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Markets for Energy Efficiency

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PREFACE

The Energy Modeling Forum (EMF) was established in 1976 at Stanford University to provide a structural framework within which energy experts, analysts, and policymakers could meet to improve their understanding of critical energy problems. The thirteenth EMF study, "Markets for Energy Efficiency," was conducted by a working group comprised of leading international energy analysts and decisionmakers from government, private companies, universities, and research and consulting organizations. The EMF 13 working group met four times between September 1992 to March 1994 to discuss key issues and analyze markets for energy efficiency.

This report summarizes the discussions of the working group study. Inquiries about the study should be directed to the Energy Modeling Forum, 406 Terman Engineering Center, Stanford University, Stanford, California 94305, USA (telephone: (415) 723-0645; Fax: (415) 723-4107). Our web site address is: http://www-leland.stanford.edu/group/EMF.

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EMF's Senior Advisory Panel continues to offer valuable advice on topics as well as comments and suggestions for improving EMF reports. We would also like to acknowledge Amy Craft, Blake Johnson, Edith Leni, Frank Siereveld, and Susan Sweeney for their assistance in the production of this report.

This volume reports the findings of the EMF working group. It does not necessarily represent the views of Stanford University, members of the Senior Advisory Panel, or any organizations providing financial support.

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EXECUTIVE SUMMARY

The threat of global climate change has thrust energy efficiency to the forefront of energy and environmental policy debates. National governments have proposed a variety of programs--taxes, standards, and voluntary conservation--to realize further energy savings.

The merits of policies for promoting more energy efficient equipment (defined as energy efficiency in this report) have been intensely debated. Technology-based evaluations are often optimistic about what can be achieved; economic-based analyses are often more cautious about how much conservation is really cost effective. Central to this debate has been the energy-efficiency "gap" or paradox: consumers appear to be underinvesting in promising technologies that would reduce energy use. Various studies have attempted to measure this gap by defining an economic potential for energy conservation, as the expected energy savings that would be cost effective with current or projected market conditions.

The thirteenth Energy Modeling Forum (EMF) working group, comprised of some 50 members from business, government, and academia, met four times between September 1992 and March 1994 to discuss energy conservation. This group defined the important issues, developed the study plan, analyzed the results, and summarized the key findings. Proprietors of 10 different models of energy equipment efficiency and demand used their respective models to simulate a half dozen different scenarios based upon standardized assumptions. The comparison of model results guided the larger group's discussion about important issues and differences of views that influence energy conservation. The group also integrated other research and analysis on the nature of the "gap" that contributed to an understanding of the policy issues.

Trends in Aggregate Energy Intensity

The results from a number of different models led to several key conclusions about the prospects for future U.S. energy demand growth in the absence of major new programs:

- Energy demand is likely to grow, but more slowly than gross domestic product, resulting in declining aggregate energy intensity for the economy. Whether policy should try to accelerate this trend is a controversial issue.

- Projected trends across the range of models considered here show aggregate energy demand growing by from 0.8% to 1.3% per year more slowly than gross national product. As with any projection, these results depend significantly upon the underlying assumptions about energy prices and about growth in population, floor space, key energy-intensive industries, and vehicle miles traveled.

- Activity-related factors such as the relative growth in households and commercial floor space as well as shifts in the composition of energy-using activities within an end-use sector account for most of this decline in energy intensity.

- Further improvements in the energy efficiency of new buildings and equipment above 1990 levels contribute well less than half of the total effect. Thus, policies directed solely at improving equipment efficiencies, such as standards and many utility rebate programs, are limited in scope because they address only one of several important mechanisms through which nations experience declining energy intensity trends economywide. Other important factors for influencing energy intensity trends include energy prices, capital costs, and the composition of goods and services and the types of household activities.

• Factors other than energy prices, which rise about 1% per year above inflation in the baseline, have the most influence on these projected trends. Declines in the aggregate energy intensity for the economy, unrelated to energy prices, range from 0.6% to 1.0% per year in these projections. These estimates are based upon an end-use engineering analysis of individual technologies and specific assumptions about economic growth in the economy and activity growth in various end-use sectors. The resulting declines appear consistent with assumptions about "autonomous energy efficiency improvements" commonly used in many more aggregate economic models for evaluating global climate change policies.

Prices and Energy Savings

Higher expected energy prices increase the value of future energy savings, justifying expenditures on energy-efficiency options with higher initial costs. In addition to adopting more energy-efficient equipment, consumers and industry will respond to higher energy prices by adjusting the rate at which they use existing equipment (e.g., miles traveled) or by shifting toward activities that use relatively less energy.

The models indicate that energy demand would fall by only 3 to 8% after 20 years with a 25% increase in delivered energy prices. These estimates appear to be less than half of previous estimates derived from the experiences of the 1970s. This range applies generally to each end-use sector, although the higher estimates occur in the industrial and transportation sectors.

Members of the working group disagreed on whether the above estimates accurately describe the opportunities for reducing energy consumption. If the demand response to price is indeed lower than previously thought, taxes, emissions charges, and other policies that raise energy prices would obviously have a more modest impact on future energy use. However, other policies that restrict energy use directly without increasing energy prices are also likely to be costly under these conditions. The cause of a lower demand response in these models results from the adoption costs increasing significantly as consumers consider additional conservation measures.

Under these conditions, several other important implications also follow:

• The failure of energy prices to incorporate pollution and other external costs would cause only modest overuse of energy, unless these price distortions are very large.

• Policies mandating increased energy efficiency would be costly unless it can be confidently shown that they also eliminate important market failures. Most studies of such policies seldom address these unmeasured costs directly.

Given the important implications of this finding for both price and nonprice energy policies, it is important to focus future research on whether and how the response of energy demand to price has changed over the last decade or two and what factors account for any observed changes. There is a critical need for further analyses, including statistical estimates, to either confirm or refute the energy demand responses represented in these models.

Market Barriers and Failures

There exists little agreement on what should be the role of government in promoting energy efficiency. Some working group members who advocate cautious policy intervention think that information problems are restricted to specific situations. Furthermore, analyses indicating large energy efficiency potential are too dependent upon unjustifiably low discount rates and the omission of important hidden costs. Others who would favor more aggressive policies view information as a systemic problem found in "normal" markets, find little direct evidence of important hidden costs, and consider high inferred discount rates as direct evidence of improperly working markets.

Despite these sharp differences, however, there emerged a somewhat unexpected common ground on certain key issues:

• Obstacles to investment (market barriers) are widespread and exist in all markets, including energy.

• Some market barriers (market failures) prevent markets from allocating available resources efficiently and hence justify government intervention; other barriers represent the cost of conducting business in any market and hence do not require intervention.

• Scarce information is not a market failure, but under certain conditions markets will not provide information efficiently to the appropriate decisionmaker, creating the principal source of market failures that account for the "gap" in energy-efficient investments.

• Where cost effective, policy might address other market failures unrelated to the "gap", e.g., divergence of average and marginal pricing in utilities, energy security, and environmental externalities.

Estimates of Energy Conservation Potential

There are alternative concepts of the potential for energy conservation, contributing to wide differences in reported estimates.

• The potential for any particular year measures the gap between a benchmark energy use and some lower energy use level that would be possible if certain conditions prevail.

• The benchmark for measuring improvements in energy efficiency is extremely important. Most studies use a future-year benchmark that allows future declines in energy intensity, based upon the gradual replacement of old equipment and upon expected economic and demographic trends without any major new policy initiatives. Improvements in new equipment efficiency due to energy prices and technology can be either incorporated in the benchmark or disallowed by "freezing" equipment efficiencies at current levels.

• A few studies use current energy use as a benchmark. This practice does not allow the benchmark's energy intensity to decline. Estimates of the conservation potential based upon such a benchmark are significantly higher than in other studies.

• Technical potential refers to the maximum possible conservation irrespective of costs. Although it may be a useful benchmark, this concept is not appropriate for evaluating the respective costs and benefits of different policy options.

• Techno-economic potential refers to the maximum conservation that would be cost effective, given expected energy prices, the costs of purchasing, installing, and maintaining new energy-efficient equipment, and assumptions about how consumers evaluate future energy savings.

• In addition to the costs of the technologies, the economic potential should also reflect the costs associated with any market barriers that cannot be eliminated cost effectively. Such barriers could include the costs of acquiring certain kinds of information useful primarily to the particular consumer in question, other adoption costs such as inconvenience or temporary shut-down of operations, or uncertainty about future prices, energy savings, and reliability. Studies of the techno-economic potential will overstate the optimal conservation to the extent that they ignore some costs that are recognized as legitimate expenses incurred in other markets.

• The techno-economic potential for 2010 outside transportation was estimated from the models to range from minimal (3%) to 15-20% of baseline energy use. These estimates are well below those reported in several prominent technology studies done previously for the United States. Benchmarks for comparing potential energy savings, representation of heterogenous consumers, and assumptions about the removal of market barriers account for much of the lower potential estimated here.

• Neither the techno-economic potential defined in terms of technology costs nor the economic potential defined in terms of a broader set of costs correctly reveals how much energy conservation society should try to achieve. Without more carefully focused studies of this problem, it is not known whether the resulting level of energy use is above or below levels currently being estimated in techno-economic studies of the potential. Both concepts focus exclusively on the markets for energy-efficient equipment and therefore ignore some potentially important market failures elsewhere. Such market imperfections as environmental pollution or utility regulation of electricity prices may cause energy to be priced below its full societal cost. Removing these market failures, if it can be done cost effectively, would improve overall economic efficiency and reduce energy use.

Future Analytical Needs

Technology-based studies provide an important view of what is happening on the energy-efficiency frontier. The detailed end-use models included in this study provide an important structural framework for incorporating decisions about new equipment efficiency and the rate of utilizing all equipment as well as for tracking the gradual replacement of old equipment with newer vintages of improved energy efficiency. Fuller development of the linkages between energy technology decisions and economywide trends will only serve to strengthen the capabilities of such frameworks.

At the same time, it is clear that technology -based studies and the end-use models, as they are currently configured, are inadequate for comprehensively addressing the policy issue of whether and how society should seek to promote additional energy conservation. This statement is not an endorsement for more aggregate (or so-called "top down") models, for the latter were not developed to address this issue. It does suggest the need for "enriching" technology-based evaluations in order to make them more useful for policy makers. Some working group suggestions in this regard include:

- a sharper distinction between conditions causing markets to operate incorrectly (market failures) and normal costs found in other markets (market barriers);

- an explicit representation of the costs associated with these market barriers and failures;

- reporting of investment costs associated with any given strategy for promoting additional energy efficiency;

- additional research on the dynamics of supply-side innovations that influence the slate of available technologies from which to choose; and

- more empirical case studies of specific vendor or utility programs providing information and incentives for investment in energy efficiency.

INTRODUCTION

The threat of global climate change has thrust energy efficiency to the forefront of energy and environmental policy debates. The accumulation of carbon dioxide and other greenhouse gas emissions may cause long-term warming of the Earth. Many policy makers consider improved energy efficiency as the most immediate and least costly approach for reducing the combustion of fossil fuels, a principal source of carbon dioxide emissions.

National governments have proposed a variety of programs--taxes, standards, and voluntary conservation--to realize further energy savings. Within the United States, electric utilities and state regulatory agencies have implemented demand side management (DSM) programs that offer rebates and other incentives to customers who adopt energy-efficiency measures approved by the utility. Originally introduced to reduce the need for building relatively expensive new power generation facilities, these DSM programs are often justified on environmental grounds. More recently, restructuring and competition within the electricity industry are causing utilities to scale back their DSM plans. Competition will force utilities to adopt only those demand-management programs that truly reduce the costs of providing electric power.

The merits of policies for promoting more energy efficient equipment (hereafter, defined as energy efficiency) have been intensely debated. Technology-based evaluations are often optimistic about what can be achieved; economic-based analyses are often more cautious about how much conservation is really cost effective. Central to this debate has been the energy-efficiency "gap" or paradox: consumers appear to be underinvesting in promising technologies that would reduce energy use. Various studies have attempted to measure this gap by defining an economic potential for energy conservation, or expected energy savings that would be cost effective with current or projected market conditions.

This report summarizes the key findings of an Energy Modeling Forum (EMF) working group formed to address the opportunities for and costs of promoting additional energy conservation. Since energy models and technology-based studies have been featured so prominently in the policy debate, the working group considered in depth the capabilities and limitations of these approaches for evaluating how much additional energy could be saved and at what cost.

Conservation Potentials And Public Policy

As expected, working group members disagreed about the relative merits of government intervention to promote energy conservation. However, they generally agreed that such policies should be considered within the broader dimension of the energy system and the economy. The group's discussion highlighted several key points in this regard.

Aggregate energy intensity, or energy use per unit of activity, e.g. households or gross domestic product (GDP), is declining (Box 1). *Improvements in new equipment explain only some of the decline in energy intensity.* Shifts in the composition of economic activity and the rate at which new equipment replaces older vintages explain well more than half of the aggregate energy intensity trends in many of the models. This conclusion holds for the residential, commercial, industrial, and transportation sectors. While this finding is not novel, it has important implications for policy which often targets individual technologies. By their nature, technology-forcing strategies are limited in scope because they address only one of several important mechanisms through

BOX 1: MEASURING ENERGY INTENSITY

In this report, energy intensity refers to energy use per unit of economic activity within a major end-use sector or the economy. Intensity declines when energy use does not increase as fast as economic activity. For the residential sector, the relevant activity variable could be the household, while for the economy it is usually gross domestic product (GDP).

Energy efficiency in this report is an engineering concept that refers to the designed energy use in physical units (e.g., BTUs) associated with a particular piece of equipment; energy efficiency increases as designed energy use decreases. Increased energy efficiency may or may not be cost effective and differs from economic efficiency, which means the best use of all inputs in improving society's economic well-being.

Energy use in this report is measured in terms of "efficiency-adjusted" units, where electricity and fossil fuels are valued in terms of their market prices. This practice is used commonly in economic studies of energy use. Traditional measures of energy use, such as British thermal units (BTUs), equate electricity and fuels in terms of their respective heat content. However, electricity is more versatile than fossil fuels, as it has many more applications. A BTU of electricity can support more economic activity than the same BTU of oil, coal, or natural gas. Hence, it is more valuable, a situation that is reflected by its higher price.

This approach results in valuing a BTU of electricity about three times more than a BTU of fossil fuel, based upon 1991 delivered prices for all end-users. The results are virtually unchanged if sector-specific end-use prices are used. Although oil and natural gas should be valued more than coal given relative fuel prices, these adjustments are relatively minor compared to the adjustment for electricity and have not been incorporated here.

The use of efficiency-adjusted units causes measured energy use to increase when a BTU of electricity "replaces" a BTU of fossil fuel in the aggregate, as it does in many of the scenarios considered here. Increasing electrification is an improvement in energy quality that increases the total units of "efficiency-adjusted" energy. Such measures of energy intensity are very similar to those obtained by valuing electricity in terms of primary BTUs (inclusive of transmission and distribution losses associated with electric power). Some analysts prefer the primary BTU approach because they think that total BTUs of fossil fuel production is a better indicator of carbon dioxide emissions and other pollutants.

which nations experience declining energy intensity trends. Other important influences include energy prices, capital costs, the composition of goods and services, and the type of household activities.

The market penetration of energy-efficient equipment is a dynamic process. Over time, the projections indicate a steady decline in the energy intensity of the U.S. economy. Mandated standards for a range of energy-using equipment are becoming more stringent over time, requiring equipment producers to sell increasingly more efficient units. In addition, equipment quality is improving. In general, good ideas take a long time to diffuse through the market. Thus, estimates of underinvestment in equipment depend importantly upon when they are measured. The measured "gap" will be substantially greater when the most energy-efficient equipment that is cost effective is compared to the stock of equipment currently in use rather than to the stock in some future year.

Estimates of energy conservation potential reveal very little about how much energy conservation society should try to achieve. Such estimates overstate the optimal conservation by ignoring some costs that are recognized as legitimate expenses incurred in other markets.[1] At the same time, these estimates may understate the optimal conservation because they ignore some potentially important market failures that cause energy to be priced below its true value to society. In general, estimates of conservation potential leave the policymaker with little guidance on what should be the best course for society.

And finally, *energy efficiency improvements in equipment may not necessarily lead to equivalent reductions in energy use.* Improved energy productivity that is truly cost effective may be a source of economic growth, stimulating energy-using activities and economic output, and hence, energy use. Historically, this has occurred in many energy-intensive industries, where energy-saving innovations have often led to significant cost reductions resulting in expanded industry output and total energy use. When the Bessemer process for making steel was introduced in the last century, it was widely touted for its potential to reduce energy use per ton of steel.[2] Although the new technology reduced the industry's energy intensity dramatically, it stimulated the use of steel throughout the economy by lowering production costs and offering a higher quality building material.

Offsetting increases in energy use, sometimes referred to as the "rebound" effect, are more modest when energy represents a small share of total costs and the new technology does not fundamentally change the product or energy service.[3] These conditions are likely to hold for many household equipment choices. Even in these less dramatic cases, however, efficiency improvements may induce some "rebound", resulting in less than proportional declines in energy use. How much rebound exists throughout the economy is an empirical issue that has yet to be resolved.

The next section provides a brief overview of the EMF process. The remainder of the report focuses on specific findings of the working group, based upon both comparative results from a set of models and qualitative discussions of the nature of market conditions that may be discouraging investment in more energy-efficient equipment. The qualitative discussion of market impediments is based upon an edited volume of individually authored papers by some EMF study participants and other experts.[4]

APPROACH

The EMF Process

The EMF provides a structured framework in which experts from government, industry, universities, and other research organizations can meet to study important energy and environmental issues of common interest. The process includes an indepth comparison of existing computer models applicable to the study topic because these models often make explicit the simple but fundamental differences in views about a problem that lead to intense policy debates. Each working group pursues the twin goals of: (1) improving the understanding of the capabilities and limitations of existing energy models and (2) using these models to develop and communicate useful information for energy planning and policy. A key objective is to foster an improved dialogue between model developers and policy makers and other potential users of model results.

Table 1. Models in Energy Conservation Study

Name	Principal Users	Principal Developers	Comments/Purpose
NEMS	U.S. Energy Information Administration	U.S. Energy Information Administration	National Energy Modeling System
DEGREES	U.S. Environmental Protection Agency	ICF, Inc and RCG Hagler Bailey	Based upon EPRI demand models**
GEMINI	U.S. Environmental Protection Agency	Decision Focus Inc	Climate change policy analysis
IDEAS	U.S. Department of Energy (Office of Policy)	The AES Corporation	Energy and environmental policy analysis
EPRI*	Electric Power Research Institute	Regional Economic Research Inc	Utility demand forescasting**
LBL*	Lawrence Berkeley Laboratory	Lawrence Berkeley Laboratory	Based upon EPRI demand models with LBL data**
LIEF	Argonne National Laboratories	Marc Ross (U. Of Michigan)	Industrial Energy Demand
CARS	U.S. Environmental Protection Agency	Kenneth Train (UC Berkeley)	Gasoline Use in Passenger Cars
CPAM	Bonneville Power Administration	The AES Corporation	Electricity in U.S. Northwest

* Refers to organization developing model system rather than the model itself. Both organizations use REEPS for residential and COMMEND for commercial energy use.

** EPRI demand models are REEPS (residential), COMMEND (commercial), and INFORM (industrial).

An ad hoc working group of some 50 members from business, government, and universities met four times between September 1992 and March 1994 to discuss energy conservation. This group defined the important issues, developed the study plan, analyzed the results, and summarized the key findings. Proprietors of 10 different models (Table 1) of energy efficiency and demand were asked to simulate eight different scenarios based upon standardized assumptions. The comparison of model results guided the larger group's discussion about important issues and differences of view that influence energy conservation. The group also integrated other research and analysis on the nature of the energy-efficiency "gap" that contributed to an understanding of the policy issues.

This report focuses upon six key scenarios that included a baseline for comparing with alternative scenarios and five cases representing changes in energy prices, hurdle or discount rates, or new equipment efficiency (Table 2). As will be discussed, the hurdle rate refers to the rate of return required to make the investment profitable. Scenarios with lower rates show what would happen if consumers were to value future energy costs savings more than they do under current market conditions. The

Table 2. Scenarios in EMF Conservation Study

Scenario	Description
Baseline	Preliminary 1993 mid-price case from EIA Annual Energy Outlook.
Frozen Technology	Efficiency for all new equipment set at 1990 level.
6% Hurdle Rate	Hurdle (discount) rate lowered from baseline levels to 6% after adjusting for inflation and taxes (approximately equivalent to rate for utility supply-side investments).
3% Hurdle Rate	Hurdle (discount) rate lowered from baseline levels to 3% after adjusting for inflation and taxes (approximately equivalent to social discount rate).
25% Energy Tax	All fuel and power prices increased by 25% above baseline levels, beginning in 1991.
Flat Price	Inflation-adjusted prices for fuel and power fixed at 1992 levels.

The working group also considered scenarios for increased standards, aggressive demand-side management (DSM), and modeler's most likely projection. Results are not reported due to either ambiguity in interpreting estimates or too few models reporting results.

working group used the results from these scenarios to discuss the nature of impediments to investment in energy-efficient equipment. They do not necessarily represent optimal conditions that society should try to achieve.

BASELINE TRENDS

Over the past two decades, industrial countries have experienced significant declines in their aggregate energy intensity. Between 1973 and 1988, for example, the OECD economies expanded by more than one-half with virtually the same total final demand for energy. Reductions in individual energy intensities for heating, industrial processes, motor vehicles, etc, account for 50% to 90% of this decline in energy intensity, while changes in the composition of output or consumer activities are responsible for the rest. Before the rapid energy price increases beginning in 1973, the decline in aggregate intensity was lower but still significant, with a fall in industrial energy intensities the main cause of the decline.[5]

As a benchmark for discussion and comparison with other cases, the working group adopted a baseline scenario consistent with a preliminary version of the Energy Administration's (EIA) 1993 reference case. The EIA scenario assumes that world crude oil prices rise more rapidly than inflation, particularly after a period of soft market conditions in the early 1990s (Figure 1). Natural gas prices rise at almost twice the rate, while electricity prices barely increase relative to inflation (Figure 2). Economic growth (GDP) progresses at 2.3% per annum, although population, commercial floor space, and vehicle miles traveled all increase by substantially less.

Figure 1. World Crude Oil Prices in Baseline Scenario

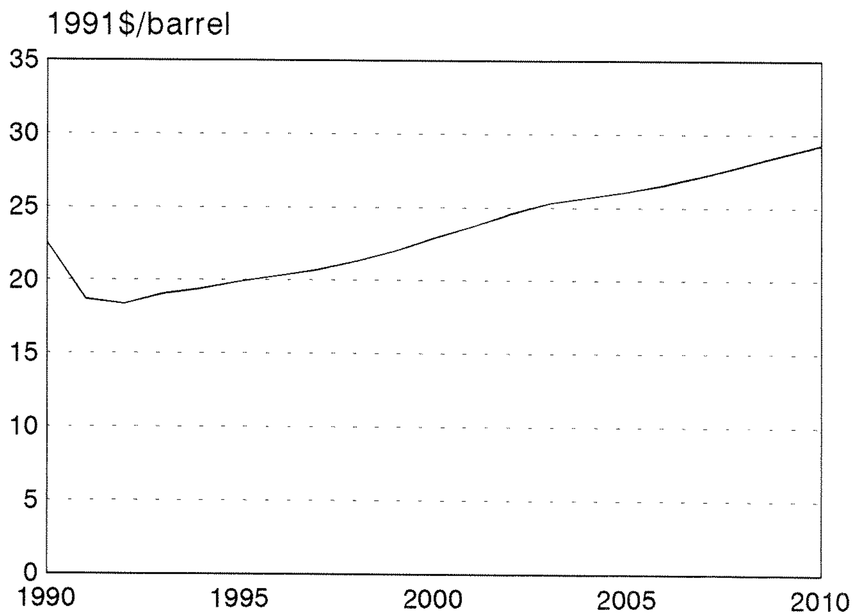
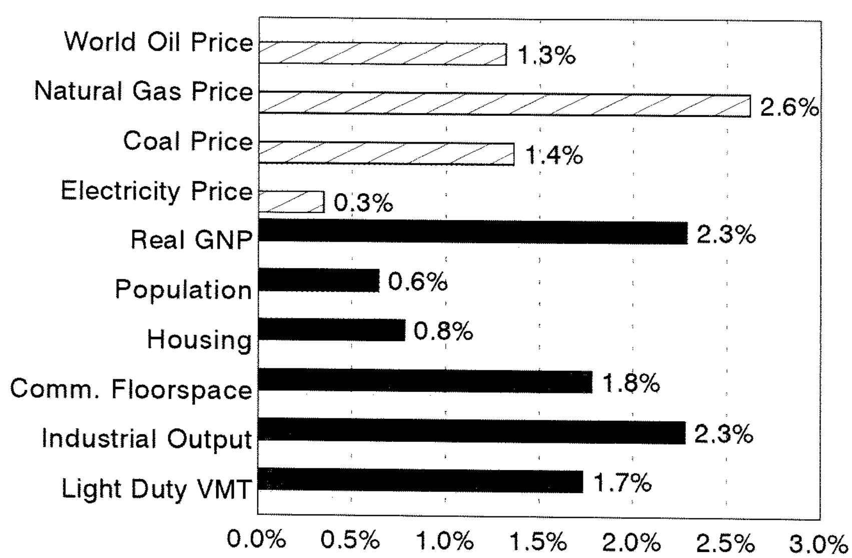


Figure 2. Standardized Inputs for Baseline (% change per annum, 1990-2010)



Energy Demand

Projected end-use energy demand grows over a 20-year period (1990-2010), but at a rate substantially below economic or activity growth in each sector. At most, annual residential energy demand in the baseline scenario grows by no more than 0.5%, considerably more slowly than the population growth of 0.8% per year. Although industrial and transportation energy demands uniformly grow by more than 1% per year, the key activity variables are also higher--2.3% per year for manufacturing output and 1.7% per year for vehicle miles traveled. Energy use in the commercial sector increases at a rate between these two, in the range of 0.7 to 1.4% per year, compared to a growth in commercial floor space of 1.8% per year. Over the 20-year period, the aggregate energy intensity (energy use per dollar of GDP) across all end-use sectors declines by 0.8% to 1.3% per year across the different models.

These projected declines in future energy intensity do not depend upon rising energy prices. Projected decreases in sectoral energy intensity are only slightly smaller when they are based upon flat energy prices with no changes in prices from 1990 levels. The projected declines in energy intensity are smaller than those experienced during the 1973-86 period, when energy prices increased sharply, but larger than those in the post-1986 period of lower prices. Since 1986, energy intensity has stabilized in all sectors but transportation, the sector most heavily dependent upon petroleum products.

Projected electricity demand grows more strongly than the demands for other fuels in the nontransportation sectors, continuing a long-term electrification trend encouraged by favorable electricity prices and new applications for electricity. Even so, changes in electricity demand lag behind those in economic activity in many models, resulting in declining electricity intensity. Projected total electricity demand in the residential, commercial, and industrial sectors grows from 0.6% to 1.8% per year, depending upon the model. As a result, the projected decline in aggregate electricity use per dollar of GDP ranges from 0.5% to 1.7% per year.[6]

Decomposing Energy Intensity Trends

Aggregated across the major end-use sectors, baseline energy intensities fall by 0.8% to 1.3% per year over the 20-year horizon. Baseline energy intensities tend to decline most rapidly in the residential sector and least rapidly in the industrial sector.

The projected baseline intensities for delivered energy are influenced by the rate of energy efficiency improvement in new equipment, the turnover rate at which old equipment is replaced by new equipment, and the growth and composition of various household activities and industries using energy. The estimates in Table 3 show the relative importance of these various influences on the baseline energy intensities projected in this study (Box 2). Whether they are induced by energy prices or other factors, improvements in the energy efficiency of new equipment (beyond today's efficiencies) account for a relatively small part of the decline in the projected baseline energy intensity. More important are the growth in energy-service demands relative to overall economic growth and the gradual replacement of old equipment with the most energy-efficient equipment available today (represented in the first two columns).[7]

Table 3. Decomposition of Baseline Aggregate Energy Intensity Trends (% Change Per Year, 1990-2010)

	(1) Activity	(2) Shift/ Turnover*	(3) Nonpriced-Induced	(4) Price-Induced	(5) Total Intensity	(6) Sectors
GEMINI	-0.40%	-0.64%	0.02%	-0.19%	-1.20%	R,C,I,T
IDEAS	-0.41%	-0.20%	-0.02%	-0.32%	-0.95%	R,C,I,T
EPRI	-0.36%	0.08%	-0.36%	-0.17%	-0.81%	R,C,I
NEMS	-1.07%	0.30%	-0.38%	-0.15%	-1.31%	R,C,T
DEGREES	-1.00%	0.42%	-0.42%	0.05%	-0.95%	R,C
LBL	-1.06%	0.02%	-0.23%	-0.03%	-1.30%	R,C
LIEF	0.24%	-0.81%	0.13%	--	-0.44%	I
CARS (gasoline)	-0.88%	-0.78%	-0.20%	-0.43%	-2.28%	T
CPAM (electricity)	-0.16%	-0.86%	-0.03%	0.00%	-1.05%	R,C,I

Aggregate delivered energy measured in efficiency-equivalent units, where electricity and fuels are valued at their respective market prices.

* Component incorporates electrification and other fuel-switching effects, shifts in the relative importance of activities within a major end-use sector, and the gradual updating of equipment efficiency to 1990 levels as old capital is replaced.

The activity effect (column 1) shows how much baseline energy intensities change due to the slower growth in households, commercial building floor space, and vehicle miles traveled than in the overall economy. Only manufacturing output keeps pace with GDP. Projected energy demand depends more upon future levels of these key activity variables than upon GDP. As a result, except for the industrial sector, the activity effect reduces energy use per dollar of GDP. When coverage includes the industrial sector, the activity effect for these baseline economic conditions is about 0.4% per year (Table 3, column 1). This effect increases to about 1.0% per year for models not reporting industrial sector energy use.

Within each major end-use sector, shifts in the composition of household activities and industries (column 2) will have an important effect on future energy intensity trends. For example, shifts in economic activity from energy-intensive to other industries reduce the industrial sector's overall energy intensity. At the same time, individual households may increase their energy use as incomes and other factors cause them to choose larger homes, more energy-intensive activities, and more electrification. Overall these shifts cause the projected U.S. baseline energy intensity to decline, except for several models, (e.g., NEMS and DEGREES) that do not report industrial sector results.

BOX 2: DECOMPOSITION OF ENERGY INTENSITY TRENDS

The decomposition of the change in aggregate energy intensity for each model is based upon input assumptions for GNP and for sectoral activity (e.g., households, commercial floor space, manufacturing output, and vehicle miles) and the model's projected change in energy demand from its 1990 level in three scenarios:

1) a baseline which incorporates EIA assumptions and no new policy initiatives;
2) a flat energy price case in which energy prices are held constant throughout the projection horizon; and
3) a frozen technology case in which the energy efficiency of new equipment does not change from its base-year value (although the average efficiency will change with capital stock turnover).

The four components are measured and defined as shown below:

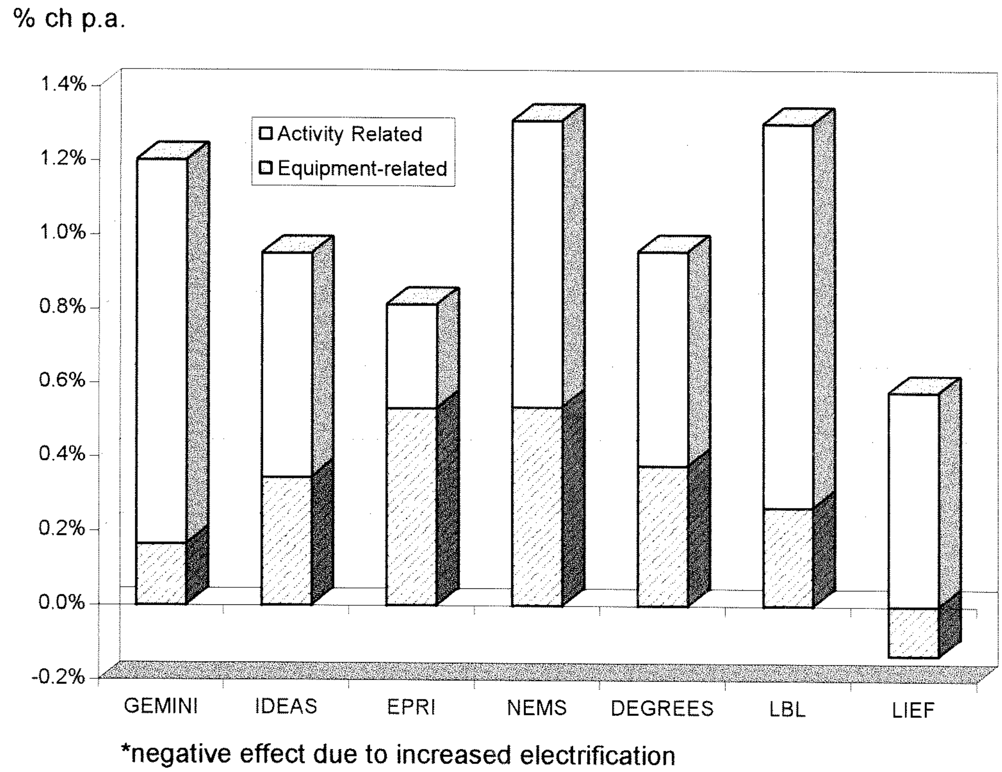
Component	Measured as the difference in the % change between:	Defined as the Effect of:	Assumptions
Price	Baseline & Flat-Price Demands	Higher energy prices	Future prices and future technologies
Nonprice Efficiency	Flat-Price & Frozen-Technology Demands	Technological advancements unrelated to prices	Today's prices and future technologies
Shift/Turnover	Frozen-Technology Demand & Activity	End-use shifts; fuel substitution; capital turnover	Today's prices and 1990 technologies
Activity	Activity & GNP	Slower growth in households, floor space, manufacturing output, vehicle miles	Today's prices and embedded technologies

Aggregate energy demand is the sum of energy demands in the residential, commercial, industrial, and transportation end-use sectors. It is measured in efficiency-equivalent terms by weighting fossil fuels and electricity by their respective 1990 prices.

Baseline energy intensities will also decline as old equipment, due for retirement, is replaced by new units even in the absence of further energy efficiency improvements for new equipment. Due to the procedure for measuring the various effects in this study, this equipment turnover effect is incorporated in the reported shift/turnover component discussed above.

The next two effects (columns 3 and 4) incorporate equipment efficiency improvements beyond 1990 levels. Several influences contribute to increasing equipment efficiency. Higher energy prices increase the value of energy savings, providing incentives for purchasing more energy efficient equipment. In addition, mandated standards already legislated and utility demand-side management programs already in place increase new equipment efficiency. The projections exclude any new energy-efficiency mandates or utility programs. Although not formally represented in the

Figure 3. Relative Importance of New Equipment Efficiency Improvements in the Total Decline in U.S. Energy Intensity, 1990-2010



models, improvements in product quality would also hasten the introduction of new energy-efficient equipment and may be reflected in these projections.

The *nonprice-induced* improvements in equipment efficiency incorporate mandated standards and similar policy initiatives as well as equipment choice based upon economic and technical factors other than the price of energy. This effect appears minimal in several models where coverage includes the industrial sector (column 3), but ranges in the 0.2% to 0.4% per year when only the residential and commercial sectors are included.

The *price-induced* efficiency improvements vary from virtually no effect in several models to 0.4 % per year in the CARS model, which focuses exclusively upon gasoline use for passenger cars. While important in CARS and IDEAS, the price-induced improvements are relatively modest sources of declining energy intensity in other models. This effect includes changes in the utilization rate of all equipment as well as the efficiency of new equipment.

Even without continued improvement in equipment energy efficiency, significant declines in aggregate energy intensity will be forthcoming. Activity-related declines in energy intensity are important and appear larger than those related to efficiency improvements in new equipment. Baseline energy intensities fall as new equipment replaces old equipment but are not strongly influenced by continued energy efficiency improvements in new equipment, beyond current efficiency levels. In Figure 3, activity-related sources (solid bars) include the activity and shift/turnover effects

BOX 3: AUTONOMOUS DECLINES IN AGGREGATE ENERGY INTENSITY

The historical record of energy efficiency improvements over time is clear in many sectors. Manufacturing industries have consistently reduced their energy intensities, or energy use/output for decades, both in times of falling energy prices and in periods of rising prices.* The energy intensity of jet aircraft has fallen steadily since its first introduction, as has the energy intensity of most large trucks. The reason is that energy is an input factor whose use tends to be reduced as the productivity of all input factors is improved.

The input share of energy fell more rapidly when energy prices rose dramatically. Energy intensities also declined sharply during periods of rapid economic growth.** Even though energy prices receded after 1985, the knowledge gained during the era of higher energy prices continues to provide ways of using energy more efficiently, as recent dramatic reductions in energy requirements for new refrigerators, lighting systems, and air craft suggest. While it is certainly true that energy prices are an important determinant of both energy efficiency and energy use, they are not the only determinant.

Analysts have referred to such improvements that are unrelated to the price of energy as autonomous energy efficiency improvements (or AEEI). When defined at the aggregate level, ie., as the ratio of energy use to GDP, this concept embodies not only changes in individual equipment or end-use energy efficiencies but also shifts in the goods and activities that consumers choose. Since 1973, changes in the composition of output in industry, the number and surface area of homes and buildings, or the distances consumers travel have contributed as much as 50% of the changes in this aggregate ratio in industrialized countries. For the United States, this structural component is about 20%. For consistency in terminology, this report refers to such changes as autonomous decreases in energy intensity rather than improvements in energy efficiency.

* Schipper, Lee and Stephen Meyers, with Richard B. Howarth and Ruth Steiner, Energy Efficiency and Human Activity: Past Trends, Future Prospects, Cambridge, U.K.: Cambridge University Press, 1993.

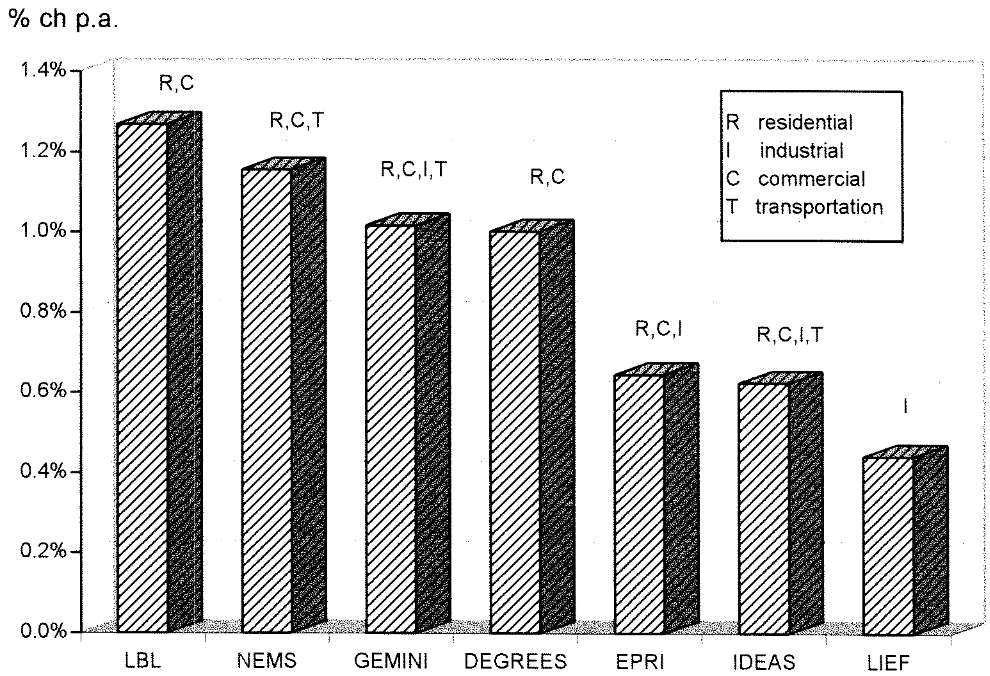
**Schurr, Sam H., Sidney Sonenblum, and David O. Wood, ed., Energy, Productivity and Economic Growth, Cambridge, MA: Oelgeschlager, Gunn & Hain, 1983.

from columns 1 and 2 of Table 3. New equipment-related sources (diagonal bars) in this figure are the nonprice and price-induced effects from columns 3 and 4. New equipment-related sources account for more than half of the total decline in aggregate energy intensity in only one model (EPRI).

Autonomous Decreases in Aggregate Energy Intensity

Previous estimates of the cost of abating carbon dioxide emissions have been sensitive to decreases in aggregate energy intensity unrelated to energy prices. These decreases are sometimes referred to as autonomous energy efficiency improvements, or AEEI, in other studies (Box 3). Greater AEEI in the baseline contributes to lower baseline carbon dioxide emissions, thus making it easier and less costly to achieve a specific emissions level based upon historical targets. In past policy studies based upon aggregate models of energy and the economy, analysts have usually assumed the AEEI to lie in the range of 0.5% to 1.0% per year.[8]

Figure 4. Autonomous Decreases in Energy Intensity by Model, 1990-2010



The assumed rate of decline used in aggregate models of climate change policy appears consistent with the decline estimated in this study from models encompassing more detailed technologies. The computed AEEI in the current study falls in a comparable range, varying from 0.6% to 1.0% per year for the economy as a whole. The estimates exceed 1.0% for several models that exclude the industrial sector and fall to about 0.4% for one model focusing on industry alone. These estimates, shown in Figure 4, incorporate the activity lag, shift/turnover, and autonomous equipment efficiency effects from Table 3.

PRICES AND ENERGY SAVINGS

Past fuel and power price increases have reduced energy use per unit of activity over a range of sectors and countries. Higher energy prices can reduce energy demand by encouraging the adoption of more energy-efficient equipment, reducing the usage of that equipment, or shifting final consumption toward goods and services that use less energy.

The response of energy demand to price provides important information about a range of different policy options. For a tax or emission permit affecting energy prices, the response indicates how much energy demand falls when prices are increased by a given amount. For a policy mandating an energy conservation target or energy-efficient standard without eliminating market failures, the response indicates how much consumers perceive their costs to increase for a given reduction in energy use. When costs are important, consumers will not willingly pursue additional conservation if they perceive these opportunities to be expensive. Note that costs include direct expenditures as well as nonmonetary considerations such as inconvenience or inferior product attributes.

Estimated Demand Response

The models in this study share the same basic approach used in engineering cost estimates of the potential for energy efficiency. They show which technologies are cost effective from an energy-efficiency perspective under different conditions. As energy prices rise, savings in energy costs increase for all technologies. Some technology options that previously created insufficient energy cost savings to cover their initial purchase and maintenance costs now become cost effective. How much becomes cost effective depends upon the cost and performance characteristics of the various technologies represented in the model. When a model indicates a large reduction in energy demand or increase in conservation in response to price, it means that there are many options to achieve more energy efficiency at costs only slightly higher than current levels.

The model results suggest that the perceived costs of reducing energy use increases rather substantially as additional conservation measures are adopted in the absence of the elimination of market failures. This factor explains why they project that energy demand would fall by only 3 to 8% below its baseline level after 20 years with a 25% increase in delivered energy prices. These estimates appear lower than previous ones derived from the experiences of the 1970s[9] and were discussed extensively by the working group. This range applies generally to each end-use sector, although the higher estimates occur in the industrial and transportation sectors.

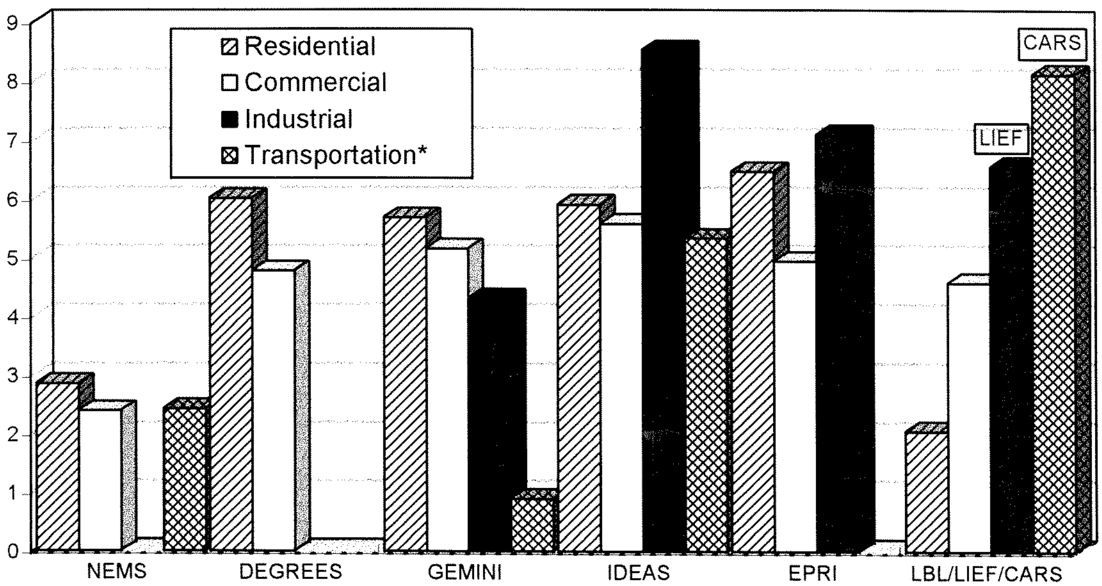
These results were derived from a scenario in which the delivered prices of all fuels (including renewable energy sources) were increased by 25% above the baseline values for all years, beginning in 1991. The demand response for aggregate energy when all fuel prices are increased will be somewhat lower than for a specific fuel when only its own price changes. The increase in natural gas prices, for example, will cause a shift towards electricity that will operate against, but not completely offset, the reduction in electricity use due to higher electricity prices.

The size of the response varies among models (Figure 5). The NEMS responses are all below 3% for the 25% energy price increase, as are the LBL residential and GEMINI transportation results. Virtually all of the other responses approach or exceed 5%. The largest reduction of 8% in the IDEAS industrial sector and in the CARS transportation sector are slightly below the lower bound for previous estimates based upon the experiences of the 1970s.[10]

The relatively small NEMS responses result from assumptions that energy cost savings do not influence some decisions in the residential and commercial sectors. For example, the home construction industry chooses equipment on the basis of initial purchase price rather than total costs of operating the equipment over the entire investment period. In the LBL results for the residential sector, homeowners value future energy savings (from reducing energy use) less than in other models for some end-use decisions. This assumption is implemented through a higher hurdle rate for these end uses than in other models.

The responses also vary by sector. The declines in both residential and commercial consumption range from about 2% to 6%, while those for industry are somewhat greater,

Figure 5. Reduction (%) in Aggregate Energy Consumption Due to 25% Price Increase, 2010



*gasoline consumption

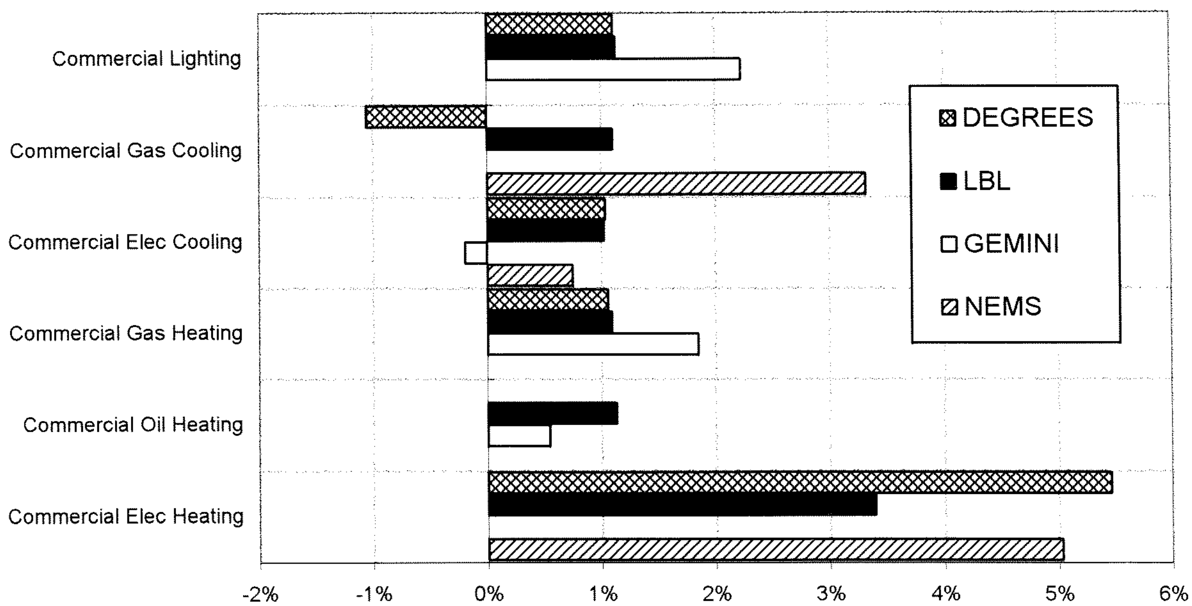
varying from 4% to 8%. The decreases in gasoline use for transportation span the widest range, between 1% to 8%, depending upon the model.

Changes in vehicle miles driven determine the relative magnitudes of the demand response to price in the fuel demand associated with light duty vehicles. The wide difference between the demand response in GEMINI and CARS is due almost entirely to differences in how fuel prices affect the demand for travel in the two models. This result underscores the potentially important effect of energy prices on the demand for energy services, an effect that is omitted by most models in projecting energy use outside the transportation sector. The effect of fuel prices on vehicle fleet efficiencies is quite small in all models reporting for light duty vehicle sector.

Estimated Equipment Efficiency Response

The demand adjustment to a higher energy price level incorporates changes in both the rate at which households and industry use their equipment and the efficiency of new equipment that they select. In response to the 25% energy price increase, projected improvements in new equipment efficiencies in the residential sector never exceed 5% in the two models reporting them.[11] Thus, even after all equipment is eventually replaced after 30 to 40 years, the long-run effect of the 25% energy price increase on equipment efficiency would be small. In the DEGREES results, higher energy prices achieve greater improvements in gas water heaters (5%), gas furnaces (4.5%), and heat pump space heating and cooling (3.5%) than in other equipment. Meanwhile, mandated national efficiency improvements in

Figure 6. Change (%) in Average Commercial Sector Equipment Efficiency (relative to baseline in 2010) Due to a 25% Energy Price Increase



refrigerators limit the opportunities for further equipment efficiency, providing one explanation for the relatively low demand response to price observed in this study. In the LBL results, improvements in all equipment are consistently less than 0.5%, although the full impact of the price increase may not have been simulated due to the way that the model is calibrated.[12]

Even after 20 years, much of the pre-1991 equipment remains installed. As a result, the average efficiency for both old and new equipment in any one end use seldom exceeds 1% in NEMS and LBL, although GEMINI reveals responses in the 2% to 5% range for refrigerators, electric water heaters, central air conditioners, and home gas furnaces. Average equipment efficiency for this scenario was not reported for other models. Again, these results suggest that energy price increases have a relatively small effect on household energy demand in these models because they have little impact on equipment efficiency. In this case, most of the reduction in residential energy demand appears to occur as a result of changes in how installed equipment is used rather than in the efficiency of the equipment stock.

Average equipment efficiency improvements induced by higher prices are larger in the commercial sector where the response is often 1% or more in many end uses (Figure 6).

Models reporting commercial electric heating appear to agree on the relatively larger effect on this end use.

Comparable equipment efficiency estimates are not available for industry because industry sector models have much less detail on individual technology characteristics and costs. The diversity of industrial activity limits the usefulness of analyses identifying individual technologies that are assumed to be operated under similar conditions in each of the many industries. As a result, industrial sector models usually represent energy use decisions within firms in more general terms rather than by specific technologies.

Factors Explaining the Estimated Response

Members of the working group disagreed on whether the above estimates accurately describe the opportunities for reducing energy consumption. One reason for the relatively modest demand responses derived from the models is that stricter end-use standards, e.g., for refrigerators, have limited the choice of efficiency levels across equipment types. In some cases, mandated standards have pushed consumers toward equipment that is more energy-efficient than they would have selected on the basis of price alone.[13] Under these conditions, the consumers' response to price is likely to be minimal. In addition, energy costs often constitute a relatively small share of the total costs associated with satisfying certain high-value end uses. For example, the electricity costs associated with operating a refrigerator are extremely modest when compared to the value of service rendered by preventing food from perishing.

In addition, unlike previous periods, some of the low-cost conservation may have already been achieved in response to the previous price increases. When prices rose during 1973-74 and again in the 1979-80 period, consumers adopted energy-efficient processes that were not undone when energy prices fell soon thereafter. The homeowner does not replace his insulation when energy prices fall, nor does he have the opportunity to revert back to less energy-efficient technologies in widespread use before the initial price hikes of the 1970s. As a result, past energy price increases may have already encouraged much of the conservation that might be expected from higher prices from today's relatively low levels.[14]

At the same time, some members thought that the models may be underestimating the response of energy demand to price.

Prices affect a range of decisions in most models: the efficiency level of new equipment, the choice of fuel, and the utilization rate of all equipment. However, the effect of energy prices on final goods and services and end-use demands in the economy is excluded in all but one model (GEMINI). Shifts away from energy-intensive goods and services have been an important source of declining energy intensity, and higher energy prices have contributed to these shifts.

In addition, these estimates may ignore the possibility that end-use technologies will improve in the future. The response of equipment efficiency to price is influenced importantly by the range in energy efficiency of different technologies allowed by a model. When the range is limited, small responses to changes in economic conditions are observed. Many models restrict the range to well-known technologies that are nearly cost-effective given current energy prices. More speculative, higher-cost options are represented as being more limited in availability. Hence, as energy prices rise, opportunities for introducing energy-efficient equipment appear more limited in the model. However, in actual markets, higher prices are likely to increase the availability of these higher-cost options, resulting in more energy efficiency. Supply innovations that lower costs or improve product quality continue to augment the availability of options at the higher end of the technology-cost spectrum.

In the residential and commercial sectors, individual technologies are identified and assumed to be operated under similar conditions. By contrast, these models determine industrial energy use by more general relationships linking energy use to economic activity within an industry and do not represent individual technologies in detail. When energy prices rise, the models assume that firms have a number of ways to change their production processes to reduce their energy use, without the analyst having to identify which options or equipment firms would select. As a result, the models allow greater flexibility in energy use decisions in this than in the other non-transportation sectors, which may explain the finding of generally higher demand responses to price within industry for these models. Of course, the observed responses may also reflect greater opportunities to substitute away from energy within industrial firms.

Policy Implications

These models portray more limited opportunities to substitute away from energy as energy prices rise than do some previous estimates. To the extent that one believes the lower estimated responses are due to real market conditions (including previously purchased efficiency) and to mandated standards, these results suggest that the failure of energy prices to incorporate external social costs such as pollution does not distort energy use very much unless these external costs are very large. For example, energy use would be only 3% to 8% lower after 20 years if the full social costs of energy, incorporating all external costs, were 25% higher than current market prices.

Moreover, the findings also imply that consumers may perceive programs mandating additional conservation measures as being costly unless these programs correct a deficiency in general information available about energy efficiency options or some other clearly delineated market failure. An important cause of a low demand response to price in these models is that the cost of adopting more energy-efficient equipment rises significantly as consumers consider additional conservation options. The higher estimate for the demand response indicates that the incremental cost for new, more energy efficient equipment would approach 25% once energy demand had been curtailed by 8% below its baseline level. The lower estimate indicates that the same 25% incremental equipment cost would be reached with only a 3% curtailment of energy use.[15]

Costs could be considerably lower, or possibly even negative, for policies that removed a clearly identifiable market failure preventing the adoption of energy-efficient equipment. Such policies cannot be evaluated in the manner described above, but require that specific failures be identified and that their costs of removal be estimated. This report considers this issue in greater depth in a later section.

Given the policy relevance of the price-response issue, it is important to focus future research on whether and how the response of energy demand to price has changed over the last decade or two and what factors account for any observed changes. More statistical studies exploring the possibility of shifts in consumer responses could help to inform this debate. While there are factors that clearly could account for the lower responses found in current end-use models of energy demand, concerns remain about how certain adjustments are incorporated. Verification of model responses against observed historical experience is extremely important, although such procedures become more difficult as energy demand models become increasingly more detailed. An important intermediate step would be to compare the total demand response to price based upon more disaggregated relationships in the model with those estimated directly from the historical experience.[16]

ECONOMIC CONSERVATION POTENTIAL

Market Barriers and Costs

The term potential implies that more can be obtained and that it is desirable to do so. There is no debate that more conservation is technically achievable and that it would not be cost-effective to reach all that is technically possible. Hence, technical potential is not a realistic policy option and is not considered in this report. Instead, attention is focused on how much more could be achieved that would be cost-effective. This cost-effective level is the economic potential.

Despite sharp differences on the magnitude of the economic potential, there emerged a somewhat unexpected common ground on certain conceptual issues:

- Obstacles to investment (market barriers) are widespread and exist in all markets, including energy.

- Some market barriers (market failures) cause resources to be misallocated and justify government intervention; other barriers do not.

- Scarce information is not a market failure, but under certain conditions markets will not provide information efficiently to the appropriate decisionmaker, creating the principal source of market failures that account for the "gap" in energy-efficient investments.

- Where cost-effective, policy might address other market failures unrelated to the "gap", e.g., divergence of average and marginal pricing in utilities, energy security, and environmental externalities.

- Conventional measures of "economic potential" for energy conservation do not resolve the issue of whether society should invest more in energy efficiency than it currently does.

Which costs are included can significantly affect the estimated economic potential. Some estimates define cost-effective options in terms of the direct investment costs associated with purchasing and installing the equipment. Technologies are considered cost-effective if their energy cost savings equal or exceed these investment costs. The actual conservation achieved in markets may fall short of this economic potential due to any number of market barriers that limit the acceptability of new energy-efficient equipment (Box 4).

Other analysts emphasize that many market barriers are real costs that adopters would be expected to incur in any other market. Consumers of other products often face uncertainty in prices and in the reliability of new products, but incorporate these conditions as market realities of buying in these markets.

BOX 4: MARKET BARRIERS AND FAILURES

Examples of Market Barriers That Do Not Require Intervention:

1. Risks associated with future price fluctuations and actual energy savings.
2. Concerns about technology's reliability.
3. Consumer dislike of qualitative product attributes.
4. Costs of acquiring specific information useful only to the user.
5. Other costs of adoption (inconvenience, temporary shut-down).
6. Limits on adoption by users untypical of "average" user.

Examples of Market Failures That May Require Intervention But That Cannot Be Corrected By Changing Energy Prices:

1. No incentive for any one user to purchase general information that is then freely available to many users.
2. Adopter demonstrates technology to other potential users.
3. Potential adopter does not pay the energy bill or does not use the equipment, e.g. ,
   landlord chooses equipment but tenant pays the bill;
   landlord pays the bill but tenant uses the equipment;
   contractor chooses equipment but owner pays the bill.

Examples of Market Failures That May Require Intervention and That Can Be Corrected by Changing Energy Prices:

1. Regulated utility prices set below the incremental costs of additional generation, transmission, and distribution.
2. Environmental costs not incorporated in market prices for energy.
3. Energy security risks not fully incorporated in oil market price.

Consumers may also avoid buying a new product because they prefer the nonmonetary attributes of the old one, such as households' preference for incandescent over fluorescent lights. These barriers are not evidence of malfunctioning markets and hence do not require government intervention. Fewer investments are cost-effective with this broader concept of costs, resulting in a lower estimate of the conservation potential.

When government and utility programs remove this type of market barrier, they may reduce the adoption costs for individual decisionmakers but not necessarily the overall costs to society.[17] An example would be free information about achieving energy efficiency in a particular home. If the program does not reduce the societal costs of acquiring information, but simply redistributes costs from the homeowner to other utility customers or taxpayers, the benefits of the home-specific information remain with the homeowner rather than being shared widely with other homeowners.[18] Under these conditions, it may be preferable to have the homeowner who benefits from the specific information to pay for it rather than require that the information be funded by a collective group of utility customers or taxpayers. Society cannot avoid paying for the cost of the information, even though the individual homeowner's cost may be reduced if it is provided free by the utility.

Market Failures

This situation contrasts with the case in which information applies generally to a number of homeowners. The development and dissemination of information and the role of early adopters in demonstrating a technology can substantially transform markets by reducing costs. In this case, one household, acting alone by obtaining the information, could simultaneously reduce the adoption costs of many other homeowners. It will have little incentive to do so, however, because it is paying all the costs but sharing the benefits with a number of other homeowners.

Under such conditions, prices become poor indicators of the societal costs of providing a good or service. In these cases, markets will produce too much or too little of the particular good, unless governments intervene to correct the conditions. Such market barriers are referred to as market failures or imperfections in this report. Examples of failures that could explain the gap, or the underinvestment in energy-efficient equipment, are shown in the middle of Box 4. They all relate to problems in providing and distributing sufficient information and in creating proper incentives to the person making the decision to adopt the technology. Changing energy prices will not correct the problem because the market failures prevent consumers from responding properly to energy prices.

Some other market failures have nothing to do with the apparent underinvestment in energy-efficient equipment caused by firms and households failing to respond properly to economic incentives. Hence, they are irrelevant for explaining why the gap exists. Nevertheless, they may cause too much use of energy and therefore are relevant to discussions about whether economies should reduce their energy consumption. These problems exist outside the markets for energy-efficiency equipment and share the common trait that certain societal costs--new electric generation, energy security risks, or environmental pollution--are not being fully reflected in market prices (the bottom of Box 4). There exists no broad agreement among energy analysts that all of these possible market failures listed in the bottom part of the box necessarily require policy intervention. Should they be required, policies should be targeted to remove the specific market failure directly. Changing energy prices through taxes or emission fees is the most direct remedy for correcting these types of market failures. Even when political constraints prevent the use of economic incentives, policymakers should focus on removing the source of the problem (i.e., the specific market failure), rather than to achieve some targeted level of energy use.

The list of market barriers and failures is suggestive but not comprehensive or definitive. What some analysts consider to be a market barrier requiring no intervention, others might view as a market failure. Some analysts are concerned that utility bills do not differentiate electricity costs by equipment usage (refrigerator, air conditioning, etc.); others note that bundled commodities are frequently offered in other markets. Similarly, some analysts believe that markets can overcome the problem created by landlords and tenants having different incentives.

A Dynamic Concept

The gap is a dynamic concept that changes over time. When a promising technology is relatively new and not widely adopted, the gap may appear large. The gap may shrink over time as consumers replace their equipment and as energy-efficient products improve. As only one example, the quality of a fluorescent lightbulb available to the homeowner improved dramatically between the first and final working group meetings for this study. The diffusion of good technologies takes a long time, often requiring important product innovations before consumers widely adopt them.

Some of the divergent opinion about the gap relates to this timing issue. Some analysts view today's apparent "gap" as transitory because market forces will ultimately lead people into making profitable investments. Over time, the appropriate conditions and supporting infrastructure will develop to ensure that the most promising options are widely adopted in those situations where they are cost effective. Premature selection of the best technology may not fully incorporate consumer preferences and could deter further innovation essential to its eventual success.

Other analysts disagree, arguing that imperfections in the markets for energy-using equipment will prevent full realization of these opportunities. In their view, policymakers can influence the selection of the best technologies through information and technical standards and develop programs that reduce the costs of adopting them. These problems would be particularly relevant in those sectors where competitive forces leading people to be cost-conscious are absent. Homeowners using small amounts of energy and purchasing energy-using equipment infrequently might not fully exploit all opportunities.

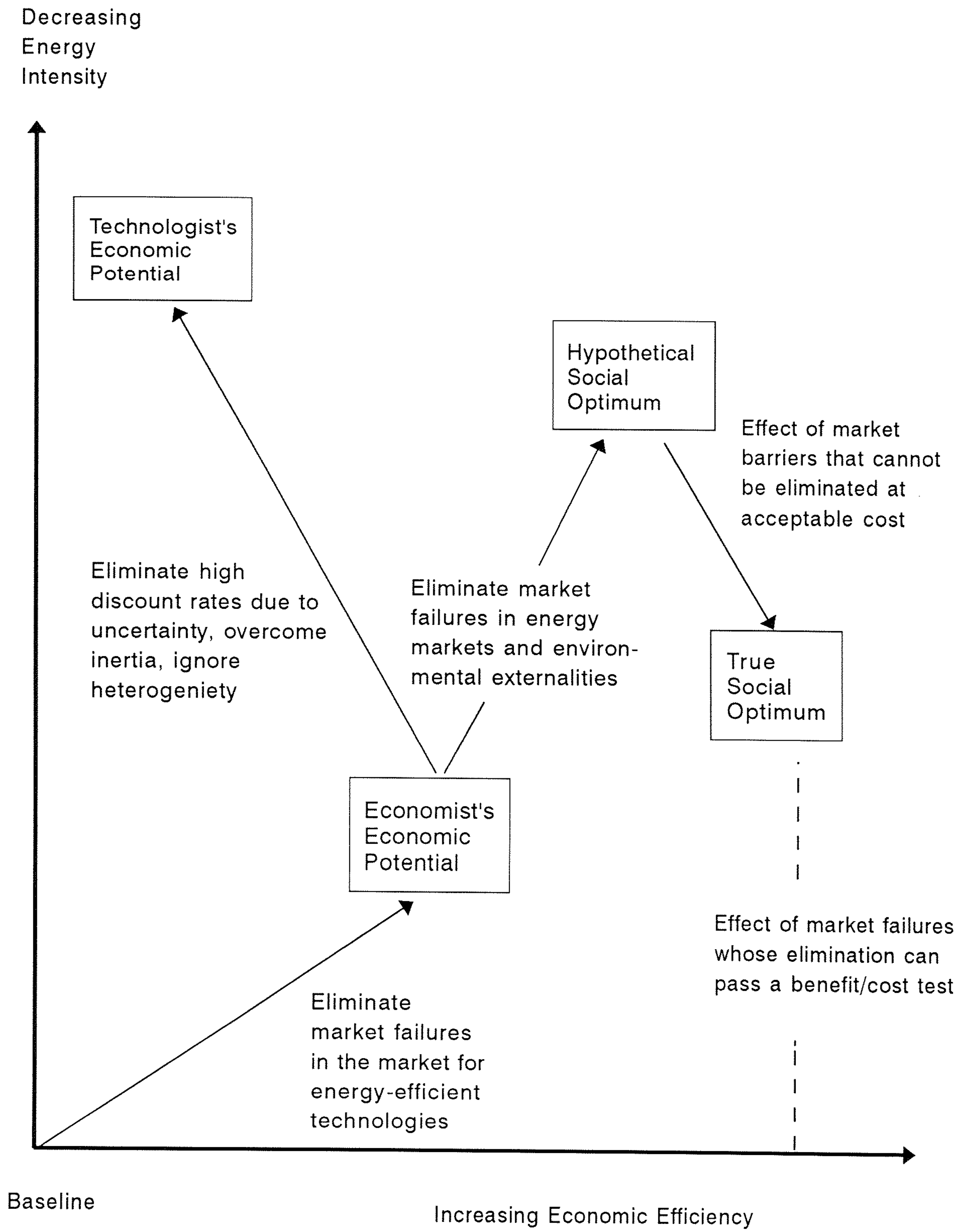
Economic Conservation Potential and Economic Efficiency

Reducing energy use will not make the best overall use of society's resources if it increases total costs or requires consumers to purchase items or adopt lifestyles that they find less desirable. While analysts on both sides of the issue agree on this point, they disagree on how to empirically measure costs.

Figure 7 shows the relationship between different concepts of economic potential and what society might find optimal from the perspective of overall economic efficiency.[19] Each box represents a different set of conditions or "scenario" that society might adopt. Moving upward in the figure results in decreasing energy intensity; moving rightward results in increasing economic efficiency. The origin represents the levels of energy intensity and economic efficiency achieved under the assumed baseline conditions. These reference levels will vary for different energy and economic projections and for different assumptions, as discussed elsewhere in this report.

"Economic potential" describes the level of energy intensity experienced if various market barriers are removed. Two different concepts of potential are possible, depending upon which barriers are removed. Eliminating only those barriers that can be considered market failures in the market for energy-efficient equipment will move society from the baseline to the economists' concept of economic potential. It moves in a northeasterly direction because the removal of these failures both decreases energy intensity and improves overall economic efficiency. Eliminating any

Figure 7. Alternative Notions of the Energy Efficiency Gap



remaining barriers in this market will move society to the technologists' concept of economic potential. These efforts realize additional decreases in energy intensity but only by incurring additional costs, either in the form of direct expenditures or required shifts in product attributes or lifestyles. Although above the baseline, the technologists' economic potential could be either to the right or the left of the baseline, depending upon the costs of removing these additional barriers.

Studies of the potential for energy efficiency employ the technologists' concept of economic potential. The modeled decisions are "optimal" only if energy efficiency is the sole criterion. All other considerations or barriers are eliminated, including the costs of adoption as well as concerns about uncertainty, product reliability, and qualitative attributes. In addition, technologies that are cost effective for the "average" energy user are assumed to be adopted by everybody, regardless of the variety of conditions in which energy consumers operate.

Additional gains in economic efficiency may be possible if energy prices are changed to remove market failures unrelated to the markets for energy-efficient equipment. Such intervention might include setting electric utility prices equal to the incremental cost of building new generation, transmission, and distribution,[20] eliminating parking and other subsidies to owners of passenger cars, or imposing taxes to incorporate energy security risks or environmental damages that might not be reflected in the market prices of energy. The removal of these market failures shifts society to the "hypothetical social optimum", which lies above and to the right of the economists' economic potential, as both energy and economic efficiency are increased.

If the gains from removing any market failure do not cover the costs, its elimination does not improve economic efficiency. Some of these market failures may not be very significant, while others may be quite costly for the government to eliminate. Only those market failures whose elimination passes a benefit/cost test should be removed, resulting in the "true social optimum" lying below (less energy efficiency) but to the right (more economic efficiency) of the hypothetical social optimum. The true social optimum may lie either above or below the economists' economic potential, depending upon how costly it is to remove the failures in the market for energy-using equipment.

The purpose of the figure is to depict the relationships among difficult concepts that are sometimes confused with each other. The exact horizontal and vertical position of any of these boxes will vary according to one's perception of the nature of market barriers and failures as well as the underlying market conditions.

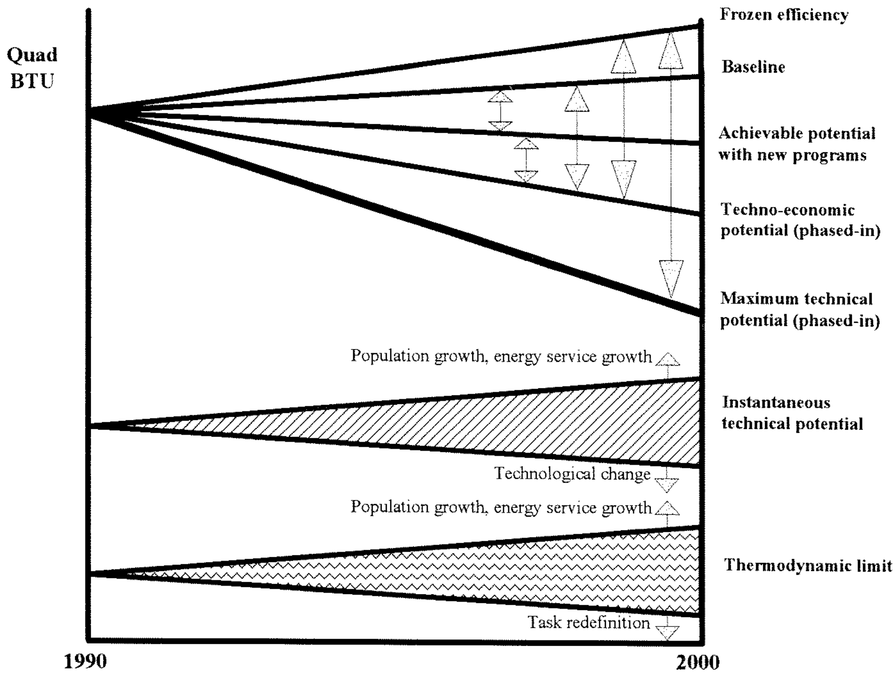
Measurement: Past Studies

The preceding discussion underscores the need for reconsidering the concept of economic potential--either the economist's or the technologist's--and its relevance to appropriate public policy. The measurement of the gap based solely upon energy efficiency criteria raises additional problems in interpreting the results of past studies, as explained in Box 5 and Appendix A.

How the gap is measured can be extremely important. Some analysts estimate how much can be achieved by immediately replacing all of the equipment currently in place with the most efficient options. This procedure can overstate the real gap by a considerable amount because

BOX 5. DEFINING AND MEASURING THE GAP*

Past studies have defined the "gap" differently, causing wide differences in their estimates. The figure below captures the various perspectives from which future energy use can be viewed. It plots total energy use on the vertical axis as a function of time on the horizontal axis.



The top two lines provide different references for measuring the gap. The Frozen efficiency line is higher than the baseline path because it disallows any further efficiency improvements in new equipment due to higher future energy prices, expected technological advances unrelated to prices, and current government programs. In the frozen efficiency case, efficiency of existing equipment is held at its base year levels (no retrofits are allowed) and efficiency of new equipment is frozen at base year levels. New equipment is allowed to replace existing equipment, thus accounting for the effect of stock turnover. A frozen efficiency case does not capture any exogenous or price-induced efficiency improvements, but it is a computationally convenient reference point against which to measure changes in efficiency and product mix.

When markets operate efficiently without failures, the baseline case captures all cost-effective efficiency improvements. If there are market failures that inhibit energy efficiency, an additional potential for realizing cost-effective energy efficiency may exist. This potential can be characterized in a "technical" or "techno-economic" fashion. The techno-economic potential is characterized by calculating a cost of conserved energy and amount of energy savings for each measure, relative to the frozen efficiency case. The technical potential is defined as the sum of all options regardless of cost.

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*Jonathan Koomey of Lawrence Berkeley Laboratory developed the discussion and figure for this box. Appendix A contains more details and discussion of the key points.

(Continued)

Box 5 (continued)

There are two basic approaches to estimate the technical and techno-economic potentials: "phased-in" and "instantaneous." The phased-in approach explicitly accounts for the gradual retirement of existing buildings and equipment when it becomes too costly to continue operating them. The instantaneous approach assumes that all currently existing buildings and equipment are instantly replaced with the most efficient currently available technology.

The technical potential described by the instantaneous approach characterizes technological limits in the same way that the lower uncertainty band in the figure describes thermodynamic limits. The latter represents the minimum energy that is thermodynamically necessary to accomplish all the tasks that human society desires to accomplish. The gap between this minimum energy and the energy actually used to accomplish the given tasks (measured by Second law efficiency) is on the order of a factor of 10. Over time, energy use in this case can be driven up by growth in population, and it can be driven down by task redefinition. The thermodynamic limits govern the ultimate extent of energy efficiency improvements.

The "Achievable" potential is usually calculated by adjusting the techno-economic potential to account for the real-world performance of efficiency technologies and programs. The achievable potential accounts for technology costs (just as for the techno-economic potential case), program costs, implementation constraints, takeback, persistence, and the fact that engineering estimates often overestimate savings. The estimates for the 6% hurdle rate case in this study are achievable potentials.

the future equipment chosen will be increasing its efficiency as old equipment is updated and as changes in energy prices and mandated standards improve the efficiency of new equipment.

Several studies have estimated the potential for additional conservation based upon detailed engineering estimates for energy savings and equipment costs (Appendix B). Based upon assumptions about the availability and penetration of new energy-efficient technologies, they typically find a significant potential for additional cost-effective energy savings, resulting in 17% to 36% reductions in carbon dioxide emissions for the U.S. The potential is largest for the residential sector, where estimates range from 22 to 52% of baseline emissions. The studies attribute all of the difference between the potential conservation and that actually achieved to market barriers that prevent access to investment funds, information, or other constraints.

In estimating the conservation potential, these studies do not analyze specific policies or examine the effect of removing certain market imperfections. Instead, they specify a hypothetical scenario in which consumers place a higher value on energy efficiency than they appear to do in actual markets. Based upon observed behavior, consumers appear to be strongly influenced by the initial equipment costs (or first costs) leading them to forego investments that appear profitable, i.e., ones that would produce energy costs savings that exceed the initial costs within a few years.

The investment hurdle rate summarizes the relationship between initial costs and future energy cost savings. It is the rate of return that consumers require before investing in energy efficiency (Box 6). Consumers apparently use relatively high hurdle rates for a range of decisions, including those related to purchasing energy-efficient equipment. Hurdle rates

BOX 6: HURDLE RATES FOR EVALUATING NEW TECHNOLOGIES

Consider a stylized technology for energy efficiency. The customer spends $1 initially for a new piece of equipment but saves $0.50 with it in place in each of the next three years. The yearly net savings, for example, might reflect a gross savings in energy costs of $0.60 offset partially by $0.10 in maintenance costs. Total net returns cumulated over the three years are $1.50, or 50% higher than the initial costs.

Direct comparison of total cumulative cost savings with the initial cost is deceiving, however, because the costs and savings occur in different years. The concept of a hurdle rate, or discount rate, adjusts the cost savings so that they can be compared with the initial year's costs.

If the consumer borrows the $1 or uses his own investment funds, his costs increase by the interest payments he incurs or foregoes. At 10% each year (compounded), the investment costs after three years increase to $1.33 inclusive of the borrowing costs. Although still profitable from a strictly energy-efficiency perspective, the investment is less attractive than before adjusting for the time value of money.

The consumer should also be concerned about the riskiness of the investment. Some new energy technologies can be quite risky because both their actual performance and future energy prices can be highly uncertain. Consumers may be able to protect themselves somewhat against price risk if certain other investment opportunities exist, but they cannot remove the technological risk associated with a new product. In addition, these investments often are not easily reversed, because it is difficult to resell the equipment if the investment ceases to be profitable. In these cases, hurdle rates should be higher. At a rate of 15% per year, the energy-efficient technology in this example ceases to be a more profitable option from a purely financial perspective.

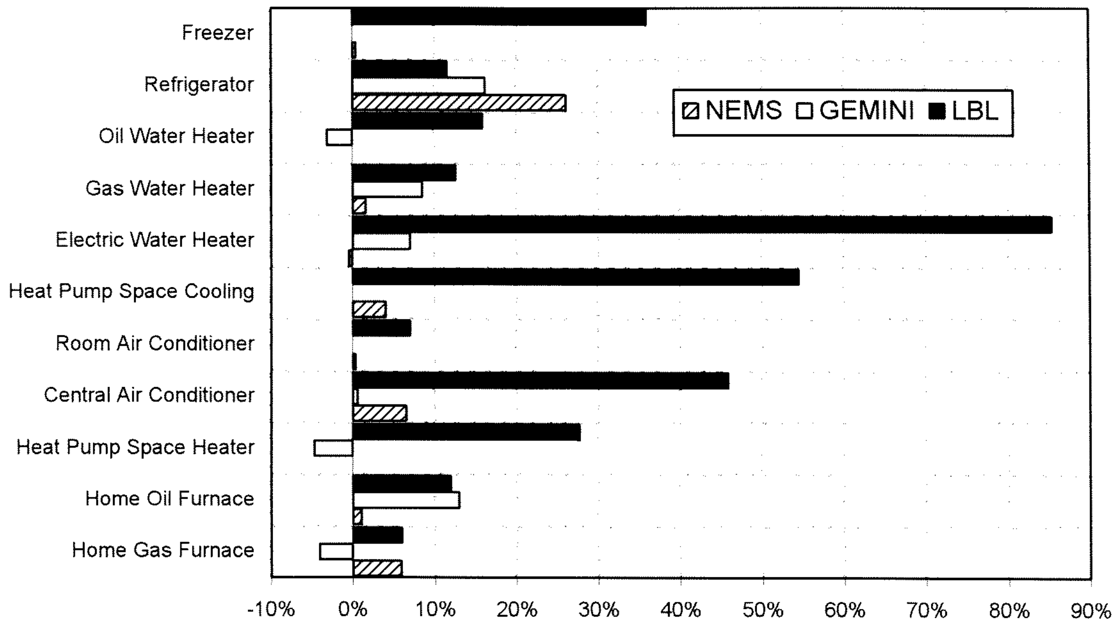
Despite its critical importance, there exists little agreement on what is the appropriate hurdle rate for the consumer. The rate should apply to an investment of comparable risk. "Social" discount rates that ignore such risks would appear to be too low, making energy cost savings more valuable than what consumers reveal in their other decisions. In addition, the rate of return on equipment operated for only a few years (as in this example) is quite sensitive to small changes in initial costs--due either to errors in estimating equipment purchase price or to the presence of omitted adoption costs discussed elsewhere in the report.

in the 20-40% range are cited quite commonly for energy-efficient equipment and are used in many models when projecting baseline energy demands representative of what is expected under normal market conditions. The hypothetical conditions for simulating the economic potential are represented by replacing these baseline hurdle rates with substantially lower ones, often as low as 3%.[21]

Measurement: Current Study

The Working Group conducted a similar exercise with the models included in this study to learn more about how estimates of economic potential are derived. Hurdle rates were lowered from the 20% or more that were used to project actual market conditions to 6%, making the future energy cost savings resulting from energy efficiency much more valuable.

Figure 8. Change (%) in Average Equipment Efficiency in 2010 Due to a 6% Hurdle Rate



This lower rate approximates the rate of return used by electric utilities to evaluate supply-side investments for power generation. Given the difference in risks and uncertainties associated with these two types of investment, there is no reason to expect that society should attempt to achieve equal hurdle rates across investments. However, the estimates from this scenario help to understand what happens when possible differences in relative riskiness are removed.

Estimated Effect on Equipment Efficiencies

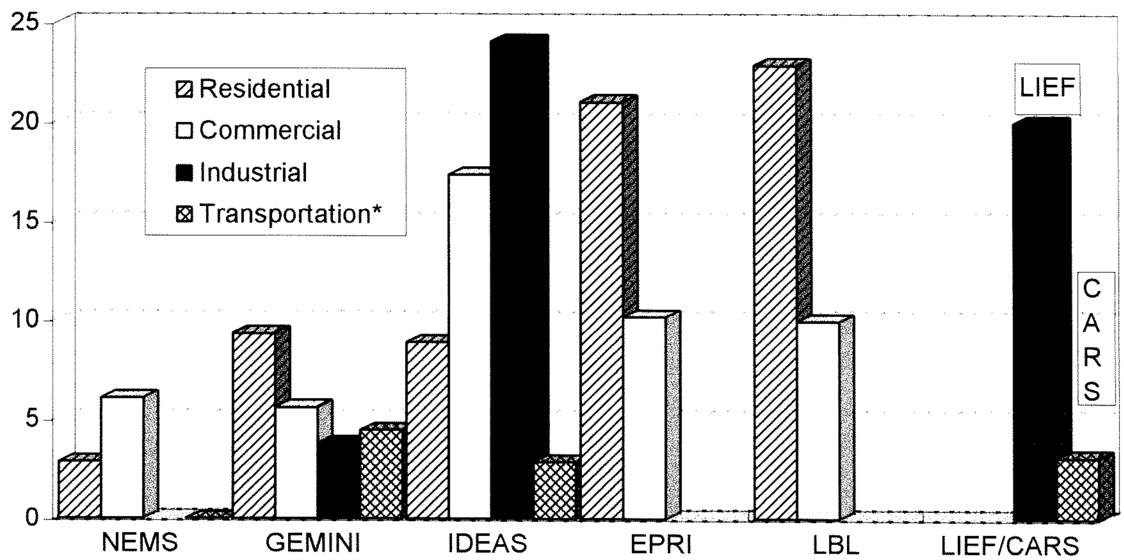
All models used in the current study chose more efficient equipment, resulting in lower energy demands across sectors. In the residential sector, for example, the lower hurdle rate increases the average equipment efficiency in each end use (Figure 8). There exists little agreement among the models on which end uses would be affected most. The percent efficiency improvements in the LBL results exceed 10%, often by a substantial amount, for all end uses except room air conditioner and home gas furnaces. By contrast, improvements in the other two sets of results remain below 10% for all end uses except refrigerators and home oil furnaces (GEMINI only).

Estimated Effect on Energy Demand

The estimated energy savings by the year 2010 vary from minimal to a range of 15 to 20% in the sectors outside transportation (Figure 9). This range is less than potentials estimated in the previous studies of energy-using technologies for several reasons.

First, the estimates here incorporate some improvements in energy efficiency in the

Figure 9. Reduction (%) in Aggregate Delivered Energy Consumption Due to 6% Hurdle Rate, 2010

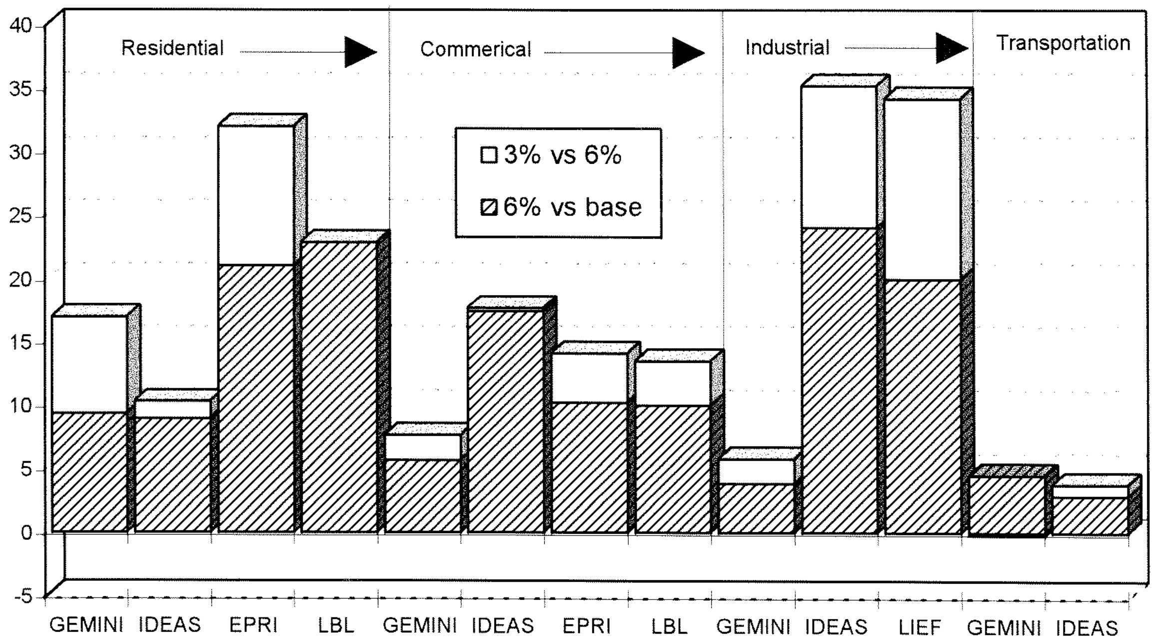


* light duty vehicle gasoline consumption for NEMS & CARS

baseline over time, recognizing that economic forces and policies in place are already reducing the gap. This approach is relevant for evaluating the potential for additional conservation policy measures that will not be undertaken given likely future market conditions. In contrast, some previous estimates measure the potential relative to a base year, thus not allowing baseline efficiencies to improve over time.

Second, the estimates in this study assume that cost-effective technologies are adopted by some but not all consumers, who operate under diverse conditions, some of which may not be suitable for the technology.[22] Some widely publicized studies fail to account for the diversity of decisionmakers and situations. It does not appear that the lower estimates of conservation potential in this study are due significantly to the use of hurdle rates above a social discount rate for evaluating public decisions. Some studies of economic potential have evaluated energy-efficient technologies at a social discount rate (often assumed to be 3%) rather than one used by private investors, e.g., utilities considering supply-side investments in power generation. This practice can be troublesome, because investments in energy efficiency compete with other investments that are privately funded, either by households and firms as consumers or by privately-financed electric utilities. As an empirical matter, however, the estimates of technical potential here are relatively insensitive to whether a social discount rate or a private hurdle rate is used to

Figure 10. Additional Reduction (%) in Aggregate Energy Consumption Due to 3% Hurdle Rate, 2010



evaluate the competing technologies. Figure 10 compares the incremental effect of lowering hurdle rates from 6% to 3% with that of replacing baseline hurdle rates with 6%. Outside the industrial sector, the incremental effect of shifting from 6% to 3% is relatively modest for most models and sectors.

Differences Among Models

Differences in results among the models reflect how they represent baseline market conditions that prevent technologies from penetrating. One approach consists of assuming high discount rates--usually 20% or more--that discourage the selection of energy-efficient options. A second approach directly adjusts the penetration of new equipment to reflect its slow diffusion and the fact that its ultimate market is limited to less than 100% of all energy consumers. While most models employ both approaches, some will depend more upon high hurdle rates as a restraint on energy efficiency while others will depend more upon adjustments to the penetration rate. The largest energy savings in Figure 9 occurred in models in which high initial hurdle rates are used to simulate market barriers to investment in further energy efficiency. In these four models (IDEAS, EPRI, LBL, and LIEF), replacing baseline hurdle rates with a 6% rate results in energy savings of between 10% to more than 20% by the year 2010. These estimates may overstate the opportunity for policy intervention to the extent that the removal of some market barriers (as represented by the previously high hurdle rates) may be costly.

In contrast, the results from two models (NEMS and GEMINI) indicate substantially less opportunity for energy savings with a lower hurdle rate. These two models represent the market conditions preventing investment in energy efficiency by directly adjusting the penetration rates for new technologies. These estimates may understate the opportunity for policy intervention to the extent that some market failures (as represented by constraints on the penetration rate) can be removed without cost to the economy.

The minimal opportunities revealed in the GEMINI results are due primarily to the relatively low hurdle rates--7% to 12% depending upon sectors--used in this model to represent the baseline conditions. Thus, the change in the hurdle rate between baseline levels and 6% is smaller in this model. In the baseline scenario, investment in energy efficiency is restrained primarily by reducing the rate at which new technologies are adopted in this model. The lower rate of adoption implicitly represents various costs and barriers not included as explicit costs in the analysis of the investment decision in the model.

The smaller estimated energy savings due to a lower hurdle rate in NEMS reflects an entirely different set of conditions. Energy consumers are separated into different groups, depending upon how they value future energy savings. Those who tend to buy more efficient equipment are assigned relatively low hurdle rates, while those more reluctant to buy the new equipment are given relatively high rates by the model. Thus, reducing the hurdle rates to 6% results in a large stimulus to buy more efficient equipment for some users but a very modest stimulus to others. In addition, in the current model, hurdle rates do not enter the decisions about building shells, reflecting the tendency of the construction industry to emphasize initial equipment (or "first") costs to the exclusion of operating costs.

These differences in model results reveal little about the cost effectiveness of policy measures promoting additional energy savings. Estimates of the economic potential for energy conservation, including those reported here, do not address this issue. Without explicit links to specific policies for removing market barriers, these estimates do not provide sufficient guidance to policy makers and regulators about the relative merits of pursuing additional conservation.

RECOMMENDATIONS FOR FUTURE ESTIMATES

The approach of projecting energy demand on the basis of decisions about equipment choice and utilization has considerable appeal, especially for policymakers interested in knowing how specific programs will influence energy use. And yet, existing estimates of the energy-efficiency gap based upon this approach can mislead public policymakers if the analyses fail to account properly for the costs and benefits of different policy options. Here we offer some recommendations for improving the analysis underlying such estimates.

Representing Barriers as Costs

Specific barriers should be identified, and where possible, their costs estimated. These additional costs could then be added to the direct investment costs to form a more comprehensive analysis of costs. This approach would eliminate the need to include in "market discount rates" a range of factors such as manufacturer and distributor behavior and cost of information.

Hurdle Rates

Hurdle rates should be reserved for representing financial market opportunities, riskiness of the investment, and consumer overall preferences for delaying future payoffs in all kinds of activities. Many frequently-cited barriers are likely to influence the gains from or costs of investing in certain technologies rather than the hurdle rates consumers use to evaluate these investments. Confusing barriers with hurdle rates makes it more difficult to evaluate properly the costs and benefits of alternative policy options.

An important difficulty with representing barriers as hurdle rates is that lower hurdle rates affect many decisions and not just the energy efficiency of equipment. The lower rates would reduce the cost of energy-using capital, encouraging consumers to choose more equipment than otherwise. For example, households would find cars less expensive if they could purchase them with financing at a lower interest rate. Similarly, commercial establishments might be encouraged to occupy more floor space if their rents reflected the lower commercial construction costs experienced by builders in a world with lower rates.

One model (GEMINI) found that energy demand would be reduced in the 6% hurdle rate case only when several key relationships, represented explicitly in the model, were ignored. When operated in its normal mode with the 6% hurdle rate, the model projected decreases in the cost of equipment in general. Consumers responded by not only selecting more energy-efficient technologies, but also by purchasing more equipment. The second effect produced increases in the demand for energy-using equipment, resulting in increases in energy demand that offset virtually all of the improved energy efficiency effect. For consistency with the other models, the results in Figure 9 were generated by omitting this effect and fixing the energy service demands at their baseline level. In general, however, changes in the investment hurdle rate should affect the amount as well as type of energy-using equipment, and estimates of the conservation potential should incorporate these effects.

In addition, many estimates of the economic potential use a social discount rate that is lower than the private rate to reflect the decreased risk associated with public investments. However, when these same lower rates are applied to investments in energy production as well as consumption, energy supplies become less costly and expand, stimulating energy consumption through lower energy prices. The net effect of both the increased energy service demands and less costly energy supplies in the GEMINI model was to completely offset the effects of improved energy efficiency, resulting in virtually no change in energy use. Few studies incorporate the broader ramifications of a world with lower investment costs, but these factors clearly influence the total level of energy use. Lower investment hurdle rates are not necessarily a panacea for protecting the environment.

Reported Costs

Almost no model in this study reported the total amount of investment that would be required to reach the economic potential. Although the models have the capability, computational complexity appears to be the primary reason for not reporting these estimates. Nonetheless, policymakers should require such estimates, so that they can compare the required investment costs with the reduced investment for energy production and judge for themselves whether the economy can achieve the implied amount of shift in capital investment required by the policy.

Moreover, simply aggregating the cost estimates for particular technologies may be quite misleading if the analysis excludes maintenance and other incurred expenses as well as the costs of removing market barriers. Broadening the concept of costs, as recommended above, would make the estimates more useful for policymakers interested in evaluating the best overall use of society's resources.

Supply-Side Innovation

The removal of barriers could stimulate producers to provide more options for increased energy efficiency. Estimates of the conservation potential are made without an explicit representation of the behavior of the suppliers of energy-efficient technologies. In the EMF scenarios, supply-side innovations were incorporated judgementally, as they are in all studies of the conservation potential, with some models allowing new more-efficient technologies to be available in the lower hurdle rate case and others relying upon a similar slate of technologies as in the baseline. Shifts in consumer demand toward more energy-efficient options (as a result of lower hurdle rates) would likely stimulate suppliers to offer more such products and perhaps with higher quality, but there is insufficient empirical evidence to assess the magnitude of this response.

Economy-Wide Interactions

Energy use is closely linked to the demand for energy services, such as lighting, heating, and the composition of economic activity. As a result, interactions between policy and energy service demands, energy production, and market interest rates could be crucial elements to incorporate. Among energy analysts, there has been a growing awareness of the importance of linking analyses of specific technologies with those of aggregate economic trends. Policymakers should encourage such developments and avoid making choices between these approaches that excludes one. The system-wide effects of lower hurdle rates (discussed above) or of changes in energy prices resulting from increased energy efficiency are important considerations when evaluating different policy options.

MEASURING BARRIERS AND COSTS

The identification of market barriers and measurement of a broader concept of costs lie at the heart of the debate about energy efficiency. While general distinctions about key concepts help to structure the discussion, resolution of the issues depends upon empirical measurement applied to specific end uses and technologies.

Diversity of Situations

The diversity of technologies and decisions makes it difficult to generalize whether it is avoidable market failures or unmeasured but real adoption costs that prevent consumers from investing in energy-efficient technologies that appear to be cost effective. In some applications, both factors may be operating.

Many homeowners prefer the light from conventional incandescent bulbs over that from the more energy-efficient compact fluorescent lights. For these people, the two alternatives are not interchangeable without some loss in convenience or satisfaction. Energy efficiency may not be a very important criteria in this decision.

On the other hand, for commercial establishments with existing fluorescent lights, replacing standard ballasts with more energy efficient core-coil ones can be done without changing the light quality. While the out-of-pocket expenditures required to convert ballasts appear quite low, thereby making the investment appear attractive, any cost or inconvenience resulting from installing the ballasts also needs to be incorporated. If these additional unmeasured costs are relatively low, the limited penetration of these ballasts could demonstrate consumer inertia or barriers to adoption that policy might be able to mitigate.

Energy-efficient refrigerators provide another example that demonstrate these alternative perspectives. To date, improvements in new refrigerator energy efficiency have been realized with little visible change in the product's attributes. As long as reliability and performance are the same, the consumer is unlikely to notice whether his refrigerator is operating with a more energy-efficient compressor or a standard one. On the other hand, manufacturers have made these improvements under the constraint that they deliver essentially the same product as before. For example, it might be less expensive to redesign the unit to have thicker walls, but the consumer would lose either valuable interior space or the flexibility to buy an appropriately-sized unit for his kitchen's configuration. The cost-effective unit is not the one involving the largest energy cost savings per dollar spent on purchasing the equipment.

Qualitative product attributes are not the only costs that do not involve direct expenditures. Some costs involve lost opportunities rather than spending money. The homeowner considering installation of insulation in an existing house can delay his investment. He purchases home insulation under the expectation that he will own the home for many years. If energy prices should fall significantly after he installs the insulation, he may regret his decision because he cannot resell the insulation. By purchasing the insulation today, he has lost the opportunity to delay his investment until he has learned more about the new economic conditions.[23] The consumer may experience similar lost opportunities when he purchases a product whose price falls or quality improves over time, as appears to be the case for some energy-efficient appliances. When opportunity costs are significant, as they can be in situations like where delay is possible, high implicit hurdle rates may reflect sound economic judgement rather than poor decisionmaking skills.

Homeowners will not be able to delay their investment when they are building a new home or need to suddenly replace their equipment, e.g., a refrigerator that suddenly stops working. Alternatively, delay may not improve the information about the investment. In these circumstances, high implicit hurdle rates cannot be attributed to the value of delaying the investment.

Commercial Lighting: An Example

To provide a better understanding of the market failures and unmeasured decision costs that create the energy efficiency "gap", the working group considered a specific application--the opportunities for increasing the energy efficiency of inside lighting in commercial and industrial buildings. The commercial building sector is responsible for about 10% of U.S. energy consumption[24]. Interior lighting is an important use of energy in commercial buildings, representing 40% of electricity use and 15% of total energy use in the commercial sector[25]. Interior lighting is also widely believed to be among the most cost-effective conservation opportunities available. Studies of potential energy conservation in interior lighting have estimated that an additional 40-70% of energy use could be cost-effectively saved[26].

In an attempt to exploit these and other apparently cost-effective opportunities in the residential, commercial, and industrial sectors, U.S. utilities spent about $2.2 billion on demand-side management programs in 1992[27]. Many programs offer product information, rebates, and often technical assistance to customers that agree to install energy-efficient technologies. Many rebate programs have been successful in encouraging participants to install energy efficient equipment in their facilities. A fundamental question is whether the societal benefits reaped by these efficient equipment installations outweigh the costs incurred by participants, other rate payers, and the utility.

The example of commercial lighting DSM programs provides numerous opportunities for estimation of customer costs and benefits. Efficient lighting equipment may be more or less pleasing to workers than the original equipment. The customer may experience inconvenience during installation and maintenance. Finally, participation in the utility program (filling out applications, walking through the site with utility personnel) may require more or less time than if the customer were forced to maintain and upgrade a building lighting system without utility technical and financial assistance. The difficulty is that these additional costs and benefits cannot be measured directly and are likely to vary greatly among customers.

The case study draws upon the experience of Massachusetts Electric Company, a subsidiary of New England Electric System. As other utilities have also found, the company experienced little success with programs that provided information only without direct financial incentives. As a result, it introduced a set of programs that offered rebates to qualifying commercial and industrial customers who purchased approved energy-efficient equipment to replace existing equipment or to be installed in new buildings or as part of a broader renovation. These programs accounted for more than three-fourths of the $43.5 million spent by the utility on demand-side-management (DSM) programs in 1992 and are widely considered within the industry to be well operated.

The particular programs are full-scale programs which offered equipment information, rebates, and technical assistance to hundreds of participants during the 1992 program year. The working group discussed several reasons for the programs' popularity, and examined customer and vendor surveys from both programs in an attempt to shed light on costs and benefits incurred by program participants.

Compensation for Omitted Costs

One explanation for the program's ability to attract participants is that the rebate compensates the participant for some of the adoption costs he incurs by selecting the new lights.[28] Such costs would include inconvenience and shut-down time during the installation process as well as the costs of acquiring information specific to the company's building and situation. Concerns about reliability and maintenance may also contribute to a company's reluctance. Prior to the rebates, consumers do not adopt the new lights due to sufficiently high adoption costs rather than to significant market failures in buying the energy-efficient lights.

In this view, the rebates compensate for, but do not reduce, these real costs, making it profitable for qualifying customers to invest. Customers not receiving the rebates continue to refrain from investing in the new lights. Society continues to incur real costs as each customer joins the program, but these omitted costs are paid by nonparticipating customers of the utility. In fact, participants adopt too much, according to this view, because their private costs (after the rebate) are below what it costs society to provide this opportunity. As electricity markets become more competitive, utilities will experience greater pressures to curtail programs that simply shift costs among rate payers rather than providing across-the-board cost reductions to all customers.

It is extremely difficult to measure these omitted costs directly and compare them to the rebates. However, one can infer how much these omitted costs would have to be to justify the customer's reluctance on economic grounds. Such estimates are referred to as the "break-even" omitted costs. Since these costs occur in the initial year of adoption while the energy cost savings accrue over time, the "break even" omitted costs depend importantly on the investor's hurdle rate, or the required rate of return after adjusting for inflation. At the 5.5% rate set by the state regulators, the omitted costs would have to be quite large indeed--more than 100% of the initial cost of the equipment. But few commercial and industrial customers use such a low rate for evaluating their other investments that would compete with energy efficiency. The required omitted costs need to be only 30% of the equipment cost at a hurdle rate of 15% and only 15% of the equipment cost at a hurdle rate of 20%.

These computations do not resolve whether this explanation is right or wrong. They do indicate that these additional adoption costs do not necessarily have to be large to explain customers' preferences for the older equipment on economic grounds. They also show that both omitted costs *and* hurdle rates are important issues in debates about the "gap".

Reduction in Omitted Costs

An alternative explanation for the program's ability to attract participants is that the rebate reduces some adoption costs for everybody by transforming the market rather than simply compensating some potential investors for their high adoption costs.[29] The utility program operates simultaneously along several dimensions. The rebate may initially attract a customer's interest, but the information and hands-on experience provided through the program educates the customer about energy-efficient equipment. At the heart of this explanation is the hypothesis that, prior to program participation, customers systematically underestimate the benefits of installing energy-efficient equipment. Information from the Massachusetts participant surveys indicates that after program participation, 65% of participants who were originally unwilling to install efficient equipment outside the program say they would now install the equipment without a rebate. Moreover, successful adoption by the initial participants reduces adoption costs for other customers by demonstrating how to use the technology successfully to others and by creating an infrastructure of information and reliable contractors from which others can benefit.[30] Adoption of the new lights would spread to other customers, even if the utility should discontinue the rebates. Under this explanation, the omitted participant costs are primarily imperfect information and search costs, which a consumer would incur trying to collect and synthesize information on efficient technologies. The utility and its contractors perform this function and present the information to the program participants. Thus, the information provided by the utility reduces costs not only for current participants but also for all future potential investors.

Utility surveys of participating customers reveal a high level of satisfaction with the application process, the utility representatives who described eligible equipment which could be installed by each customer, the contractors who installed the equipment and provided maintenance information, and the utility representatives who performed follow-up inspections of each customer's installation. Some analysts interpret this lack of dissatisfaction expressed in these surveys as evidence that the omitted adoption costs are minimal.

Some Concluding Remarks

Many companies operating in other markets use rebates to attract first-time buyers to spread information about the availability of a new product. In this respect, the rebates for commercial lighting may be providing a similar stimulus. What is different in this program is that the rebate is being offered by another industry (the utility) producing a substitute product (electricity) rather than by the equipment manufacturers who should have considerable incentives to see their markets expand. The debate between economists and technologists probably has more to do with the form of the rebate--essentially a cross subsidization from one industry to another--than with the notion that rebates can fundamentally change consumption patterns, aside from the direct effect of the subsidy itself.

The commercial lighting example also underscores the need for more careful evaluation of specific end-use applications. In such evaluations, there is a clear need to identify and measure the range of adoption costs that frequently are excluded from engineering and utility cost-benefit analyses. At the same time, efforts to identify specific market failures with observed underinvestment in energy-efficient appliances are needed to facilitate the dialogue on the "gap" issue. For example, it appears that households who rent are less likely to adopt energy-efficient equipment.[31] The available evidence for commercial establishments appears more ambiguous.[32]

Finally, empirical studies are needed to verify how investors' behavior changes with and without the program. If the programs fundamentally transform the market, then interest in the new technologies would continue even if the rebates were discontinued. Existing participants would continue to invest as they gain experience with the technology, and nonparticipants would be attracted to the new equipment as the infrastructure develops. To date, there have been few definitive studies that either confirm or refute such behavior.

CONCLUSION

Energy demand is likely to increase, but at a rate that lags behind the gross national product, resulting in declining aggregate energy intensity. Whether policy should try to accelerate this trend is a controversial issue.

Projected trends reported in this study show aggregate energy demand growing by 0.8% to 1.3% per year more slowly than gross national product. Activity-related factors such as the relative growth in households and commercial floor space or shifts in the composition of energy-using activities within an end-use sector account for most of this decline in energy intensity. Further improvements in the energy efficiency of new buildings and equipment above 1990 levels contribute well less than half of the total effect. Thus, policies directed solely at improving equipment efficiencies, such as standards and many utility rebate programs, are limited in scope, because they address only one of several important mechanisms through which nations experience declining energy intensity trends economy-wide. Other important factors for influencing energy intensity trends include energy prices, capital costs, and the composition of goods, services and household activities.

Factors other than energy prices have the most influence on these projected trends. Autonomous declines in the aggregate energy intensity for the economy, unrelated to energy prices, range from 0.6% to 1.0% per year in these projections. These estimates are based upon an end-use engineering analysis of individual technologies and specific assumptions about economic growth in the economy and activity growth in various end-use sectors. The resulting declines appear consistent with assumptions about "autonomous energy efficiency improvements" commonly used in many more aggregate economic models for evaluating global climate change policies.

There exists little agreement on what should be the role of government in promoting energy efficiency. Some working group members who advocate cautious policy intervention think that information problems are restricted to specific situations and that analyses indicating large energy efficiency potential are too dependent upon unjustifiably low discount rates and the omission of important hidden costs. Others who would favor more aggressive policies view information as a systemic problem found in "normal" markets, find little direct evidence of important hidden costs, and consider high inferred discount rates as direct evidence of improperly working markets.

Despite sharp differences on the magnitude of the economic potential, there emerged a somewhat unexpected common ground on certain conceptual issues:

- Obstacles to investment (market barriers) are widespread and exist in all markets, including energy.

- Some market barriers (market failures) cause resources to be misallocated and justify government intervention; other barriers do not.

- Scarce information is not a market failure, but under certain conditions markets will not provide information efficiently to the appropriate decisionmaker, creating the principal source of market failures that account for the "gap" in energy-efficient investments.

- Where cost-effective, policy might address other market failures unrelated to the "gap", e.g., divergence of average and marginal pricing in utilities, energy security, and environmental externalities.

- Conventional measures of "economic potential" for energy conservation do not resolve the issue of whether society should invest more in energy efficiency than it currently does.

Previous estimates of the energy conservation potential provide little direct guidance to policymakers on deciding how much additional conservation should be pursued and which policies might achieve such targets. Without more information about the costs of removing market barriers, policymakers do not know how much of this potential would be cost effective to realize. It may be possible to remove some failures at little or no cost, as would be the case for some market failures identified in this report. In this case, appropriate policies might be designed that would capture these benefits. It may be relatively expensive to eliminate other market barriers. Under these conditions, public intervention would not be justified. Moreover, estimates of the potential focus exclusively on impediments in the markets for energy-efficient equipment, ignoring possible market failures such as pollution that result because energy may not be priced to reflect its social cost. These external effects are important to incorporate in evaluating how much energy conservation should society seek to achieve.

APPENDIX A: TECHNICAL NOTES ON DEFINING AND MEASURING THE "GAP"[33]

This appendix summarizes technical points on defining and measuring the energy-efficiency gap. All discussion refers to the figure contained in Box 5.

Baselines

The highest line on the graph represents the frozen technology or efficiency case. This case is calculated using a baseline forecast of building/appliance sales and retirements, as well as the efficiency of new and existing devices in the base year. Efficiency of existing equipment is held at its base year levels (no retrofits are allowed) and efficiency of new equipment is frozen at base year (1990) levels. New equipment is allowed to replace existing equipment, thus accounting for the effect of stock turnover.

Immediately below this line is the baseline case, sometimes referred to as "business-as-usual". This case includes price-induced changes in the efficiency and usage of energy using devices, as well as the effects of current government policies affecting efficiency (e.g., appliance and building efficiency standards, utility programs). It is not always possible to estimate this case accurately, because characterizing responses to price is complex and capturing the effects of the many state building standards on total US energy use is difficult. A frozen efficiency case does not capture any exogenous or price-induced efficiency improvements, but it is still a useful construct: it is a computationally convenient reference point against which to measure changes in efficiency and product mix. The business-as-usual case is more difficult to calculate, but it provides the most realistic estimate of how energy use is likely to change in the future, based on current knowledge.

"Potentials" cases

Each study defines a case that attempts to capture the potential for improving energy efficiency. These cases should measure the extent of efficiency improvements that improve societal welfare in the broadest sense. It is only in this sense that one can consider such improvements "cost effective".

When markets operate efficiently, the baseline case captures all cost-effective efficiency improvements. If there are market failures that inhibit energy efficiency, then an additional potential may exist. This potential can be characterized in a "technical" or "techno-economic" fashion. Estimating such a potential requires detailed knowledge of how energy is used in particular end uses, as well as the cost and effectiveness of different technologies to reduce that energy use. The techno-economic potential is characterized by calculating a cost of conserved energy (CCE) and a BTU savings for each measure, relative to the frozen efficiency case. The technical potential is defined as the sum of all options regardless of cost.

There are two basic approaches to estimate the technical and techno-economic potentials: "phased-in" and "instantaneous". The phased-in approach explicitly accounts for the gradual retirement of existing buildings and equipment when it becomes too costly to continue operating them. This approach gives the most realistic picture of potential energy savings when recognizing real limits on how fast the capital stock is replaced.[34] The savings are usually calculated relative to the frozen efficiency baseline, principally for computational and explanatory convenience.

The instantaneous approach assumes that all currently existing buildings and equipment are instantly replaced with the most efficient currently available technology.[35] The instantaneous approach has heuristic and explanatory value. It is simpler to calculate than the phased-in potential, and it measures in some crude way the potential for efficiency improvements based on known technology. Over time, energy use in such an instantaneous potential case can be driven up by growth in energy service demand or population, and it can be driven down by technological improvements.

The potential described by the instantaneous approach characterizes technological limits in the same way that the lower uncertainty band in Figure A-1 describes thermodynamic limits. These limits represent the minimum energy that is thermodynamically necessary to accomplish all the tasks that human society desires to accomplish. Almost two decades ago, analysts[36] demonstrated that the gap between this minimum energy and the energy actually used to accomplish the given tasks (measured by the Second law efficiency) is on the order of a factor of 10. Over time, energy use in this case can be driven up by growth in population, and it can be driven down by task redefinition. The thermodynamic limits govern the ultimate extent of energy efficiency improvements.

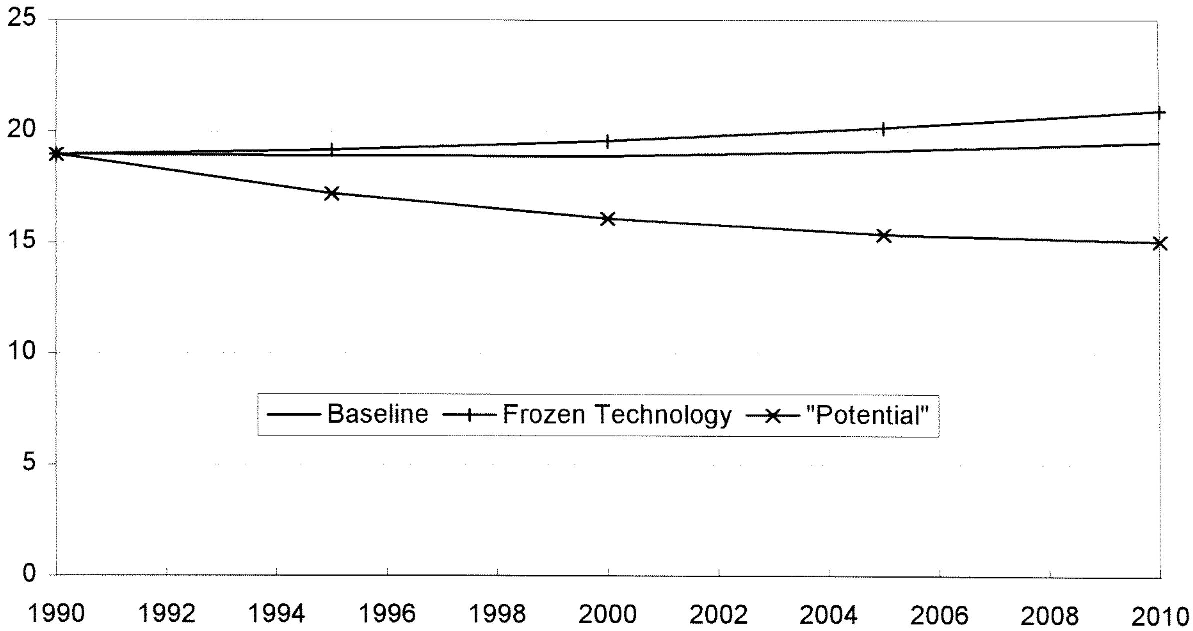
The "Achievable" potential is usually calculated by adjusting the techno-economic potential to account for the real-world performance of efficiency technologies and programs. The achievable potential accounts for technology costs (just as for the techno-economic potential case), program costs, implementation constraints, takeback, persistence, and the fact that engineering estimates often overestimate savings.[37]

Study's Estimates

The estimates here focus upon the potential represented by the difference between the baseline (or business-as-usual case) and the achievable potential case. This comparison is more directly applicable to defining the possible role for promoting new energy-efficient technologies through additional government policies and utility programs. If the estimates incorporate all costs, including direct expenditures as well as nonmonetary costs, the existence of cost-effective efficiency technologies that will not ultimately be adopted implies the existence of market failures. Under these conditions, the precise market failures causing the underinvestment need to be identified in order to design appropriate policies for removing the market failure and correcting the problem.

Figure A-1 plots the total residential energy demand for one model (LBL) in three cases: frozen technology, baseline, and "potential" (or 6% hurdle rate case). The potential case is closest to "achievable" potential discussed above. In this study, the gap is measured as the difference between the baseline (not the frozen technology) and "potential" for the reasons discussed above. As elsewhere in the report, energy demand is measured in efficiency-adjusted units, where electricity is weighted by the ratio of electricity to fossil fuel prices.

Figure A-1. Residential Aggregate Energy in LBL Model
(Efficiency-equivalent energy units)



APPENDIX B: INTERPRETING RESULTS FROM PREVIOUS POLICY STUDIES[38]

Four widely publicized policy studies have estimated a larger potential for additional cost-effective energy conservation than estimated by the models used in this study. These studies focused on mitigating fossil fuel emissions and global climate changes. They include: *America's Energy Choices*, published by the Union of Concerned Scientists, Alliance to Save Energy, American Council for an Energy Efficient Economy, and Natural Resources Defense Council; *Changing by Degrees*, by the congressional Office of Technology Assessment; *Policy Implications of Greenhouse Warming*, by the National Academy of Sciences/National Research Council, and *An Alternative Energy Future* by the Alliance to Save Energy, American Gas Association, and Solar Energy Industries Association.

The table below summarizes the estimated percent reduction in carbon dioxide emissions attributable to achieving the energy conservation potential. Each study defined the potential differently, thus complicating efforts to compare the results of these studies with each other as well as with estimates in this study. Nevertheless, their results suggest considerably greater opportunity for reducing energy use cost-effectively than does this study. Methodological differences appear to contribute to the higher estimates of energy conservation potential in these studies. Each study tends to overstate the opportunities for cost-effective conservation policies due to one or more of the following methodological deficiencies (not necessarily found in each study):

1. Without a clearly defined baseline of future energy consumption under current policies, the potential for additional conservation cannot be evaluated.

2. Social discount rates are used to estimate net private costs and savings for businesses and consumers. Such rates are consistently lower than hurdle rates used by firms and consumers for their other investments.

Percent Reduction in Carbon Dioxide Emissions

	America's Energy Choices	National Academy of Sciences	Office of Technology Assessment	Alternative Energy Future
Year for Estimate	2010	1989	2015	2010
Residential/Commercial	28	52	30	22
Industrial	10	28	17	15
Transportation	30	18	10	13
Total	26	36	24	17

ENDNOTES

1. This conclusion applies particularly to several highly publicized reports on energy conservation potential conducted at the national level. See Appendix B for a summary of some of the problems in interpreting results from such studies. Studies of conservation focused on a particular regional electricity market tend to conduct a more comprehensive assessment of costs. For example, see Northwest Power Planning Power Council, 1991 Northwest Conservation and Electric Power Plan, Volume 2, Parts 1 and 2, Portland, OR, 1991. However, even in these cases, some important adoption costs may be too difficult to measure properly.

2. Nathan Rosenberg, Exploring the Black Box: Technology, Economics and History, Cambridge, U.K.: Cambridge University Press, 1994, p. 166. Bessemer's 1856 paper describing the technology, was entitled, "Manufacture of Malleable Iron and Steel Without Fuel," thus underscoring the energy-saving character of the new technology.

3. For example, it appears that 10-30% of the energy savings due to increased efficiency in automobiles is lost within the first 1 to 3 years to people driving more miles in response to reduced driving costs. See David Greene, "Vehicle Use and Fuel Economy: How Big is the 'Rebound' Effect?" *The Energy Journal*, 1992, 13(1): 117-143 and Clifton T. Jones, "Another Look at U.S. Passenger Vehicle Use and 'Rebound' Effect from Improved Fuel Efficiency," *The Energy Journal*, 1993, 14(4):99-110.

4. "Markets for Energy Efficiency," edited by Hillard Huntington, Lee Schipper, and Alan Sanstad, special issue, *Energy Policy*, October 1994."

5. Lee Schipper and Stephen Meyers, with Richard B. Howarth and Ruth Steiner, Energy Efficiency and Human Activity: Past Trends, Future Prospects, Cambridge, U.K.: Cambridge University Press, 1993.

6. The more rapid growth of transportation energy demand, where future electricity is expected to remain small, makes the intensity trends for electricity and total energy appear similar.

7. This conclusion does not depend upon how the activity variables are defined in the decomposition of the baseline energy intensities. For example, commercial sector activity could have been defined in terms of employment (growing by 1.6% per year in the baseline) rather than floor space (growing by 1.8%). This new definition would have changed the relative importance of the activity and shift effects but not the estimates of the price and nonprice-induced efficiency improvements. The latter two effects are determined by changes in the energy efficiency improvements of new equipment being projected by each model.

8. See the Energy Modeling Forum cost estimates discussed in John P. Weyant, Costs of Reducing Global Carbon Emissions, *Journal of Economic Perspectives*, Fall 1993, 7(4): 27-46.

9. A change in energy demand of 3% represents a price elasticity of -0.12, while that of 8% equals an elasticity of -0.32. In a comparison of energy demand models, the Energy Modeling Forum reported the long-run price elasticity to lie in the -0.3 to -0.7 range when measured at the secondary (i.e., wholesale or refinery) level. Adjusting for differences be-

tween secondary (industrial) and average delivered energy prices for all sectors, this estimate is equivalent to -0.4 to -1.0. See Energy Modeling Forum, "Aggregate Elasticity of Energy Demand," Stanford University, Stanford, CA, 1980, reprinted in *The Energy Journal*, April 1981, 2(2): 37-76.

10. The observed responses to price increase over time but at a slower rate. By the year 2010, it appears that much of the long-run adjustment has occurred, except for the GEMINI model. The complete long-run adjustment to price may be higher than reported here for this model, in which energy prices affect both the composition of the demands for end uses as well as the equipment efficiency and utilization decisions for particular end uses.

11. Although other models apparently track equipment efficiency, projections were not reported in this study.

12. The LBL model is calibrated for the year 1991, which is also the year of the 25% price increase in the scenario. As a result, much of the price increase is removed by calibration.

13. This is an important issue, where empirical research is beginning to emerge. A statistical analysis of diffusion of thermal insulation in new homes concludes that regulations had virtually no effect, while economic signals have a significant effects. Perhaps more interestingly, adoption costs were more influential than expected energy prices (even when controlling for this discount rate). See Adam B. Jaffe and Robert N. Stavins, "Dynamic Incentives of Environmental Regulations: The Effects of Alternative Policy Instruments on Technology Diffusion," *Journal of Environmental Economics and Management*, 1995, 29(3), November: S43-S63.

14. There is some econometric evidence that oil consumers have behaved in this way and that demand responses to price will be relatively low as long as oil prices remain below their peak of the early 1980s. See Dermot Gately, "The Imperfect Price-Reversibility of World Oil Demand," *The Energy Journal*, 1993, 14(4): 163-182.

15. Consumer misperception do not cause the relatively low demand response to price observed in the models. As with engineering cost studies of energy efficiency, the models assume that consumers are motivated primarily by value of service and costs; misperceptions and other anomalies do not directly influence their decisions when energy prices rise.

16. Some modelers base the response of equipment utilization rates and fuel choice to prices on their interpretation of statistical and other studies of energy demands. However, the response of efficiency levels to price is likely to be more judgmental.

17. See the discussion below for this situation when regulated electricity prices fail to fully account for the incremental cost of new generation, which was a motivation for many early demand-side management programs. Today, the disparity between average prices and incremental generation costs appears to be much smaller or even eliminated in many U.S. regions.

18. Incorporating the benefits associated with less pollution and other social costs is discussed in the next section.

19. This figure and the accompanying discussion are based upon work presented at the EMF meetings and explained in Adam B. Jaffe and Robert N. Stavins, "The Energy Efficiency Gap: What Does It Mean?", *Energy Policy*, October 1994.

20. Historically, regulated utility prices have been set below these incremental costs, stimulating energy use. In today's market, it is unclear whether such a bias is important or whether incremental costs even exceed utility prices in many regions.

21. Hurdle rates in this report are adjusted for inflation and taxes. Nominal, before-tax rates are substantially higher.

22. A simple example demonstrates the problem with cost estimates based upon an "average" consumer to represent a heterogenous group. Suppose that the analyst chooses a house in Maryland to select the best home-heating technology based upon comparative costs. For simplicity, assume that homes vary only in their heating requirements depending upon climate; each homeowner faces the same set of energy prices and other key factors. If the technology passes this cost test, the analyst then assumes that all members of this group (i.e., all U.S. households, in this case) will find it cost-effective to select this technology. For homes with higher heating requirements (Minnesota), this procedure may be unbiased because the technology will be cost effective for that climate if it is determined to be so in Maryland. However, for homes with lower heating requirements (Florida), this procedure will mistakenly assume that the technology will be cost-effective in this warmer climate. In this example, the biases created by "averaging" do not cancel each other

23. Kevin A. Hassett and Gilbert E. Metcalf, "Energy Conservation Investment: Do Consumers Discount the Future Correctly?," *Energy Policy*, June 1993, 21(6): 710-716.

24. Energy Information Administration, "Commercial Buildings Energy Consumption and Expenditures 1989," Washington, D.C.

25. Energy Information Administration, "Annual Energy Outlook 1994," Washington, D.C.

26. B. Atkinson, J. McMahon, E. Mills, P. Chan, T. Chan, J. Eto, J. Jennings, J. Koomey, K. Lo, M. Lecar, L. Price, D. Rubinstein, O. Sezgen, and T. Wenzel, "Analysis of Federal Policy Options for Improving U.S. Lighting Energy Efficiency: Commercial and Residential Buildings," LBL-31469, Berkeley, CA; and Energy Information Administration, "Energy Consumption Series: Lighting in Commercial Buildings," Washington, D.C.

27. Energy Information Administration, "Annual Energy Outlook 1994," Washington, D.C.

28. Albert L. Nichols, "Demand-Side Management: Overcoming Market Barriers or Obscuring Real Costs?," *Energy Policy*, October 1994.

29. Mark Levine and Richard Sonnenblick, "On the Assessment of Utility Demand-Side Management Programs," *Energy Policy*, October 1994.

30. The market transformation concept includes the idea that infrastructure will develop to reduce the purchase price and maintenance cost of the new technology. Economists consider this effect to be a "pecuniary" externality, in which one person's decision influences the prices paid by others. Such an externality is not a justification for government intervention, but it does mean that future adoption costs may decline significantly, thereby altering a technology's future cost effectiveness

31. V. Brechling and S. Smith, "The Pattern of Energy Efficiency Measures among Domes-

tic Households in the UK," Commentary #31, The Institute for Fiscal Studies, London, 1992.

32. Ronald J. Sutherland, "An Analysis of Conservation Features in Commercial Building," *Energy Systems and Policy*, 1990, 13:153-166.

33. Jonathan Koomey of Lawrence Berkeley Laboratory provided the figure and basic discussion points accompanying it.

34. Jonathan Koomey, C. Atkinson, A. Meier, J.E. McMahon, S. Boghosian, B. Atkinson, I. Turiel, M.D. Levine, B. Nordman, and P. Chan, The Potential for Electricity Efficiency Improvements in the U.S. Residential Sector, Berkeley Laboratory, LBL-30477, July, 1991.

35. A.P. Fickett, C.W. Gellings, and A.B. Lovins, "Efficient Use of Electricity," Scientific American, September, 1990, p. 64.

36. American Institute of Physics, Efficient Use of Energy: Part 1PA Physics Perspective, AIP Conference Proceedings, No. 25, Editors: Walter Carnahan, K.W. Ford, A. Prosperetti, G.I. Rochlin, A.H. Rosenfeld, M. Ross, J. Rothberg, George Seidel, and R.H. Socolow, 1975.

37. Richard E. Brown, Estimates of the Achievable Potential for Electricity Efficiency in U.S. Residences, M.S. Thesis, Energy and Resources Group, University of California, Berkeley, 1993.

38. This appendix summarizes the conclusions in W. David Montgomery, Paul D. O'Rourke, and Gary R. Fauth, Review of Technology-Based Studies of Costs of Controlling Carbon Emissions, Charles River Associates, Washington, D.C., 1993.