Chapter 2

INTRODUCTION AND BACKGROUND[1]

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

2.1 BACKGROUND ON CLIMATE CHANGE

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

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

The Balance of Evidence on Climate Change

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

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

2.1.1 The Role of Carbon Dioxide

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

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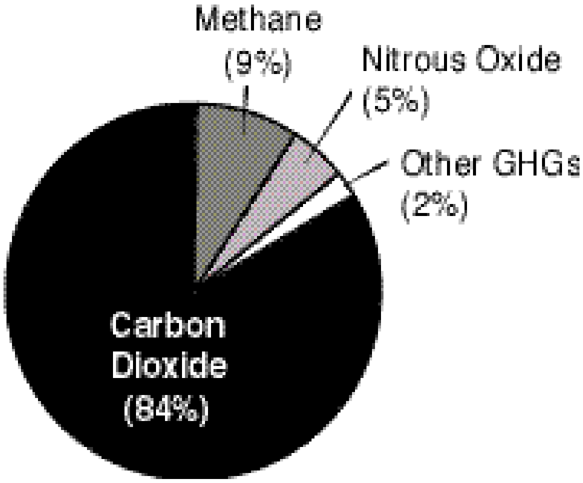
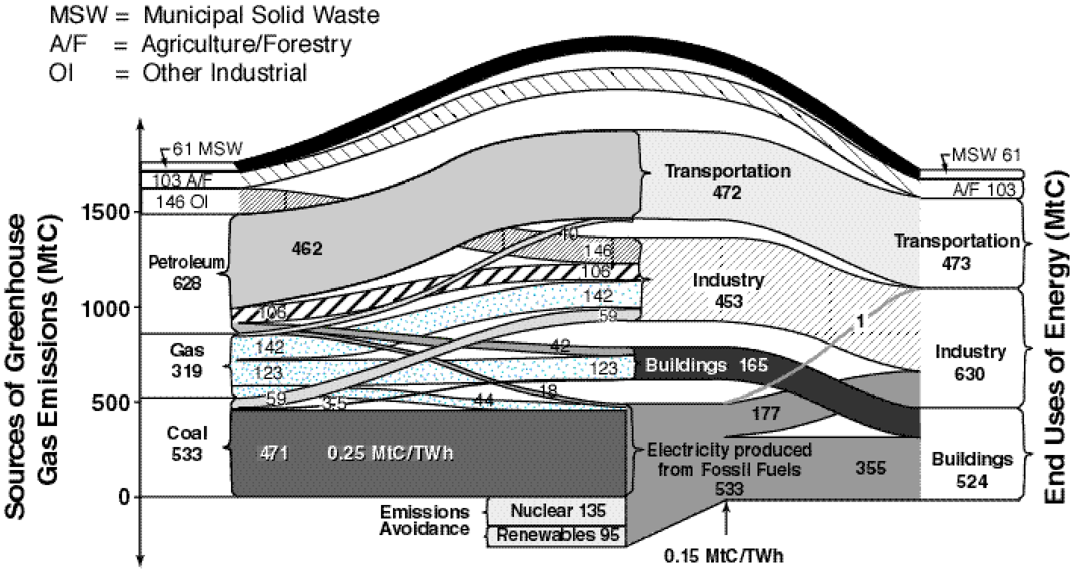
This report describes the greenhouse gas reduction benefits of its scenarios principally in terms of carbon emission reductions. Carbon dioxide units are converted into carbon units (i.e., million tonnes of carbon – MtC) by dividing by 44/12 or 3.67. This ratio is the molecular weight of carbon dioxide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

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



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

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



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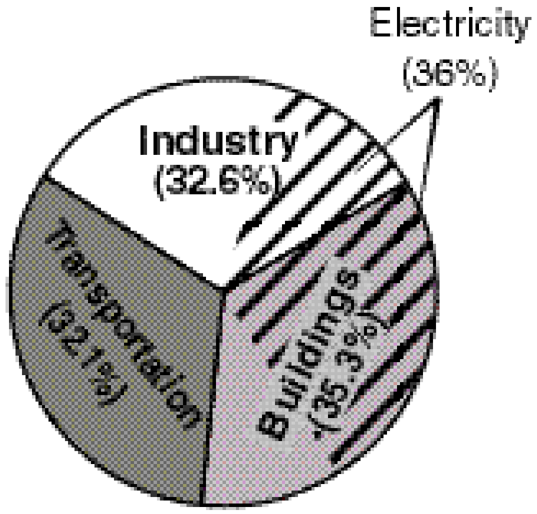
[2] This approach has been adopted for two reasons. First, carbon dioxide is most commonly measured in carbon units in the scientific community, in part because it is argued that not all carbon from combustion is, in fact, emitted in the form of carbon dioxide. Second, carbon units are more convenient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

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

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

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



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

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

Options for Reducing Atmospheric Carbon

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

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

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

Adaptation Strategies

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

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

2.1.2 Other Greenhouse Gas Emissions

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

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

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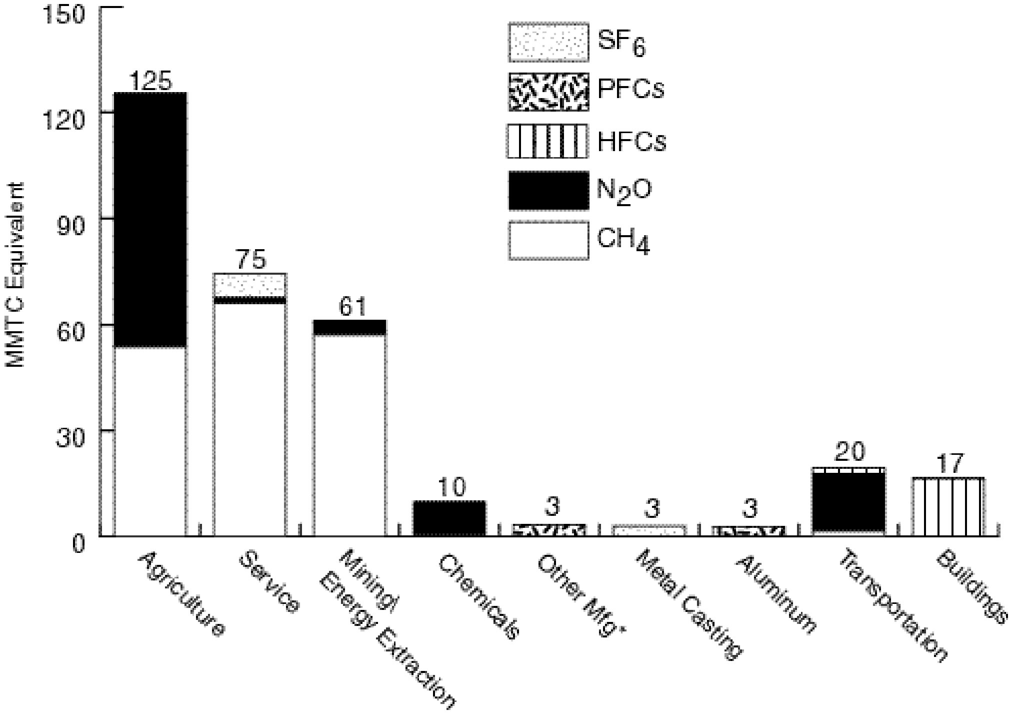
[3] Specifically, the GWP of a greenhouse gas is the ratio of global warming, or radiative forcing (both direct and indirect), from one unit mass of a greenhouse gas to that of one unit mass of carbon dioxide over 100 years.

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

Fig. 2.4 Emissions of Non-CO_2 Greenhouse Gases by End-Use Sector and Industry
[(Sources: EIA (1998b) Tables 15, 25, and 30, and pp. 54-56, and EPA (1999a) Table ES-11)]



*Mainly semiconductors

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

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

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

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

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

2.2 HISTORICAL ENERGY AND CO_2 *EMISSION TRENDS*

2.2.1 National Trends

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

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

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

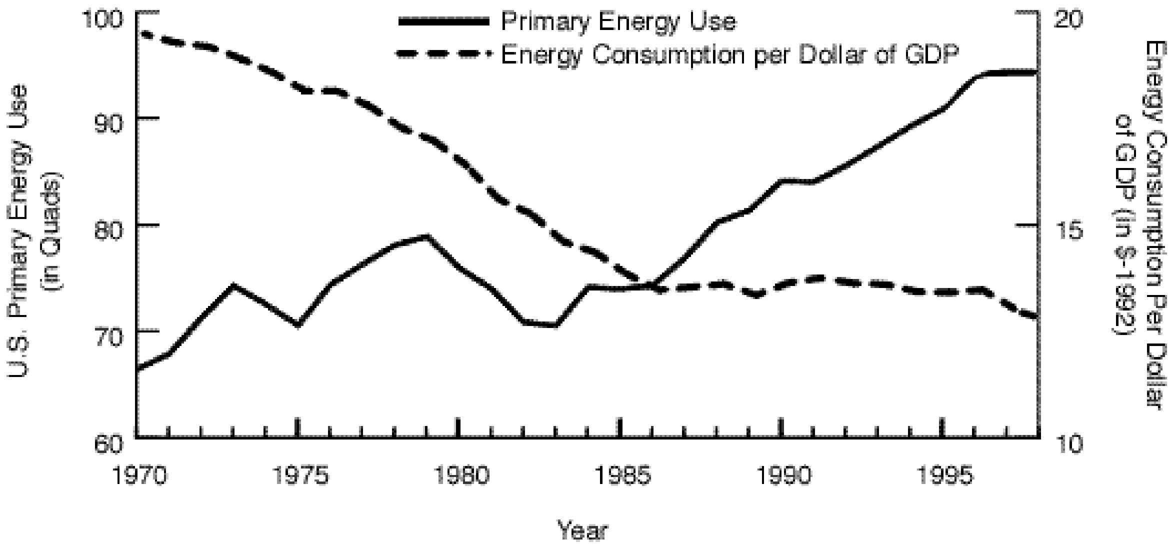
energy-conscientious period. Americans purchased more fuel-efficient cars and appliances, insulated and caulked their homes, and adjusted thermostats. Businesses retrofitted their buildings with more efficient heating and cooling equipment and installed energy management and control systems. Factories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

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

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

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

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



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

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

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

2.2.2 Sectoral Trends

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

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

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

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

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

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

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

Table 2.3 Historical Growth Rates: 1973-1997

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

AAGR = Average Annual Growth Rate

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

2.3 THE ENERGY EFFICIENCY GAP

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

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

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

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

2.3.1 Case Studies of Individual Technologies

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

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

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

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

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

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

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

2.3.2 What Accounts for the Energy Efficiency Gap?

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

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

Externalities and Public Goods

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

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

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

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

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

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

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

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

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

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

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

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

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

2.3.3 Sectoral Differences in Market Failures and Barriers

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

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

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

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

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

2.4 THE GOVERNMENT ROLE

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

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

2.4.1 Transaction Costs

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

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

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

2.4.2 Externalities and Public Goods

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

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

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

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

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

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

2.5 PAST ENERGY POLICY AND PROGRAM SUCCESSES

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

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

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

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

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

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

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

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

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

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

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

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

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

The policies and programs used here to illustrate past successes have been described primarily in terms of their energy benefits. Results reported in Elliott et al. (1997) and Laitner (1999) indicate that the total benefits – including both energy and non-energy savings – that accrue from so-called "energy-saving" projects can be much greater than those from the energy savings alone. In fact, based on numerous case studies, the authors conclude that the average total benefits received from "energy-saving" projects in industry are typically two to four times the value of the energy savings alone. Similarly, Romm and Ervin (1996) describe some of the public health benefits that have resulted from advances in energy-efficient technologies, such as clean air and water. Other collateral benefits include the productivity and product quality gains that have accompanied many investments in industrial efficiency improvements (Romm, 1994; Romm, 1999) and the growth in export markets for energy technologies. Because many non-energy impacts are difficult to monetize they are often excluded from cost/benefit calculations.

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