ELSEVIER

Energy Policy 29 (2001) 1197–1207

ENERGY POLICY

www.elsevier.com/locate/enpol

Market failures and barriers as a basis for clean energy policies ☆

Marilyn A. Brown*

Energy Efficiency and Renewable Energy Program, Oak Ridge National Laboratory, PO Box 2008, Oak Ridge, TN 37831-6186 USA

Received 12 April 2001

Abstract

This paper provides compelling evidence that large-scale market failures and barriers prevent consumers in the United States from obtaining energy services at least cost. Assessments of numerous energy policies and programs suggest that public interventions can overcome many of these market obstacles. By articulating these barriers and reviewing the literature on ways of addressing them, this paper provides a strong justification for the policy portfolios that define the "Scenarios for a Clean Energy Future," a study conducted by five National Laboratories. These scenarios are described in other papers published in this special issue of *Energy Policy*. © 2001 Elsevier Science Ltd. All rights reserved.

Keywords: Market failures; Efficiency gap; Clean energy

1. Background

Examination of energy trends following the 1973–74 oil embargo has highlighted the great strides in energy efficiency that have made the US 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, 2000; 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 analyses indicate the continued existence of a sizeable untapped reservoir of highly cost-effective investments that could have a significant impact on US energy use and greenhouse gas emissions.

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?

Energy markets are not unique in their imperfections. Other products and services face obstacles that hinder their adoption, even when their consumer economics appear to be favorable. Conditions hindering cost-effective investments in energy efficiency and clean energy resources have received considerable attention because of their widespread environmental, national security, and macroeconomic repercussions. The motivation behind the re-examination presented in this paper

☆ Several individuals provided valuable comments on this paper and Chapter 2 in the CEF study, which is summarized here. These include: Mary Beth Zimmerman (US Department of Energy, Office of Energy Efficiency and Renewable Energy), Marty Schweitzer and Dave Bjornstad (Oak Ridge National Laboratory), Jon Koomey (Lawrence Berkeley National Laboratory) and Skip Laitner (Environmental Protection Agency). Their insights are greatly appreciated.

*Tel.: +1-865-576-8152; fax: +1-865-241-0112.

E-mail address: brownma@ornl.gov (M.A. Brown).

0301-4215/01/$ - see front matter © 2001 Elsevier Science Ltd. All rights reserved.
PII: S0301-4215(01)00067-2

was to provide a foundation for the *Scenarios for a Clean Energy Future* (CEF) Study (Brown et al., 2001; Interlaboratory Working Group, 2000). The CEF study is a comprehensive assessment of policy opportunities to accelerate the market penetration of efficient and clean energy technologies. Understanding the barriers to this penetration was essential to defining potentially effective policies.

This paper provides 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 clean energy policies and programs.

2. The efficiency gap

The term "efficiency gap" refers to the difference between the actual level of investment in energy efficiency and the higher level that would be cost-beneficial from the consumer's (i.e., the individual's or firm's) point of view. The existence of this gap has been documented in many case studies.

2.1. 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.

Efficient magnetic ballasts for fluorescent lighting were commercially available as early as 1976. They were a well-tested technology, with performance characteristics equal to or better than standard ballasts by the early 1980s. 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 magnetic ballast paid back its investment in less than two years for virtually all commercial buildings (Koomey et al., 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.)

In a more general study of efficient lighting investments 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 the level of investments made in energy-efficient lighting projects. Impediments to these investments include capital rationing and lack of organizational rewards for energy managers who reduce utility bills.

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. The higher purchase price of the efficient model was presumably the principal barrier to its purchase.

To enable the use of remote controls for *televisions* in the early 1990s, it became necessary for televisions to consume some amount of power continuously. Typical televisions with remote controls at that time used 5–7 W of standby power for that purpose. The Energy Star television program was able to reduce these power losses by requiring that televisions qualifying for the Energy Star label must reduce standby power to three watts or less, a savings of roughly 50%. The resulting price increase had a payback period of 1–2 years for consumers. Because this saving was no more than a few dollars a year per television, there was no public outcry for manufacturers to deliver the improvement. At the same time, the aggregate savings to the nation of widespread market penetration was significant. Through the labeling program, the lack of consumer interest could be overcome. About ten major manufacturers now offer such televisions, and several of them have reduced standby losses to 0.5 W (Interlaboratory Working Group, 2000, Chapter 4).

Industrial motor systems represent the largest single end use of electricity in the American economy—23% of US 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 11–18% 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.

Table 1
Market failures and barriers inhibiting energy efficiency

Market failures	Market barriers
Misplaced incentives	Low priority of energy issues
Distortionary fiscal and regulatory policies	Capital market barriers
Unpriced costs	Incomplete markets for energy efficiency
Unpriced benefits	
Insufficient and inaccurate information	

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.

2.2. What accounts for the energy efficiency gap?

Numerous market failures and barriers contribute to the efficiency gap (Table 1). "Market failures" occur when there is a flaw in the way markets operate. They are conditions of a market that violate one or more of the neoclassical economic assumptions that define an ideal market for products or services such as rational behavior, costless transactions, and perfect information. Market failures can be caused by (1) misplaced incentives; (2) distortionary fiscal and regulatory policies; (3) unpriced costs such as air pollution; (4) unpriced goods such as education, training, and technological advances; and (5) insufficient and incorrect information (Jaffe and Stavins, 1994; IPCC, 1996). By failing to account for such market imperfections, assessments of energy policies and climate mitigation options based on neoclassical economic models underestimate their full range of potential benefit (Laitner et al., 2000).

It is widely argued by neoclassical economists that the existence of market failures is a prerequisite for market intervention. However, the existence of such failures is also seen as an insufficient justification for government involvement. Feasible, low-cost policies must be available that can eliminate or compensate for these market failures.

"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 US 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 emissions from fossil fuel combustion, it is important to understand the full range of obstacles to clean energy technologies. These include: (1) the low priority of energy issues among consumers, (2) capital market imperfections, and (3) incomplete markets for energy-efficient features and products.

The following sections discuss each of these failures and barriers.

2.3. Market failures

Misplaced incentives inhibit energy-efficient investments in each sector of the economy. This is typically labeled the "principal-agent problem" in the economics literature. This problem occurs when an agent has the authority to act on behalf of a consumer, but does not fully reflect the consumer's best interests. Examples of this failure are numerous. Architects, engineers, and builders, who generally seek to minimize first costs, select the energy technologies that homeowners and apartment dwellers must use. In this case, the consumer's best interest would be better met by selecting technologies based on life-cycle costs. Similarly, 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.

Lovins (1992) describes how typical fee structures for engineers and architects cause incentives to be distorted, thereby penalizing efficiency. Interviews with more than fifty design professionals and analysts showed that the prevailing fee structures of building design engineers are based on a percentage of the capital cost of the project. Such fee structures are pernicious because additional first costs are typically needed to enable the installation of superior heating, ventilation, and air-conditioning systems that reduce operating costs. These additional expenditures beyond the typical "rule-of-thumb" equipment sizing used by most engineers result in a net penalty for designers of efficient systems. Even though this type of fee structure has been strongly discouraged in the United States since the early 1970s, both the designer and procurer of design services still generally base their fee negotiation on percentage-of-cost curves.

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, new car purchasers have a dominant influence on the design decisions of automakers and are not representative of the driving public, many of whom purchase their vehicles secondhand. In particular, new car purchasers are substantially wealthier than average drivers, which skew their purchase preferences away from fuel economy and towards ride quality, power, and other vehicle qualities.

Another example of misplaced incentives is the landlord-tenant relation in the buildings sector. 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. About 90% of all households in multifamily buildings are renters, which makes misplaced incentives particularly problematic in this segment of the market.

Distortionary fiscal and regulatory policies can also restrain the use of efficient and clean energy technologies. A range of these distortionary policies was recently identified in an analysis of 65 projects aimed at installing distributed generation (Alderfer et al., 2000). Distributed generation is modular electric power located close to the point of use. It includes environmentally-friendly renewable energy technologies such as wind turbines and photovoltaics, as well as fossil-fuel technologies such as reciprocating engines, 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 permitting requirements 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.

An example of a distortionary fiscal policy is the tax treatment of capital versus operating costs. US tax rules require capital costs for commercial buildings and other investments to be depreciated over more than 30 years, whereas operating costs can be fully deducted from taxable income. Since efficient building technologies typically cost more than standard equipment on a first-cost basis, this tax code penalizes efficiency (Lovins, 1992). Similarly, many states are uneven in their sales tax policies. In 1990, twelve states charged sales taxes on residential energy-saving devices but not on residential fuels and electricity; only one state did the opposite (Koomey, 1990).

Electricity pricing policies of State legislatures and regulatory commissions also prevent markets from operating efficiently and subdue incentives for energy efficiency. The price of electricity in most retail markets today is not based on time of use. It therefore does not reflect the real-time costs of electricity production, which can vary by a factor of ten within a single day (Hirst and Kirby, 2000). Because most customers buy electricity as they always have—under time-invariant prices that are set months or years ahead of actual use—consumers are not responsive to the price volatility of wholesale electricity. Time-of-use pricing would encourage customers to use energy more efficiently during high-price periods. Metering, communications, and computing technologies are needed to support such dynamic pricing and voluntary-load-reduction programs. The cost of designing and installing this infrastructure represents another potential barrier to real-time pricing. While this might be cost prohibitive for some customers, the cost of this infrastructure would likely not be a barrier to many larger retail customers.

Unpriced costs include a range of negative impacts from the discovery, extraction, production, distribution, and consumption of fuels and power. A strong case can be made that energy fuels are underpriced, because market prices do not take full account of a variety of social costs associated with fuel use. Fossil energy using today's conversion technologies produces a variety of unpriced costs (or negative externalities) including greenhouse gas emissions; air, water, and land pollution; and oil supply vulnerabilities associated with the need to import oil and the uneven geographic distribution of petroleum resources.[1] As a result of these unpriced costs, more fossil energy is consumed than is socially optimal.

Negative externalities associated with fossil energy combustion can be "internalized" through policy interventions. 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 the CEF study.

Existing environmental control costs are embedded in some energy costs. For instance, the US Environmental Protection Agency (EPA) regulations enforcing the Clean Air Act and other Federal legislation impose control costs on the marginal emitter of criteria pollutants like SO_2 and NO_x. However, not all existing fossil generators incur operating cost penalties. Furthermore, there are several emissions produced by fossil fuel combustion that are not capped today. These include

[1] 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.

carbon, mercury, and smaller particulates (2.5 μm). No costs are currently included to account for damages from these pollutants. Because energy prices do not include the full cost of environmental externalities, they understate the societal cost of fossil energy use based on today's combustion technologies.

Unpriced (public) goods also dampen the energy productivity of the economy. A public good is a 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 "non-excludability." Because public goods are unpriced, markets tend to under produce them. 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 public goods nature of education, training, and research is an important rationale for government support. Investments by employers in creating a well-educated, highly trained workforce, for instance, are dampened because of the firm's inability to ensure that the employee will work long enough for that firm so as to repay its costs. The difficulties of selecting and installing new energy-efficient equipment compared to the simplicity of buying energy may prohibit many cost-effective investments from being realized. This is a particularly strong barrier for small and medium-sized enterprises (Reddy, 1991). In many firms (especially with the current trend towards *lean* firms) there is often a shortage of trained technical personnel (Office of Technology Assessment, US Congress, 1993). Government programs that pay university engineering faculty and students to conduct energy audits of industrial plants can overcome this barrier by training the next generation of energy professionals while delivering energy diagnostics and audit recommendations to plant managers (Martin et al., 1999).

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 payback from advances in energy-efficient and clean energy technologies is not only experienced by the sponsoring company, but also flows to the public, to the company's competitors, and to other parts of the economy. The problem is especially pronounced when an industry is as fragmented as the construction and homebuilding industries (Brown, 1997; Oster and Quigley, 1977). Fragmentation is also a problem in the commercial buildings sector, with the design and engineering of buildings split between many small firms.

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. The problem is particularly difficult in the newly restructured electric sector, where R&D funding has decreased dramatically. Companies will not fund the optimal societal level of basic R&D of new technologies, since many of the benefits of such research will flow to their competitors and to other parts of the economy. This is true of many industries, and is one of the main rationales for government-funded long-term, pre-competitive research in industries that have a vital role in the US economy.

A report by the Council of Economic Advisers (CEA, 1995) estimated that the private returns from RD&D are 20–30%, 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).

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 (Office of Technology Assessment, US Congress, 1993; Levine et al., 1995).

For example, residential consumers get a monthly electricity bill that provides no breakdown of individual end-uses. 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.

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. Reliable information on the marginal cost of fuel economy may be obtainable, but the effort required for an individual consumer to secure such information could be prohibitive.

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 into a higher resale value for the building. The complexities of decision making is one form of transaction cost.

Note, however, that if consumers were extremely concerned about life-cycle energy savings and determined to base their purchasing decisions on them, product manufacturers would have a strong incentive to provide consumers with better information about energy efficiency and with clearer tradeoffs. It can be argued that the lack of such information and choices is simply the consequence of consumer disinterest in using energy efficiently…the first of several market barriers discussed below.

2.4. Market barriers

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 US energy system 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.

In most cases, energy is a small part of the cost of owning and operating a building, a factory, or a car. Of course, there are exceptions. For low-income families, the cost of utilities to heat, cool, and provide other energy services in their homes can be a very significant part of their income–averaging 15% compared to 4% for the typical US citizen (Berry et al., 1997). For energy-intensive industries such as aluminum and steel, energy can represent 10–25% of their production costs. In these cases, energy costs may be a major concern, but other constraints, operate as important barriers to energy efficiency.

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 emissions savings can be important when summed across all consumers. This is one reason 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 reductions that rapidly propagate through the economy due to falling production costs as market shares increase (Arthur, 1990).

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 virtually 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; Levine et al., 1995). 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. 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. 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. Such 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 hurdle rates that are much higher than the cost of capital, especially for small projects (Ross, 1986).

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 option 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.

2.5. Sectoral differences in market failures and barriers

Each end-use sector functions differently in the US 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 all 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 purchasing 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 is used. For example, cars, lighting, and air conditioners turn over more quickly than industrial boilers. There are also differences in fuel flexibility. The US 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 building 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, NO_x, and particulate matter since most of the energy consumed in buildings is fossil-generated electricity. This is yet one more reason why the public policies and programs examined in the *Scenarios for a Clean Energy Future* are customized specifically to meet the needs of each sector.

3. 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. For each of the four major sectors of the economy, the CEF study 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.

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 with the maximum cost-effective level of energy efficiency could 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.

The public goods nature of R&D can be addressed through direct government funding. 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. US 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 US 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 road mapping, collaborative priorities for the development of advanced energy-efficient and low-carbon technologies, and cost sharing.

4. Past energy policy and program successes

Many different types of policies and programs comprise the policy implementation pathways that are analyzed in "Scenarios for a Clean Energy Future." 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. The following sampling of policy successes provides further evidence that energy-use decisions are not made in efficient markets. Further, they verify that policy mechanisms exist that can eliminate, reduce, or compensate for market imperfections.

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 (GAO, 1996), 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,[2] and annual greenhouse gas emissions reductions to be 16 MtC equivalent (Table 2).

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 5050 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,

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

Table 2
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	28.7	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.

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.

Government-run *voluntary and technical assistance programs* have strongly stimulated the adoption of many cost-effective, energy-efficient technologies, thereby narrowing the efficiency gap. The voluntary programs of the EPA have amassed detailed 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 that are highly cost-effective but were not adopted by manufacturers until EPA launched the Energy Star Program. (This program is now operated jointly with the US Department of Energy.) 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.

In addition to working with manufacturers, voluntary and technical assistance programs have also transformed markets for energy efficiency by publicizing trendsetting consumers. Using a "share capture" model, Horowitz et al. (2000) estimate that 40% of the rapid growth of electronic ballasts in the 1990's can be attributed to EPA's Green Lights Partnerships and other market transformation programs. These programs encourage building owners and operators to install high-efficiency lighting products by certifying the performance of the technology and publicizing the "green" choice made by program partners.

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 (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, 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, 1996). 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), Romm (1994, 1999) and Laitner and Finman (2000) 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 a review of 25 manufacturing case studies, Laitner and Finman (2000) conclude that the average non-energy benefits received from "energy-saving" projects in industry are typically equivalent to the value of the energy savings alone. As a result, the average payback from these investments falls from four years when only energy savings are included in the analysis, to less than two years when both energy and non-energy savings are included. Non-energy ''co-benefits'' include public health benefits from cleaner air and water (Romm and Ervin, 1996) as well as improved comfort of building occupants and increased labor productivity. Because many non-energy impacts are difficult to monetize they are often excluded from cost/benefit calculations.

5. Conclusions

Homes, offices, factories, cars, and trucks are rarely built to use energy efficiently, despite the sizeable costs that inefficient designs impose on consumers and the nation. The evidence of this efficiency gap is compelling, and the reasons for it are numerous. Statistical analysis and case studies underscore the widespread existence of this gap and the array of different market obstacles that cause it. By improving our understanding of these obstacles, it may be possible to design more effective policy interventions and to explain their rationale to the public. Past policy successes show that at least some of the energy-efficiency gap can be successfully addressed by policy initiatives. This optimism is the basis of the *Scenarios for a Clean Energy Future*, which examines the impacts of more than 50 public policies and programs designed to accelerate the penetration of energy-efficient and clean energy technologies. The considerable breadth and depth of the policies modeled in the CEF study reflect the wide-ranging diversity of market imperfections and barriers that hinder energy efficiency throughout the economy.

References

Alderfer, R.B., Eldridge, M.M., Starrs, T. J., 2000. Making connections: case studies of interconnection barriers and their impact on distributed power project. National Renewable Energy Laboratory, Golden, CO, NREL/SR-200-28053, May.

Arthur, W.B., 1990. Positive feedbacks in the economy. Scientific American 92–99.

Berry, L.G., Brown, M.A., Kinney, L.F., 1997. Progress Report of the National Weatherization Assistance Program. Oak Ridge, TN, Oak Ridge National Laboratory, ORNL/CON-450.

Brown, M.A., 1993. The effectiveness of codes and marketing in promoting energy-efficient home construction. Energy Policy 21 (2), 391–402.

Brown, M.A., 1997. Energy-efficient buildings: does the marketplace work? In: Proceeding of the 24th Annual Illinois Energy Conference. University of Illinois Press, Chicago, Illinois, pp. 233–255.

Brown, M.A., Mihlmester, P.E., 1995a. Actual vs. anticipated savings from DSM programs: an assessment of the California experience. Proceedings of the 1995 International Energy Program Evaluation Conference, 1995, pp. 295–301.

Brown, M.A., Mihlmester, P.E., 1995b. What Has Demand-Side Management Achieved in California? Proceedings: Delivering Customer Value (7th National Demand-Side Management Conference), EPRI TR-105196, June, 1995, pp. 229–234.

Brown, Marilyn, A., Mark, D. Levine, Walter Short, Jonathan G. Koomey., 2001. Scenarios for a clean energy future. Energy Policy 29(14), 1179–1196.

Council of Economic Advisers (CEA). 1995. Supporting Research and Development to Promote Economic Growth: The Federal Government's Role. Council of Economic Advisers, Washington, DC, October.

DeCanio, S.J., 1998. The efficiency paradox: bureaucratic and organizational barriers to profitable energy-saving investments. Energy Policy 26 (5), 441–454.

DeCanio, Stephen, 1993. Barriers within firms to energy-efficient investments. Energy Policy 21(9), 906.

Elliott, R.N., Laitner, S., Pye, M., 1997. Considerations in the estimation of costs and benefits of industrial energy efficiency projects. Presented at the Thirty-Second Annual Intersociety Energy Conversion Engineering Congress, Honolulu, HI, July 27–August 1, Paper # 97–551.

Environmental Protection Agency, 1999. Driving investment in Energy Efficiency: Energy Star and Other Voluntary Programs, US Environmental Protection Agency, Washington, DC, June.

Geller, H., McGaraghan, S., 1996. Successful Government–Industry Partnership: The US Department of Energy's Role in Advancing Energy–Efficient Technologies. American Council for an Energy Efficient Economy, Washington, D.C.

Geller, H., Thorne, J., 1999. US Department of Energy Office of Building Technologies: Successful Initiatives of the 1990s. American Council for an Energy-Efficient Economy, Washington, DC.

General Accounting Office (GAO), 1996. DOE's Success Stories Report, Washington, DC, General Accounting Office, GAO/RECD-96-120R.

Greening, L.A., Sanstad, A.H., McMahon, J.E., 1997. Effects of appliance standards on product price and attributes: an hedonic pricing model. The Journal of Regulatory Economics 11(2), 181–194.

Hassett, K.A., Metcalf, G.E., 1993. Energy conservation investment, do consumers discount the future correctly? Energy Policy 21, 710–716.

Hausman, J.A., 1979. Individual discount rates and the purchase and utilization of energy-using durables. Bell Journal of Economics 10 (1), 33.

Hirst, E., Brown, M.A., 1990. Closing the efficiency gap: barriers to the efficient use of energy. Resources, Conservation and Recycling 3, 267–281.

Hirst, E., Kirby, B., 2000. Retail-Load Participation in Competitive Wholesale Electricity Markets. Report prepared for Edison Electric Institute, Washington, DC.

Horowitz, M.J., Lewis, K., Coyle, A., 2000. . Green Lights and Blue Sky: Market Transformation Revealed, 2000 ACEEE Summer Study on Energy Efficiency in Buildings, Vol. 6. American Council for an Energy-Efficient Economy, Washington, DC.

Intergovernmental Panel on Climate Change (IPCC). 1996. Climate Change 1995. In: J.T. Houghton, L.G. Miera Filho, B.A. Callander, N. Harris, A. Kattenberg, K. Maskell (Eds.), The Science of Climate Change. Cambridge University Press, Cambridge, UK.

Interlaboratory Working Group. 2000. Scenarios for a Clean Energy Future, Lawrence Berkeley National Laboratory, Berkeley, CA (LBNL-44029), National Renewable Energy Laboratory, Golden, CO (NREL-xxx), and Oak Ridge National Laboratory, Oak Ridge, TN (ORNL/CON-476), November, http://www.ornl.gov/ORNL/Energy_Eff/CEF.htm.

Jaffe, A.B., Stavins, R.N., 1994. The energy-efficiency gap. Energy Policy 22 (10), 804–810.

Koomey, J., 1990. Energy Efficiency in New Office Buildings: An Investigation of Market Failure and Corrective Policies, Ph.D. dissertation. University of California, Berkeley.

Koomey, J., Sanstad, A.H., Shown, L.J., 1996. Energy-efficiency lighting: market data, market imperfections, and policy success. Contemporary Economic Policy 14(3), 98–111.

Laitner, J.A., Finman, H., 2000. Productivity Benefits from Industrial Energy Efficiency Investments. A monograph prepared for the EPA Office of Atmospheric Programs, Washington, DC.

Laitner, J.A., DeCanio, S.J., Peters, I., 2000. Incorporating Behavioral, Social and Organizational Phenomena in the Assessment of Climate Change Mitigation Options. Presented at the IPCC Expert Meeting on Conceptual Frameworks for mitigation Assessment from the Perspective of Social Science, Karlsruhe, Germany, pp. 21–22.

Levine, M.D., Sonnenblick, R., 1994. On the assessment of utility demand-side management programs. Energy Policy 22(10), 848–866.

Levine, M.D., Koomey, J.G., McMahon, J.E., Sanstad, A., Hirst, E., 1995. Energy Efficiency Policy and Market Failures. Annual Review of Energy and the Environment 20, 535–555.

Lovins, A., 1992. Energy-Efficient Buildings Institutional Barriers and Opportunities. Strategic Issues Paper, E-Source, Boulder, CO.

Mansfield, E., 1994. The Contributions of New Technology to the Economy," Conference on the Contributions of Research to the Economy and Society. American Enterprise Institute, Washington, DC, October 3.

Martin, M., Tonn, B., Schmoyer, R., Overly, J., Schexnayder, S., Johnson, D., 1999. Industrial Assessment Center Program Impact Evaluation, ORNL/CON-473. Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Meier, A., Whittier, J., 1983. Consumer discount rates implied by purchases of energy-efficient refrigerators. Energy 8(12), 957–962.

National Academy of Sciences. 1992. Policy Implications of Greenhouse Warming: Mitigation, Adaptation, and the Science Base. National Academy Press, Washington, DC.

National Energy Program Evaluation Conference. 1999. Evaluation in Transition: Working in a Competitive Energy industry Environment. Omni Press, Madison, WI.

National Science Foundation (NSF). 2000. Data Brief: US Industrial R&D Performers Report Increased R&D in 1998. National Science Foundation, Arlington, VA, NSF 00-320.

Office of Technology Assessment (OTA), US Congress. 1991. Changing by Degrees: Steps to Reduce Greenhouse Gases, OTA-0-482. US Government Printing Office, Washington, DC.

Office of Technology Assessment, US Congress, 1993. Industrial Energy Efficiency, US Government Printing Office, Washington, DC, USA.

Oster, S.M., Quigley, J.M., 1977. Regulatory barriers to the diffusion of conservation: some evidence from building codes. Bell Journal of Economics 8 (2), 361–377.

Parfomak, P., Lave, L., 1996. How many kilowatts are in a megawatt? Verifying ex post estimates of utility conservation impacts at the regional scale. The Energy Journal 17(4), 59–60.

Reddy, A.K.N., 1991. Barriers to Improvements in Energy Efficiency. Energy Policy 19, 953–961.

Romm, J.J., 1994. Lean and Clean Management. Kodansha America Inc., New York.

Romm, J.J., 1999. Cool Companies: How the Best Companies Boost Profits and Productivity by Cutting Greenhouse Gas Emissions. Island Press, Covelo, CA.

Romm, J.J., Ervin, C.A., 1996. How energy policies affect public health. Public Health Reports 5, 390–399.

Ross, M., 1990. Capital Budgeting Practices of Twelve Large Manufacturers. In: Philip Cooley, (Ed.), Advances in Business Financial Management. Dryden Press, Chicago, pp. 157–170.

Ross, M.H., 1986. Capital budgeting practices of twelve large manufacturers. Financial Management, 1986, pp. 15–22.

Ruderman, H., Levine, M.D., McMahon, J.E., 1987. The behavior of the market for energy efficiency in residential appliances including heating and cooling equipment. The Energy Journal 8 (1), 101–123.

Sanstad, A.H., Blumstein, C., Stoft, S.E., 1995. How high are options values in energy efficiency investments? Energy Policy 23, 739–743.

Sassone, P.G., Martucci, M.V., 1984. Industrial energy conservation: the reasons behind the decisions. Energy 9, 427–437.

Tellus Institute. 1997. Policies and Measures to Reduce CO_2 Emissions in the United States: An Analysis of Options for 2005 and 2010, Tellus Institute, Boston, Massachusetts.

US Department of Energy, Office of Energy Efficiency and Renewable Energy (DOE/EE). 2000. Clean Energy Partnerships: A Decade of Success. DOE/EE–0213. US Department of Energy, Washington, DC, March 2000.

US Department of Energy (DOE), Office of Policy. 1996a. Corporate R&D in Transition, U.S. Department of Energy, Washington, DC, March.

US Department of Energy (DOE), Office of Policy and International Affairs. 1996b. Policies and Measures for Reducing Energy Related Greenhouse Gas Emissions. DOE/PO–0047. US Department of Energy, Washington, DC, July.

US Department of Energy, Secretary of Energy Advisory Board (DOE/SEAB). 1995. Task Force on Strategic Energy Research and Development, Annex 3, Department of Energy, Washington, DC, US, June.

Xenergy, Inc. 1998. United States Industrial Electric Motor Systems Market Opportunity Assessment. Xenergy Inc.,Burlington, MA, December, http://www.motor.doe.gov/pdfs/mtrmkt.pd.