sector CHP potential 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. In the BAU scenario, 8.8 GW of new CHP is projected, based 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.

Table 5.10 Potential market penetration of industrial cogeneration for the years 2010 and 2020 for the Moderate and Advanced scenario.

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
Generated Electricity (TWh)	31	98	201	62	278	539
Net Fuel Used (TBtu)	112	463	947	223	1340	2560

In the moderate scenario, the projected additional CHP-capacity grows to approximately 16 GW by 2010 and 40 GW by 2020. This includes almost 4 GW of integrated black liquor gasification cogeneration. It is expected that expanded research and development will result in black liquor gasifier combined cycle technology by 2010, which will result in several demonstration projects by 2010 and an installed base of 1.2 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. Newly installed CHP increases industrial natural gas consumption by approximately 1.03 Quads, and 0.3 Quads of biomass by 2020. This offsets natural gas and other fossil fuel use in the power sector, and leads to net savings of primary energy. The savings depend on the replaced power generation capacity.

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. 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. Industrial natural gas use increases with 1.8 Quads, while biomass use increases by 0.75

Quads by 2020. This is offset by savings in fuel use for central power generation. In the advanced scenario, industrial CHP is likely to reduce total primary energy use over 1 Quad by 2020, reducing total U.S. CO₂ emissions by 1-1.5%, assuming mostly natural gas based power generation and some coal based capacity is replaced.

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 EAFs 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 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 (Khrushch 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 CO₂ 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 comprehensive set 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 with 1 Quad in 2020, and reduce GHG emissions accordingly. However, only an integrated CEF-NEMS model could quantify the potential impact. 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 of innovative technologies in energy modeling is an important topic that may need more attention.

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 CO₂ 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) in NEMS assumes no autonomous improvement trend in the baseline scenario. Only when energy prices increase over a specified threshold, energy intensity would 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 which are studied in detail in this study; steel (Worrell et al., 1999), cement (Martin et al., 1999) and paper (Khrushch 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 CO₂ 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 CO₂ 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 (-8%), 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 526 MtC (-9%) under the moderate, and 411 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 will reduce the primary energy consumption in some industrial sub-sectors further. 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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5.10 ENDNOTES

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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.

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 CO₂ emission at 138.3 kgC/tonne clinker (IPCC, 1996), which is equivalent to 125.4 kgC/ton clinker.

⁴ 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.

⁵ This compares to an average electricity consumption of EAFs of 436 kWh/ton steel in 1994 (Worrell et al., 1999).

⁶ Portland composite cement consists of 65% clinker, 30% additives, and 5% filler, as defined by the European cement standard ENV 197-2.

⁷ 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.

⁸ Plants are often re-built during the life-time, 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.

⁹ 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.

¹⁰ 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.

¹¹ 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.

¹² 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.

¹³ 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.

¹⁴ Distributed Power Economic Rationale Selection (DISPERSE) model.

¹⁵ 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.