NCEP Technical Appendix

Chapter 3: Improving Energy Efficiency

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ENERGY EFFICIENCY IN BUILDINGS AND EQUIPMENT: REMEDIES FOR PERVASIVE MARKET FAILURES

Prepared for the National Commission on Energy Policy
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Evidence abounds regarding barriers to patently cost-effective energy efficiency improvements in buildings and equipment.[1] In this context, references to "market failures" typically involve distorted energy prices and/or a gap between the private discount rate that households and businesses apply to energy-efficiency investment decisions and the social discount rate.[2] Absent such failures, energy solutions can and should be left to markets. This paper undertakes to summarize the evidence on both the principal problems and the best solutions.

Where market failures exist, remedial tools include more accurate prices, government efficiency standards, incentives delivered through either tax codes or utility programs, and publicly-funded technology R&D. Integrated packages of all these approaches can be much more effective than any in isolation. Measures that address new buildings and equipment are especially promising, because the costs of integrating efficiency are lowest at that stage and "approximately 2 million new residential buildings and 200,000 commercial buildings [are] constructed each year": annual rates of growth and replacement "have been approximately 2 percent for residential buildings and 4 percent for commercial buildings over the last 20 years."[3] This does not, of course, in any way detract from the importance of efficiency opportunities in the much larger stock of buildings that are now in use.

Across the entire spectrum of building and equipment types, evidence of pervasive market imperfections that lead to underinvestment in energy efficiency has

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[1] Commissioner Marilyn Brown is herself a dominant figure in this field. See, e.g., M. Brown, The Effectiveness of Codes and Marketing in Promoting Energy-Efficient Home Construction, 21 Energy Policy 391-402 (April 1993); M. Brown, Energy-Efficient Buildings: Does the Marketplace Work?, in Proceedings of the Twenty-Fourth Annual Illinois Energy Conference (University of Illinois Press, 1997); pp. 233-55 ; and (in press at Elsevier Science) M. Brown, Obstacles to the Efficient Use of Energy. My own publications include R. Cavanagh, L. Mott, R. Beers & T. Lash, Choosing an Electrical Energy Future for the Pacific Northwest: An Alternative Scenario, pp. 119-22 (U.S. Department of Energy: 1980) (energy price distortions); R. Cavanagh, Least-Cost Planning Imperatives for Electric Utilities and Their Regulators, 10 Harvard Environmental Law Review 299, 318-20 (1986) (disparities between private and social discount rates in energy efficiency context); R. Cavanagh, Energy Efficiency Solutions: What Commodity Prices Can't Deliver, 20 Annual Review of Energy and the Environment 519 (1995) (contending that more accurate energy price signals are needed, but price strategies are not by themselves sufficient to realize more than a fraction of our cost-effective energy efficiency opportunities); R. Cavanagh & R. Sonstelie, Energy Distribution Monopolies: A Vision for the Next Century, Electricity Journal (1998), pp. 18-20 (reviewing ways that electricity industry restructuring may exacerbate market barriers to energy efficiency).

[2] The social discount rate is captured (imperfectly) for some purposes by the regulated return on utility investment in gas and electric infrastructure, for which energy efficiency could substitute. A much more extensive treatment of market barriers appears in M. Brown, Obstacles to the Efficient Use of Energy (2003 manuscript).

[3] National Research Council, Energy Research at DOE: Was it Worth It?, pp. 24-25 (2001).

been marshaled in recent years by the National Research Council of the National Academy of Sciences, the U.S. Congress's Office of Technology Assessment, the national laboratories, and the National Association of Regulatory Utility Commissioners, among many others. Although "[t]he efficiency of practically every end use of energy can be improved relatively inexpensively,"[4] "customers are generally not motivated to undertake investments in end-use efficiency unless the payback time is very short, six months to three years . . . The phenomenon is not only independent of the customer sector, but also is found irrespective of the particular end uses and technologies involved."[5]

These customers are demanding annual rates of return of 40-100+%, and of course such expectations differ sharply from those of investors in electric generation (and much else). For example, utilities' returns on capital typically average 15 percent or less, and long-term contracts with utilities or outright utility ownership remain the dominant basis for financing power plant and grid construction across North America. The imbalance between the perspectives of investors in efficiency and generation (and other grid infrastructure) invites large, relatively low-return investments that could have been displaced cost-effectively with energy efficiency. These widely documented market failures generate "systematic underinvestment in energy efficiency," resulting in electricity consumption at least 20-40% higher than cost-minimizing levels.[6]

For North America as a whole, market failures like these mean that energy prices alone are a grossly insufficient incentive to exploit a continental pool of inexpensive savings: "a 2-year payback customer paying average rates of 7 cents/kWh can be expected to forego demand-side measures with costs of conserved energy of more than 0.9 cents/kWh."[7] That is, energy prices would have to increase about eightfold to overcome the gap that typically emerges in practice between the perspectives of investors in energy efficiency and production, respectively.

There are many explanations for individuals' and businesses' almost universal reluctance to make what appear to be relatively lucrative energy efficiency investments given reasonable estimates of the cost of capital faced by consumers.[8] Decisions about efficiency levels often are made by people who will not be paying the electricity bills,

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[4] U.S. National Academy of Sciences Committee on Science, Engineering and Public Policy, Policy Implications of Greenhouse Warming, p. 74 (1991); see also National Research Council, note 2 above, at pp. 20-43.

[5] National Association of Regulatory Utility Commissioners, Least Cost Utility Planning Handbook, Vol. II, p. II-9 (December 1988). See also M. Brown, note 2 above, at 12 (concluding, based on extensive review, that "[t]he evidence of this efficiency gap is compelling, and the reasons for it are numerous"); P. Joskow, Utility-Subsidized Energy-Efficiency Programs, 20 Annual Review of Energy and the Environment 526, 531 (1995) (noting "fairly compelling evidence that consumers use what appear to be very high implicit discount rates when they evaluate energy-efficiency investments" but cautioning that the causes are not clear).

[6] See M. Levine, J. Koomey, J. McMahon, A. Sanstad & E. Hirst, Energy Efficiency Policy and Market Failures, 20 Annual Review of Energy and the Environment 535, 536 & 547 (1995).

[7] National Association of Regulatory Utility Commissioners, note 5 above, p. II-10.

[8] An extensive assessment appears in U.S. Congress, Office of Technology Assessment, Building Energy Efficiency, at pp. 73-85 (1992).

such as landlords or developers of commercial office space. Many buildings are occupied for their entire lives by very temporary owners or renters, each unwilling to make long-term improvements that would mostly reward subsequent users. And sometimes what looks like apathy about efficiency merely reflects inadequate information or time to evaluate it, as everyone knows who has rushed to replace a broken water heater, furnace or refrigerator.

In the specific and particularly consequential case of commercial building design, the most recent National Research Council review of market barriers to efficiency notes that

> The architects and consulting engineers who design commercial buildings are generally paid as a percentage of the job cost and have little incentive to take extra time to design more energy-efficient buildings given the constraints of minimizing first costs. Moreover, architects and consulting engineers must comply with a plethora of building codes and standards on health and safety in addition to energy efficiency. Many buildings are constructed "on spec," that is, based on what the architect/engineer specifies, and first costs of labor and materials are typically the primary concern of the builder.[9]

For mass-produced equipment, an extensive empirical assessment of market failures to energy efficiency appeared in a joint 1995 publication by staff scientists at the Oak Ridge National Laboratory and the Lawrence Berkeley Laboratory. It found "systematic underinvestment in energy efficiency" in the specific context of lighting, refrigeration, office equipment, standby power supplies, heating and air conditioning. These were chosen as

> examples of cases in which a product (a) is commercially available (i.e. can be easily obtained by consumers), (b) provides identical amenity or utility to the customer, (c) has a much higher return on investment for energy efficiency than either market or social rate of return, (d) results in no increased risk to the consumer, and (e) causes the consumer no known hidden cost, such as inconvenience in installation, or higher maintenance cost.[10]

The Oak Ridge/Lawrence Berkeley study also evaluated the efficacy of government efficiency standards as a response to market barriers, and determined that the first generation of federal standards would produce

[9] National Research Council, note 3 above, p. 25.
[10] M. Levine et al., note 6 above, p. 537.

- "A cumulative net benefit of $46 billion to the nation for appliances sold from 1990-2015. This consists of a net present cost of $32 billion for higher priced appliances and a net present savings of $78 billion;"[11] and

- "The standards yield a benefit-to-cost ratio to consumers of more than 2.5 (at a real discount rate of 6%), not including the value of environmental externalities. The standards will reduce power plant construction by more than 40 500-MW units over the next 20 years, have not reduced the choice of appliances or the services they provide, and have drawn almost no objection from consumers."[12]

These conclusions are both reaffirmed and reinforced in a 2003 essay by Commissioner Marilyn Brown for the Encyclopedia of Energy.[13]

In September 2001, a committee of the National Research Council reached comparable conclusions in an assessment of the coordinated use of public R&D, utility incentives and efficiency standards to promote energy efficiency in refrigeration, lighting, and glazing. In the refrigeration case, for example:

> From 1947 to 1974, average consumption per unit had quadrupled, and there was little reason to expect the process to reverse. The subsequent need to remove chlorofluorocarbons added to the challenge, since many experts believed initially that any affordable substitutes would further increase electricity needs The refrigerator story is one of industry and government cooperation, based on the integration of federal and private sector R&D, utility-financed incentives for customers to purchase efficient models, and government efficiency standards at both state and federal levels . . . A reinforcing cycle . . . continues to this day, under which targeted federal R&D helps make possible the introduction of increasingly efficient and life-cycle cost-effective new refrigerator models, which themselves become the basis for tightening the minimum efficiency standards . . . The refrigerator standards that DOE promulgated in 1990, 1993 and 2001 have been credited with net life-cycle costs to consumers of about $15 billion, and cumulative primary energy savings through 2005 will be about 2.6 quads.[14]

On the issue of efficiency standards for new buildings, another noteworthy finding of the NRC report involved public health impacts, given widespread earlier concerns that tighter building envelopes might worsen indoor air pollution. With regard specifically to the principal model codes "that have guided the development of building standards throughout the United States (and indeed the world)":

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[11] Id., p. 543.
[12] Id., p. p. 547.
[13] M. Brown, Obstacles to the Efficient Use of Energy (manuscript, 2003).
[14] National Research Council, note 3 above, at pp. 29-30.

> Compliance with these standards has resulted in significant energy, environmental and security benefits. That conclusion draws further support from the committee's review of DOE research on indoor air quality, infiltration and ventilation, initiated more than 20 years ago to address the concerns about potential linkages between improved energy efficiency and poorer indoor air quality. DOE contributed significantly to the development of standards and technologies that have allowed for the integration of energy-efficiency and public-health objectives, resulting in net improvements in indoor air quality along with reduced energy needs for heating and cooling.[15]

CONCLUSION

Energy efficiency standards are a proven antidote to market failures that obstruct cost-effective energy efficiency improvements. Standards work best in coordination with targeted incentives and R&D programs. The "market failures" at issue include distorted energy prices and a gap between the private discount rate that households and businesses apply to energy efficiency decisions and the social discount rate (as revealed in investment decisions by regulated utilities). Interventions to overcome these failures should aim to minimize the life-cycle cost of the reliable energy services that a healthy economy needs.

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[15] Id., p. 27.

Retrospective Examination of Demand-Side Energy Efficiency Policies

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Abstract

Energy efficiency policies are a primary avenue for reducing carbon emissions, with potential additional benefits from improved air quality and energy security. We review literature on a broad range of existing non-transportation energy efficiency policies covering appliance standards, financial incentives, information and voluntary programs, and government energy use (building and professional codes are not included). Estimates indicate these programs are likely to have collectively saved no more than 4 quads of energy annually, with appliance standards and utility demand-side management likely making up at least half these savings. Energy Star, Climate Challenge, and 1605b voluntary emissions reductions may also contribute significantly to aggregate energy savings, but how much of these savings would have occurred absent these programs is less clear. Although even more uncertain, reductions in CO_2, NO_X, SO_2, and PM-10 associated with energy savings may contribute about 10% more to the value of energy savings.

Key Words: energy efficiency policy, appliance standards, information, incentives, voluntary programs

JEL Classification Numbers: Q48; Q41

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Retrospective Examination of Demand-Side Energy Efficiency Policies

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Executive Summary

Energy efficiency plays a critical role in energy policy debates because meeting our future energy needs boils down to only two options: increasing supply or decreasing the demand for energy, and the latter implies demand-side energy efficiency policies. The issue is also particularly salient due to the problems of climate change, air pollution, and energy security, all of which cast an undesirable shadow over the prospect of focusing exclusively on increasing energy supply to meet a growing demand. Current U.S. greenhouse gas emissions are approximately 1.58 billion metric tons of carbon equivalent per year and are rising each year (EIA 2003d), posing a daunting challenge to policymakers attempting to grapple with the issue of climate change. Some energy efficiency advocates maintain that much of the problem could be solved, or at least ameliorated, at very low or no cost through the vigorous use of demand-side energy efficiency policies, alongside fuel switching and carbon sequestration.

Several key questions therefore immediately arise regarding the role of policies supporting energy efficiency within a portfolio of prospective energy and climate policies. First, what types of energy efficiency policies have been implemented in the United States, and how well has each of these policies worked in terms of saving energy? And, second, how much have these policies cost the public and private sector, and how cost-effective have they been?

To address these questions, we perform a comprehensive review of energy efficiency programs in the United States, with a focus on the adoption of energy efficient equipment and building practices, rather than on energy research and development. We further limit the scope of the study by omitting building codes, professional codes, and Corporate Average Fuel

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Economy (CAFE) Standards to focus on the remaining programs. We find that the applicable programs and policies tend to fall into the general categories of appliance standards, financial incentives, information and voluntary programs, and the management of government energy use.

Our review of these past energy conservation programs suggests that, taken together, the conservation programs we include likely save no more than 4 quadrillion Btu (quads) of energy per year and reduce annual carbon emissions by as much as 63 million metric tons of carbon equivalent (MMtCE). These estimates typically reflect the cumulative effect of programs (e.g., all appliance efficiency standards currently in effect) on annual energy consumption. This total energy savings represents at most 6% of annual nontransportation energy consumption, which has hovered around 70 quads in recent years. Most of these energy savings come from reduced energy use associated with residential and commercial buildings (as opposed to more efficient industrial processes), so another relevant basis of comparison is total energy use in buildings, which accounts for 54% of the 70 quads of nontransportation consumption. Thus, 4 quads of energy saved represents approximately 12% of all buildings-related energy use (EIA 2003b). This also represents about a 3.5% reduction in current annual carbon emissions.

Table E-1 summarizes energy savings, costs, and carbon emissions savings for the largest-scale conservation programs, according to available information. Moving down the table roughly indicates our confidence in the reliability of the estimates. Existing estimates suggest that minimum efficiency standards and demand-side management (DSM) programs have provided some of the largest energy savings—about 1.2 and 0.6 quads, respectively, in 2000. Estimates of energy savings associated with the Energy Star, Climate Challenge, and 1605b registry programs are also sizable (0.9, 0.8, and 0.4 quads, respectively, in 2000), but it is less clear what portion of these savings would have occurred in the absence of these programs. Energy savings from other programs are relatively small or unavailable. We emphasize the use of quads for comparison purposes between programs because many of the programs cover nonelectricity reductions, which have a different heat rate than electricity.

Table E-1. Summary of Estimates of Energy Savings from Largest Conservation Programs in 2000

Program Name	Date	Energy Savings (quads)	Costs (billion $2002)	Cost-Effectiveness (billion $2002 per quad)	Carbon Emissions Savings (MMtCE)
Appliance standards	2000	1.200	$3.359	$2.799	17.753
Utility DSM	2000	0.626	$3.487	$5.570 (high $6.089) (low $3.001)	10.188
Energy Star	2001	<0.933	$0.050*	-	<13.800
1605b registry	2000	<0.411	$0.0004*	-	<6.083
DOE Climate Challenge	2000	<0.814	-	-	<12.038

Note: * indicates that only direct government administrative costs are included. < indicates a likely upper bound of energy savings or emissions reductions. Billion dollars per quad can be roughly converted to cents/kWh by multiplying by 1.166, which assumes all of the savings come from electricity using the average mix of generating facilities.

These cost-effectiveness estimates paint a mixed picture about how the average costs of achieving energy savings compare to the average value of the resulting energy savings. Estimates of overall cost-effectiveness are available only for efficiency standards ($2.8 billion/quad saved in 2000) and DSM ($5.6 billion/quad, including only utility costs).[1] Comparing these estimates to the average price of nontransport energy ($6.1 billion/quad) suggests that, as a group, efficiency standards are likely to have had positive net benefits (not including environmental benefits). DSM does not appear to be as cost-effective, suggesting that closer scrutiny of individual DSM programs may be warranted to identify and emphasize those with high net benefits, including highly valued peak-period energy savings. Of course one must be careful about applying aggregate estimates to draw conclusions about the value of individual program elements.

Although even more uncertain, including the environmental benefits from lower emissions of carbon dioxide (CO_2), nitrogen oxides (NO_X), sulfur dioxide (SO_2), and particulate matter (PM-10) as a result of energy efficiency programs may add approximately 10% to the value of the energy savings. Based on national average emissions rates and available estimates of monetized benefits, the majority (7%) of these benefits come from CO_2 reductions, with fewer

[1] Note that higher dollars per quad cost-effectiveness estimates imply the program is *less* cost-effective (i.e., it costs more per quad saved)

benefits from NO_X (2%), and SO_2 and PM-10 (0.5% each). Cost-effectiveness estimates of appliance standards and utility DSM with the above environmental externalities included would amount to \$2.5 billion/quad and \$5.1 billion/quad (including only utility costs), respectively. The inclusion of environmental benefits strengthens the case for energy efficiency programs, but does not appear to dramatically change their value based simply on energy savings.

The studies reviewed here raise several issues concerning past efforts to measure both the effectiveness and cost-effectiveness of conservation programs. Measuring the effectiveness or total energy savings from a conservation initiative or program can be problematic due to failure to define the right baseline, failure to correct for free riding or the "rebound" effect, use of inappropriate discount rates, and double counting of the same energy savings attributed to multiple government programs. The main question that arises when measuring program costs or cost-effectiveness is whether or not all of the salient costs (costs to business, costs to consumers, including consumer surplus losses due to quality changes, and costs to the government) are being accounted for.[2] All of these issues combined suggest that considerable care must be taken in interpreting existing estimates of the effectiveness and cost of energy efficiency programs.

This study reveals a lack of independent and detailed ex post academic analyses of conservation programs. Almost all available quantitative estimates are from institutions either administering or advocating the programs themselves. Several studies have presented general critiques of methods used to estimate energy savings and costs of appliance standards and of DSM programs, but there are no independent studies that take a detailed look at the effectiveness and the costs of specific programs. Such analysis is key to understanding the robustness of the effectiveness and cost-effectiveness estimates reported here to changes in assumptions about discount rates or assumptions about underlying growth in energy demand. Detailed analysis would be particularly important for classes of programs, such as appliance standards, that policymakers may plan to use more widely in the future.

The continued use of energy efficiency policies over more than two decades and the prospect of expanded and new policies on the horizon suggest that this approach to achieving energy and carbon reductions will have a lasting presence. This is particularly true if

[2] Of course, it is also important that all of the benefits of the program be accounted for and thus we estimate the environmental benefits as well as the energy savings from these programs..

conservation programs have positive net benefits in their own right and thus yield emissions reductions at zero or negative net cost. Even if these estimates are overly optimistic, energy efficiency programs would likely be an important part of a relatively low-cost moderate climate policy, with the effect of existing efficiency programs being of a similar magnitude to what rough estimates suggest might come from a moderate carbon tax. While existing estimates indicate that the current impact of these policies is modest, it does appear that well-designed future programs have the potential to reduce energy and emissions, although the magnitude of potential reductions and the cost of achieving those reductions is an open question.

1. Introduction

Energy efficiency plays a critical role in the debate on energy policy, as the only options for meeting our future energy needs boil down to increasing supply or decreasing the demand for energy, the latter of which implies demand-side energy efficiency policies. The issue is particularly salient due to the problems of climate change, air pollution, and energy security, all of which cast an undesirable shadow over the prospect of focusing exclusively on increasing energy supply to meet a growing demand. Current U.S. greenhouse gas emissions are approximately 1,580 millions of metric tons of carbon equivalent per year and are rising each year, posing a daunting challenge to policymakers attempting to grapple with the issue of climate change (EIA 2003d). Many energy efficiency advocates maintain that much of the problem could be solved, or at least ameliorated, at very low or no cost through the vigorous use of demand-side energy efficiency policies, alongside fuel switching and carbon sequestration. This paper begins to address some of the principal questions that arise in thinking about where demand-side energy efficiency policies might fit into comprehensive energy policy by examining the past performance of energy efficiency policies and programs.

We aim to address the following questions. What policies and programs have been implemented in the past? How much has been spent on them by both the public and private sectors? What have they accomplished, and how do they compare? And, finally, what does the literature indicate about how cost-effective these programs have been? This paper is a descriptive, rather than critical, survey designed to provide an overview of the literature on demand-side energy efficiency policies. Thus, we do not attempt to analyze the existing studies in depth; however, we do attempt to present findings representing the variety of perspectives on the issue. Ultimately, this review can provide the basis for critical study of the potential for future energy efficiency policies.

The focus of this review is on adoption of energy efficient equipment and building practices, rather than on energy research and development. Even given this focus, the universe of demand-side management energy efficiency policies is quite broad. The applicable programs and policies tend to fall into the general categories of appliance standards, financial incentives, information and voluntary programs, and the management of government energy use, as summarized in Table 1. We further limit the scope of the study by omitting building codes, professional codes, and Corporate Average Fuel Economy (CAFE) Standards to focus on the remaining programs. This review is organized into the following sections. Section 2 examines the history and literature on the effectiveness and cost of appliance standards. Section 3 examines financial incentives for energy efficient investments, first through a discussion of utility demand-side management programs, then income tax credits or deductions, and finally emissions allowances allocated to demand-side investments. Section 4 reviews the broad spectrum of information and voluntary programs. Section 5 examines the management of government energy use. Section 6 pulls together the key energy savings, cost-effectiveness, and emissions reduction numbers to provide an overview of the literature. Finally, Section 7 provides our conclusions, with lessons learned and implications for future research.

2. Appliance Standards

2.1 History of State and Federal Standards

Minimum energy efficiency standards for appliances in the United States can trace their origins to the energy crises of the mid-1970s. These energy crises, combined with environmental concerns related to new power plant siting, drove many states, particularly California and New York, to consider appliance standards to cut the growth in energy demand (Nadel 1997). This momentum culminated in the passage of the first energy appliance legislation, the 1974 California Warren-Alquist Energy Resources Conservation and Development Act, establishing the California Energy Commission with the authority to set appliance standards. Several other states quickly followed suit (e.g., New York adopted some standards by 1976), leading manufacturers to begin putting pressure on the federal government to develop national standards that would supercede the many state standards (Martin 1997).

The first federal energy appliance legislation, the 1975 Energy Policy and Conservation Act (EPCA), started slowly, by directing the National Institute of Standards and Technology (NIST) to develop standards test procedures for measuring the energy efficiency of appliances. The stage was then set for the more controversial 1978 National Energy Conservation Policy Act (NECPA). NECPA directed the Department of Energy to set mandatory standards for 13 residential household appliances and gave those federal standards pre-emption over state standards under most circumstances. In 1980, DOE proposed standards for eight products, but, with an unreceptive administration and opposition from some manufacturers, these standards were never finalized (Geller 1997).

By 1986, the further proliferation of varying state standards led many manufacturers to seek uniform national standards to simplify product planning and marketing. The 1987 National Appliance Energy Conservation Act (NAECA) was hammered out through negotiations among manufacturers, energy efficiency advocates, and DOE (Geller 1997). NAECA established, in the law itself, national standards for 12 categories of household appliances, with strengthened pre-emption over state standards (IEA 2000). These appliances are: refrigerators, freezers, kitchen ranges, kitchen ovens, room air conditioners, direct heating equipment, water heaters, pool heaters, central air conditioners, central heat pumps, furnaces, and boilers. NAECA also contains deadlines for DOE rulemakings to update the initial standards as technology progresses. Several updates to the initial standards have occurred, most notably in 1989 for refrigerators and freezers, taking effect in 1993. In addition, further discussions between manufacturers and energy efficiency advocates have led to amendments to NAECA creating standards for other appliances. In 1988, NAECA was amended to set standards for fluorescent light ballasts, taking effect in 1994. In 1991, standards were added for clothes washers, clothes dryers, and dishwashers, also taking effect in 1994 (Geller 1997).

The next major energy efficiency standards legislation was the 1992 Energy Policy Act. The act updated existing standards and established new standards for other appliances in the law itself, temporarily superceding the DOE rulemaking process (IEA 2000). The act extended standards to a variety of lamps, induction motors, and most types of commercial heating and cooling equipment. Since the Energy Policy Act, DOE has issued several updates to the federal standards in the late 1990s, some still remaining to take effect between 2004 and 2007.

A notable feature of the history of appliance standards in the United States is the distinctive pattern of standards-setting that emerged. States, particularly California, would first set new standards on unregulated appliances and, after much negotiation between industry and energy efficiency advocates, Congress would set pre-emptive national standards on those appliances. In effect, appliance standards activity shifted back and forth between the states, primarily California, and the federal government (Table 3). This pattern still continues to the present, with several states setting their own standards on appliances that the federal government does not yet regulate (Martin 1997).

In the most important case, California, there are state-wide standards on the following appliances not covered by federal standards: distribution transformers, traffic lights, commercial refrigerators/freezers, exit signs, plumbing fittings/fixtures, beverage vending machines, space heaters, and central ventilation devices (California Energy Commission 2003). Other states that have had individual state standards in the past include New York, Florida, Oregon, Virginia, Massachusetts, Maine, and Minnesota (Newell 1997). More recently, most state efforts outside of California have been usurped by federal standards, as most states do not have the resources or commitment to set their own standards (Martin 1997). Maryland has been a recent exception. On January 14, 2004, the Maryland General Assembly voted to override Governor Ehrlich's veto of a bill to set with new energy efficiency standards on a variety of home appliances. The products covered by the bill include: (1) torchiere lighting fixtures, (2) ceiling fans, (3) low-voltage dry-type transformers, (4) commercial refrigerators and freezers, (5) traffic signal modules, (6) illuminated exit signs, (7) large packaged air-conditioning equipment, (8) unit heaters, and (9) commercial clothes washers. Attempts to implement or update state standards are also underway in Massachusetts, Connecticut, New Jersey, New York, and Pennsylvania.

2.2 Federal Standards

Federal appliance standards currently cover an array of residential and commercial appliances, and standards for several more appliances are on the drawing board. Table 2 summarizes the years in which standards became effective and revised. The final rulings on the 2004–2007 standards have been completed and the standards are set to go into effect in the corresponding years, as indicated in Table 2 (Meyers et al. 2003).

Cost-effectiveness Estimates. Many studies have been published evaluating the effectiveness of appliance standards as a whole or particular appliance standards. Most of these studies are ex ante studies, performed for DOE by researchers at Lawrence Berkeley National Laboratory or the American Council for an Energy-Efficient Economy. In addition, there is an extensive body of ex ante analysis in DOE Technical Support Documents. A few studies also present estimates of ex post policy effectiveness and this section focuses on these.

One such study, Levine et al. (1994), provides cumulative estimates of appliance standards effectiveness that combine ex post and ex ante analyses. Levine et al. estimate that cumulative federal government expenditures for the appliance efficiency program total $50 million from 1979 to 1993 (in 1994 dollars), amounting to approximately $61 million in 2002 dollars. Levine et al. also estimate that the total net benefit of appliance standards for appliances sold from 1990 to 2015 is $46 billion in 1994 dollars ($56 billion in 2002 dollars), which can be decomposed into a net present cost of $32 billion for higher priced appliances and a net present savings of $78 billion due to saved energy operating costs (in 1994 dollars, discounted at 7%). The study estimates that energy savings in 1994 alone from appliance standards amounted to 0.1 quads, or almost $1 billion in 1994 dollars ($1.23 billion in 2002 dollars). The study also estimates a 1.5% to 2% reduction of total national emissions of carbon dioxide by 2015 as a result of the standards.

In a widely cited ex ante study, Geller (1995) estimates the prospective total energy savings in the year 2000 from appliance standards to be 1.23 quads. Geller et al. (2001) provides similar savings estimates based on another combined ex post and ex ante study, Geller and Goldstein (1998). Energy savings in 2000 are estimated at 1.2 quads, and the cumulative net benefit through 2030 is estimated to be $186 billion in 2000 dollars, discounted at 7% ($196 billion in 2002 dollars).

In one of the few completely ex post analyses of appliance standards, McMahon et al. (2000) provide retrospective estimates of energy savings, net benefits, and carbon reductions for each year 1990–1997. As only a few appliance standards took effect before 1990, cumulative estimates from McMahon et al. are roughly comparable to other cumulative estimates covering 1987–1997. McMahon et al. find cumulative energy savings of 2.0 EJ (approximately 1.9 quads) between 1990 and 1997. This provides a cumulative benefit from energy savings of $15.2 billion in 1997 dollars, discounted at 7% ($17 billion in 2002 dollars) and a reduction in carbon dioxide emissions of 29.5 MMtC. The largest component of energy savings and emissions reductions comes in the final few years of the study; 45% of the benefits and 46% of both the energy savings and emissions reductions occur in the final two years, 1996 and 1997. McMahon et al. attribute this to the increasing percentage of appliances in use that meet the appliance standards as new appliances are bought each year. Correspondingly, the study also contains ex ante forecasts of future energy savings, net benefits, and emissions reductions from appliance standards that continue to greatly increase.

The most recent published analysis of the effectiveness of appliance standards, Meyers et al. (2003), again provides both ex post and ex ante estimates. Meyers et al. approximate the past cost to the government of implementing the appliance standards between 1987 and 2000 to be between $200 and $250 million. The cumulative net benefit for those years is estimated to be $17 billion in 2001 dollars, discounted at 7% ($17.4 billion in 2002 dollars). This is added to some ex ante estimates to yield a cumulative net benefit from 1987 to 2050 of $150 billion in 2001 dollars ($153.6 billion in 2002 dollars) and carbon dioxide emissions reductions of 1,216 MtC. An additional ex ante cumulative emissions reduction estimate is provided for the years 1987–2030 and is calculated to be 964 MtC.

Finally, McMahon (2004) estimates the 2000 annual energy savings and aggregate cost to consumers and the government of implementing residential appliance standards. The 2000 residential annual energy savings are estimated to be 0.59 quads of electricity and 0.19 quads of natural gas, for a total of 0.78 quads. Using the 2000 average electricity price of $6.34 billion per quad, these energy savings translate to $4.94 billion in savings annually. McMahon estimates the total cost of achieving these savings to be $1.9 billion in 1999 dollars ($2.05 billion in 2002 dollars). These estimates imply a cost-effectiveness of $2.63 billion/quad for residential appliance standards.

Critiques and Responses. All of the above estimates originated from the work done by researchers affiliated with Lawrence Berkeley National Laboratory, Oak Ridge National Laboratory, or the American Council for an Energy-Efficient Economy. Several far more skeptical studies do exist in the literature. For example, Khazzoom (1980) suggests that mandated standards are not likely to lead to significant energy savings and, moreover, are even less likely to be cost-effective. The major rationale behind this finding is that energy efficiency improvements reduce the effective cost of energy services, leading to increased demand, and thus inducing less than proportional reductions in energy use. This effect has become known in the literature as the “take-back” or “rebound” effect. It implies that mandated standards would not yield the energy savings that ex ante estimates indicate they would, and that for some major end-uses, mandated standards may even backfire by increasing the demand for energy.

Brookes (1990) expands this claim further, using macroeconomic theory to suggest that cost-effective energy efficiency improvements may be considered a form of technological progress that improves productivity, promotes capital investment, enhances economic growth, and ultimately leads to increased energy demand. Saunders (1992) uses neoclassical growth theory to assert that the combination of Brookes’ growth effect and the take-back effect could overwhelm the energy-demand-reducing effect of increasing energy efficiency under reasonable conditions—conditions he claims may hold in the U.S. economy. Inhaber and Saunders (1994) use historical evidence to come to similar conclusions, particularly in reference to the growth effect. These arguments, while containing some merit, seem to be taken to extreme conclusions with little supporting empirical evidence.

In another skeptical paper on appliance energy efficiency standards, Hausman and Joskow (1982) provide an overview of several inherent weaknesses they feel must be considered in any evaluation of standards. First, while minimum appliance efficiencies can be controlled for by standards, actual energy use is determined by much more uncertain consumer behavior, including issues like the take-back effect. Second, uniform national standards do not seem well-suited to a country with substantial differences in weather characteristics and energy prices. Third, uniform national standards do not allow for heterogeneity in consumer tastes for energy using services and appliance choice. For instance, it may be very efficient for a consumer who uses an air conditioner for only a few days per year to purchase an inexpensive model with low energy efficiency. Fourth, when there is uncertainty about the appropriate level of standards for promoting economic efficiency, rigid standards may not be the best option, as they are difficult to adapt to new information about consumer behavior or costs. Finally, the negative impacts of appliance standards are more likely to fall on lower-income households, implying that appliance standards are a regressive policy. The degree to which these effects are empirically relevant is not explored by Hausman and Joskow.

More recently, Sutherland (1996, 1991) argues that much of the market failures theory that underlies many optimistic net benefit estimates is misguided. Instead, Sutherland contends that there is little or no evidence that such programs make consumers truly better off, simply because if such large net benefits could be gained, consumers would already be taking advantage of them. Moreover, Sutherland echoes Hausman and Joskow in suggesting that the cost burden of appliance standards would likely fall on low-income consumers who are least able to bear the burden. All of these skeptical studies claim that empirical evidence backs up their theoretical findings, although they do not typically present empirical evidence.

The only alternative estimates by the skeptics are provided by Sutherland (2003). As in his other papers, Sutherland criticizes most of the estimates in the literature for using unrealistic discount rates and baseline energy efficiency improvement assumptions. He performs a sensitivity analysis by varying these parameters and finds that with higher assumed discount rates and greater baseline autonomous energy efficiency improvements, the net present value of appliance standards is negative. For instance, with a 14% discount rate and 50% autonomous energy efficiency, the net present value of the standards is -$26.77 billion per year, according to Sutherland. [Sutherland mentions that the CAPM approach indicates 12% should be used]

The contentions of the skeptics are refuted in numerous papers in the literature, with various reasons provided. Grubb (1990) disputes that the take-back effect has much policy relevance, stating that the conditions under which it would be important do not apply in the case of appliance efficiency standards. Dumagan and Mount (1993) find that the take-back effect is numerically unimportant in an empirical study of the effect of efficiency improvements on residential electricity demand in New York state. Stoft (1994) criticizes Sutherland's work and presents a brief analysis suggesting that appliance standards are not regressive. Howarth and Sanstad (1995) suggest that the energy market is replete with market failures, such as asymmetric information, bounded rationality, and high transactions costs, and that policy intervention, such as appliance standards, could help to correct for the market failures

Howarth (1997) presents a model to analyze the hypothesis of Brookes, Saunders, and Inhaber and Saunders that cost-effective energy efficiency investments could, in the long run, lead to greater energy use than there would be in a world without the investments, due to the take-back effect and increased economic growth. Howarth finds that improved energy efficiency would not lead to increased energy use unless these two implausible conditions hold: energy costs dominate the total costs of energy services (energy services are composed of energy costs and nonenergy costs), and expenditures on energy services constitute a large share of economic activity. Weil and McMahon (2003) provide a theoretical rationale suggesting that well-designed appliance standards are beneficial and cite several empirical studies as evidence.

Finally, McInerney and Anderson (1997) present a manufacturer's perspective on appliance standards. They find that past appliance standards have turned out to be cost-effective and not too much of a burden on manufacturers, but it is not clear that similar cost-effective gains can be made by forcing continued investment in energy efficiency through more stringent standards.

3. Financial Incentives

Financial incentive programs encourage energy efficiency through direct financial enticements for consumers or companies to purchase energy efficient equipment, cut their demand for energy, or invest in energy efficiency.

3.1 Utility Demand-Side Management Programs

Utility-based demand-side management (DSM) programs cover a variety of policies that allow utilities to better match their demand with their generating capacity (Gellings 1996). The term "demand-side management," when used in reference to utilities, originally meant "the planning and implementation of those utility activities designed to influence customer use of electricity in ways that will produce desired changes in the utility's load shape" (EPRI 1984). More recently, the term has become synonymous with utility energy conservation and load management programs (Chamberlin and Herman 1996). Current utility-based financial incentive programs for consumer purchases of energy efficient equipment and electricity load management fall under the auspices of utility DSM programs. Our review of DSM programs is organized in the following sections: 3.1.1 provides an overview of utility DSM programs that provide financial incentives for consumer purchases, 3.1.2 provides an overview of utility DSM electricity load management programs, and 3.1.3 presents estimates of the cost-effectiveness of utility DSM programs.

3.1.1 Financial Incentives for Consumer Purchases

Following the first energy crisis of the 1970s, federal regulators and state public service commissions began implementing utility policies that led to the creation of utility DSM programs. The Energy Policy and Conservation Act (1975), Energy Conservation and Production Act (1976) and the National Energy Conservation Policy Act (1978) all laid the groundwork for utility DSM by providing the basis for utility conservation and load management activities. In addition, the Public Utility Regulatory Policies Act (1978) required state public service commissions to bring energy conservation considerations into their rate-making practices, furthering the impetus for utility DSM programs (EIA 1997).

Information and Loans. The first utility programs in the 1970s were most often information and loan programs, designed to educate consumers and businesses about the cost-effectiveness of energy efficiency measures and to provide low-cost subsidized financing for investments in those measures. Utilities gradually learned that education alone produced limited energy savings. In addition, most consumers were not interested in subsidized loans (Stern, Berry, and Hirst 1985). Thus utilities were led to consider programs that contained stronger financial incentives to convince consumers to make energy saving choices (Nadel and Geller 1996).

Rebates. The first financial incentive programs to be used extensively were rebate programs, with cash rebates given out by utilities to consumers who purchased designated energy efficient equipment. Rebate programs, as well as other financial incentive programs, received a considerable boost in the 1980s with the advent of integrated resource planning (IRP), also known as least-cost planning. IRP is a process in which utilities consider a broad range of resource options to meet the future energy needs of their customers. These resource options include new transmission capacity, new generation, and demand-side management. The decision of which resource to use is in theory based on assessing the costs and benefits to society of each resource. The DSM programs considered under IRP were often known as "resource acquisition" programs because they were expected to meet the demand for energy services at a lower cost than that of acquiring generation services (Blumstein, Goldman, and Barbose 2003).

With demand-side management explicitly part of the planning process, utilities devoted considerably more resources toward achieving energy savings through DSM programs, leading to the proliferation of financial incentive programs (Nadel and Geller 1996). Nevertheless, many utilities found that rebates, while more effective than information programs, still tended to have low participation rates and did not provide the desired energy savings that the utilities (or their regulators) were seeking (Nadel, Pye, and Jordan 1994). Rebate programs also sometimes had a high rate of "free-riding," meaning that many people who received the rebates would have purchased the equipment anyway (Gehring 2002).

In sum, the results of rebate programs have been heterogeneous; some programs have been very cost-effective, with little free-riding, and others much less so. Successful programs often have featured simple application procedures, catchy marketing materials, active involvement of equipment dealers and other trade allies, free energy audits to help consumers identify conservation measures, or extensive personal marketing. In some residential appliance rebate programs, free ridership has been minimized by carefully setting how efficient an appliance must be to qualify for the program. If a high percentage of the available models qualify for rebates, there may be high gross participation rates, but also very high free ridership in the program (Berry 1990).

Comprehensive DSM. Utilities that desired further energy savings often added or switched to more comprehensive and more expensive DSM programs, such as comprehensive/direct installation programs. These programs often included an informational component and a significant financial component. For instance, many comprehensive/direct installation programs provided long-term individual assistance to help typically larger customers identify, finance, and install comprehensive packages of DSM measures (e.g., a more energy efficient cooling system combined with better insulation). Others focused on residential and small commercial customers by conducting one-time energy audits and arranging for installation of energy efficient equipment. In either case, utilities paid a large percentage of the costs of implementing the energy efficiency measures, either through rebates or other cost-sharing agreements (Nadel and Geller 1996). Aside from their cost, the more comprehensive programs also had the disadvantage that projects with individual customers took a long time, and thus only a limited number of customers could be served each year (Nadel, Pye, and Jordan 1994).

Market Transformation and the Apex of DSM. Market transformation strategies were the next solution that utilities began to emphasize by the 1990s. The term “market transformation” itself was first coined in 1992 and it describes a process of changing the market for particular types of equipment or energy services so that more efficient practices become the norm (Nadel et al. 2003). This process typically consists of a coordinated series of demonstration projects, training/informational projects, and financial incentives, with the hope that once a market is completely “transformed,” there will be substantially greater energy savings as the participation or market penetration rate approaches 100%. In principle, once a market is “transformed,” no additional resources are required for energy savings in that market. The downside of market transformation efforts is that they require significant organizational effort up-front and coordination of diverse parties (Geller and Nadel 1994).

The early 1990s marked the apex of utility DSM, with substantial financial incentives in place and considerable resources devoted by utilities to DSM programs in general and increasingly toward market transformation programs. By this point, DSM programs had matured into standard operating procedure for a large number of utilities. For example, in 1990, over 14 million residential, 125,000 commercial, and 37,500 industrial customers nationwide were involved in DSM programs run by over a thousand utilities, large and small (Chamberlin and Faruqui 1992). In that year, of the 1,194 large utilities with sales greater than 120 GWh in 1990, about one-third (363) reported DSM programs; many of the larger utilities had numerous DSM programs (Hirst 1992b). Utilities in the states of California, Washington, New Jersey, Rhode Island, Maine, Massachusetts, Minnesota, and Oregon led the way with the most emphasis on DSM programs (Nadel and Kushler 2000). For instance, in 1990, DSM expenditures exceeded 2% of utility revenues in Maine, Massachusetts, Rhode Island, and Wisconsin (Hirst 1994).

Golden Carrot Programs. The "Golden Carrot" Super-Efficient Refrigerator program (SERP) of the early 1990s constituted one of the first major market transformation programs. It spawned many other smaller market transformation programs with similar objectives and incentives including: Super-Efficient Apartment-sized Refrigerator Initiative (SEAR), Residential Clothes Washer Initiative, Super-Efficient Home Appliance Initiative (SEHA), High Efficiency Residential Lighting Initiative, High Efficiency Residential Central Air Conditioning and Heat Pump Initiative, High Efficiency Commercial Ice-maker Initiative, and the Energy Efficient Traffic Signals Program. All of the aforementioned programs were coordinated by the Consortium for Energy Efficiency (CEE) and tended to utilize utility DSM or government funding to achieve their market transformation goals (CEE 2003).

In general, Golden Carrot programs refer to a category of market transformation programs where some type of significant incentive, usually in the form of a financial prize, is awarded to a company that develops a product meeting certain energy efficiency and other design criteria within a specified time period. The only large-scale Golden Carrot program to actually be implemented was the Super Efficient Refrigerator Program (SERP), which ran during the peak of utility DSM. The idea for the SERP was conceived in 1990 during discussions between the utility Pacific Gas & Electric (PG&E) and the Natural Resources Defense Council (NRDC) on how utilities could best implement market transformation DSM programs. Later that year, EPA hosted a meeting with PG&E, NRDC, the American Council for an Energy Efficient Economy (ACEEE), and the Washington State Energy Office to organize SERP, which was intended to be just the first of many Golden Carrot programs. The goal was to switch the focus of utility DSM programs from offering financial rebates to consumers who purchased energy efficient refrigerators to offering incentives to manufacturers to sell more energy efficient refrigerators. At the same time, SERP was planned to address the concern that converting refrigerators from CFC insulation to non-CFC insulation by 1995 would lead to reductions in energy efficiency. The hope was that the "golden carrot" could induce the development of a CFC-free refrigerator at least 30% more efficient than the planned 1993 federal standard that would be competitive with less efficient models in terms of style, features, look, and price (L'Ecuyer et al. 1992).

To fund SERP, 25 utilities pledged a total of $30.7 million of their utility DSM funds with the goal of creating an incentive for manufacturers to transform the market for refrigerators. A contest was held, in which the manufacturer who could achieve the most energy savings by building an energy efficient CFC-free refrigerator would receive guaranteed rebates for selling the super-efficient refrigerators in the participating utilities' service areas. Manufacturers submitted bids that included a design for a prototype of the super-efficient refrigerator to be built, a delivery schedule for that refrigerator, and a value for the desired incentive payment per refrigerator delivered. Each utility taking part would then be able to take credit for a specified number of the winning super-efficient units shipped to its service area, providing a quantifiable energy savings to each utility. This specified number of units shipped to each utility's service area was intended to be proportional to the size of the pledge. The total value of the rebates to the winning manufacturer could equal up to the pooled $30.7 million, with the actual value depending on the number of SERP refrigerators sold in the utilities' service areas. The SERP incentive scheme was designed to reward bidders for maximum energy savings, minimum incentive payments, and commitment to a speedy delivery schedule. It also required all bidders to develop a plan for tracking where the units were sold so that each utility could be charged for the incentive payments for units sold in their service area. Utilities had the option of paying their commitment up-front or following a periodic payment schedule between June 1994 and January 1997 (Feist et al. 1994).

In October 1992, SERP received 14 bids and narrowed those down to bids from Whirlpool Corporation and Frigidaire Corporation. After final offers were submitted, Whirlpool Corporation won the competition and was awarded a contract in July 1993 to ship the new super-efficient units in 1994. These new models showed a substantial improvement over past models, with an average 20 cubic foot Whirlpool refrigerator in 1992 using $72 worth of electricity per year and the new super-efficient models using only $51 worth of electricity per year. The new

Whirlpool models came in three different sizes (22, 25, and 27 cubic feet) with the smallest of those first shipped in February 1994. The two larger sizes were shipped to Whirlpool dealers in May of 1995 (Ledbetter et al. 1999).

In the winning bid, Whirlpool had originally proposed to sell 250,000 of the super-efficient refrigerator units nationwide, with an incentive payment to Whirlpool of approximately $120 per SERP refrigerator sold in participating utilities' service areas. However, by 1998 Whirlpool had pulled their line of super-efficient refrigerators after selling far fewer than had been planned, with correspondingly lower total payments made to Whirlpool. Evaluators were unable to learn the exact number of units sold, but by the end of April 1997, fewer than 100,000 had been purchased nationwide—much below expectations. According to SERP administrator David Gardner in April 1997, "Whirlpool has shipped a lot more units than have been sold" and many are "either in dealer showrooms or in somebody's warehouse" (Energy NewsData 1997).

Several possible reasons are given in the literature as to why the SERP refrigerators did not sell as well as expected. First, the SERP refrigerator model was a large, high-end model with a relatively high price compared to most refrigerators on the market. Lee and Conger (1996) find that the particular design of the SERP tracking system led to higher prices of the SERP refrigerators than comparable models. In fact, Lee and Conger estimate that the SERP model retail prices were on average approximately $101 more than comparable units. They find this to be the case primarily because many dealers were unaware that Whirlpool would pay a $100 rebate back to them (independent of the incentive payments made by the SERP program to Whirlpool) for submitting the requisite tracking materials, causing many dealers to price the SERP models higher than Whirlpool intended them to. Many of these dealers did not return the tracking documentation at all, further contributing to the difficulty in determining the exact number of units sold.

In addition, the relatively large size and side-by-side refrigerator-freezer design of the SERP models likely played a role. Whirlpool intentionally designed the refrigerator to be large because the bid scoring system used in the SERP provided credit for the total number of kilowatt-hours saved, rather than the percentage of kilowatt-hours saved. For the same percentage improvement in efficiency, a larger refrigerator saves more kilowatt-hours, but it is limited in its sales potential. Compounding this, the SERP refrigerator model filled a relatively small market niche, as side-by-side refrigerator-freezers such as the SERP model were only approximately 30% of the total refrigerator market in the mid 1990s (Energy NewsData 1997). Several other reasons were also cited, such as: the lack of effective promotion of the units to both purchasers and retailers, Whirlpool's lack of communication and training for dealers and distributors, and the burden on the dealers of filling out all of the tracking paperwork (Suozzo and Nadel 1996).

While no SERP refrigerator models were produced by Whirlpool after 1998, SERP is credited with contributing to significant energy efficiency increases in other Whirlpool refrigerator models as well as modest increases in the average efficiency of all other brands (Lee and Conger 1996). However, Moezzi (1998) notes that the SERP refrigerators may not actually save energy if consumers whose purchasing decisions are based on energy efficiency are induced to buy the larger SERP refrigerators, rather than the average refrigerator on the market, which is less energy efficient but so much smaller that it uses less energy. No evaluation exists of SERP that provides ex post estimates of energy savings or cost-effectiveness of the SERP program.

SERP is recognized as being one of the first major market transformation efforts bringing together many different groups, particularly public utilities and manufacturers, to work toward the goal of transforming a market. It also is credited with demonstrating that more efficient refrigerators can be built cost-effectively, contributing to the 2001 refrigerator standard. Of the several other market transformation efforts that can trace their roots to SERP, the most notable is the Super-Efficient, Apartment-sized Refrigerator Initiative (SEAR), started in 1996 and continuing today. SEAR is more limited in scope than SERP was, focusing on public and multi-family housing, primarily in New York. A competitive bidding process for bulk orders of small super-efficient refrigerators for public housing by the New York State Power Authority is coordinated by CEE and designed to allow other sponsors to join in the order. Over 200,000 super-efficient apartment-sized refrigerators had been sold by 2003 through the program (CEE 2003). While there were originally plans for many other Golden Carrot market transformation programs, the drying up of utility DSM funds after deregulation made it more difficult for substantial financial incentives to be offered.

Deregulation and Restructuring. Around the same time that utility market transformation efforts got fully underway in the early 1990s, pressure was building for deregulation of the electricity industry. With the pressure for restructuring and deregulation, prospects dimmed for funding of utility DSM programs. The 1992 Energy Policy Act that was so important for appliance standards also included a mandate requiring the Federal Energy Regulatory Commission (FERC) to devise rules for opening the transmission grids to independent power producers to sell electricity in the wholesale markets under its jurisdiction. In 1996, FERC issued Orders 888 and 889 to comply with its mandate (Brennan 1998). The Energy Policy Act was in many ways a harbinger for the wave of retail electricity deregulation, done at the state level, which is even more critical to utilities and more directly impacts their DSM programs. In 1994, California became the first state to begin restructuring its utility industry, with the goal of giving customers the choice of electricity suppliers. Soon after, many other states began considering and implementing similar restructuring and deregulation. By 2000, a total of 23 states and the District of Columbia had passed an electric industry restructuring policy.

To prepare for the onslaught of competition, many utilities cut discretionary spending, including DSM programs. In addition, the new regulatory environment provided utilities with fewer incentives to spend money on DSM programs, as rate-of-return regulation and IRP requirements were substantially rolled back. In the new regulatory environment, price caps and greater reliance on markets for setting electricity prices created strong incentives for utilities to cut costs and seek new opportunities to increase profits by increasing electricity sales, both of which served to diminish incentives for DSM programs (Nadel and Kushler 2000). In fact, utility DSM spending declined 55% from a high of $3.44 billion in 1993 to a low of $1.55 billion in 1999 (in 2002 dollars), as shown in the second column of Table 4. Note, however, that utility DSM did not completely disappear after restructuring, as has sometimes been suggested. In 1996, for example, 600 utilities conducted over 2,300 DSM programs, involving over 20 million participants (Gellings 1996, Hirst and Hadley 1994).

Public Benefit Funds. As DSM spending plummeted in the mid to late 1990s, states began to recognize that deregulation was the leading cause, and began establishing mechanisms to stem the decline. The most common approach that regulators have taken has been to establish a public benefit fund (PBF) to fund DSM and other programs. In particular, PBFs are designed to fund energy efficiency programs, renewable energy programs, programs to assist low-income families to pay their energy bills, and a few other designated public benefit activities (Nadel and Kushler 2000). Each state or jurisdiction has its own rules for PBFs, but they are all typically funded by a per-kWh "wires charge" on the state regulated electricity distribution system (Khawaja, Koss, and Hedman 2001). These wires charges are often referred to as "systems benefit charges" or "public benefit charges." The systems benefit charge rate is usually set based on historic spending for public benefit programs, such as utility DSM energy efficiency spending. The level of the charges is typically between 0.5 and 3.0 mills per kWh (a mill being a tenth of a cent) (Nadel and Kushler 2000). A frequently cited advantage of systems benefit charges is that they are considered competitively neutral because they are added to all electricity generation (Khawaja, Koss, and Hedman 2001).

By 2000, 20 states had included specific provisions encouraging PBFs, and utility DSM spending for the past three years has been back on the rise. Market transformation programs still receive the most emphasis and, under the umbrella of market transformation programs, financial incentives for consumer purchases play a prominent role. The disastrous collapse of the energy market in California in the winter of 2000–2001 changed the regulatory landscape in many states, leading to more emphasis on short-term and peak-load reduction energy efficiency programs, rather than longer-term financial incentives for consumer purchases. However, financial incentives for consumer purchases continue to be used often and still make up a large portion of utility DSM spending (Blumstein, Goldman, and Barbose 2003).

3.1.2 Electricity Load Management

Electricity load management programs evolved simultaneously to financial incentives for consumer purchases, with similar timing of the peak and trough of interest in them. These programs aim to limit peak electricity loads, shift peak loads from peak to off-peak hours, or encourage consumers to change demand in response to changes in utilities' cost of providing power. In essence, they serve the original definition of demand-side management, which primarily referred to changing the shape of the load curve for utilities for better reliability and peak-load reduction to avoid new power plant construction. Some examples include direct load control programs, interruptible load programs, voluntary demand response programs, real-time pricing tariffs, and demand bidding programs. A common thread in all of these load management programs is the use of financial incentives to entice consumers to take part in the programs.

Direct load control programs allow the utility to directly control the customer's equipment, interrupting the power supply during periods of peak system demand. Direct load control is typically associated with utilities periodically interrupting the power to residential air conditioning units during the summer peak demand. Customers usually receive a rebate or discount on their electric bill for providing this service to the utility. *Interruptible load programs* encompass a range of programs that involve a contractual agreement between a utility and a customer to interrupt consumer demand, either through direct control by the utility system operator or by the direct request of the utility system operator. Interruptible load programs allow large commercial or industrial customers to receive discounted 'interruptible rates' for electricity that can be stopped at any point by the utility during periods of peak demand or when the market price of electricity rises above an agreed upon rate (EIA 1997). Some interruptible load programs are designed more as an emergency load management technique for utilities than standard operating procedure, and hence are used sparingly. Thus, they are often called emergency load curtailment programs.

Voluntary demand response programs are similar to interruptible load programs, but there is no contractual obligation by customers to reduce their load. However, utilities still pay the customers for load reductions on request. Some utilities have used real-time pricing tariffs to pass on high wholesale market prices to consumers, thus encouraging the shift of equipment operation from high-cost to low-cost time periods. Real-time pricing tariffs provide customers with the flexibility to switch or reduce their load to reduce their electricity bill. They tend to be most often used by industrial customers and, to a lesser extent, commercial customers.

Demand bidding programs allow consumers to specify their own reservation bid for a certain amount of load reduction. If the market-clearing price of electricity at a given time is at or above the reservation bid price, the consumer is required to reduce electricity demand by the specified amount in exchange for a payment for the reductions. In some regions, a day-ahead market for load reductions has formed in conjunction with the day-ahead electric markets to facilitate the use of demand-bidding for companies (Energy Info Source 2003).

There are also several other types of electricity load management programs. One type consists of utility programs that fund or subsidize technologies that shift all or part of a load from one time of day to another (e.g., space heating and water heating storage systems). Another type consists of utility programs that promote consumer load reduction through the use of distributed generation in response to a signal from the utility. In the past, as part of their DSM strategies, utilities also have implemented some electricity load-building programs aimed at increasing the use of electricity at the expense of other energy sources. But, since they increase rather than decrease the consumption of energy, most analyses of utility DSM ignore spending on these programs (EIA 1997).

From the beginning of utility DSM in the 1970s, electricity load management programs were an integral part of utility DSM programs, as they provided a clear and immediate benefit to utilities in the form of reduced need for additional peak generating capacity and improved system reliability. Since then, interest in load management programs has waxed and waned as the needs of utilities changed. The early programs generally required a contractual obligation on the part of the consumer, as in interruptible load or direct load control programs.

However, utilities often had difficulty finding many participants for interruptible load or direct load control programs on a long-run basis. They found that consumers were more interested in emergency demand response programs and voluntary programs that served to forestall imminent power shortages. Many consumers were not willing to expend the effort of tracking wholesale electricity prices or participating in these programs on a regular basis. Few consumers found it simple to just cut off their electricity demand any time at the request of the utility. For example, most manufacturers have deadlines, and stopping production at a moment's notice is not really an option. Only the largest and most flexible consumers were found to have an active interest in load management programs on a regular basis (Energy Info Source 2003).

More recently, in an effort to raise the participation rate, utilities have shifted to more voluntary demand response programs, which provide consumers the flexibility to continue or halt production at their discretion. While longer-term contractual interruptible load programs were the norm under Integrated Resource Planning in the 1980s and early 1990s, electricity restructuring clarified the wholesale spot price of electricity, leading to a shift toward shorter-term demand-side bidding and real-time pricing programs. However, all of the above categories of load management programs are still active and play an important role in utility DSM (Brennan, Palmer, and Martinez 2002).

Another important point is that load management programs may or may not lead to an actual decrease in total energy use. Many of the programs just shift the energy use from one time period to another. These programs could potentially still have positive environmental benefits if they allow for less peak generating capacity to be built, thereby decreasing resources used in construction. However, the opposite may also be true if the baseload generation is primarily coal and marginal peak generation is natural gas, in which case switching load from peak to base could lead to higher emissions. Either way, the total energy use remains the same whenever energy use is completely substitutable between time periods.

Some programs, such as direct control programs, are more likely to reduce total energy use because consumers are less likely to switch their energy use to another time. For instance, residential consumers are unlikely to use much more air conditioning at night just because they were slightly warmer during the day when the utility temporarily shut off the air conditioner. The degree of time substitutability is likely to be greater in other programs, such as interruptible load programs for industrial consumers involved in production, leading to correspondingly smaller total energy savings. Hence, utility DSM spending for financial incentives that are used for electricity load management may be useful for other utility objectives, but not primarily for the goal of energy savings.

3.1.3 DSM Cost-effectiveness Estimates

Several estimates of the costs, energy savings, and cost-effectiveness of utility DSM programs do exist. These estimates all consider utility DSM as a whole rather than breaking it down into subcategories. Utility DSM programs are a broad and easily defined category of programs, and utilities have been required since 1990 to report total utility DSM spending and energy savings from such programs to the federal government (in form EIA-861). However, it is difficult to accurately assign many utility DSM programs to separate categories because they contain elements of several types of programs—informational, financial incentives for consumer purchases, and load management. Some evidence suggests that information programs make up a small percentage of utility DSM spending and a correspondingly small percentage of energy savings (Nadel and Geller 1996). It is also probable that the bulk of energy savings are derived from financial incentives for consumer purchases, as load management programs are more likely to shift energy use than to actually reduce it.

The estimates that exist for the cost-effectiveness of utility DSM tend to fall into these categories: "negawatt" cost, dollars spent by utilities on DSM, and energy savings. Negawatt cost or "negawatthour" cost is a term used since the late 1980s, typically to refer to the full life-cycle cost per kilowatt-hour saved due to a DSM program. Negawatt costs include all of the costs of running the DSM program and installing the equipment, but do not include the dollar value of the resulting savings in electricity costs. Negawatt costs are useful in comparing the cost-effectiveness of different DSM programs, but they require information or assumptions about the life cycle of the program.

Estimates of dollars spent by utilities on DSM and energy savings from DSM programs tend to be annual, and most programs have an up-front cost that generates savings extending many years into the future, making it difficult to meaningfully compare those estimates with negawatt cost estimates. While it is difficult to summarize the range of the findings succinctly, we compile the following ranges to provide some sense of the state of the literature. The findings for negawatt costs range from \$0.008 to as high as \$0.071 in 2002 dollars per kilowatt-hour saved, although several papers in the literature suggest that the true cost is more likely at or even above the higher end of the range. While estimates for energy savings differ from year to year, cumulative energy savings from all utility DSM projects through 1998 range from 49,167 to 56,866 gigawatt-hours (GWh), with incremental or new energy savings estimated around 3,379 GWh. Estimates of utility DSM spending in 1998 range from \$1,580 to \$1,744 in 2002 dollars (see Table 4 and Table 5).

Negawatt Costs. Some of the early papers on the cost-effectiveness of utility DSM programs focus on negawatt costs (all expressed in dollars per kilowatt-hour saved). Nadel (1992) estimates the range of utility DSM negawatt costs to be between \$0.014 and \$0.05 in 1991 dollars (\$0.019 and \$0.067 in 2002 dollars).[3] In the same general range, Jordan and Nadel (1993) find a negawatt cost for industrial rebate programs of \$0.019 in 1989 dollars (\$0.028 in 2002 dollars). Other commonly cited estimates of negawatt costs in the early 1990s include \$0.006 in 1990 dollars (\$0.008 in 2002 dollars) by Amory Lovins of the Rocky Mountain Institute and \$0.026 in 1990 dollars (\$0.036 in 2002 dollars) by the Electric Power Research Institute (EPRI) (Fickett, Gellings, and Lovins 1990). For the purposes of general comparison, the levelized operating cost of energy from new generating units in the United States in 1991 is in the range of \$0.05 to \$0.10 in 1991 dollars per kWh, or \$0.067 and \$0.133 in 2002 dollars per kWh (Nadel 1992).

[3] In this section we inflation adjust all of our negawatt cost estimates to 2002 dollars for a rough comparison. However, it must be noted that a potentially more relevant comparison may be between the nominal negawatt cost and the nominal price of energy in a particular year. On the other hand, the number of years over which the energy investment is paid off and the price of energy in all future years in which there are energy savings are also relevant considerations. Given these considerations and our desire to compare negawatt costs across studies, we choose to inflation adjust the estimates in the literature.

These optimistic estimates of negawatt cost, particularly the Lovins estimate, were critically examined in detail in Joskow and Marron (1992). Joskow and Marron make the case that the true cost to utilities of purchasing negawatts is substantially higher than either the Lovins or EPRI estimates due to the unaccounted-for effects of free riders, under-reporting by utilities of all relevant costs, and optimistic assumptions in the engineering analysis of energy savings that are not based on actual experience (e.g., assuming consumers keep equipment for its entire lifetime, rather than retiring it early). Joskow and Marron suggest that the actual societal cost of negawatts is underestimated by a factor of two or more on average, indicating that even the high estimate in Nadel (1992) of $0.05 in 1991 dollars may be too low.

However, after Joskow and Marron (1992), several researchers produced estimates of negawatt costs below the upper bound of the Nadel (1992) estimate. Eto et al. (1995) find a negawatt cost for all utility DSM programs of $0.032 in 1995 dollars ($0.038 in 2002 dollars). Raynolds and Cowart (2000) cite a 1994 EIA study that shows the mean reported utility cost for energy efficiency programs to be $0.029 in 1994 dollars ($0.035 in 2002 dollars). Nadel and Geller (1996) provide ranges of negawatt estimates from both the utility cost and the total resource cost perspectives based on a review of several studies. The utility negawatt cost perspective is simply based on the cost to the utility for the program, while the total resource cost perspective is based on the cost to the utility and the cost to the consumer. While not explicit, the previous estimates have tended to focus on the utility negawatt cost, with the exception of Joskow and Marron (1992). Nadel and Geller (1996) estimate utility costs per negawatt ranging between $0.025 and $0.035 in 1995 dollars ($0.030 and $0.042 in 2002 dollars) and total resource costs per negawatt between $0.04 and $0.06 in 1995 dollars ($0.048 and $0.071 in 2002 dollars). The negawatt total resource cost estimates presented in Nadel and Geller (1996) are much closer to the numbers Joskow and Marron (1992) suggested would be appropriate.

Annual Energy Savings and DSM Spending. While not comparable to negawatt cost estimates, annual energy savings and utility spending estimates still provide useful information about the cost-effectiveness of utility DSM programs. One of the early papers with useful ex post energy savings and utility spending estimates is Hirst (1992c). Hirst finds that utilities saved 14,800 GWh and 17,100 GWh in 1989 and 1990, respectively. These savings cost utilities $890 million and $1,210 million in 1990 dollars for 1989 and 1990, respectively ($1,235 million and $1,678 million in 2002 dollars). Note that the annual savings in Hirst (1992c), as well as all of the papers to follow unless otherwise indicated, account for the benefits of past as well as present utility DSM programs. Several other figures in Hirst (1992c) provide a sense of the extent of energy savings and utility spending: in 1990, utility DSM expenditures accounted for 0.7% of total annual U.S. electric revenues, with a corresponding energy savings of 0.6% of the total annual energy use. Hirst (1992b) also estimates the energy savings from utility DSM programs in 1992 at 0.5% of the total annual energy use.

In addition to negawatt estimates, Nadel (1992) also provides an estimate of utility DSM energy savings in 1990 of 32,995 GWh, an estimate considerably higher than Hirst's (1992c). Moreover, Hirst (1994) estimates the energy savings from 1989 through 1992 and obtains the following values: 16,300 GWh, 18,700 GWh, 23,300 GWh, and 31,800 GWh, respectively. Again, these estimates are much smaller than the Nadel (1992) figures. More recently, Raynolds and Cowart (2000) estimate that the cumulative energy savings from all DSM programs over the years 1973–1998 sums up to 27 quads.

After 1990, utilities were required to submit form EIA-861 with their estimates of DSM spending and energy savings, greatly improving the reliability of the estimates from previous studies. The EIA estimates of energy savings and spending for the years 1992–2001 are provided in EIA (EIA 2003b) and reported in Table 4. Incremental energy savings refers to savings associated with new participants in existing DSM programs and all participants in new DSM programs in a given year, annualized to indicate the effects assuming the participants had been initiated into the program on January 1st of that year. Annual effects are the total effects on energy use caused by all participants in DSM programs in a given year. Incremental effects are not simply the annual effects of a given year minus the annual effects of the prior year, since these net effects would fail to account for program attrition, equipment degradation, building demolition, and participant dropouts (EIA 1997). These numbers imply that utility DSM saved 1.6% of all electricity energy in 2001, assuming that all utility DSM energy savings are derived from reductions in electricity use. Nadel and Kushler (2000) modify the annual EIA estimates and add their own estimates for some of the prior years (Table 5). In Section 6 (Synthesis), we use these estimates to develop a measure of the cost-effectiveness of utility DSM.

Note that the EIA estimates are far from perfect, as utilities self-report the energy savings. Hirst (1992a) discusses this issue and provides several reasons why the utility energy savings estimates may have problems. First, utilities may use different definitions of what counts as a DSM program. For example, some utilities may have included load-building programs in their reported data, even though the EIA explicitly stated that they should not. Second, there is no standardized method of estimating the effects of DSM programs. Utilities using engineering life-cycle data are likely to have higher estimates than those using billing data or load-research data (Nadel and Keating 1991). Some utilities also might report energy savings at the consumer meter and others at the generator, with differences of 5% to 15% due to losses in the transmission and distribution systems. Finally, some utilities may account for free riders and report the savings that can be attributed directly to the program, while others may just report total savings. The methods used to account for free riders differ among utilities as well.

There are different schools of thought in the literature about how to best interpret some of the cost-effectiveness numbers. Both Nichols (1994) and Train (1994) are critical of many of the common ways that the costs of utility DSM programs are calculated, building upon some of the criticisms of the EIA data in Hirst (1992a). Nichols particularly takes issue with the total resource cost method, suggesting that total resource cost calculations leave out three potentially important factors. First, they do not account for costs or benefits associated with effects that are not directly paid out of pocket (e.g., differences in quality, comfort, etc). Second, there are unaccounted for costs or benefits associated with program participation (e.g., time spent filling out forms). Third, there are differences between the utility's discount rate and the rate applied by participants to their own cash flows. Instead, Nichols proposes using estimates based on consumer surplus, which yield much lower net benefits than the total resource cost method. Train (1994) discusses why many of the commonly used methods of calculating net savings by utilities are overstated due to the way they handle free ridership. Train suggests an alternative means of estimating net savings based on a treatment group and control group. Several other papers in the literature make more general statements about the theoretical cost-effectiveness of utility DSM programs that are consistent with the Nichols (1994) and Train (1994) interpretation that the costs of the programs are typically understated. Wirl (2000) provides a summary of these arguments, suggesting that utility DSM conservation programs suffer from: the rebound/take-back effect (just as in appliance standards), private information leading to adverse selection (free riders), and moral hazard (deferring conservation investment to wait for a financial incentive program). Braithwait and Caves (1994) make some of the same points, with more of a focus on how DSM rebates change consumers' behavior, a moral hazard issue that leads to the over-estimating of energy savings from the rebate program. Hughes (1992) also brings up similar points and focuses on the free-ridership issue. Krietler (1991) estimates that up to 80% of energy savings in some programs is from free riders, adding credibility to some of the arguments by Hughes (1992), Wirl (2000), and Train (1994).

However, some papers in the literature take the view that free riders and moral hazard are not major issues in most utility DSM programs, and that utility DSM energy savings are for the most part correctly estimated. Levine and Sonnenblick (1994) differ with Nichols (1994); they make the case that the total resource cost method more accurately represents actual program results and, moreover, may even underestimate the true benefits of the utility DSM program. Levine and Sonnenblick base their arguments on empirical evidence from a survey of the participants in a particular program. They find low levels of free ridership and "hidden costs" of the program (e.g., lower levels of comfort, time taken to fill out forms to participate in the program). Sanstad and Howarth (1994) also suggest that the engineering approach (i.e., total resource cost method) is the correct approach to estimate the benefits of energy conservation programs in general, but do not provide specific examples relating to utility DSM programs or the problem of moral hazard and free ridership.

Finally, Gehring (2002) presents another view, suggesting that in the past, many savings estimates provided by utilities to the EIA were related more to political compromise than engineering and economic reality. But, he still suggests that DSM programs can be targeted and managed to provide energy savings to consumers and peak-load reductions for utilities. Gehring acknowledges that free ridership is an important and often unaccounted-for problem and also indicates why past utility DSM energy savings estimates were unreliable. He points out that the estimates were often based on engineering estimates and billing analysis complicated by weather, lack of end use data, and an inability to account for the impacts of human behavior.

3.2 Income Tax Credits or Deductions

Income tax credits or deductions at either the federal or the state level have occasionally been used as a policy instrument to encourage energy conservation. At the federal level, there is no current income tax credit or deduction for residential energy efficiency investments, although there is a current federal tax deduction for individuals who purchase clean fuel or electric vehicles. This deduction went into effect in 2002 at $2,000 and will be phased out by 2006 in increments of $500 each year (IRS 2003). The Bush administration's proposed FY 2004 budget also includes tax credits for hybrid vehicles, and pending energy legislation includes tax credits for energy efficient appliances (S. 1149) and energy efficient improvements to existing homes (S. 1149 and H.R. 6) (OMB 2003).

In the late 1970s and early 1980s, there was a tax credit at the federal level for residential energy efficiency investments. The federal Energy Tax Act of 1978 (ETA78) was passed in response to the energy crises of the 1970s and provided federal income tax credits to homeowners for specified energy conservation investments. These investments included: insulating walls and ceilings, replacing furnace burners and ignition systems, and installing storm or thermal windows and doors, clock thermostats, and weather stripping. These weatherization, insulation, and similar conservation activities received an income tax credit of 15% of the total cost with a credit ceiling of $300 and the restriction that the credits could only be taken on buildings constructed prior to 1977. ETA78 also encouraged residential investment in solar, wind, and geothermal energy and those investments received a higher credit of 30% for the first $2,000 and 20% on the next $10,000, with a maximum credit of $2,600 (Walsh 1989).[4]

The conservation incentives in ETA78 were designed to expire on December 31, 1987, but were curtailed earlier in the mid-1980s as a result of tax reform legislation under the Reagan Administration. From 1978 to 1985, about 30 million claims for the conservation tax credits were filed, cumulatively amounting to nearly $5 billion (nominal dollars) in lost tax revenues or approximately $166 per claim (U.S. Congress Office of Technology Assessment 1992). The conservation tax credits were commonly perceived as relatively ineffective at inducing investment and, until recently, there has been relatively little discussion of reviving them at the federal level. Nevertheless, conservation tax credits or deductions at the state level have been in existence since before ETA78 and have continued to the present in several states. For instance, during period 1979–1985 when the federal conservation tax credits existed, Arizona, California, Colorado, Hawaii, Montana, and Oregon offered credits of some form and Arkansas, Idaho, and Indiana offered deductions (Hassett and Metcalf 1995). Currently, several states still have some

[4] The Crude Oil Windfall Profits Act of 1980 increased the tax credits available for those solar, wind, and geothermal energy systems to 40%, with a maximum credit of $10,000 and no restriction on the age of the residence.

type of conservation tax credit or deduction, including Georgia, California, New York, Hawaii, Oregon, and Montana.[5]

A small body of literature exists analyzing how effective energy conservation tax credits are at inducing conservation investment. The empirical evidence from this literature is mixed, with some of the earlier papers suggesting that tax credits are a very ineffective policy, while some of the later papers point to limited effectiveness. Carpenter and Chester (1984) take a large survey (5,366 responses) of homeowners in the western United States, and focus their analysis on behavior in response to the ETA78 federal tax credit. They find that while 86.8% of those surveyed were aware of the tax credit, only 34.5% of those aware of the tax credit actually made a claim between 1978 and 1980, and, of those who made a claim, 94% stated that they would have made the conservation investment regardless of the availability of the tax incentive. Durham et al. (1988) uses different data from the same survey to econometrically test whether state tax credits effectively encourage solar installation; the results indicate that the level of tax credits has a statistically significant effect on the probability of solar installation, with an elasticity of 0.76 with respect to the level of the tax credit.

Two other studies, Dubin and Henson (1988) and Walsh (1989) econometrically estimate the effect of tax incentives on all conservation investment. Dubin and Henson find that the coefficient estimates of tax incentives' effect on conservation investment is insignificant and very small. Moreover, Walsh finds that tax incentives not only do not induce investment, but appear to slightly decrease investment.

Hassett and Metcalf (1995) examine the studies by Dubin and Henson (1988) and Walsh (1989) and find methodological reasons for why the studies do not find a statistically and economically significant relationship between tax incentive programs and conservation investment. First, state tax programs that are deduction programs may not be correctly accounted for in some of the earlier papers, as deductions are more complex than tax credits. Second, and more important, Hassett and Metcalf (1995) state that there are individual specific effects, such as conservation "taste" factors and attributes of housing, that are likely to be correlated with the explanatory variables (i.e., whether or not a state introduces a tax credit or deduction). After controlling for these individual effects, they find a positive and significant

[5] Information on these programs comes from state tax forms.

effect of the implicit tax price of conservation deductions/credits, implying that a 10 percentage point change in the tax price for energy investment leads to a 24% increase in the probability of making an investment.

Williams and Poyer (1996) have similar econometric findings; tax credits play a statistically significant role in explaining energy conservation improvement activity. These findings, with those of Hasset and Metcalf, lend some credibility to tax credits or deductions as effective policy instruments.

3.3 Emissions Allowances Allocated to Demand-Side Investments

The concept of emissions allowances allocated to demand-side investments has been discussed as a possible addition to recently proposed tradable permit systems to regulate air pollutants from electricity generation. Title IV of the 1990 Clean Air Act implemented such an approach with the Conservation and Renewable Energy Reserve of allowances, in which 300,000 SO_2 allowances were set aside. These allowances, roughly valued at a maximum of $45 million (based on the 2000 average allowance price of approximately $150 per ton if all 300,000 were awarded), were available to utilities that employed efficiency and renewable energy measures to produce early emissions reductions before their generating units became subject to the Acid Rain Program. For every 500 megawatt-hours saved through demand-side energy efficiency measures or generated by renewable energy, utilities could acquire one reserve allowance. Utilities then could use their reserve allowances in the same way they would any other Title IV allowance—use them for compliance, sell them, or bank them for future use.

In order for a utility to apply for the reserve allowances, the electricity saved must be a qualified demand-side measure or from a qualified renewable energy generating resource. The qualified demand-side measures must be noninformational (i.e., it must contain financial incentives), implemented in a residence or facility of a utility customer, and considered cost-effective. The qualified measures must be listed in Appendix A in Title IV, which lists over 50 measures covering almost all imaginable DSM programs and renewable generating resources. For example, everything from investments in drip irrigation systems, to investments in caulking/weather stripping, to electricity generation equipment monitoring is covered. Qualified renewable energy generating resources are: biomass, solar, geothermal and wind.

To be qualified to apply, utilities must use a regulator approved least-cost planning approach to resource planning and be subject to "net income neutrality." Net income neutrality refers to a state rate-making process requiring that energy efficiency measures be profitable or that the utility be compensated for any lost sales due to the measures. Existing utility DSM programs that meet the qualifications can be used to apply for reserve allowances; the programs do not have to be new (EPA 2002b).

In order to apply for the reserve allowances for an eligible DSM program, utilities were required to go through an extensive process with the following components: document the energy savings, document certain features of their state utility regulatory policies (e.g., least-cost planning, net income neutrality), have the state public utility commission (PUC) review and certify the application, have the state PUC certify that the utility was regulated under a regulatory scheme that qualifies, and finally, submit the application to EPA. These requirements were originally designed during the pre-restructuring era of the late 1980s and early 1990s to encourage state PUCs to adopt policies, such as least-cost planning and net income neutrality, and to encourage utility DSM and renewable energy (Kruger 2003). Utilities that were affected by Phase I of the Acid Rain Program could apply for reserve allowances for energy efficiency or renewable energy generation measures undertaken between January 1, 1992 and their compliance date of January 1, 1995. The same held true for Phase II utilities until their compliance date of January 1, 2000. After January 1, 2000, no new reserve allowances could be earned, but utilities have until 2010 to apply for reductions that occurred before the deadline (EPA 2002b).

Had the Conservation and Renewable Energy Reserve been entirely used, EPA (2002b) estimates that the 300,000 reserve allowances would represent a conversion of 150 billion kWh to energy efficiency or renewable energy, displacing 885 million pounds of SO_2, 825 million pounds of NO_X, and 225 billion pounds of CO_2. In reality, at the present only 47,493 reserve allowances have been allocated (15.8% of the total) and it is likely that all eligible reserve allowances have already been applied for. These could be roughly valued at $7.12 million based on an average allowance price of $150 in 2000. Of the allocated allowances, 36,360 were allocated toward energy efficiency programs (76.7% of the total), with the rest going toward renewable energy generation (2003). In addition to the low participation rate, it is unlikely that the program spurred actions that would not have happened in the absence of the program. The conservative award formula, the high transactions costs of submitting a claim, and low allowance prices all contributed to the program not providing an adequate incentive to spur new DSM programs (EPA 2003b). Moreover, larger utilities were more likely to take advantage of the reserve allowances because of economies of scale in lowering the relative transactions costs; only 39 utilities have taken part in the program (Kruger 2003). In effect, the main result of the Title IV reserve allowances is that utilities that already had qualifying programs received an extra benefit from those programs.

The concept of allocating allowances to encourage energy conservation activities has continued to be floated as part of new air pollution regulation legislation. For instance, in S. 366 (Jeffords multi-pollutant bill), set-aside allowances are a part of the tradable allowance system for SO_2, NO_X, and CO_2. S. 366 would allocate no more than 20% of all SO_2, NO_X, and CO_2 allowances each year toward conservation and renewable energy activities. Any of the following would qualify: renewable generation facilities, owners of energy efficient buildings, producers of energy efficient products, entities that carry out energy efficient projects, owners of new "clean" fossil-fuel electricity generating units, and owners of combined heat and power generating facilities (Burtraw et al. 2003).

4. Information and Voluntary Programs

The information and voluntary programs we consider all attempt to induce energy efficient investment by providing information about potential energy savings or by demonstrating examples of programs that have made such energy savings. In many of the programs, firms voluntarily agree to take on goals to improve efficiency or save energy.

4.1 1605b Voluntary CO_2 Reductions

Section 1605b of the 1992 Energy Policy Act (Public Law 102-485) mandated the creation of a national inventory of greenhouse gases and a national database of voluntary reductions in greenhouse gas emissions. In doing so, Section 1605b directed the Department of Energy to establish a procedure for voluntary reporting of greenhouse gas emissions and emissions reductions by companies from the year 1987 forward, on a yearly basis. These voluntarily reported reductions in emissions could come from any possible measure, including fuel switching, forest management practices, tree planting, use of renewable energy, manufacture or use of low-emissions vehicles, greater appliance efficiency, methane recovery, cogeneration, chlorofluorocarbon capture and replacement, power plant heat rate improvement, or even nonvoluntary measures such as facility closings or governmental regulations (Public Law 102-485).

The intention of Section 1605b was to encourage companies to voluntarily reduce their greenhouse gas emissions. The database also allows companies to make public commitments to reductions in greenhouse gases in the future, giving them the opportunity to set goals and thereby improve their public image. In 1994 the 1605b program cost the Energy Information Administration (EIA) $1 million ($1.4 million in 2002 dollars) to administer. The cost then rose in 1995 to $1.4 million ($1.65 million in 2002 dollars) and eventually dropped in 1998 to $0.4 million ($0.44 million in 2002 dollars) (GAO 1998). The administrative cost leveled off from there; in 2000 it cost $0.44 million for the data collection, software updates, and report publication ($0.46 in 2002 dollars) (McArdle 2003).

While little empirical work has been done on the behavioral effect on companies of the existence and use of the voluntary reporting database, it is clear that some companies are investing the time and resources to register their emissions reductions. For instance, in 2001 228 different entities (companies or government agencies) voluntarily reported reductions in greenhouse gas emissions for 1,705 projects. The vast majority of these were either utilities or alternative energy companies, while a few were industrial companies or government agencies.

The emissions reductions reported in 2001 totaled 222 million metric tons of carbon dioxide equivalent in direct reductions, 71 million metric tons in indirect reductions, 8 million metric tons of reductions from carbon sequestration, and 15 million metric tons of unspecified reductions. This is equivalent to a total savings of 84 million metric tons of carbon equivalent from non-carbon-sequestration reductions. Direct emissions reductions are those from sources wholly owned (or leased) by the reporting entity; indirect emissions reductions are those not owned by the reporting entity but are due to the entity's activities. For instance, both the manufacturers and owners of more efficient automobiles can register emissions reductions resulting from the ownership of those vehicles. Thus, there is a potential for double counting, but as the purpose of the program is to encourage voluntary reporting, the EIA does not prohibit double reporting. Instead, it only attempts to identify instances of potential double counting (EIA 2003e).

One important aspect of the Section 1605b voluntary reporting program is that most entities reporting tend to be affiliated with one or more other government-sponsored voluntary programs. For example, of the 1,705 projects reported for 2001, 1,412, or 83%, were affiliated with other government programs.[6] This suggests that most projects reported tended to take advantage of other government programs and were not solely induced to reduce emissions by the registering of those emissions reductions with the national database.

Including only relevant energy efficiency conservation projects not associated with any other government voluntary or utility DSM program, reductions amounting to 6.083 MMtCE were registered with 1605b in 2000 (McArdle 2003).[7] This represents an energy savings of about 0.411 quads.[8] Some percentage of these registered emissions reductions would likely have occurred in the absence of the 1605b program, but we have no way of knowing the amount that was induced and the amount that would have happened anyway. Theoretically, the emissions reductions that were induced by the program could vary between zero and 6.083 MMtCE, although common sense suggests that the true value likely falls somewhere in between.

4.2 DOE Climate Challenge

The DOE Climate Challenge program is a voluntary partnership between electric utilities and DOE designed to facilitate voluntary greenhouse gas emissions reductions by utilities. The Climate Challenge program is complementary to the registration of voluntary CO_2 reductions under section 1605b of the 1992 Energy Policy Act. The program was set up in a Memorandum of Understanding signed April 20, 1994 by the DOE secretary and all of the national utility trade associations. All emissions reductions done as part of Climate Challenge are intended to be voluntary efforts that make sense on their own merits. To take part in the program, a utility must agree to three points. First, the utility must report annually to DOE on their progress. Second, the utility must be available to confer occasionally with DOE on progress to discuss potential

[6] 1,041 were affiliated with the Climate Challenge Program, 180 with the Landfill Methane Outreach Program, 57 with the Climate Wise Recognition Program, 37 with the U.S. Initiative on Joint Implementation, 33 with various Energy Star programs, 17 with the EPA Green Lights Program, 16 with the Natural Gas STAR Program, nine with the Sulfur Hexafluoride Emissions Reduction Partnership, nine with the Coal-bed Methane Outreach Program, seven with Compressed Air Challenge, and six with WasteWise

[7] Registered emissions reductions from sequestration (geologic or biologic) or any other non-energy efficiency program are also excluded.

[8] Calculated using an average nontransportation emissions rate of 14.75 MMtCE/quad (EIA 2003b).

measures that the utility may be well positioned to implement. Third, the utility must agree to one or more of six pre-specified types of reduction commitments.

The following are the six commitments that utilities could agree to. First, they could reduce greenhouse gas emissions by a specified amount below the utility's 1990 baseline level by the year 2000. Second, utilities could reduce greenhouse gas emissions to the utility's 1990 baseline level by the year 2000. Note that the first two commitments ended in 2000, and thus do not currently apply. Third, utilities could reduce greenhouse gas emissions to a particular level expressed in terms of emissions per kWh generated or sold. Fourth, utilities could reduce greenhouse gas emissions by or to some other specified level. Fifth, utilities could undertake or finance specific projects or actions to reduce greenhouse gas emissions. Sixth, utilities could make a specified contribution to any particular industry initiatives coordinated with Climate Challenge and designed to reduce greenhouse gas emissions. These six commitments are sufficiently broad so as to encompass almost all potential greenhouse gas reducing measures utilities could take, no matter what the size or structure of the utility.

DOE (2003b) suggests several incentives for utilities to participate in the Climate Challenge program: (1) national and international government officials are watching the program carefully, implying that effective voluntary efforts may prevent mandatory regulation; (2) involvement in the Climate Challenge program may lead to the allocation of possible credits in a potential future carbon policy for emissions reductions done currently with the program, which is provided under the Section 1605b voluntary registration of emissions reductions; and (3) most of the efforts that reduce emissions also tend to reduce costs or otherwise improve operations, creating potential "win-win" situations for utilities. In addition, publicizing emissions reductions under the Climate Challenge program can provide a public relations benefit.

As several of the commitments in the Climate Challenge program were focused on the year 2000, after that year the program stopped accepting new applicants. However, it is still run by DOE for current participants, who are regularly encouraged to make new commitments. As of 2000, there were 124 partnerships with national industry trade associations representing 651 utilities, with commitments made to reduce carbon emissions by over 47.6 million metric tons of carbon equivalent between the start of the program and the year 2000 (DOE 2003b). Many, if not most, of these commitments were fulfilled with utility DSM programs, so the energy savings and reductions in greenhouse gas emissions associated with utility DSM programs may have been encouraged in part by the Climate Challenge program.

The nonutility DSM Climate Challenge emissions reductions that were registered with 1605b in 2000 amounted to 12.038 MMtCE (McArdle 2003). This translates into an energy savings of about 0.814 quads.[9] Just as in the 1605b program, we cannot determine what percentage of these registered emissions reductions would have occurred in the absence of the Climate Challenge program. Thus, Climate Challenge-induced emissions reductions could range from zero to 12.038 MMtCE. Unfortunately, little or no empirical work has been done in the literature to analyze the effectiveness of Climate Challenge.

4.3 Energy Star Programs

Energy Star is an umbrella term encompassing a broad range of programs, all designed to encourage energy efficient investments. Energy Star began with a limited agenda in the early 1990s, after the 1992 Energy Policy Act directed EPA to implement a program to identify and designate particularly energy efficient products and to provide estimates of the relative energy efficiency of products. This legislation was designed to reward the most energy efficient products with positive publicity, thereby encouraging consumers to buy those products and other manufacturers to improve the energy efficiency of their own products. The Energy Star designation is completely voluntary and has been used by manufacturers as a selling point. Currently, EPA and DOE jointly run the voluntary labeling program.

The program started with only computers and monitors and, by 1995, expanded to include additional office products and residential heating and cooling equipment. In 1996, EPA partnered with DOE to add other product categories to the labeling program. In the following years, the Energy Star voluntary labels were extended to cover a wide array of products, with over 35 product categories, including: major appliances, office equipment, home electronics, and even new homes and commercial and industrial buildings. See Table 6 for a selected listing of products covered, their percentage energy savings over standard new products in 2000, and their market share in 2000. The definition of qualifying Energy Star products is different for each

[9] As with the 1605b estimates, energy savings are calculated using an average nontransportation emissions rate of 14.75 MMtCE/quad (EIA 2003b).

product category, but tends to include only the most efficient products on the market—a small fraction of the total market. This is not always the case, however. The vast majority of computers, monitors, copiers, faxes, VCRs, TVs, and exit signs are Energy Star-qualified.

In addition to the Energy Star voluntary labeling program, Energy Star also encompasses a range of public-private partnerships, many of which began as separate programs and were moved under the auspices of Energy Star in the late 1990s. For instance, the EPA Green Lights Program was started in 1991 to advance the adoption of energy efficient lighting systems in industrial and commercial facilities through information and demonstration activities. Similarly, the EPA Climate Wise program was created in the mid-1990s to provide information and assistance to industrial and commercial facilities to identify and implement greenhouse gas emissions-reducing activities. These programs joined the Energy Star umbrella of programs in the late 1990s due to their similarity in mission to the core Energy Star mission. Other programs include: the Green Power partnership encouraging organizations to buy renewable energy, the Combined Heat and Power partnership between the government and industry, and Energy Star Home Sealing, which helps homeowners improve the energy performance of their homes during remodeling and renovation. By 2001, Energy Star facilitated partnerships between the government and over 7,000 public and private sector organizations (EPA 2003a).

EPA has published several reports documenting the effects of Energy Star programs and a small body of academic literature analyzing these programs does exist. For instance, EPA (2002a) has several estimates of energy and dollar savings of activities associated with the Energy Star programs. EPA (2002a) estimates that in 2001, these activities saved more than 80 billion kilowatt hours and avoided using 10,000 megawatts of peak generating capacity. The Energy Star label is widely known, recognized by over 40% of the American public, and over 750 million Energy Star products have been purchased through 2001. Over 57,000 Energy Star labeled homes have been constructed, providing an estimated savings from lower energy costs of more than $15 million annually. It is difficult to determine the degree to which these energy savings were induced by the Energy Star program; some likely would have occurred irrespective of the existence of Energy Star.

EPA (2002a) provides estimates of the net present value through 2012 of all Energy Star-related investments made through 2001, finding energy bill savings of $75.9 billion (in 2001 dollars), incremental technology expenditures of $10.7 billion, and thus net savings of $65.2

billion. These savings are also associated with an estimated greenhouse gas emissions reduction through 2012 of 241 MMtCE.

In recent years, EPA has spent around $50 million on administering all Energy Star programs (Malloy 2003). We could find no estimates in the literature of the cost to consumers of taking part in Energy Star programs, although EPA (2002a) suggests that there are no costs, as the reduced spending on energy due to Energy Star programs more than makes up for any costs incurred by participating in the programs.

A few other papers in the literature address the cost-effectiveness of Energy Star programs. DeCanio (1998) statistically analyzes data on how the Energy Star Green Lights program induces investment in energy efficient equipment and concludes that organizational and institutional factors are important impediments to such investment. DeCanio then suggests that voluntary programs such as the Green Lights program have the potential to induce energy saving investment, improve corporate performance, and reduce pollution. DeCanio and Watkins (1998) also econometrically analyze data from the Green Lights program, coming to similar conclusions.

Webber et al. (2000) contains an ex post analysis of the Energy Star labeling program up to 1999, providing estimates of cumulative energy savings, undiscounted energy bill savings, and avoided carbon emissions (Table 7). Howarth et al. (2000) reviews the Energy Star Green Lights and voluntary labeling programs, and develops a model suggesting that these programs are successful in achieving energy savings by reducing market failures relating to problems of imperfect information and bounded rationality. The findings in Howarth et al. also suggest that these programs do not suffer greatly from the "take-back" or "rebound" effect of Khazzoom (1980) (see section on appliance standards).

4.4 DOE Energy Efficient Buildings Programs

The Department of Energy runs a suite of programs dedicated to improving the energy efficiency of buildings. These programs include: Building America, Rebuild America, the High Performance Buildings Initiative, and the Zero Energy Buildings Initiative. All of these programs work through the development of voluntary public-private partnerships.

The Building America program provides technical assistance to homebuilders and facilitates dialogue on energy efficiency between different segments of the home-building industry that traditionally work independently of one another. The dialogue and creation of teams comprised of different segments of the home-building industry is intended to apply a systems engineering approach to the construction process. The rationale for a systems engineering approach is that features of one component in a house can greatly influence others, so that looking at the construction process holistically can enable teams to incorporate energy saving strategies at no extra cost. As of 2000, there were five teams with a total of more than 150 participating companies. By 2000, over 2,000 houses in 24 states were constructed using the Building America approach (2001a).

The Rebuild America program is designed to build partnerships among communities, states, and the private sector to improve the energy efficiency of any type of building, with a focus on commercial, government, and public-housing buildings. In these partnerships, DOE offers technical assistance in the form of suggestions for energy efficiency improvements that can be made during renovations and retrofits, as well as general energy audits. A major goal of the program is to help teach local and state officials to identify prospects for energy efficient upgrades and then to provide technical assistance in the undertaking of the upgrades themselves.

DOE (2002) provides several statistics on the Rebuild America program. By the end of 2002, the program involved nearly 500 public-private partnerships and engaged in more than 800 projects in 2002 (up from 600 projects in 2001). The annual energy savings from these projects amounted to 9 trillion Btu, with energy cost savings of $131 million (in 2002 dollars). Annual reductions in pollution reached 3,349 metric tons of SO_2, 1,576 metric tons of NO_X, and 768,239 metric tons of CO_2, as estimated from reduced electricity consumption.[10] DOE (2002) also estimates that every federal dollar invested in the program saved $18.43 (in 2002 dollars) and generated $9.38 in private energy efficiency investments.

The High Performance Buildings Initiative is a research and informational initiative in which DOE works with engineers, architects, building owners and occupants, and contractors on projects to improve the energy efficiency of new commercial buildings. The initiative primarily

[10] Note that if these energy savings are from electricity (as opposed to fuel oil), it is not likely that this level of annual reductions continued once the Title IV cap on SO_2 was implemented.

focuses on new office buildings. The Zero Energy Buildings Initiative is dedicated to fostering the construction of new residential homes that are super energy efficient and rely on renewable distributed generation for most of their energy needs, potentially resulting in net zero energy consumption over the year. To do so, DOE has partnered with four home-building teams to develop the concept further and provide information to homebuilders. Both the High Performance Buildings Initiative and the Zero Energy Buildings Initiative are small, relatively new programs and few assessments have been done to determine their cost-effectiveness (DOE 2003a).

4.5 Partnership for Advanced Technology in Housing (PATH)

The Partnership for Advanced Technology in Housing (PATH) program is a voluntary public-private partnership between homebuilders, product manufacturers, insurance companies, and financial companies and the U.S. Department of Housing and Urban Development (HUD). It is dedicated to improving the energy efficiency, affordability, durability, environmental sustainability, and resistance to natural disasters of residential housing. The PATH partnerships perform the following activities: provide information about the latest advances in residential housing technologies, demonstrate innovative housing projects to serve as models, promote research on new housing technologies, and attack institutional barriers to housing innovation (e.g., risk and liability concerns) (PATH 2003).

While energy efficiency is not the only objective of PATH, it is one of the primary objectives. For instance, in 2000, PATH set a goal to reduce energy use in 15 million existing residential homes by 30% or more by the year 2010 (HUD 2000). An independent National Academy of Sciences review of PATH in 2000 found this to be a laudable but largely unattainable goal, due to other somewhat incompatible competing goals, such as lowering the cost of housing, and the technology-demonstration/development focus of the program (National Academy of Sciences 2001). For instance, more than 80% of PATH's annual funding from Congress—$980,000 in 1998, $10 million in 1999 through 2001, and $8.75 million in 2002—is dedicated to R&D activities (National Academy of Sciences 2003).

Another National Academy of Sciences review in 2002 evaluated 56 PATH activities initiated between 1999 and 2001 and made a series of recommendations to improve the program, but the review provided no estimates of energy savings or cost savings due to the energy efficiency component of the program (National Academy of Sciences 2003). Little or no other literature exists on PATH.

4.6 Industrial Energy Audits

The Department of Energy's Office of Industrial Technologies runs two programs primarily focused on industrial energy audits: Industrial Assessment Centers (IAC) and Plant-wide Assessments (PWA).

DOE's Industrial Assessment Centers (IAC) program is one of the oldest voluntary programs, originating in 1976. The IAC program is designed to encourage improvements in industrial energy efficiency by conducting energy, waste, and productivity assessments for small to medium-sized companies. These assessments are performed at no cost to the manufacturer by teams of faculty and students from 26 university-based IACs across the United States. Students are trained in the skill of energy audits and industrial assessments while providing a free service to manufacturers. Each IAC tends to complete approximately 25 assessments per year.

The assessments themselves are made up of three components. First, the IAC team conducts a plant survey, followed by an in-depth one- to two-day audit of energy, waste, and productivity in the industrial facility. Within 60 days, the plant manager receives a report detailing the team's analysis and recommendations, along with estimated costs, performance, and payback periods for those recommendations. Finally, in six to nine months, the IAC follows up with the plant to determine which, if any, recommendations were actually implemented and the results. A database is also kept of all IAC assessments and the detailed recommendations made.

These assessments are estimated to save the average participating manufacturing facility $55,000 annually (DOE 2001b). Through 1992, DOE (1996) estimates that between 50% and 61% of the recommendations were implemented. In that same time period, implementation rates are roughly the same for all types of plants, but certain recommendations are more or less likely to be implemented. Recommendations that have high initial upfront costs and are relatively complex are less likely to be implemented (DOE 1996). Cumulatively, between 1977 and 2001, DOE estimates that almost 467 trillion Btu of energy have been saved by the IAC program, for an undiscounted cumulative savings of nearly $2 billion in 2001 dollars (DOE 2003c). The current cost to DOE to administer the program is about $7 million per year (in 2002 dollars) (Anderson and Newell 2002).

The PWA program is intended for larger manufacturers who do not qualify to receive a free IAC audit. Manufacturers are invited to submit proposals in response to a PWA solicitation, usually offered once a year. To submit a proposal, manufacturers complete a plant-wide assessment and identify potential energy efficiency investments. DOE then judges the proposal's potential energy savings and the degree to which it demonstrates cutting-edge energy efficient technologies. The energy efficient investments of accepted proposals are then partially subsidized by DOE, which provides funding of up to $100,000 per proposal. The manufacturer's cost share must be at least 50%. DOE (2003d) estimates that companies participating in assessments typically can expect to realize a minimum of $1 million in savings from energy costs, with a payback of less than 18 months.

There is little empirical literature on the cost-effectiveness of the IAC or PWA programs. In one of the few papers, Tonn and Martin (2000) present a model to describe an industrial firm's energy efficiency decisionmaking over time and then statistically analyze how IAC influences this decisionmaking process. Tonn and Martin suggest that three IAC benefits influence firms' energy efficiency decisionmaking: the direct energy assessment, the employment of a student alumni of an IAC program, or the use of energy efficiency information from an IAC website. In addition, Tonn and Martin find that all three are associated with a significant increase in the number of energy efficiency investments made by firms within a relatively short period of time.

Anderson and Newell (2002) also analyze the technology adoption decisions of manufacturers in response to IAC energy audits. They find that, while there are unmeasured project-related factors influencing the energy efficiency investments, most plants do respond to the costs and benefits presented to them in the energy audits, with a typical investment payback threshold of 15 months or less, corresponding to an 80% or greater hurdle rate. They also find that plants reject about half of the recommended projects, with the stated reasons primarily reflecting economic undesirability.

4.7 State Industrial Energy Efficiency Programs

In addition to the Department of Energy, many states and regional bodies have industrial innovation and competitiveness programs, many of which are specifically dedicated to industrial energy efficiency improvement. Approximately 300 of these programs exist, with some of the most well-known programs found in the states of Iowa, New York, Texas, and Wisconsin.

These programs vary in scope and focus. For instance, the Iowa Energy Center focuses on agriculture and energy audits, while the Energy Center of Wisconsin and the LoanSTAR program in Texas focus more on demonstration projects. The New York State Energy Research and Development Authority (NYSERDA) focuses more on industrial energy efficiency R&D. In general, the state programs are active in the areas of information dissemination, energy auditing, demonstration, and R&D of energy efficient industrial technologies, much like the DOE industrial information programs. Many of these state programs have partnerships with the DOE Office of Industrial Technologies to coordinate activities (Interlaboratory Working Group 2000).

Since there is such a broad range and large quantity of state programs, there is little in the literature on the cost-effectiveness and energy savings from these programs as a whole.

4.8 Product Labeling Requirement (EnergyGuide)

In response to a directive in the Energy Policy and Conservation Act of 1975, the Federal Trade Commission (FTC) issued the Appliance Labeling Rule, 44 FR 66466, in November 1979. This Appliance Labeling Rule created the well-known "EnergyGuide" label, providing information to consumers about the energy efficiency of major household appliances. The following categories of appliances are covered: refrigerators and refrigerator-freezers, freezers, dishwashers, clothes washers, water heaters, room air conditioners, furnaces, and central air conditioners (IEA 2000).

On the standardized EnergyGuide label for each appliance, manufacturers are required to include an energy consumption or energy efficiency figure and a "range of comparability." This range allows consumers to compare the efficiency of the particular model with other similar models by indicating the highest and lowest energy consumption for similar models in the market. The EnergyGuide label also contains an estimate of the yearly cost to operate the model, based on national averages.

To be in compliance with the Appliance Labeling Rule, manufacturers must annually report for each of their appliances the estimated energy consumption or energy efficiency rating calculated from DOE test procedures. Each year, FTC analyzes the range of comparability for each appliance and, if the upper or lower limit changes by more than 15%, a new range is devised (FTC 2003).

In contrast to the Energy Star voluntary labeling program, the EnergyGuide labeling program is mandatory, but both programs have a similar informational purpose. Put simply, both are intended to convince consumers to take energy efficiency into account in their appliance purchasing decisions. However, little analysis has been done in the literature to determine whether consumer behavior is significantly influenced by the EnergyGuide labeling program. Anecdotal evidence presented in Weil and McMahon (2003) suggests that labeling programs such as EnergyGuide can successfully induce energy savings. Newell, Jaffe, and Stavins (1999) find that with product-labeling requirements in effect, energy price increases are more effective at encouraging manufacturers to offer more energy efficient products.

However, some of the literature on utility DSM informational programs also mentions labeling programs in general as a fairly ineffective policy tool (e.g., Levine et al. (1994), and Thorne and Egan (2002)). This could be attributed in part to a lack of compliance at the retail level with the EnergyGuide labeling requirements. For instance, in 2001, the FTC inspected 144 showrooms in the United States and found that 70 of them were not in compliance with the mandated EnergyGuide labeling requirement (FTC 2001).

4.9 Federal Weatherization Assistance Programs

Federal weatherization assistance programs were some of the first federal energy conservation programs. These programs have the overarching purpose of assisting low-income households with their energy bills, primarily through the financing and implementing of residential energy conservation investments, resulting in corresponding energy savings. Low-income families typically spend larger fractions of their income on energy and, at the same time, low-income residences are often older and in greater disrepair than those of higher-income groups, presenting opportunities to assist low-income families while "picking the low-hanging fruit" in residential energy conservation.

The now-defunct Community Services Administration (CSA) oversaw the first federal weatherization program between 1974 and 1981, formed in response to high energy bills caused by the Arab oil embargo of 1973. It consisted of local grants to assist low-income households weatherize their homes, and also provided some subsidies to assist low-income households pay their energy bills (U.S. Congress Office of Technology Assessment 1992). Currently, two major federal residential weatherization programs exist, the DOE Weatherization Assistance Program

(WAP) and the Department of Health and Human Services Low-Income Home Energy Assistance Program (LIHEAP). These programs have been a major focus of past federal efforts to conserve energy in buildings, and the combined budgets of the two programs have consistently been higher than any other federal program funding aimed at energy conservation in buildings.

4.9.1 DOE Weatherization Assistance Program (WAP)

WAP was authorized under Title IV of the Energy Conservation and Production Act (Public Law 94-385) in 1976 to fund weatherization measures for low-income households to reduce their energy use. WAP prioritizes services to low-income families with children, the elderly, people with disabilities, and low-income households with a high energy burden. The program works through partnerships between DOE and state and local agencies in which DOE provides program grants. Currently, there are over 970 local agencies that receive grants for work in every state, the District of Columbia, and on Native American Reservations. Since 1976, around 5 million households have received weatherization services out of the nearly 27 million eligible households. Each state sets its own criteria for eligible households, with the minimum criterion being households with incomes below 125% of the poverty line.

The program is completely voluntary, and each local agency determines to whom they should be offering the program services. These services begin with an energy audit of the home, followed by implementation of the most cost-effective measures. These measures include: sealing ducts, tuning and repairing heating and cooling systems, mitigating air infiltration, and installing insulation. In addition, the weatherization crews perform a health and safety audit of the house to test for problems such as: gas leaks, electrical system safety, moisture damage, and unsafe heating and cooling systems. The crews will also implement solutions to any health and safety issues (Schweitzer and Eisenberg 2003).

WAP appropriations are set by Congress on a yearly basis and have varied throughout the program's lifetime (Table 8). In FY 2002, WAP weatherization funding represented 40% of the total federal investment in weatherization. To allocate the funds, DOE first sets aside no more than 10% of the total funding to states for training and technical assistance at the state and local levels. The remaining funds are distributed to states according to an allocation formula that was last revised in 1995 before a significant funding cut for the program in FY1996. The allocation formula first sets aside a fixed base allocation that differs by state, in order to prevent large swings in funding that could disrupt programs. The remaining funds are allocated to states based on the following three factors: low-income population, climatic conditions, and residential energy expenditures by low-income households (WAP 2003).

A few figures are provided in the literature that help gauge the cost-effectiveness of the program. Berry and Schweitzer (2003) perform a meta-evaluation of WAP, bringing together many smaller surveys to estimate that the average net savings of the roughly 100,000 homes weatherized annually is 29.1 million Btu per home per year, corresponding to a total fuel reduction of 21.9%. The promotional material for WAP expands this estimate further, claiming that WAP reduces national energy demand by the equivalent of 15 million barrels of oil per year on average. In addition, WAP estimates that it reduces annual carbon dioxide emissions on average by 0.85 metric tons of carbon for homes heated with natural gas and 0.475 metric tons of carbon for homes heated with electricity. The avoided energy costs to the 5 million households weatherized in the program since its inception totaled approximately $1 billion during the winter of 2000-01 (WAP 2003).

4.9.2 Low-Income Home Energy Assistance Program (LIHEAP)

LIHEAP is an outgrowth of the Community Services Administration Crisis Intervention program, part of CSA's low-income energy assistance program, which ended in 1981. The Department of Health and Human Services' LIHEAP was authorized by Title XXVI of the Low-Income Home Energy Assistance Act of 1981, with the primary aim of assisting with the heating and cooling bills of eligible low-income households. To achieve this goal, states are provided block grants to assist low-income households through direct home heating and cooling assistance, energy crisis assistance, and home weatherization. Home energy assistance consists of assistance in the form of cash, vouchers, coupons, or two-party checks to eligible households that can be paid to either landlords or home energy suppliers to defray the cost of energy bills. Energy crisis assistance provides cash, shelter, emergency supplies, or supplemental heating sources to households without heat or in imminent danger of having their fuel supplies terminated. The allocation to each state is a product of complex political compromise, but is vaguely based on the same principles as the WAP state allocations (Kaiser and Pulsipher 2002).

States can allocate up to 15% of their LIHEAP funds for home weatherization programs, and in most typical years, states spend on average around 10% of their LIHEAP funds on weatherization. Total LIHEAP funding has generally ranged over the years between $1 billion and $2 billion (2002 dollars) with a few years in the mid-1980s having higher levels. For example, in FY 2002, LIHEAP had a total allocation of approximately $1.7 billion and contributed $201 million (approximately 12%) toward weatherization activities (LIHEAP 2003). Note that the heating/cooling assistance and energy crisis assistance are effectively energy subsidies for low-income households and are more likely to *increase* energy consumption than to decrease it. Thus, the vast majority of the funding for LIHEAP serves to increase energy consumption and the program, in net, likely has a positive effect on energy consumption.

4.9.3 Other Funding for Weatherization

There is some other funding available for low-income household weatherization activities. Beginning in the 1980s, a Federal Petroleum Violation Escrow (PVE) Fund was established from legal penalties assessed against oil companies for violating price controls. By 2002, most states had exhausted their PVE funds, so that the total in FY 2002 amounted to only $6.9 million. However, even at their peak, PVE funds were never as large a funding source for weatherization as WAP or LIHEAP funds. Other funding for low-income housing weatherization activities comes from utility DSM programs, state general fund revenues, property owner contributions, and rehabilitation grants. This "other" funding category was estimated in FY 2002 to total $122 million (LIHEAP 2003).

Together, WAP, LIHEAP, and the other weatherization funding in FY 2002 is estimated to have allowed the weatherization of 186,779 homes, with past years tending to range around 200,000 to 250,000 homes (LIHEAP 2003). It is difficult to determine the cumulative energy savings and the cost-effectiveness from these weatherization activities, due to the variety of programs.

5. Management of Government Energy Use

The Federal government is the nation's largest energy consumer, and has considerable influence on markets for energy efficient products as a consumer that spends around $200 billion annually on products and services. Thus, several programs and regulations have been implemented to promote the conservation of energy by federal government agencies.

5.1 Federal Energy Management Programs (FEMP)

The Department of Energy's Federal Energy Management Program (FEMP) was established in 1973 with a mandate to encourage effective energy management in the federal government in order to save taxpayer dollars and reduce emissions. FEMP's services can be grouped into four main categories: financing, technical assistance, outreach, and policy.

FEMP assists government agencies with acquiring financing for energy efficient investments through methods such as: Utility Energy Service Contracts (UESCs), Energy Savings Performance Contracts (ESPCs), utility rebates, and public benefits funds. With UESCs, utilities typically finance the capital cost of an energy conservation project in return for a contract in which the utility is repaid for the costs of the project over the term of the contract from the cost savings generated by the project. ESPCs are similar in concept to UESCs, but a contractor pays the upfront capital cost of an energy conservation project in return for payments over the term of the contract from the project's subsequent cost savings. There is a streamlined version of ESPCs called Super ESPCs, which are umbrella contracts with energy service companies (ESCOs), allowing agencies to undertake multiple energy projects under a single contract. FEMP helps government agencies find financing through utility rebates and public benefits funds by explaining the procedure through which financing can be acquired via these methods.

FEMP also provides technical assistance directly to government agencies by helping federal energy managers identify, design, and implement new construction and facility improvement projects. To do so, FEMP offers services such as energy audits for government buildings and analytical software tools that help agencies choose the most effective energy and water project investments. The outreach services FEMP provides are mostly informational and recognition services, in which agencies are informed of the latest energy saving strategies and are rewarded for exemplary energy management leadership. The policy services of FEMP primarily consist of reporting on agencies' progress annually, managing interagency working groups, and otherwise coordinating across agencies to meet national goals. For instance, Executive Order 13123 requires all federal agencies to reduce energy use in federal buildings by 35% from 1985 levels by 2010 (FEMP 2003).

The FEMP budget for FY 2002 was $24.8 million. More than half of that funding was allocated toward project financing assistance ($8.7 million), and technical guidance and assistance ($7.9 million) (FEMP 2002). Little analysis has been done to determine the aggregate benefits and the cost-effectiveness of this funding. However, FEMP has published a few statistics. FEMP (2002) estimates that between FY 1985 and FY 2001, the government has reduced its buildings energy intensity by 23%, with six agencies achieving reductions of more than 20% in buildings energy use per gross square foot in that time. With total federal energy use in buildings of about 0.3 quads, this amounts to an annual savings of about 0.07 quads relative to a 1985 base. As there have been significant changes in government energy use (e.g., military base closings), it is unclear whether these intensity reductions are due to technological improvements or simply a change in the breakdown of federal energy use. Furthermore, it is unclear how much of this improvement would have happened in the absence of FEMP.

5.2 Federal Procurement

The federal government is one of the largest buyers in the world for many products, purchasing at least 10% of all energy using products in the United States. Executive Order 13123, signed by President Clinton in 1999, requires that federal agencies select "life-cycle cost-effective" Energy Star products over any other products {, 1999 #192}. For product categories that do not have Energy Star labels, agencies are required to select products in the upper 25% of energy efficiency, as designated by FEMP. FEMP also facilitates federal procurement of energy efficient products through interagency outreach and training, and the publication of "Energy Efficient Recommendations" for more than 30 product categories of energy using products often purchased by federal agencies. One of the many programs under the auspices of Energy Star, the Energy Star Purchasing Program, also encourages similar policies at the state and local government level.

Harris and Johnson (2000) estimate the potential energy, cost and CO_2 savings from the federal energy efficient procurement policies (i.e., Executive Order 13123). The estimates provided are ex ante, for the year 2010, but they are some of the only estimates provided in the literature. Harris and Johnson estimate that by 2010 the combined savings from federal energy efficient procurement policies will range from 11 to 42 trillion Btu/year, representing a reduced federal energy cost of $160 to $620 million per year, or approximately 3% to 12% of the 2000 energy use in federal buildings. Harris and Johnson also project the annual savings in 2010 from energy efficient purchasing by states, local governments, and schools as a result of the Energy Star Purchasing Program to range from 40 to 150 trillion Btu/year. Combined, these savings are estimated to translate into a reduction in annual CO_2 emissions of about 2.4 to 8.6 million metric tons of carbon in 2010 or about 0.1% to 0.5% of projected U.S. carbon emissions of approximately 1.8 billion metric tons of carbon equivalent (EIA 2003a).

5.3 Air Traffic Management

A joint program by EPA and the Federal Aviation Administration (FAA) is designed to reduce the demand for energy and the corresponding emissions by optimizing the traffic control system to reduce the time planes spend waiting "on line" on the ground and circling around airports while waiting for landing spots. The program, started in 1997, is known as CNS/ATM (Communications, Navigation, and Surveillance/Air Traffic Management) and involves changing flight procedures and installing a network of technologies to more precisely locate aircraft (Interlaboratory Working Group 2000). FAA estimated in an ex ante study that, by optimizing flight patterns, the program would reduce aircraft energy use by up to 6%, or 10 billion pounds of fuel by 2015 (Liang and Chin 1998).

6. Synthesis

Assessing the overall and comparative effectiveness and cost-effectiveness of the collection of energy conservation programs reviewed here is a nearly impossible task given the limitations of existing information and the incompatibility of data from different programs. We nonetheless attempt the impossible by combing the literature for estimates of annual energy savings and the annual costs of obtaining those savings for 2000 or a proximate year. Where possible, we report the cost-effectiveness of different conservation programs in dollars per quad of energy saved. In the case of utility DSM, where we have information from multiple sources, we report a range of cost-effectiveness estimates from the literature. The cost-effectiveness estimates can then be compared to the value of the energy saved, including any additional social value associated with reduced energy related environmental harm. In some cases we develop our own estimates of annual energy savings or costs based on related measures (multi-year program costs, for example) from the literature. We also report estimates of carbon emissions avoided due to the reported energy savings. These estimates are presented in Table 9; the underlying sources and assumptions, including critical assessment thereof, are the subject of this section. Table 10 summarizes the sources used to create Table 9.

6.1 Appliance Standards

Gellar et al. (2001) present a combined ex ante/ex post assessment of federal appliance standards and estimate that appliance standards saved a total of 1.2 quads of energy in 2000, approximately equal to the Gellar (1995) ex ante prediction for 2000. McMahon et al. (2000) provide annual estimates of energy savings from appliance standards between 1990 and 1997; 1997 energy savings are estimated to be 0.474 quads. McMahon (2004) estimates 2000 residential energy savings of 0.78 quads.

On the cost side, it is important to recognize that the equipment cost of energy efficiency investments in a particular year will yield energy savings several years into the future. In other words, energy savings in 2000 can be thought of as the result of a stream of past investments in equipment subject to the standards that were in effect when those investments were made. The annualized economic cost in 2000 of this stream of past investments includes the annual depreciation plus financing costs (assuming that someone borrowed money to make that initial investment and had to pay off the loan over time). Unfortunately, the published literature, which in some cases provides estimates of annual expenditures on energy efficient equipment, provides no estimates of the annual economic costs in 2000 as we have defined it.

In order to develop an estimate of annual economic costs in 2000, we rely on a more aggregate multi-year estimate of appliance standard costs and make certain assumptions to convert that estimate to an annualized cost. Levine et al. (1994) estimate the net present cost of appliance standards between 1990 and 2015 at $32 billion (1994 dollars), not including energy savings. The set of appliance standards being evaluated by Levine et al. is nearly the same as those in effect in 2000, and most of those that came into effect between 1994 and 2000 were anticipated at the time of the 1994 study. Thus, we use this prospective multi-year estimate to derive a very rough estimate of the annual cost of appliance standards that were in effect in 2000. We assume a 7% discount rate (as in the Levine et al. study) and a constant annual stream of costs to translate the $32 billion present value into an annual cost of just under $3.4 billion per year (in 2002 dollars) over the 25 years of the estimate.[11] This implies a cost-effectiveness of almost $2.8 billion per quad, using an estimate of 1.2 quads saved in 2000. This $2.8 billion per quad estimate for all appliance standards compares favorably with the $2.6 billion per quad cost-effectiveness for residential appliances standards implied by McMahon (2004). Note that the cost to the government of implementing the standards is estimated by Meyers et al. (2003) to be $200–250 million between 1987 and 2000, or about $15 million a year—orders of magnitude lower than the rough estimate of cost to consumers.

We calculate carbon emissions reductions associated with appliance standards by multiplying total energy savings times the average carbon emissions rate for nontransportation energy use in 2000 of 14.79 million metric tons per quad (EIA 2003b). The computed value is 17.75 million metric tons of carbon equivalent in 2000.

All of the estimates reported here are drawn from or based on the small, predominantly engineering-based, quantitative literature evaluating appliance standards. A major problem with these studies is that they typically ignore behavioral responses to the program and their effects on energy savings and costs. These behavioral responses could result in actual energy savings that are either higher or lower than estimated energy savings, but typically will result in higher costs due in part to the failure to account for the costs of limiting consumer choices. Another complicating factor is identifying the baseline level of energy consumption in the absence of the standards. In addition, the discount rate used for computing the present value of energy savings is typically assumed to be 7%, which is lower than the opportunity cost of funds for many consumers. Increasing the discount rate from 7% to 14%, for example, lowers the present value of a 15 year stream of constant benefits by about 50%. Several authors, including Hausman and

[11] In this exercise, we assume that annual investments in energy efficient appliances are identical over our 25year period (i.e., investment in 1995 was the same as in 1999). If the $32 billion present value cost number is actually the present discounted value of a growing stream of investments over time (particularly after 2000), then we have likely over-estimated the costs. On the other hand, we do not include the incremental costs of complying with appliance standards that occurred prior to 1990, potentially contributing to an underestimate of the annual economic costs.

Joskow (1982), criticize the engineering approach to evaluating appliance standards, suggesting that energy savings are often overestimated and costs underestimated, but none of these critical studies offers alternative estimates of their effectiveness or cost-effectiveness.

Appliance standards do appear to yield positive net benefits to consumers on average. The average price of energy for all nontransportation uses in 2000 was $6.08 billion (in 2002 dollars) per quad, while the cost of the appliance standards was just under $2.8 billion per quad. Even if unaccounted for costs of appliance standards are so large as to be equal to those included in the study, *or* if actual energy savings are half of what is estimated, the package of appliance standards would still yield positive net benefits on average. Adding in the positive environmental benefits of reduced electricity consumption would strengthen the argument that appliance standards can be worth the cost.

6.2 Financial Incentives: Utility DSM

The only financial incentive programs for which we were able to find estimates of energy savings were utility DSM programs.[12] EIA survey data indicate that the total annual energy savings from utility DSM programs in 2000 was 53,702 GWh. Based on an average delivered heat rate of 11,660 Btu per kWh, this estimate equates to 0.626 quads of energy saved. The annual cost associated with all the DSM programs contributing to these energy savings in 2000 is not reported by EIA. Instead, for each year of the survey, EIA reports the incremental costs to utilities of DSM programs in that year. These utility expenditures typically are expected to yield energy savings for many years into the future. To account for all the costs to utilities associated with energy savings obtained in 2000, we use data on past expenditures on DSM programs and assumptions about depreciation and average annual utility capital costs to estimate the levelized annual cost of DSM programs in 2000 at $3.487 billion (2002 dollars).[13] This yields a cost-

[12] EPA also reports energy savings associated with the Conservation and Renewable Energy Reserve (CRER) under Title IV of the Clean Air Act. However, the energy savings from these programs typically overlap to a large extent with existing utility DSM programs (as having an integrated resource planning program is a prerequisite for participating in the CRER) and thus we do not count these energy savings separately.

[13] To estimate this cost, we use the perpetual inventory method and EIA data on total and incremental energy savings from utility DSM nationwide to estimate an annual depreciation rate of DSM savings of 7.1%. We then use this depreciation rate combined with incremental real expenditures on DSM from 1989 through 2000 to build up a rough estimate of the real amount of aggregate DSM "capital stock" in 2000. The annual cost of using that capital is equal to the product of the utility's cost of capital, assumed to be 9.1% per year, plus the depreciation rate, again assumed to be 7.1%, times the total amount of DSM capital stock in 2000.

effectiveness estimate of $5.57 billion (2002 dollars) per quad saved.[14] This estimate includes only costs to utilities and does not include any out-of-pocket expenditures by consumers or other costs borne by consumers such as diminished service quality (e.g., less water in the shower due to low-flow shower heads) or transaction costs associated with participation in the DSM program. Our rough cost-effectiveness estimate for all utility DSM in 2000 falls in the high end of the range of estimates of negawatt costs reported in the literature in the mid 1990s. These estimates typically range from a low of $3 billion (2002 dollars) per quad for utility costs (from EIA, reported in Raynold and Cowart (2000)) to $6 billion per quad for total resource costs (Nadel and Geller 1996). The $6 billion dollar per quad number also happens to be the result of doubling the EIA estimate, an adjustment proposed by Joskow and Marron (1992) to deal with the understating of costs and overstating of energy savings that they believe plague most estimates of negawatt costs.[15]

The carbon emissions savings from utility DSM programs of just under 10.2 million metric tons of carbon equivalent, or approximately 0.6% of total U.S. emissions, follow directly from combining the estimates of energy savings with the average carbon emissions rate for the electricity sector in 2000 of 16.3 million metric tons of carbon per quad of primary energy (EIA 2003b).

As discussed in section 3.1.3, all of these estimates are subject to a substantial amount of error due to a host of issues ranging from inconsistencies across utilities in how to measure energy savings, adjustment of these estimates for free riders, and measurement of these savings at the generator rather than the consumer meter. As with appliance standards, estimates based on engineering models typically don't capture changes in consumer behavior, and, as a result,

[14] An alternative approach to looking at cost-effectiveness would be to look at DSM expenditures in a particular year and relate them to all future energy savings resulting from those expenditures. We use the EIA data on annual expenditures and incremental energy savings to forecast the stream of energy savings resulting from expenditures in each year from 1992 through 2001 (assuming that DSM program performance erodes at a depreciation rate of 7% per year and savings happen for 16 years into the future). We then find the present discounted value of all future energy savings associated with utility DSM expenditures in each year. We divide DSM expenditures in each year by this estimate of the PDV of energy savings to obtain a measure of the cost-effectiveness of DSM expenditures in each year for which we have data. The average cost-effectiveness estimate using this method is about $6 billion per quad over the last decade (and over the 2000-2001 time span), which is proximate to our estimate of the levelized cost of DSM energy savings achieved in 2000.

[15] $6 billion per quad would translate to 7.0 cents per kWh (using a conversion factor of 1.166 cents per kWh/billion dollars per quad) assuming all of the utility DSM energy savings came in the form of electricity (again, using a heat rate of 11,660 Btu per kWh).

tend to overstate energy savings. Free riding is also a problem as programs may claim benefits for investments that energy users would have made without the program.

Whether DSM programs, in the aggregate, provide positive net benefits or not is difficult to determine. The average price of electricity in 2002, a proxy for the average value of electricity saved due to DSM, was $6.33 billion per quad (in 2002 dollars).[16] This number is above the high end of the range of DSM cost-effectiveness estimates reported in Table 9. However, many of the estimates of costs included in that range are based on utility costs only, and accounting for costs to consumers would likely further extend the range upward. Similarly, a downward adjustment in energy savings to account for free-rider or take-back effects would also extend the cost-effectiveness range upward. On the other hand, pollution reductions are not accounted for, and these reductions should be part of the value of the social benefits of DSM.

Finally, there is considerable heterogeneity within the class of utility DSM programs. The costs reported here combine both high- and low-cost DSM programs and thus DSM programs with lower costs and larger positive net benefits than our average do exist. In practice, one would want to emphasize those specific DSM activities with the highest cost-effectiveness and eliminate those activities that are bringing down the average cost-effectiveness of DSM.

6.3 Information and Voluntary Programs

Obtaining reliable estimates of the energy savings from information and voluntary programs is even more challenging than for appliance standards or utility DSM. All of the available estimates come from the agencies that administer these programs, and information on the methods and assumptions used to generate most of these estimates is not available to us. In addition, some voluntary programs tend to overlap substantially with other programs such as utility DSM, which makes estimating the incremental savings for a particular program even more challenging.

Taking the numbers reported in the literature as given, we find that annual savings from those voluntary and informational programs for which we have estimates total as much as 2.27

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[16] Note that $6.33 billion per quad is the *average* price of electricity and if utility DSM programs disproportionately save the higher priced electricity during peak hours, then $6.33 billion per quad is an underestimate of the value of electricity saved due to DSM.

quads per year. The largest components of these savings are associated with EPA's Energy Star program, with associated activities saving an estimated 0.9 quads per year in 2001.[17] Annual costs to the federal government of this program are roughly $50 million per year and no estimates of costs to firms and consumers are available. We estimate the associated carbon emissions reductions to be about 13.8 million metric tons of carbon.[18]

Following Energy Star, the next largest components of these estimated savings are from the 1605b voluntary registration of emissions reductions and the DOE Climate Challenge programs. According to DOE estimates, energy efficiency nonutility DSM activities registered under these programs save as much as 0.411 and 0.814 quads per year, respectively (McArdle 2003). The1605b program does not make any attempt to distinguish those emissions reductions that would have occurred independently of the programs. Thus, the reductions actually induced by the program could range from zero (no induced reductions) to the upper bound (all induced reductions), with the true estimate not likely to be at either extreme.

The remaining savings estimates we have come from the Weatherization Assistance Program (WAP), the Industrial Assessment Centers (IAC) program, and DOE's Rebuild America program. Annual energy savings from the WAP program are estimated at 15 million barrels of oil equivalent per year, which translates to 0.087 quads saved and an associated reduction of roughly 1.3 million metric tons of carbon.[19] In 2000, administering WAP cost $141 million (2002 dollars), with similar figures for other recent years. The IAC program has yielded approximately 0.02 quads of energy savings per year over the last 25 years, with associated carbon emissions reductions based on 2000 emissions rates for industrial energy users of 268,000 metric tons (DOE 2003c). The administrative cost of the IAC program is currently approximately $7 million per year (2002 dollars) (Anderson and Newell 2002). DOE estimates that its Rebuild America program saved 0.009 quads of energy in 2002 and estimates associated carbon emissions reductions of 0.21 million metric tons of carbon. Cost estimates are not available for the Rebuild America program.

[17] This number comes from converting EPA's estimate of 80 billion kWh of energy saved in 2001 to quads, using an average annual heat rate of 11,660 Btu per kWh.

[18] This estimate comes from multiplying the energy saved estimate times the average carbon emissions rate for electricity of 16.3 million metric tons per quad of primary energy.

[19] Carbon emissions reductions are calculated using the average residential carbon emissions rate in 2000 from the Annual Energy Review (EIA 2003b).

6.4 Government Energy Use

Ex post estimates of reductions in government energy use are only available for the Federal Energy Management Program. Estimates suggest that government energy use has declined by roughly 0.067 quads per year, with associated emissions savings of just under 1 million metric tons of carbon. It is not clear to what extent these savings are the result of the program and would not have occurred otherwise.[20] It is unlikely that FEMP has saved no energy, but we have no further information on which to base a range.

6.5 The Big Picture

As Table 9 shows, the effectiveness and cost-effectiveness picture for energy conservation programs is like a puzzle with many missing pieces. Taking the estimates within this literature as given, these studies collectively suggest that programs for which ex post quantitative estimates of energy savings exist are likely to have collectively saved no more than 4.1 quads of electricity annually . These estimates typically reflect the *cumulative* effect of programs (e.g., *all* appliance efficiency standards, past and present) on annual energy consumption. This total energy savings represents about 6% of annual nontransportation energy consumption, which has hovered around 70 quads in recent years. Most of these energy savings come from reduced energy use associated with residential and commercial buildings (and not from more efficient industrial processes), so another relevant basis of comparison is total energy use in buildings, which accounts for approximately 37.1 quads (or 53%) of the 70 quads of nontransportation consumption. On this basis, the program saved no more than 12% of residential/commercial consumption.

Estimates suggest roughly 1.2 quads of this 4.1 quad maximum annual total energy savings, or roughly 30%, is attributable to federal appliance standards and 0.6 quads (or 15%) to DSM programs. Energy Star, Climate Challenge, and 1605b programs are likely to contribute no more than 0.9, 0.8, and 0.4 quads per year, respectively. Estimates of small amounts of energy savings from the Industrial Assessment Center program and the Federal Energy Management

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[20] The estimate is based on a reduction in government buildings energy use between 1985 and 2001, some of which may have occurred independent of the program, as there has been a significant change in government energy use over that time.

program (less than 0.1 quads each), and the DOE Rebuild America program and the Weatherization Assistance Program (0.009 and 0.003 quads, respectively), constitute the remainder of the roughly 4.1 quad maximum total.

Differing viewpoints in the literature suggest that this aggregate estimate could be either too low or too high. Our range does not fully account for many of these subtle factors, but the estimate is likely to be on the high side, as some of the included programs contain activities that would likely have occurred in the absence of the programs. On the one hand, the 4.1 quad maximum total excludes estimates of energy savings associated with a number of smaller-scale information programs and with past tax incentive programs, although the latter is likely to be small and no federal tax incentives for conservation have been in existence for over a decade. On the other hand, many of the estimates that make up this total are taken directly from studies that have been criticized for attributing too much energy savings to particular programs due to free-rider effects and the difficulty of accurately representing the no-policy baseline, among other factors.

The aggregate costs and cost-effectiveness of these programs are much more difficult to summarize than the energy savings due to incomplete information and inconsistencies in the way costs are measured across programs and studies. For example, studies of the costs of appliance standards include the costs to consumers of more expensive appliances as well as the costs to the government of administering the standards, while the aggregate data on DSM program costs collected by EIA includes only the costs to utilities of running the program. For most of the other programs, either no cost information is available or the available data are limited to the administrative costs born by the government. These discrepancies make it extremely difficult to calculate and compare cost-effectiveness across energy-efficiency programs. The rough estimates we derive for appliance standards and DSM programs suggest that appliance standards as a group likely provide positive net benefits, while the case is less convincing for the complete set of DSM programs.

The studies reviewed here suggest that aggregate carbon emissions reductions associated with this set of conservation programs are likely to be at most 3.5% of total annual U.S. carbon emissions. Again, these estimates are subject to potentially large errors for all of the same reasons listed above for the difficulties with measuring energy savings, but they suggest that the reductions are roughly equivalent to the percentage reductions that might arise with about a $35 (in 2002 dollars) per metric ton tax on carbon emissions (Weyant and Hill 1999).

6.6 Environmental Benefits

To quantify the ancillary environmental benefits associated with energy efficiency programs, we perform some simple calculations for each of the major pollutants that result from electricity production. Our goal is to roughly approximate the additional benefits per quad from reducing environmental externalities through reduced electricity use. There are likely to be savings in other forms of energy besides electricity—such as reduced home heating oil use—but to simplify this exercise, we assume that all savings are in the form of electricity. To be comparable with Table 9, we use estimates as proximate as possible to 2000 and assume recent policies are in place, providing a sense of what the environmental benefits would be for near-term energy efficiency policies.

We report environmental benefits in dollars per quad and as a percent of energy savings benefits per quad under the assumption that these energy savings benefits are equal to the 2000 national average price of electricity of $6.34 billion per quad (in 2002 dollars). The percentage measure can be thought of as the environmental "bonus" associated with a reduction in energy use. We address each of the pollutants: CO_2, NO_X, SO_2, PM-10, and mercury separately. No reliable environmental/health benefits in dollars per ton reduced (i.e., damages per ton) exist in the literature for mercury, so mercury is excluded from the final sum. This final sum amounts to an increase in benefits of roughly 10% due to reduced emissions of the other pollutants (Table 11). The sources of the data used to create Table 11 are summarized in Table 12.

To calculate the benefits due to reduced emissions of CO_2, we use an emissions factor of 14,368,862 metric tons of carbon per quad from the EPA E-grid database (EPA 2004a) and the mean value of environmental damages from CO_2 of $30 per metric ton of carbon based on studies surveyed by Working Group III of the Second Assessment Report (SAR) of the Intergovernmental Panel on Climate Change (IPCC) (Pearce et al. 1995). The results of this survey were reaffirmed in the Third Assessment Report of the IPCC (2001), and the two additional studies by Plambeck and Hope (1996), and Tol (1999) were added. The estimates of incremental damages of carbon dioxide emissions from each of these studies are compiled in Table 13. Multiplying the emissions factor by the averted damages in dollars per ton reduced yields \$0.431 billion per quad of energy reduced. This is 6.80% of the 2000 electricity price of \$6.34 billion per quad.

Calculating the benefits from reduced emissions of NO_X due to energy efficiency programs is less straightforward because of the caps on NO_X emissions in certain parts of the country. Specifically, there is a cap on NO_X emissions in approximately 20 eastern states subject to EPA's NO_X SIP Call and in Southern California under the Regional Clean Air Incentives Market (RECLAIM) program. Under these caps, the allowances freed up by reductions in emissions from energy efficiency policies would be sold on the allowance market, allowing another facility to emit more NO_X and resulting in no net reductions in NO_X emissions. Under a cap, reductions in pollution due to energy efficiency policies will nonetheless serve to reduce the costs of emissions control to attain that cap.

At present, the NO_X SIP Call grants approximately 544,000 allowances throughout the Northeast, each allowance representing one short ton of NO_X (EPA 1998). In 2000, the RECLAIM program granted 16,970 allowances, with each allowance again representing one short ton of NO_X (Coy et al. 2001). Thus, we compute the percentage of NO_X under a cap as the total capped metric tons of NO_X divided by the appropriate estimate of nationwide emissions of NO_X. Nationwide emissions of NO_X in 2000 were 5,117,967 metric tons (EPA 2004a). After the SIP Call NO_X cap comes into full effect, emissions will be reduced to about two-thirds of their previous levels (Burtraw et al. 2001), so, for an appropriate comparison, we assume nationwide NO_X emissions of 4,788,869 metric tons. We find that 10.63% of nationwide NO_X emissions will be subject to a cap and thus not affected by energy-efficiency programs.

When emissions caps are in place, energy conservation programs can help to reduce the cost to industry of complying with the aggregate emissions cap. For purposes of simplification, we assume that the reductions in NO_X emissions from energy efficiency policies will have a negligible effect on the price of allowances, and thus the emissions control cost savings per ton for the emissions covered by the cap will be roughly equal to the allowance price. Since 2000, the allowance price has hovered around \$700 (EPA 2004c), so we use \$700 per metric ton to approximately capture the cost savings from energy efficiency policy-induced NO_X emissions reductions.

The damages per ton of NO_X emissions are estimated at \$1,157 per metric ton (Banzhaf, Burtraw, and Palmer 2002), and this estimate is applied to the 89.3% of emissions that are not capped. The weighted average of control cost savings and emissions damages per metric ton of NO_X emissions is multiplied by the emissions factor of 115,150 metric tons of NO_X per quad from the EPA E-grid database to estimate the additional benefit from energy efficiency policies of $0.128 billion per quad. This translates to an environmental bonus associated with NO_X emissions reductions of 2.01% over the energy savings from energy efficiency policies.

SO_2 emissions from the electricity sector are under a nationwide cap, simplifying the calculations. The emissions factor for SO_2 is estimated to be 234,968 metric tons per quad (EPA 2004a). Just as in the case of NO_X, we use the SO_2 allowance price to roughly estimate the cost savings per ton for SO_2 emissions covered under the cap (i.e., all of them). The mean allowance price in 2000, averaged over the different brokerages, equates to $163.4 per metric ton (in 2002 dollars) (EPA 2004b). The damages from emissions of SO_2 are estimated to be $3,857 per metric ton (Banzhaf, Burtraw, and Palmer 2002), but under the cap, no net nationwide emissions reductions would occur from energy efficiency policies.

The SO_2 cost savings estimate is multiplied by the emissions factor, with the resulting $0.038 billion per quad in additional benefits from SO_2. Thus, there is a 0.61% additional bonus from SO_2 that is not captured by the energy savings alone, again based on the 2000 electricity price of $6.34 billion per quad.

For PM-10, the emissions factor is based on the estimate of 762,584 metric tons of PM-10 in 2000 (EPA 2004a), and the 38,181 quads of electricity produced in 2000 (EIA 2003b). The resulting emissions factor for PM-10 is 19,973 tons per quad. There is no cap on PM-10 emissions and current regulations on PM-10 would not change the emissions reductions from energy efficiency policies. Banzhaf et al. (1996) estimate damages from PM-10 in Minnesota under a variety of conditions ranging from $530 to $6,054 per short ton emitted, with a likely estimate that can be applied nationwide of $1,873 per short ton ($2,064 per metric ton). The benefits from reductions in PM-10 equal $0.041 billion per quad. Again, using the 2000 electricity price of $6.34 billion per quad, there is a 0.65% additional benefit from reducing PM-10 emissions. Note that PM-2.5 is included in the estimates we use for PM-10, consistent with the literature. We were also careful to use estimates that differentiate PM-10 from the primary particulates that form NO_X and SO_2 to avoid double counting. This results in a more accurate, but lower estimate of PM-10 damages than studies including primary particulates that form NO_X and SO_2.

The benefits from the reduction in mercury emissions cannot be as easily estimated, given the lack of available estimates of the damages from mercury emissions. Instead, we solve for what the damages from mercury emissions would have to be for mercury benefits to equal one percent of the energy savings benefit. The emissions factor for mercury is estimated to be 13.6 metric tons per quad (EPA 2004a). For a one percent additional benefit, there must be an additional benefit of $0.061 billion per quad, or damages from mercury amounting to $4,450,000 per metric ton. One of the few studies that ventured to estimate the health effects of mercury emissions, Rowe et al. (1995) obtained a high estimate of $35,000 (1995 dollars) per quad ($41,348 per quad in 2002 dollars). This approximate estimate, while far from definitive, suggests that the benefits from reduced mercury emissions are likely to be much less than one percent of energy savings benefits.

Although more uncertain than the energy reductions from which they result, the four pollutants for which we have estimates may provide a total additional benefit of just over 10% to the value of energy savings from energy efficiency policies. A cursory sensitivity analysis with higher values of $/ton environmental benefits indicates that even environmental benefits values that are double our estimates for NO_X, SO_2, and PM-10 would not change the overall result of 10% by more than a few percentage points.

7. Conclusions and Implications for Future Research

Greater energy efficiency of the economy is one of the primary avenues for reducing carbon emissions associated with the combustion of fossil fuels, along with switching to low- and no-carbon fuels and carbon sequestration. Improved energy efficiency may also serve "energy security" goals by lessening the effect of fuel supply disruptions and/or helping to re-shape electricity load profiles to avoid peak-use problems. Several key questions therefore immediately arise regarding the role of policies supporting energy efficiency within a portfolio of prospective energy and climate policies. First, what types of energy efficiency policies have been employed in the United States and how well has each of these policies worked in terms of saving energy? Second, how much have these programs cost the public and private sector and what has been their cost-effectiveness? Finally, what are the prospects for future energy savings and carbon reductions from policies directly promoting energy efficiency? In other words, how large a role might we expect energy efficiency improvements to play in meeting carbon mitigation goals?

Providing answers to these seemingly straightforward questions quickly runs up against data problems, limits to information, and deep-seated methodological challenges and debates about how to properly measure and predict the costs and effectiveness of past and prospective policy. Some analysts maintain, for example, that a substantial amount of carbon emissions reductions could come from greater energy efficiency at very low, zero, or even negative cost to the U.S. economy (Brown et al. 2001, Interlaboratory Working Group 2000). Many economists are much more skeptical. One can get some perspective on this debate by analyzing the effectiveness and cost-effectiveness of current and past government programs to bring about greater energy conservation.

Our review of existing estimates of the effects of energy conservation programs suggests that, taken together, the conservation programs we reviewed are likely to have saved no more than 4.1 quads of energy per year and reduce annual carbon emissions by no more than 63 million metric tons, or about 4%, of 2000 emissions. According to the estimates in the literature, the lion's share of these energy savings and associated emissions reductions come from appliance standards and utility DSM programs; EPA's Energy Star Program, 1605b, and Climate Challenge also may provide large benefits. Even rough measures of cost-effectiveness are only available for appliance standards and utility DSM, and these paint a mixed picture about how the average costs of achieving energy savings compare to the average value of the energy cost savings they produce. Appliance standards as a group appear to be cost-effective and typically yield positive net benefits from energy savings alone and additional benefits from ancillary carbon emissions reductions. DSM programs are more borderline in their cost-effectiveness and, if unaccounted costs to consumers are high, these programs would, on average, not be yielding energy savings in excess of costs. However, the programs do produce ancillary reductions in air pollution that would augment reported benefits. In addition, the costs reported here combine both high- and low-cost DSM programs and thus there are lower-cost DSM programs with larger positive net benefits. These results suggest there may be benefits to emphasizing DSM activities with the highest cost-effectiveness and eliminating those activities that are bringing down the average cost-effectiveness of DSM.

Including the additional environmental benefits from reducing emissions of CO_2, NO_X, SO_2, and PM-10 could add a bonus of approximately 10% to the value of energy savings from energy efficiency programs. The majority (7%) of these benefits are derived from CO_2, with fewer benefits from NO_X (2%), and even fewer from SO_2 and PM-10 (0.5% each). Cost-effectiveness estimates of appliance standards and utility DSM with the above environmental externalities included would amount to $2.5 billion/quad and $5.1 billion/quad (including only utility costs), respectively. The inclusion of environmental benefits strengthens the case for both appliance standards and utility DSM, although not by a large percentage.

The studies reviewed here raise several issues concerning past efforts to measure both the effectiveness and cost-effectiveness of conservation programs. For almost all of the energy efficiency programs reviewed, estimates of effectiveness and cost-effectiveness are controversial. Measuring the effectiveness or total energy savings from a conservation initiative or program can be problematic.

Questions arise about what energy consumption would have been in the absence of the program (the baseline definition issue) and whether or not some of the energy savings attributed to the program would have happened anyway (the free-riding issue). Estimates of energy savings from particular efficiency enhancing investments also often fail to account for the fact that energy demand may rise with the investment (i.e., the “rebound” effect), particularly if it lowers the marginal cost to consumers of energy services such as heating, lighting, or hot water. The discount rate assumed for computing the present value of energy savings also can have a large effect on the estimated benefits of these programs. Effectiveness could also be mismeasured and double-counted when the same energy savings are attributed to multiple government programs.

The main question that arises when measuring program costs or cost-effectiveness is whether or not all of the salient costs (costs to business, costs to consumers, including consumer surplus losses due to quality changes, and costs to the government) are being accounted for. Estimates of costs are also plagued by many of the same sources of error that affect estimates of energy savings, including potential misspecification of baselines, free-rider effects, omission of relevant costs, double-counting across programs, and the use of inappropriate discount rates. All of these potential sources of error suggest that considerable care must be taken in interpreting existing estimates of the costs and energy savings from energy efficiency programs.

Our survey of the literature reveals a striking lack of independent and detailed academic ex post analyses of conservation programs. Several studies have presented general critiques of methods used to estimate energy savings and costs of appliance standards and of DSM programs, but there are no independent academic studies that take a detailed look at the effectiveness and the costs of specific programs after they have been implemented. Such an analysis is key to understanding the robustness of the effectiveness and cost-effectiveness estimates reported here to changes in assumptions about discount rates and other assumptions regarding the growth in future energy demand. Detailed analysis would be particularly important for classes of programs, such as appliance standards, that policymakers may plan to use more widely in the future.

Several recent policy initiatives and proposals suggest that efforts to promote energy conservation will continue in the future. The conference draft of the energy efficiency part of the 2003 Energy Bill calls for further reductions in energy intensity at federal buildings, cumulating to 20% below 2001 levels by 2020. The bill also provides tax credits for efficiency investments, expands energy efficiency standards to new products, and provides federal funding for state-run rebate programs to encourage the replacement of existing inefficient appliances with Energy Star appliances and for energy efficiency enhancements in public housing, among other proposals.

Recent legislation (S. 366) sponsored by Senator Jeffords (I-VT)[21] to cap emissions of multiple pollutants from electricity generators uses a cap and trade approach and calls for allocating 20% of the emissions allowances to new renewable generation, new combined heat and power capacity, and energy conservation initiatives. This approach is analogous in some ways to the Conservation and Renewable Energy Reserve (CRER) feature of Title IV, although the incentives created by set-aside allowances in S. 366 would be much stronger than the CRER set-asides, due to both a greater number and value of the allowances.

The continued use of energy efficiency policies over more than two decades, and the prospect of expanded and new policies on the horizon suggest that this approach to achieving energy and carbon reductions will have a lasting presence. While existing estimates indicate that the current impact of these policies is modest, it does appear that well-designed future programs

[21] For more information, see www.rff.org/multipollutant (accessed 11/3/03).

have the potential to reduce energy and emissions, although the magnitude of potential reductions and the cost of achieving those reductions are open questions.

Tables

Table 1. Overview of Demand-Side Energy Efficiency Policies/Programs

Program	Brief Description
Energy Efficiency Standards	
Federal Appliance/Equipment Standards	First promulgated by the 1987 National Appliance Energy Conservation Act. Updated several times, most notably by the 1992 Energy Policy Act. Currently covers: refrigerators, freezers, air conditioners, furnaces, water heaters, space heaters, clothes washers/dryers, dishwashers, ranges/ovens, pool heaters, certain lamps, ballasts, electric motors, and commercial heating/cooling equipment.
State Appliance/Equipment Standards	Provided the impetus for federal standards, but today largely usurped by federal standards. Several state appliance standards do exist in the following markets: distribution transformers, traffic lights, commercial refrigerators/freezers, exit signs, plumbing fittings/fixtures, space heaters, and demand control ventilation devices.
Building Codes	Many state and local building codes have energy efficiency clauses mandating construction techniques or energy efficient materials.
Professional Codes	Primarily the ISO 14001, which is a series of international standards that have been developed for incorporating environmental concerns into corporate operations and product standards. Companies can be registered to ISO 14001 through the implementation of a company-wide environmental management system in accordance with the specified standards, which include energy efficiency concerns in product life-cycle assessment, environmental performance evaluation, and environmental labeling.
Corporate Average Fuel Economy (CAFE) Standards	The 1975 Energy Policy and Conservation Act required all passenger car and light truck manufacturers to meet the fleet-wide CAFE standards. These standards have since been updated several times, most recently in 1995 to 27.5 miles per gallon for cars and 20.7 miles per gallon for light trucks.
Financial Incentives for Energy Efficient Investment	
Financial Incentives for Consumer Purchases	Rebates and low-interest loans provided by utilities to consumers who purchase energy efficient appliances or equipment, as part of utility DSM programs. Golden Carrot programs are designed to transform the market for a particular good, generally through utility-provided financial incentives to manufacturers.
Electricity Load Management	Provides a financial incentive to electricity consumers in exchange for a reduction in electricity demand. This can be done through contracts between the utility and the consumer as in direct load control, interruptible load programs, voluntary demand response programs, and demand-side bidding programs.
Income Tax Deductions	Federal tax deductions for individuals who purchase clean fuel or electric vehicles starting in 2002 at $2,000 and phased out by 2006. From 1978 to 1986, a $2,000 residential energy conservation credit also existed.
Emissions Allowances Allocated to Demand-Side Investments	Under Title IV of the 1990 Clean Air Act, 300,000 SO_2 allowances were set aside into a reserve fund to be awarded to utilities that employed renewable or energy efficiency measures. Only 47,493 were actually awarded. Pending legislation proposes to include a similar reserve.

Table 1. Overview of Demand-Side Energy Efficiency Policies/Programs

Program	Brief Description
Information and Voluntary Programs	
Voluntary CO_2 Reductions	Voluntarily reported and registered under Section 1605b of the 1992 Energy Policy Act.
DOE Climate Challenge	A voluntary public-private partnership between electric utilities and DOE, designed for utilities to set goals for emissions reductions and report periodically to DOE on their progress.
Energy Star Programs	Provides Energy Star labels to energy efficient products, equipment and buildings. The program also has partnerships with public and private organizations to provide technical information and advice on choosing the most energy efficient practices. The EPA Climate Wise program is an example of a partnership program under the auspices of Energy Star.
DOE Energy Efficient Buildings Programs	Homebuilders are provided with technical assistance to help them build more energy efficient homes in the DOE Building America program. DOE Rebuild America creates public-private partnerships at the community level to find and implement opportunities for energy savings improvements.
Partnership for Advanced Technology in Housing (PATH)	PATH is a Department of Housing and Urban Development coordinated public-private initiative dedicated to accelerating the development and use of new technologies in the housing sector, including more energy efficient technologies.
Industrial Energy Audits	Provides free comprehensive industrial assessments, including energy audits, to small and medium-sized manufacturers through the Industrial Assessment Center (IAC) program and for large manufacturers through the Plant-wide Assessment (PWA) program.
State Industrial Energy Efficiency Programs	These programs vary, but are typically energy audit and informational programs. There are approximately 300 programs.
Product Labeling Requirement (EnergyGuide)	In 1980 the FTC's Appliance Labeling Rule became effective, requiring "EnergyGuide" labels on most new energy intensive consumer appliances to show the relative energy use compared to other models of the same type of appliance.
Weatherization Assistance Programs	DOE Weatherization Assistance program and Low-Income Home Energy Assistance Program (LIHEAP) both provide technical assistance and some financial assistance to end-users, particularly low-income end-users, to improve home energy efficiency.
Management of Government Energy Use	
Federal Energy Management Program (FEMP)	Provides technical assistance to government facilities to promote the use of energy efficient equipment and to better manage government energy use.
Federal Procurement	Among other regulations, the Federal Acquisition Regulations 1997 requires the federal government to purchase Energy Star equipment and build Energy Star certified homes. The 1992 Energy Policy Act also gave DOE the authority to develop a government fleet acquisition program to encourage clean fuel and energy efficient vehicles.
Air Traffic Management	EPA and FAA are working together on the Communication, Navigation, Surveillance/Air Traffic Management (CNS/ATM) system to better manage flight patterns so as to reduce aviation energy use and emissions. Other improved operating practices are also being examined.

[take a look at this changed table (to include ’05 and ’10) and see what you think

Table 2. Effective Dates of Appliance Efficiency Standards, 1988–2007

Equipment type	88	90	92	93	94	95	00	01	04	05	06	07	10
Clothes dryers	X				X								
Clothes washers	X				X				X			X	
Dishwashers	X				X								
Refrigerators and freezers		X		X				X					
Kitchen ranges and ovens		X											
Room air conditioners		X					X						
Direct heating equipment		X											
Fluorescent lamp ballasts		X											
Water heaters		X							X				
Pool heaters		X											
Central a.c. and heat pumps			X								X		
Furnaces—central and small			X										
Furnaces—mobile home		X											
Boilers			X										
Fluorescent lamps—8 ft					X					X			X
Fluorescent lamps—2, 4 ft						X				X			X

Source: EIA (1999) and Meyers (2003)

Table 3. Comparison Between California and the Federal Government for the Setting of Appliance Standards.

Year	California	Federal Government
1976	Adopted standards for refrigerators and A/Cs	
1977	Adopted standards for heating, water heating, and water use	
1978/79		Published test methods for consumer appliances
1980		Proposed standards for consumer appliances
1982		"No-standard" policy of Reagan administration
1983	Adopted standards for fluorescent lamp ballasts	
1984	Adopted tougher refrigerator and A/C standards	
1985	Adopted tougher heat pump standards	
1987		National Appliance Energy Conservation Act (NAECA)
1988		Amendments to NAECA for ballasts
1992		Energy Policy Act (EPAct)
1994	Received petition for more stringent ballast, water heater, and clothes washer standards	
1996		Temporary Congressional moratorium on standard development
1997		Adopted tougher refrigerator standards
2001		Tougher refrigerator standards take effect

Source: Martin (1997)

Table 4. EIA Estimates of Utility Demand-Side Management Spending, 1992–2001.

Year	DSM Spending (millions 2002 dollars)	Incremental Energy Savings (GWh)	Annual Energy Savings (GWh)
1989	$1,276	N/A	14,672
1990	$1,633	N/A	20,458
1991	$2,401	N/A	24,848
1992	$3,034	6,712	35,893
1993	$3,442	9,002	45,294
1994	$3,322	8,248	52,483
1995	$2,880	8,243	57,421
1996	$2,198	6,857	61,842
1997	$1,848	4,860	56,406
1998	$1,580	3,379	49,167
1999	$1,549	3,103	50,563
2000	$1,648	3,364	53,702
2001	$1,678	5,318	54,762

Source: EIA (2003c) and EIA (2003b)

Table 5. Nadel and Kushler Estimates of Utility Demand-Side Management Spending, 1989–1998.

Year	DSM Spending (millions 2002 dollars)	Annual Energy Savings (GWh)
1989	$1,220	14,672
1990	$1,576	20,458
1991	$2,324	24,848
1992	$2,943	35,563
1993	$3,351	45,294
1994	$3,240	52,483
1995	$2,823	57,421
1996	$2,177	61,842
1997	$1,839	57,193
1998	$1,744	56,866

Source: Nadel and Kushler (2000)

Table 6. Selected Products in the Energy Star Labeling Program, 2003.

Product	Agency	Energy Savings Above 'Standard' New Products	Market Share of Qualifying Products in 2000
Computer (Home)	EPA	27%	95%
Computer (Work)	EPA	52%	95%
Monitor (Home)	EPA	27%	97%
Monitor (Work)	EPA	52%	99%
Copiers	EPA	42%	90%
Faxes	EPA	40%	99%
Televisions	EPA	24%	46%
VCRs	EPA	29%	94%
TV/VCRs	EPA	30%	76%
Audio	EPA	69%	31%
Central Air Conditioners	EPA	24%	20%
Furnaces (Gas)	EPA	15%	27%
Programmable Thermostats	EPA	20%	36%
Clothes Washers	DOE	38%	10%
Dishwashers	DOE	25%	20%
Refrigerators	DOE	10%	17%
Room Air Conditioners	DOE	10%	13%
Lighting Fixtures	EPA	66%	3-5%
Lighting Bulbs	DOE	66%	3%
Exit Signs	EPA	75%	75%
Windows	DOE	range	range

Source: EPA (2003a)

Table 7. Cumulative Savings Through 1999 from Energy Star Labeling Program.

Product	Start Year	Energy Savings (petajoules or millions GJ)	Energy Bill Savings, Undiscounted (millions 2002 dollars)	Carbon Emissions Avoided (MtC)
Computers/Monitors	1993	360	$2,757.7	6.6
Copiers	1995	26	$198.6	0.48
Faxes	1995	21	$165.5	0.39
Multifunction devices	1997	0.41	$3.0	0.0075
Scanners	1997	27	$198.6	0.50
Printers	1993	150	$1,103.0	2.8
Televisions	1998	6.3	$49.6	0.12
VCRs	1998	3.0	$24.3	0.055
TV/VCRs	1998	0.50	$4.0	0.0092
Audio	1999	1.9	$15.4	0.035
Central Air Conditioners	1995	0.83	$6.6	0.020
Furnaces (Gas or Oil)	1995	1.4	$9.7	0.015
Air-source heat pumps	1995	0.54	$4.3	0.010
Geothermal heat pumps	1995	0.14	$1.1	0.0026
Gas-fired heat pumps	1995	0.00036	$0.002	0.0000064
Boilers (gas or oil)	1995	0.069	$0.5	0.011
Programmable Thermostats	1995	39	$287	0.62
Clothes Washers	1996	31	$242.7	0.55
Dishwashers	1996	5.3	$42.0	0.091
Refrigerators	1996	21	$165.5	0.38
Room Air Conditioners	1996	7.3	$59.6	0.13
Lighting Fixtures	1997	14	$109.2	0.250
Exit Signs	1995	41	$297.8	0.75
New Homes	1995	0.8	$6.0	0.013

Source: Webber et al. (2000)

Table 8. DOE Weatherization Assistance Program Appropriations, 1977-2003.

Year	DOE Appropriations to WAP (millions 2002 dollars)
1977	$81.6
1978	$179.2
1979	$492.8
1980	$434.2
1981	$346.1
1982	$268.3
1983	$442.3
1984	$328.8
1985	$319.3
1986	$298.7
1987	$255.3
1988	$245.2
1989	$233.9
1990	$222.9
1991	$262.6
1992	$248.6
1993	$230.7
1994	$250.9
1995	$253.4
1996	$128.0
1997	$135.3
1998	$137.7
1999	$143.5
2000	$141.0
2001	$155.3
2002	$230.0
2003	$219.9

Source: WAP (2003)

Table 9. Summary of Estimates from Existing Studies of the Effects of Energy Efficiency Programs in 2000.

Program	Date	Energy Savings (quads)	Costs (billion $2002)	Cost-Effectiveness (billion $2002 per quad)	Carbon Emissions Savings (MMtCE)
Appliance Standards	2000	1.200	$3.359	$2.799	17.753
Financial Incentives					
Utility DSM	2000	0.626	$3.487	$5.570 (high $6.089) (low $3.001)	10.188
Tax Incentives	-	-	-	-	-
Emissions Allowances	-	-	-	-	-
Information and Voluntary Programs					
1605b registry	2000	<0.411	$0.0004	-	<6.083
DOE Climate Challenge	2000	<0.814	-	-	<12.038
Energy Star	2001	<0.933	$0.050*	-	<13.800
DOE Rebuild America	2002	0.009	-	-	0.210
PATH	2000	-	$0.002*	-	-
Industrial Assess. Centers (IAC)	~2000	0.019	$0.007*	-	0.268
Energy Guide		-	-	-	-
Weatherization Assistance Program	2003	0.087	$0.141*	-	1.349
LIHEAP	2002	-	$0.201*	-	-
Government Energy Use					
Federal Energy Management Program	2002	<0.067	$0.025*	-	<0.991
Federal Procurement	-	-	-	-	-
Air Traffic Management	-	-	-	-	-
Total		**<4.1**			**<62.7**

Note: * indicates that only direct government administrative costs are included. < indicates a likely upper bound of energy savings or emissions reductions. Billion dollars per quad can be roughly converted to cents/kWh by multiplying by 1.166, which assumes all of the savings come from electricity, using the average mix of generating facilities. We emphasize the use of quads because many of the programs cover nonelectricity reductions, which have a different heat rate than electricity.

Table 10. Sources of Estimates in Table 9

Program	Energy Savings	Costs	Carbon Emissions Savings
Appliance Standards	Geller et al. (2001)	authors' calculations based on Levine et al. (1994)	authors' calculations based on EIA (2003b) and Geller et al. (2001)
Financial Incentives			
Utility DSM	authors' calculations based on EIA (2003a)	authors' calculations based on EIA (2003a)	authors' calculations based on EIA (2003b) and EIA (2003a)
Tax Incentives	-	-	-
Emissions Allowances	-	-	-
Information and Voluntary Programs			
1605b registry	McArdle (2003)	GAO (1998)	McArdle (2003)
DOE Climate Challenge	McArdle (2003)	-	McArdle (2003)
Energy Star	EPA (2002a)	Malloy (2003)	authors' calculations based on EIA (2003b) and EPA (2002a)
DOE Rebuild America	DOE (2002)	-	DOE (2002)
PATH	-	NAS (2003)	-
Industrial Assess. Centers (IAC)	DOE (2003c)	Anderson and Newell (2002)	DOE (2003c)
Energy Guide	-	-	-
Weatherization Assistance Program	WAP (2003)	WAP (2003)	WAP (2003)
LIHEAP	-	LIHEAP (2003)	-
Government Energy Use			
Federal Energy Management Program	FEMP (2002)	FEMP (2002)	FEMP (2002)
Federal Procurement	-	-	-
Air Traffic Management	-	-	-

Table 11. Annual Environmental Benefits of Emissions Reduction (circa 2000).

Pollutant	Emission factor (ton/quad)	Cost savings under cap ($/ton)	% under cap	Environmental Benefits ($/ton)	% not capped	Additional benefit from reduction (billion $/quad)	% increased benefit or "bonus"
Carbon	14,368,862		0%	30	100%	0.431	6.80%
NO_X	115,150	700	10.6%	1,157	89.3%	0.128	2.01%
SO_2	234,968	163.4	100%	3,857	0%	0.038	0.61%
PM-10	19,973		0%	2,064	100%	0.041	0.65%
Total							10.08%
Mercury	13.6		0%	4,650,000*	100%	0.061	1.00%

* indicates what the environmental benefits would have to be to result in a 1% increase in the energy savings benefits.
Note: all metric tons; all 2002 dollars

Table 12. Sources of Estimates in Table 11

Pollutant	Emission factor (ton/quad)	Cost savings under cap ($/ton)	Environmental Benefits ($/ton)	% capped
Carbon	EPA (2004a)		See Table 13	
NO_X	EPA (2004a)	EPA (2004c)	Banzhaf et al. (2002)	authors' calculations
SO_2	EPA (2004a)	EPA (2004b)	Banzhaf et al. (2002)	
PM-10	EPA (2004a)		Banzhaf et al. (1996)	
Mercury	EPA (2004a)			

Table 13. Incremental Damages of Carbon Dioxide Emissions for 2001–2010.

Study	**Damages** (US$2003 per ton of carbon)
Nordhaus (1994b) (expected value from SAR Table 6.11)	24
Ayres and Walter (1991) (from SAR Table 6.11)	43
Cline (1993d) (Cline's preferred scenario)	72
Peck and Teisberg (1992) (from SAR Table 6.11)	17
Fankhuser (1994b) (from SAR Table 6.11)	30
Maddison (1994) (from SAR Table 6.11)	11
Plambeck and Hope (1996) (their preferred scenario)	28
Tol (1999) (see Table 4 of paper)	17
Median	**26**
Mean	**30**

Note: See IPCC Second Assessment Report (SAR), Working Group III, Chapter 6 (1995) and the IPCC Third Assessment Report, Working Group II, Chapter 19 (2001) for detailed references. Figures inflated to 2003 dollars using the GDP price index.

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Energy Efficiency Standards and Codes for Residential/Commercial Equipment and Buildings: Additional Opportunities

Prepared for National Commission on Energy Policy *

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Introduction

Energy efficiency standards and codes set minimum levels of energy efficiency that must be met by new products or buildings. Depending on the dynamics of the market and the level of the standard or code, the effect on the market for a given product or type of building may be small, moderate, or large.

Energy efficiency standards and codes address a number of market failures that exist in the buildings sector. Decisions about efficiency levels often are made by people who will not be responsible for the energy bill, such as landlords or developers of commercial buildings. Many buildings are occupied for their entire lives by very temporary owners or renters, each unwilling to make long-term improvements that would mostly reward subsequent users. And sometimes what looks like apathy about efficiency merely reflects inadequate information or time invested to evaluate it. In the case of commercial building design, the architects and consulting engineers who design commercial buildings are generally paid as a percentage of the job cost and have little incentive to take extra time to design more energy-efficient buildings given the constraints of minimizing first costs. In addition to these sector-specific market failures, energy efficiency standards and codes address the endemic failure of energy prices to incorporate externalities.

Energy efficiency standards and codes have a long history in the U.S. Energy efficiency standards for consumer products were first implemented in California in 1977. They were followed by national standards that became effective starting in 1988. By the end of 2001, national standards were in effect for over a dozen residential appliances, as well as for a number of commercial sector products. Updated standards will take effect in the next few years for several products. Outside the U.S., over 30 countries have adopted minimum energy performance standards.

The inclusion of energy efficiency considerations in building codes also began in the 1970s and has become widespread since then. Since building codes are implemented at the State level, their nature varies somewhat across the country.

Technologies and markets are dynamic, and additional opportunities to improve energy efficiency exist. There are two main avenues for extending the benefits of energy efficiency standards and codes in the U.S. One is upgrading standards and codes that already exist for specific products and building end uses. The other is adopting standards for products that are not covered by existing standards.

In the absence of new and upgraded energy efficiency standards and codes, it is likely that many new products and buildings will enter the stock with lower levels of energy efficiency than would otherwise be the case. Once in the stock, it is either impossible (for most products) or more costly (for buildings) to improve the energy efficiency. Therefore, by not expanding or upgrading energy efficiency standards and codes, opportunities for saving energy would be lost.

In the past two decades, standards and codes have significantly raised the minimum level of energy efficiency for new products and buildings. How much more might be gained by making standards and codes more stringent on products and buildings already subject to them, or by extending standards to products not yet covered? This report addresses that question.

The main goal of this study is to estimate key national impacts of potential upgrades in energy efficiency standards and building codes for residential and commercial buildings and equipment. These impacts approximate the opportunity for national benefits that may be lost if energy efficiency standards and building codes for residential and commercial buildings and equipment are not upgraded and expanded from current levels. This study also identifies the end uses where the largest opportunities exist.

This analysis was prepared for the National Commission on Energy Policy (NCEP). It employs a similar analytical approach as the U.S. Department of Energy (DOE) uses to set standard levels. It relies on much less data and uses greatly simplified assumptions in most instances, rather than the detailed and complex formulations used in DOE's standard-setting process. The results of this analysis should thus be viewed by the reader as first approximations of the impacts that would actually be achieved by new standards.

End Uses Considered

Residential sector: space heating, air conditioning, refrigeration, water heating, dishwashing, lighting, motors, and miscellaneous electronics.

Commercial sector: space heating, air conditioning, ventilation, lighting, water heating, refrigeration, and office products.

Within each of the above end uses, we considered equipment standards for specific products, as shown in Table 1. For some of the products listed, we determined that additional standards would not be cost-effective on a national-average basis. These products are listed later. We considered building codes that affect residential space heating and air conditioning, and commercial space heating, air conditioning, and lighting.

Products that we did not consider include those listed below. The reasons for not considering them were one or more of the following: (1) a more stringent standard is probably not cost-effective (e.g., clothes dryers); (2) the impact of a new standard would probably be low because the market for the product is small and shrinking (e.g., boilers); and (3) lack of adequate data. We also did not consider plumbing fixtures that can reduce hot water consumption in the residential and commercial sectors.

<u>Residential Equipment</u>:
Freezer
Clothes dryer
Oil furnace
Boiler

Furnace fan
Cooking equipment
Television

Commercial Equipment:
Electric heat pump
Gas unit heaters
Gas cooking equipment
Commercial clothes washers
Distribution transformers
Miscellaneous -- such as service station equipment, automated teller machines, telecommunications equipment, medical equipment, pumps, emergency electricity generators.

Table 1: End Uses and Products Considered for Equipment Standards

End Use	Products Considered
Residential	
Space heating	Gas furnaces Heat pumps
Air conditioning	Room air conditioners Central air conditioners and heat pumps
Refrigeration	Refrigerator-freezers
Water heating	Electric water heaters
Dishwashing	Dishwashers
Lighting	Torchieres
Electric motors	Ceiling fans, pool pumps, well pumps, miscellaneous small motors
Household electronics	Various products
Commercial	
Space heating	Gas furnaces and boilers
Air conditioning	Air-source and water-source air conditioners and heat pumps
Ventilation	Various products
Lighting	Fluorescent lamps HID lamps
Water heating	Gas-fired storage water heater Gas-fired instantaneous water heater
Refrigeration	Various products
Office equipment	PC and Other Equipment

Technology Cost-Efficiency Analysis

For each considered product, we estimated the incremental consumer cost of technologies providing higher energy efficiency relative to a specific baseline technology, as well as the associated reduction in annual energy use. Key data sources include the technical analyses published by the Department of Energy (DOE) for its equipment standards rulemakings, data from the analysis for the "Scenarios for a Clean Energy Future" study,[1] and LBNL reports on residential and commercial building shell-related energy savings measures.

Box 1 provides an example of the key data inputs, sources and results for a product. In this and other cases, we selected the most common type of product to serve as a proxy for the product category. Appendix 1 provides a description of the cost-efficiency analysis for each considered product. All monetary values are in 2002 dollars.

Box 1: Example of Technology Cost-Efficiency Analysis

Sector: Residential
End Use: Air conditioning
Product: Room air conditioner
Lifetime (years): 12.5

Baseline Technology: 8,000-13,999 Btu/hr, with louvered sides, without reversing valve, 9.85 EER

	Technology for 2010 Standard	**Technology for 2020 Standard**
Description	10.11 EER	Same as 2010
Increase in end user first cost* ($)	$8	$7
Annual energy savings* (kWh)	17	17
CCE (¢/kWh)	5.2	4.5
Decrease in LCC* ($)	$4	$5

* Relative to baseline technology with first cost of $482 in 2010, annual energy use of 657 kWh, and LCC in 2010 of $930.

Source(s): U.S. Department of Energy (DOE)-Office of Codes and Standards. 1997. "Technical Support Document for Energy Conservation Standards for Room Air Conditioners, Volume 2 – Detailed Analysis of Efficiency Levels " Washington, DC.

Space heating, air conditioning, and commercial sector lighting are affected by both equipment standards and building codes. The residential building codes result in improvements in shell measures such as insulation, glazing, and infiltration. In new homes, they impact the heating and cooling load that any heating and cooling equipment must meet. Equipment standards increase the efficiency of some of the products in these end uses and thus further reduce the energy use.

For residential building codes, we conducted analysis for each Census Division. Each Division has a specific baseline construction practice with respect to insulation and glazing, and measures to meet upgraded codes. For commercial building codes, we only considered glazing and lighting. For glazing, we considered construction practice by building type for “hot” and “cold” climate zones. For lighting, we analyzed overall lighting power density (watts per sq. foot) for different building types. Appendix 2 describes the cost-efficiency analysis for building codes.

Our estimates of technology costs in 2010 and 2020 assume that a decline occurs from current costs due to a "learning curve" effect. The central idea is that manufacturers develop efficiencies of production as the industry as a whole matures. Accordingly, the empirical learning curve typically uses cumulative production of the product in question as a measure of experience accumulated. The key impact of this learning is the reduction of input use per product – and thus the cost.

To estimate a “learning parameter” for this study, we rely on an empirical analysis that developed a product-characteristics model of energy-using consumer durables.[2] As described in Appendix 3, one result of this analysis is estimates of a “learning parameter” for three appliances. Based on the results for the three appliances, we applied a decrease of 1.5% per year to the current estimates of incremental cost for each product and for new buildings. We also address how the results might change if no learning effect was incorporated.

For each higher-efficiency technology, we calculated cost-of-conserved-energy (CCE) values that spread the initial incremental cost over the lifetime of the equipment. Calculation of CCE values requires application of a Present Worth Factor (PWF) to spread the initial incremental cost over the lifetime of the equipment. The PWF uses a discount rate to effectively amortize costs over time. We derived separate discount rates for consumer costs as shown below (Table 2). Appendix 4 provides a discussion of the derivation of these discount rates.

Table 2: Discount Rates for Types of Costs

Type of Cost	Discount Rate (%)	Basis for Rate
Upgraded residential building codes	4.2	New home mortgage rates
Upgraded residential equipment standards	5.6	Opportunity cost for households of investment in energy efficiency
Upgraded commercial building codes	5.7	Weighted cost of capital for commercial sector firms that own buildings
Upgraded commercial equipment standards	6.1	Weighted cost of capital for typical commercial sector enterprises

Note: the rates reflect adjustment for inflation and for tax impacts (such as deduction of mortgage interest).

Consumer Impacts Analysis

To estimate the impacts of upgraded equipment standards and building codes on residential and commercial consumers, we used life-cycle cost (LCC) analysis. The LCC for a building or piece of equipment includes the initial capital cost and the operating costs over an assumed lifetime, with the operating costs discounted to a present value. Using the data from the technology cost-efficiency analysis, and the discount rates shown above, we calculated the LCC for each technology considered for each product.

For some considered products, technologies that are more energy-efficient than the baseline technology have a higher LCC than the baseline. Such products in the residential sector are central air conditioners and heat pumps and gas water heaters. There are also such products in the commercial sector. For these products, we do not consider an upgraded standard.

Ideally, a consumer impacts analysis should use marginal energy prices to calculate the reduction in energy costs associated with standards and codes. Marginal energy prices are the prices consumers pay for the last unit of energy used in a given billing period. Since marginal prices reflect a change in a consumer's bill associated with a change in energy consumed, such prices are appropriate for determining energy cost savings associated with efficiency standards.

For commercial sector electric end uses, we estimated end-use-specific marginal electricity prices for air conditioning, lighting, and refrigeration. We made use of past analysis by DOE/LBNL on estimating marginal electricity prices for commercial unitary air conditioners in this study.[3] That analysis looked at actual commercial sector tariffs for utilities across the U.S. to derive the marginal prices faced by consumers. As we did not have similar analysis for commercial sector natural gas prices, we used average prices.

For residential consumers, we did not have data on marginal energy prices, so we used average electricity and natural gas prices. Given the structure of residential tariffs, one would expect that the difference between marginal and average prices is less in the residential sector than in the commercial sector.

For residential end uses and commercial natural gas end uses, the life-cycle energy costs utilize projections of average sectoral natural gas and electricity prices from the DOE-Energy Information Administration's (DOE-EIA) *Annual Energy Outlook 2004 (AEO 2004)*.[4] (The *AEO* projections go through 2025. We extrapolated the projected trends in 2015-2025 to estimate prices for later years.) For commercial sector electric end uses, we applied the trend in the EIA projections to the estimated marginal prices in 2002. Figures 1 and 2 below show the price projections used.

We also consider changes in maintenance costs where the standards have a significant impact.

Figure 1: Projected Electricity Prices

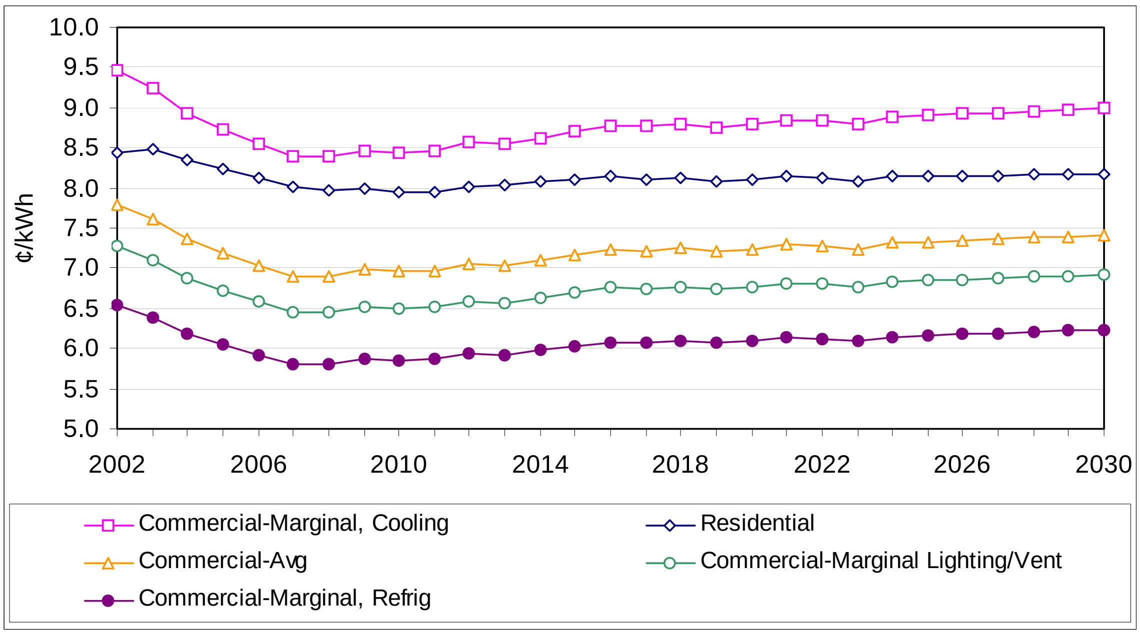
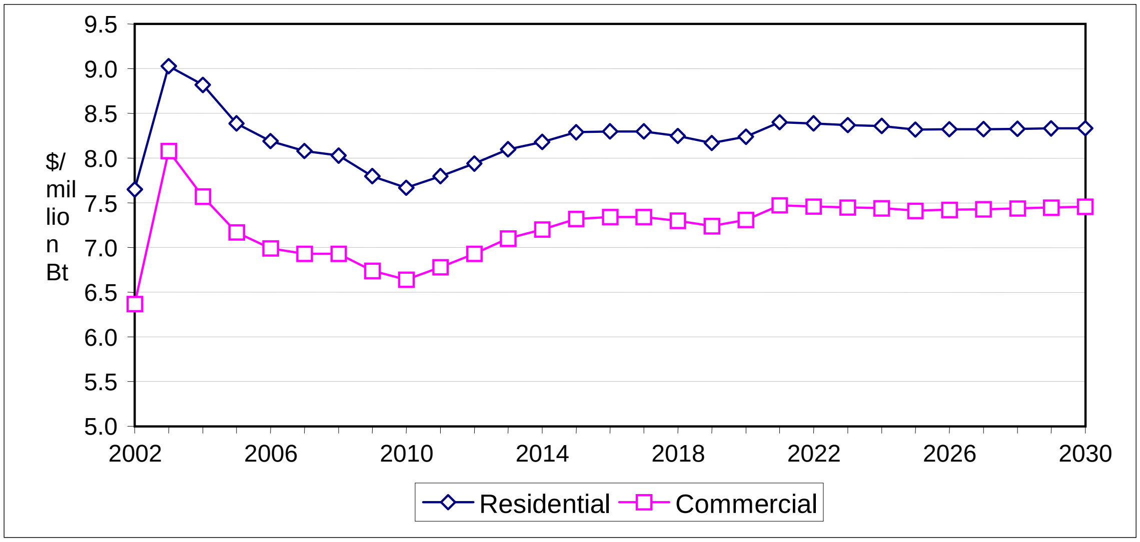


Figure 2: Projected Natural Gas Prices



Selection of Efficiency Levels for Upgraded Standards and Building Codes

Based on the LCC analysis, we selected the technology for each product with the lowest LCC in 2010 and 2020 for the 2010 and 2020 standards. As mentioned above, upgraded standards were not cost-effective relative to the baseline technology for a few of the considered products. Table 3 illustrates the results for the case of residential refrigerators. The technology with the lowest LCC in 2010 and 2020 is selected for the standard level in each of those years.

Table 3: LCC Example - Residential Refrigerators

Technology Option	LCC in 2010	LCC in 2020
484 kWh/yr (baseline)	$1,046	$964
473 kWh/yr	$1,041	$958
444 kWh/yr	$1,030	$945
437 kWh/yr (2010 std)	$1,029	$943
426 kWh/yr	$1,031	$943

For residential building codes, we selected measures in each Census Division that have a simple payback of less than 15 years. To obtain national average values, we weighted the percentage reduction in average energy use achieved by the standard level in each Census Division by the relevant shares of new housing construction.

For commercial building codes for lighting, we selected measures that are cost-effective towards meeting the ASHRAE 90-1 2004 amendment for a standard that would become effective in 2015. For commercial building codes for glazing, we selected measures with the minimum LCC for each considered building type. To obtain national average values, we weighted the percentage reduction in average energy use achieved by the standard level for each building type by shares of new construction.

Tables 4 and 5 show the technologies selected for 2010 and 2020 standard levels and their cost of conserved energy for the residential and commercial sectors, respectively. For many products, an upgrade of the 2010 standard in 2020 is not cost-effective, so the 2020 standard is the same as the 2010 standard. Note that even if the standard is the same, the CCE is lower in 2020 due to the assumed decrease in equipment costs over time.

Product standards that were considered but judged not cost-effective on a national-average basis are central air conditioner, electric heat pump, gas water heater, and clothes washer. In each case, new DOE standards either took effect in 2004 or will take effect in 2006-07. Improvement beyond those standards is not cost-effective given the costs and energy prices currently envisioned.

Table 4: Technologies Selected for Upgraded Standards and Codes – Residential Sector

End Use/Product	Baseline Technology	Technology for 2010 Standard	CCE for 2010 Standard	Technology for 2020 Standard	CCE for 2020 Standard
Space heating					
Equipment standards					
Gas furnace	80% AFUE	81% AFUE using 2-stage modulation	\$6.20/MMBtu	Same as 2010	\$5.40/MMBtu
Building codes*	Current practice	Improved insulation and glazing	\$3.80/MMBtu and 5.8 ¢/kWh	Improved insulation and glazing	\$3.70/MMBtu and 5.6¢/kwh
Air conditioning					
Equipment standards					
Room air conditioner	9.85 EER	10.11 EER	5.2¢/kwh	Same as 2010	4.5¢/kwh
Building codes	Current practice	Improved insulation and glazing	3.3¢/kwh	Improved insulation and glazing	3.1¢/kwh
Refrigeration	484 kWh/yr	426 kWh/yr	4.9¢/kwh	Same as 2010	4.2¢/kwh
Lighting					
Torchiere	Incandescent	Fluorescent	6.8¢/kwh	Same as 2010	5.9¢/kwh
Water heating					
Electric	92 EF	92 EF	n/a	Heat pump	3.9¢/kwh
Dishwashing**	2.14 kWh/cycle	1.96 kWh/cycle	4.2¢/kwh	Same as 2010	3.6¢/kwh
Motors					
Ceiling fans	Current practice	Higher efficiency	3.4¢/kwh	Same as 2010	2.9¢/kwh
Pool pumps	Single-Speed	Two-Speed	4.6¢/kwh	Same as 2010	4.0¢/kwh
Misc. electronics	High Standby	1W Standby	0.5¢/kwh	Same as 2010	0.5¢/kwh

* The 2010 and 2020 codes have separate CCEs for gas and electric end uses.

** The values include the energy savings from reduced water heating associated with a higher-efficiency dishwasher.

Table 6 shows the relevant energy prices to which the CCEs may be compared. As Figures 3 and 4 illustrate, the CCE for the 2010 standards is well below the relevant energy price for most products. This result indicates that most of the standards would be cost-effective even if we did not assume that manufacturing costs decline over time due to a learning effect.

Table 5: Technologies Selected for Upgraded Standards/Codes--Commercial Sector

End Use/Product	Baseline Technology	Technology for 2010 Standard	CCE for 2010 Standard	Technology for 2020 Standard	CCE for 2020 Standard
Space Heating	Thermal Effc'y	Thermal Effc'y	$/MMBtu	Thermal Effc'y	$/MMBtu
Equipment standards					
Packaged Boilers, Gas-Fired, HW (400 kBtu/hr)	75%	79%	1.00	same as 2010	0.90
Packaged Boilers, Gas-Fired, HW (800 kBtu/hr)	75%	78%	3.30	88%	5.00
Packaged Boilers, Gas-Fired, HW (1500 kBtu/hr)	75%	88%	2.70	same as 2010	2.30
Packaged Boilers, Gas-Fired, HW (3000 kBtu/hr)	75%	88%	1.60	same as 2010	1.40
Packaged Boilers, Gas-Fired, Steam (400 kBtu/hr)	72%	76%	3.30	same as 2010	2.80
Packaged Boilers, Gas-Fired, Steam (800 kBtu/hr)	72%	76%	2.90	same as 2010	2.50
Packaged Boilers, Gas-Fired, Steam (1500 kBtu/hr)	72%	79%	3.30	same as 2010	2.80
Packaged Boilers, Gas-Fired, Steam (3000 kBtu/hr)	72%	80%	1.90	same as 2010	1.70
Warm-Air Furnaces, Gas-Fired (250 kBtu/hr)	78%	80%	6.50	same as 2010	5.60
Warm-Air Furnaces, Gas-Fired (400 kBtu/hr)	78%	80%	5.10	same as 2010	4.40
Building codes	Current practice	Improved glazing	3.90	same as 2010	3.70
Air conditioning	EER	EER	¢/kWh	EER	¢/kWh
Equipment standards					
3-Phase, Single-Package, Air-Source AC (<65 kBtu/h)	9.7	12	4.2	same as 2010	3.6
3-Phase, Split-System, Air-Source AC (<65 kBtu/h)	10	12	6	same as 2010	5.2
3-Phase, Single-Package, Air-Source HP (<65 kBtu/h)	9.7	12	4.6	same as 2010	3.9
3-Phase, Split-System, Air-Source HP (<65 kBtu/h)	10	13	5.2	same as 2010	4.5
Central, Air-Source AC (>65 kBtu/h and <135 kBtu/h)	10.1	11.5	3.2	12	4.5
Central, Air-Source HP (>65 kBtu/h and <135 kBtu/h)	10.1	11.5	3.2	12	4.5
Central, Water-Source HP (>65 kBtu/h and <135 kBtu/h)	12	12.5	7.2	13	7.4
Central, Water-Cooled AC (>65 kBtu/h and <135 kBtu/h)	11.5	12.4	5.9	14	6.9
Central, Air-Source AC (>135 kBtu/h and <240 kBtu/h)	9.5	11.5	2.7	12	3.6
Central, Air-Source HP (>135 kBtu/h and <240 kBtu/h)	9.5	11.5	2.7	12	3.6
Central, Water-Cooled AC (>135 kBtu/h and <240 kBtu/h)	11	11.5	2.9	same as 2010	2.5
Central, Water-Cooled AC (<65 kBtu/h)	12.1	12.1	0	12.5	7.5
Central, Water-Source HP (<17 kBtu/h)	11.2	11.2	0	12.5	7.8
Central, Water-Source HP (>17 kBtu/h and <65 kBtu/h)	12	13.1	7.1	same as 2010	6.1
Packaged Terminal Air Conditioners (PTACs) (< 7kBtu/h)	9.4	11	5.8	same as 2010	5.0
Packaged Terminal Air Conditioners (PTACs) (7-10 kBtu/h)	9	10.8	3.8	same as 2010	3.3
Packaged Terminal Air Conditioners (PTACs) (10-13 kBtu/h)	8.3	10.5	4.1	same as 2010	3.6
Packaged Terminal Air Conditioners (PTACs) (>13 kBtu/h)	7.9	10	1.9	same as 2010	1.7
Packaged Terminal Heat Pumps (PTHPs) (< 7kBtu/h)	9.3	10.8	5.8	same as 2010	5.0
Packaged Terminal Heat Pumps (PTHPs) (7-10 kBtu/h)	8.9	10.6	3.4	11.4	4.5
Packaged Terminal Heat Pumps (PTHPs) (10-13 kBtu/h)	8.2	9.7	2.8	same as 2010	2.4
Packaged Terminal Heat Pumps (PTHPs) (>13 kBtu/h)	7.8	10	4.7	same as 2010	4.0
Building codes	Current practice	Improved glazing	4.7	same as 2010	4.1
Ventilation	Efficiency	Efficiency	¢/kWh	Efficiency	¢/kWh
Air Distribution					
Large Unitary (10 HP)	85%	92%	0.5	same as 2010	0.4
Exhaust Fan (0.5 HP)	60%	80%	0.2	same as 2010	0.2
Room Fan Coil (0.17 HP)	50%	75%	0.9	same as 2010	0.7

End Use/Product	Baseline Technology	Technology for 2010 Standard	CCE for 2010 Standard	Technology for 2020 Standard	CCE for 2020 Standard
Central Station AHU (10 HP)	87%	93%	0.6	same as 2010	0.5
Hydronic Hot and Chilled Water Circulation					
Centrifugal Chiller (25 HP)	90%	95%	0.5	same as 2010	0.5
Screw Chiller (10 HP)	90%	94%	1.4	same as 2010	1.2
Reciprocating Chiller (10 HP)	88%	93%	1.5	same as 2010	1.3
Absorption Chiller (25 HP)	90%	95%	0.5	same as 2010	0.4
Hydronic heating (10 HP)	90%	94%	0.8	same as 2010	0.7
Cooling Water Circulation					
Centrifugal Chiller (25 HP)	90%	95%	0.5	same as 2010	0.4
Screw Chiller (10 HP)	90%	94%	1.0	same as 2010	0.9
Reciprocating Chiller (10 HP)	88%	93%	1.9	same as 2010	1.6
LiBr -- Water Absorption Chiller (25 HP)	90%	95%	0.5	same as 2010	0.4
Heat Rejection					
Large Unitary (5 HP)	85%	90%	1.4	same as 2010	1.2
Air Cooled Screw Chillers (2 HP)	85%	92%	0.1	same as 2010	0.1
Air Cooled Reciprocating Chillers (2 HP)	85%	92%	0.1	same as 2010	0.1
Cooling Tower (10 HP)	85%	92%	1.4	same as 2010	1.2
Water Heating	Thermal Effc'y	Thermal Effc'y	$/MMBtu	Thermal Effc'y	$/MMBtu
Storage Water Heater, Gas-Fired (120 kBtu/hr)	80%	82%	4.00	same as 2010	3.50
Storage Water Heater, Gas-Fired (199 kBtu/hr)	80%	82%	4.10	same as 2010	3.50
Storage Water Heater, Gas-Fired (360 kBtu/hr)	80%	82%	4.30	same as 2010	3.70
Instantaneous Water Heater, Gas-Fired (1000 kBtu/hr)	80%	83%	4.80	same as 2010	4.10
Instantaneous Tank Water Heater, Gas-Fired (500 kBtu/hr)	80%	82%	4.30	same as 2010	3.70
Lighting	Technology	Technology	¢/kWh	Technology	¢/kWh
Equipment standards					
Fluorescent Lamp/ballast	Current Practice	Hi-perf T8 w/elec and hi-perf ballast	1.9	Hi-perf T8 w/ hi-perf ballast	1.1
HID -- Lo Bay	MV 20%, MH 55%, HPS 25%	PMH 75% & HPS 25%	3.0	PMH/SSB 75% & HPS 25%	2.9
HID -- Hi Bay	MV 20%, MH 55%, HPS 25%	PMH 75% & HPS 25%	1.0	PMH/SSB 75% & HPS 25%	1.0
Building codes	2010 standards	ASHRAE 90-1 (2004)*	1.4	same	1.5
Refrigeration	Technology	Effc'y Improvement	¢/kWh	Effc'y Improvement	¢/kWh
Supermarket Units	Current technology	16%	1.2	same as 2010	1.1
Beverage Merchandiser Units	Current technology	61%	2.1	same as 2010	1.8
Reach-in Freezers	Current technology	52%	2.5	same as 2010	2.3
Reach-in Refrigerators	Current technology	38%	1.9	same as 2010	1.6
Ice Machines	Current technology	23%	2.8	same as 2010	2.4
Refrigerated Vending Machines	Current technology	51%	2.9	same as 2010	2.5
Walk-in Coolers	Current technology	46%	1.2	same as 2010	1.0
Walk-in Freezers	Current technology	48%	3.0	same as 2010	2.6
Office equipment					
Personal Computers & Monitors	Current technology	Low standby	1.0	Not applicable	0.1
Other	Current technology	Low standby	1.0	Not applicable	0.2

* Building code takes effect in 2015; requires lighting power density that may be met by using CFLs instead of incandescents in some applications.

Figure 3. Comparison of Cost of Conserved Energy for 2010 Standards to Projected Electricity Price in the Residential Sector

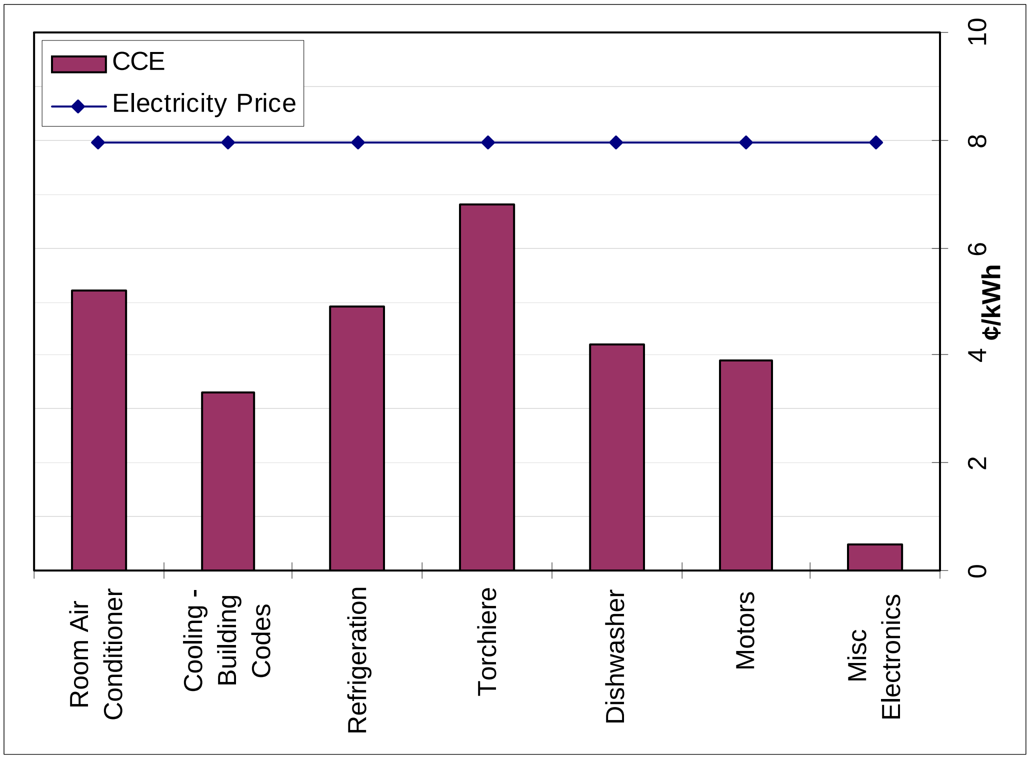
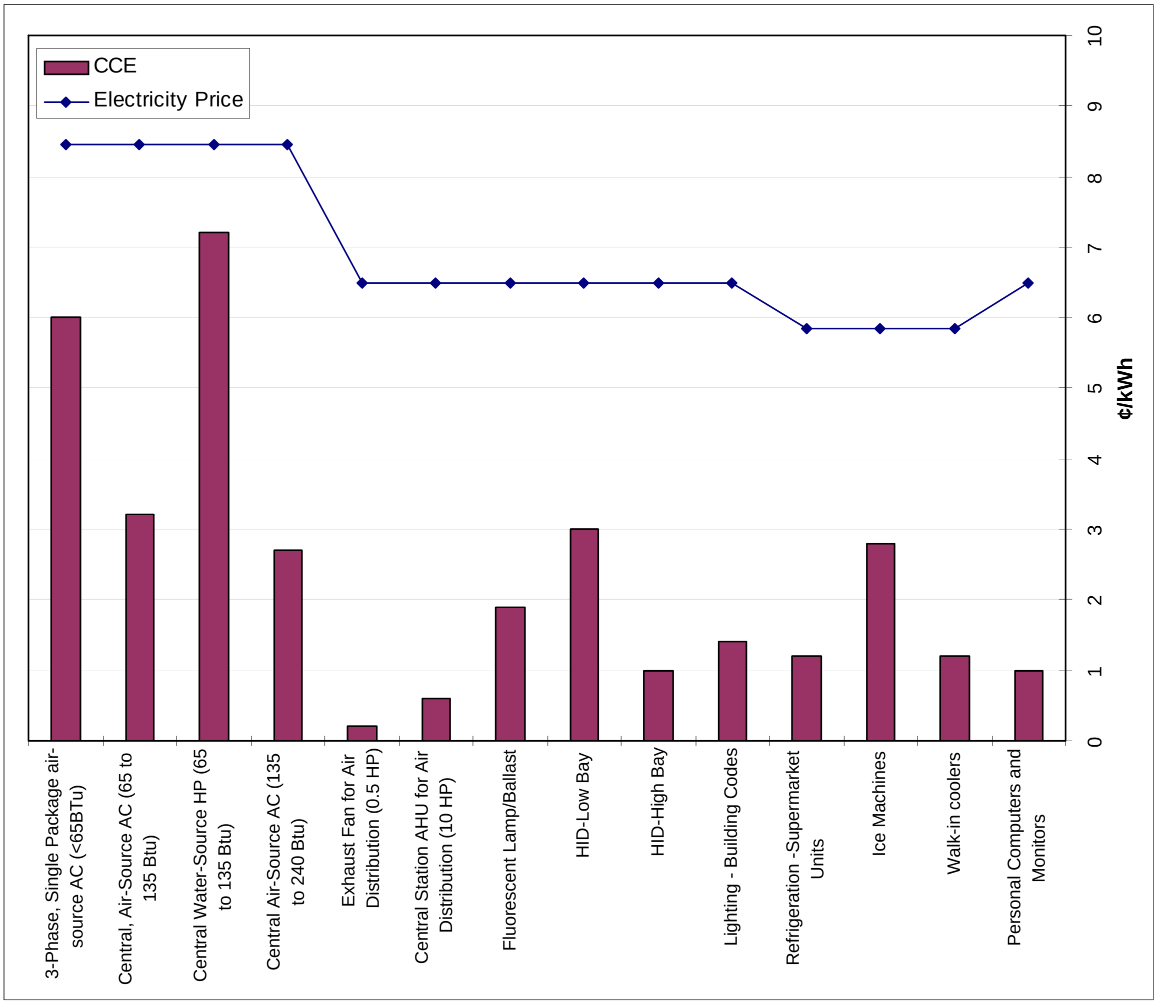


Figure 4: Comparison of Cost of Conserved Energy for Representative 2010 Standards to Marginal Electricity Price in the Commercial Sector



Our analysis considers the consumer perspective. Another perspective of interest is how the CCEs compare to the avoided costs of providing a unit of electricity and natural gas to consumers. In the short run, energy conservation mainly affects a utility's energy costs. In the long run, energy conservation may affect decisions about expanding generating and transmission and distribution capacity.[5] The impact of energy efficiency standards and codes on decisions about expanding generating and load distribution capacity varies across the U.S. On average, however, the impact of such standards is sufficiently large to have an impact on capacity expansion. This situation supports the use of long run avoided costs to measure the impacts of energy efficiency standards and codes.

Determining the appropriate avoided costs at a national level for a future time period is not a simple exercise. One would expect the long run avoided costs of electricity and natural gas to be somewhat less than the retail prices we have used in this analysis. Given that the CCE for most of the considered standards is well below the forecast retail price, however, it is likely that most of the standards would be cost-effective compared to the long run avoided cost.

Table 6: Energy Prices for CCE Comparison

	Residential Sector	Commercial Sector
Electricity (¢/kWh)		
Price in 2010-20 period	8.5-9.0	7.0-7.2*
Price in 2020-30 period	8.8-9.0	7.2-7.4*
Natural gas ($/MMBtu)		
Price in 2010-20 period	7.7-8.3	6.7-7.3
Price in 2020-30 period	8.4	7.4

* These are average prices. Prices are 8.5-9.0 ¢/kWh for air conditioning, 6.5-6.9 ¢/kWh for lighting and ventilation, and 5.8-6.1 ¢/kWh for refrigeration. See Figure 1.

Estimation of National Impacts

The Base Case (Business-as-usual) provides a reference against which we measure the potential impacts of upgraded standards and codes. Our Base Case uses the reference energy consumption projections in *AEO2004* through 2025 and extrapolated values thereafter. It includes all standards that have already been promulgated by DOE as of January 2004.[*] It implicitly assumes that new buildings meet recent State building codes. As a result of these and other factors, the Base Case shows ongoing efficiency improvement in each end-use. Therefore, the Base Case does not consist only of the baseline technologies considered in the technology cost-efficiency analysis.

The Upgraded Standards Case assumes upgraded and new standards and codes take effect in 2010, and more stringent standards take effect in 2020. The standards affect products installed from the effective date through 2030. We consider the impacts over the lifetime of all products installed and buildings constructed in the 2010-2030 period.

To estimate impacts of upgraded equipment standards for each product, we first estimate the fraction of current energy consumption in each end use that is accounted for by the considered product. We assume this fraction remains constant over time.[†] We then use a stock model to estimate what share of the stock of each product in each future year consists of units installed after the standard effective date. Such products include replacements for retired products as well as products installed in new buildings. The stock model makes use of the estimated current stock, the mean lifetime of each product,

[*] The base case includes existing standards as of 2004, including those with effective dates in the future, such as the revised standard for clothes washers that will take effect in 2007. It does not include standards that are still under consideration by DOE.

[†] Ideally, one would model potential change in the share. Such analysis was not possible for this study.

a retirement function, and projected installations due to new construction of residential and commercial buildings. Projections of new construction are based on *AEO 2004.*

The share of products installed after the standard effective date represents those products affected by standards. These products would be at a lower efficiency level were it not for the upgraded standards. We assume that these products utilize the baseline technology considered in the technology cost-efficiency analysis.* In the Upgraded Standards Case, we apply the percentage reduction in average annual energy consumption associated with the standard (relative to the baseline technology) to the share of Base Case energy consumption that is accounted for by products installed after the standard effective date.

For example, the 2010 standard for refrigerators results in 10% reduction in the average annual energy consumption compared to the baseline technology. Products installed after 2010 account for a growing share of total Base Case energy consumption for refrigerators. We calculate total annual energy savings by multiplying: (1) the 10% reduction by (2) the UEC of the baseline technology by (3) the number of products installed after 2010.

To estimate impacts of upgraded residential building codes, we begin with the total projected Base Case energy use for space heating and air conditioning. We then use the stock model to estimate what share of the energy consumption in each end use in each future year is attributable to new homes. We then apply the percentage reduction in average energy use due to the upgraded codes to the share of Base Case energy consumption. The percentage improvement is a national average weighted by regional shares of new home construction in 2002.

To estimate impacts of upgraded commercial building codes, we begin with the total projected energy use for space heating, air conditioning and lighting. We then use the stock model to estimate what share of the end use energy in each future year is attributable to new buildings. We then apply the percentage reduction in average energy use due to the upgraded codes to this Base Case energy consumption. The percentage improvement is a national average weighted by shares of different building types in new construction in 2002. For commercial lighting, part of the reduction in lighting power density is achieved by the 2010 lighting equipment standards. We attribute the remainder of the reduction to the building code.

Appendix 5 provides further discussion of the accounting framework used to estimate national-level impacts. The approach used is obviously a simplification of a complex reality, and many of the assumptions are subject to a fair amount of uncertainty.

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* For the residential sector, we had data that allowed estimation of the share of the products in the base case that are more efficient than the upgraded standard, and thus would not be impacted by upgraded standards. We estimated the share of units sold expected to be more efficient than the upgraded standard based on recent market statistics on Energy Star products.

We express the annual electricity and natural gas savings from upgraded standards in total primary (source) energy using annual primary-to-site energy factors based on *AEO 2004*.*

Value of Energy Savings

One way to measure the value of the energy impacts of standards and codes is to consider the costs avoided by energy suppliers. In the short run, energy conservation mainly affects a utility's energy costs (though there may also be short-run avoided capacity costs). In the long run, energy conservation may affect decisions about expanding generating and transmission and distribution capacity.

The view that the long-run avoided utility cost is the appropriate measure for energy efficiency was actively discussed in the context of utility energy conservation programs, and various approaches for estimating it were debated for many years. *Least-Cost Utility Planning,* a handbook for public utility commissioners published by the National association of Regulatory Utility Commissioners, discusses several methods for measuring long-run avoided costs of conservation programs.[5]

The impact of energy efficiency standards and codes on decisions about expanding generating and load distribution capacity varies across the U.S. On average, however, the impact of such standards is sufficiently large to have an impact on capacity expansion, which suggests that long run avoided utility costs are a more appropriate measure of the avoided cost associated with energy efficiency standards and codes.

Estimating such costs on a national level is difficult, however. For this report, we calculate the value of the energy savings from upgraded standards and codes by using the same energy prices as in the consumer impacts analysis. This value reflects the consumer perspective.

We calculate the Net Present Value (NPV) to consumers as the difference between the national operating cost savings due to the equipment standards/building codes and the increased national equipment/building costs associated with the standards/codes. We express future costs and benefits in present (2004) value terms by using alternative national-level discount rates. Selection of appropriate discount rates should reflect the fact that public investments and regulations displace both private investment and consumption.

In its analyses of the national economic impacts of equipment energy efficiency standards, DOE relies on guidance issued in 1992 by the Office of Management and Budget. OMB stated, "benefit-cost analyses of proposed investments and regulations should report net present value and other outcomes determined using a real discount rate of 7 percent. This rate approximates the marginal pretax rate of return on an average

* The *AEO 2004* projections go through 2025. We extrapolated the past trends to estimate prices for later years.

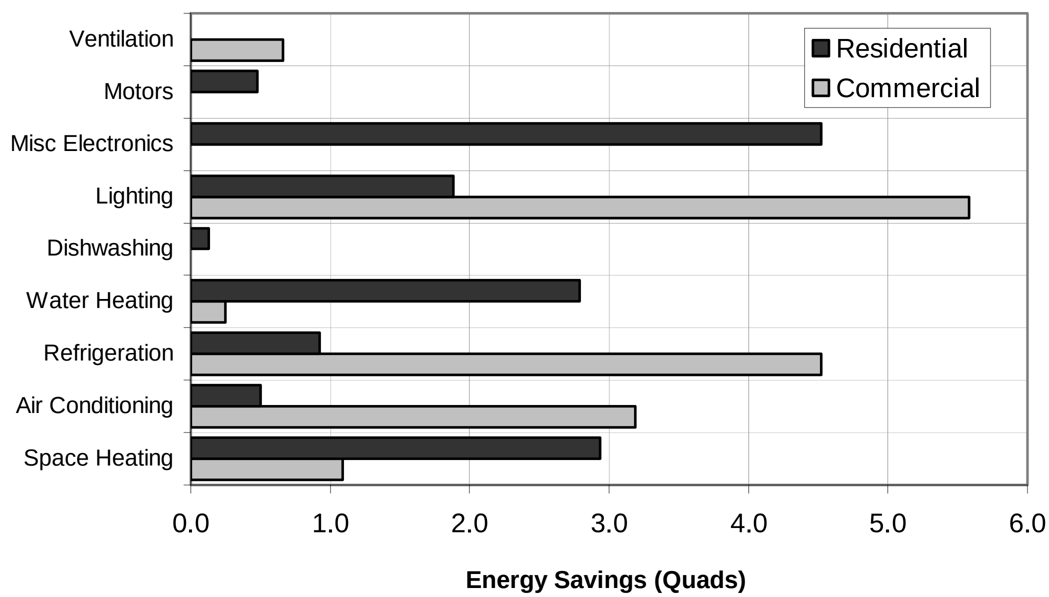
investment in the private sector in recent years." DOE uses this rate in its analysis of national economic impacts of equipment standards, and we apply it here.

An alternative discount rate may reflect displacement of private consumption. Economist Kenneth Arrow notes that "Since consumption is much larger than investment [in the economy], it is reasonable to assume that the appropriate hurdle rate should be closer to the consumption rate… Most estimates of the rate of return on consumption are on the order of 3 or 4 percent."[6] Based on this line of reasoning, we also apply a "consumption discount rate"of 3.5%.

Results

Figures 5 and 6 show the cumulative primary energy savings and cumulative net present value due to equipment standards and building codes by end use for the residential and commercial sectors. The values reflect the lifetime impacts from products and buildings installed in the 2010-2030 period. The largest energy savings are associated with standards for commercial lighting and refrigeration, and for residential space heating and water heating.

Figure 5 Cumulative primary energy savings from upgraded standards and codes for products installed in 2010-2030 period



In tabular form, Tables 7 and 8 show the cumulative primary energy savings and cumulative net present value due to upgraded equipment standards and building codes by end use for the residential and commercial sectors, respectively. In the residential sector, the substantial energy savings estimated for standards for torchieres, electric water heaters, small motors, and miscellaneous electronics suggest that these products merit closer examination. In the commercial sector, the results suggest further examination of standards for refrigeration equipment, lighting products, and air conditioners.

The total cumulative energy savings amount to 31 quads. Equipment standards account for 83% of the total energy savings. The total NPV is $48 billion using a 7% discount rate, but $103 billion using 3.5%. The commercial sector accounts for a greater share of the total energy savings and NPV than the residential sector.

Figure 6 Net present value of consumer benefit from upgraded standards and codes for products installed in 2010-2030 period (7% discount rate)

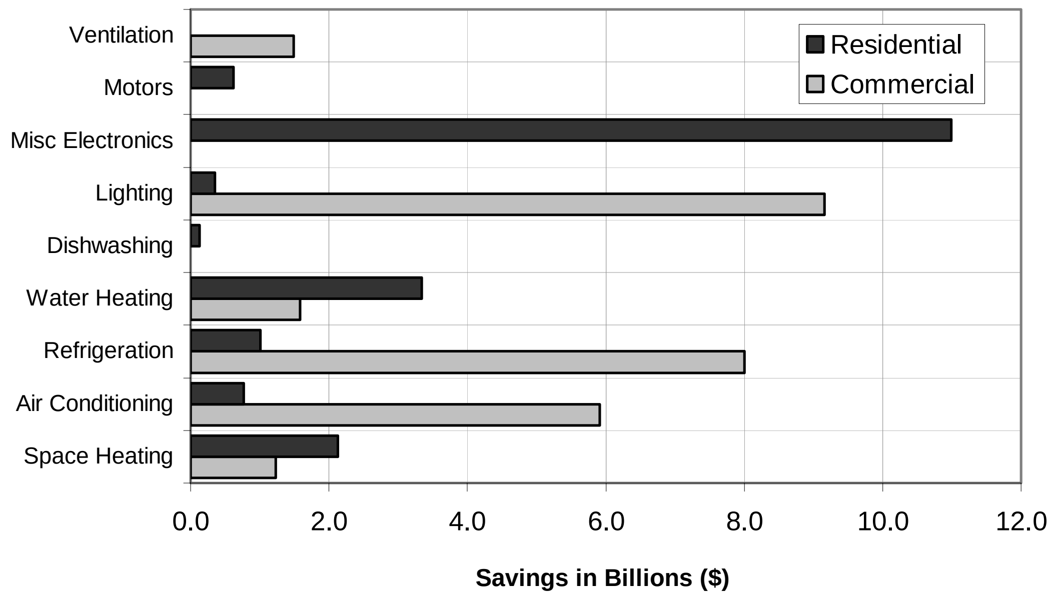


Table 7: Residential Sector Energy Savings and Consumer Benefit for Products Installed in 2010-2030 Period

End Use	**Cumulative Primary Energy Savings (quads)**	**NPV of Consumer Benefit (billion $)**	
		7% discount rate	**3.5% discount rate**
Gas Space Heating			
Equipment standards	1.1	0.5	2.6
Building codes	1.39	1.6	5.8
Electric Space Heating			
Building codes	0.40	0.04	1.0
Air Conditioning			
Equipment standards	0.10	0.08	0.26
Building codes	0.40	0.68	2.1
Refrigeration			
Equipment standards	0.92	1.0	3.1
Lighting			
Equipment standards	1.9	0.36	1.3
Water heating			
Electric	2.8	3.3	10.1
Dishwashing*	0.13	0.13	0.31
Motors	0.48	0.62	1.3
Misc electronics	4.5	11.0	20.8
TOTAL RESIDENTIAL	**14.2**	**19.3**	**40.4**
Equipment standards	12.0	17.0	31.4
Building codes	2.2	2.3	9.0

* Includes water heating savings derive from the higher-efficiency dishwasher, which uses less hot water.

Table 8: Commercial Sector Energy Savings and Consumer Benefit for Products Installed in 2010-2030 period, and Total Residential and Commercial Sector Savings

End Use	Cumulative Primary Energy Savings (quads)	NPV of Consumer Benefit (billion $)	
		7% discount rate	3.5% discount rate
Space Heating			
Equipment standards	0.71	1.05	2.42
Building codes	0.38	0.18	0.74
Air Conditioning			
Equipment standards	3.02	5.80	12.46
Building codes	0.17	0.11	0.43
Ventilation			
Equipment standards	0.66	1.49	2.92
Water Heating			
Equipment standards	0.25	1.58	2.91
Lighting			
Equipment standards	3.10	5.53	11.50
Building codes	2.48	3.63	8.59
Refrigeration			
Equipment standards	4.52	8.00	15.05
Office Equipment			
Equipment standards	1.55	3.7	5.66
TOTAL COMMERCIAL	**16.8**	**31.0**	**62.7**
Equipment standards	13.8	27.1	52.9
Building codes	3.0	3.9	9.8
TOTAL RESIDENTIAL + COMMERCIAL	**31.0**	**48.3**	**103**
Equipment standards	25.8	42.1	84.3
Building codes	5.2	6.2	18.8

References

1. Interlaboratory Working Group, *Scenarios for a Clean Energy Future,* November, 2000, Oak Ridge National Laboratory and Lawrence Berkeley National Laboratory. Oak Ridge, TN and Berkeley, CA. Report No. ORNL/CON-476 and LBNL-44029.

2. Newell, R. G., *DRAFT Incorporation of Technological Learning into NEMS Building Modules,* September, 2000, U.S. Department of Energy, Energy Information Administration. Washington, DC.

3. U.S. Department of Energy-Office of Building Technologies, *Commercial Unitary Air Conditioners and Heat Pumps, Energy Conservation Standards Rulemaking, Life Cycle Cost Analysis Spreadsheet Model (Tariff-Based Electricity Prices)*, 2004. Washington, DC. <http://www.eere.energy.gov/buildings/appliance_standards/commercial/ac_hp.html.>

4. U.S. Department of Energy - Energy Information Administration, *Annual Energy Outlook 2004: With Projections Through 2025,* January, 2004. Washington, DC. Report No. DOE/EIA-0383(2004). <http://www.eia.doe.gov/oiaf/aeo>

5. Krause, F. and J. Eto, *Least-Cost Utility Planning Handbook for Public Utility Commissioners. Volume 2 - The Demand Side: Conceptual and Methodological Issues,* December, 1988, National Association of Regulatory Utility Commissioners. Washington, DC. Prepared by Lawrence Berkeley National Laboratory.

6. Arrow, K., A Comment on Cooper. *The World Bank Research Observer*, 2000. 15(2).

Appendix 1

Methods and Sources Used for the Appliance Cost-Efficiency Analysis

General Approach

For each considered product, we estimated the incremental consumer cost of technologies providing higher energy efficiency relative to a specific baseline technology, as well as the associated reduction in annual energy use. This appendix describes the key inputs and results, and presents the sources for the input data.

For some of the products, we used the most common type as a proxy for the entire class. For example, for refrigerator-freezers, we used a top-mount auto-defrost refrigerator-freezer with 21.4 cu.ft. adjusted volume as a proxy for the class.

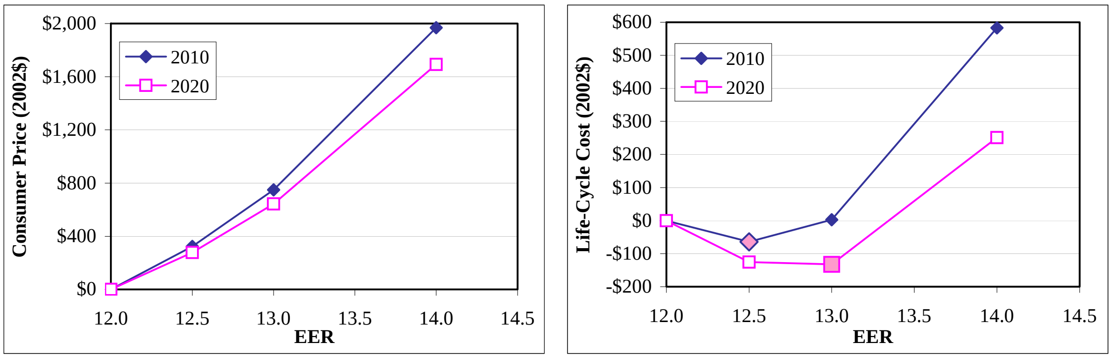
The tables in this appendix present data for the technologies that were selected for the 2010 and 2020 standards. One summary statistic for each technology is the cost of conserved energy (CCE), which spreads the initial incremental cost over the lifetime of the equipment. Calculation of CCE values requires application of a Present Worth Factor (PWF) to spread the initial incremental cost over the lifetime of the equipment. The PWF uses a discount rate to effectively amortize costs over time. We derived separate discount rates for residential and commercial consumers, as discussed in Appendix 4.

Another summary statistic is the life-cycle cost (LCC). The LCC for a piece of equipment includes the initial capital cost and the operating costs over an assumed lifetime, with the operating costs discounted to a present value. We calculated the LCC for each technology using the same discount rates as for the CCE calculation.

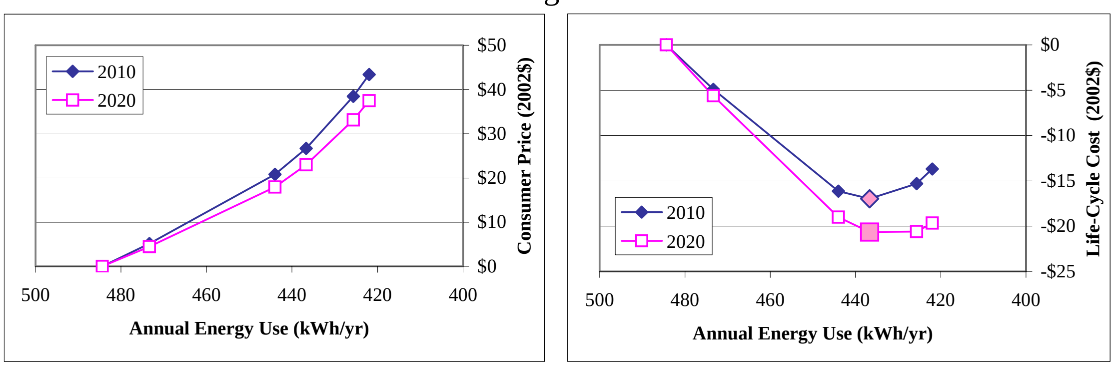
The tables include first costs, annual energy consumption and LCC for the baseline model of each technology, where available. For some technologies, only incremental costs and consumption were available; baseline data are not listed for these technologies.

For each considered product, we actually analyzed a number of technologies. Figures 1-4 provide examples of the range of technologies considered, and show how the first cost and the LCC change with efficiency.

Figures 1 and 2. Price and Life-Cycle Cost Change vs. Efficiency for Commercial Central Air Conditioner, Water-Source HP >65 kBtu/h and <135 kBtu/h



Figures 3 and 4. Price and Life-Cycle Cost Change vs. Efficiency for Top-Mount Auto Defrost Refrigerator-Freezer



Residential Sector Products

Sector: Residential
End Use: Natural Gas and LPG Space Heating
Product: Gas Furnace
Lifetime (years): 20
Baseline Technology: 80% Annual Fuel Utilization Efficiency (AFUE)
Baseline Installed Cost in 2010: $1,792
Baseline Annual Energy Consumption: 64.9 MMBtu
Baseline Life Cycle Cost in 2010: $8,214

	Technology for 2010 Standard	**Technology for 2020 Standard**
Description	81% AFUE using two-stage modulation	Same as 2010
Increase in end user installed cost* ($)	$155	$136
Annual energy savings* (MMBtu)	2.1	2.1
CCE ($/MMBtu)	$6.20	$5.40
Decrease in LCC* ($)	$41	$75

* Relative to baseline technology.

Notes:
Incremental costs for LPG equipment are assumed equivalent to those for natural gas furnaces, since most manufacturers market an LPG furnace of nearly identical design to their natural gas models. The annual savings, CCE, and LCC change given are specific to natural gas furnaces.

81% 2-stage modulation furnace uses Category I venting system.

Source(s):
House Heating load – RECS97.

Other inputs – DOE Residential Furnaces and Boilers Proposed Rulemaking, Preliminary Engineering Analysis - September 22, 2002

http://www.eere.energy.gov/buildings/appliance_standards/residential/furnaces_boilers.html

Sector: Residential
End Use: Air conditioning
Product: Room air conditioner
Lifetime (years): 12.5
Baseline Technology: 8,000-13,999 Btu/hr, with louvered sides, without reversing valve, 9.85 EER
Baseline Installed Cost in 2010: $482
Baseline Annual Energy Consumption: 657 kWh
Baseline Life Cycle Cost in 2010: $930

	Technology for 2010 Standard	**Technology for 2020 Standard**
Description	10.11 EER	Same as 2010
Increase in end user installed cost* ($)	$8	$7
Annual energy savings* (kWh)	17	17
CCE (¢/kWh)	5.2	4.5
Decrease in LCC* ($)	$4	$5

* Relative to baseline technology.
Source(s): U.S. Department of Energy (DOE)-Office of Codes and Standards. 1997. "Technical Support Document for Energy Conservation Standards for Room Air Conditioners, Volume 2 – Detailed Analysis of Efficiency Levels (Docket Numbers EE-RM-90-201 & EM-RM-93-801-RAC)." Washington, DC. September, 1997.

Sector: Residential
End Use: Refrigeration
Product: Refrigerator-freezer
Lifetime (years): 19

Baseline Technology: Top-mount auto-defrost refrigerator-freezer, 21.4 cu.ft. adjusted volume, using 484 kWh/year
Baseline Installed Cost in 2010: $603
Baseline Annual Energy Consumption: 484 kWh
Baseline Life Cycle Cost in 2010: $1,046

	Technology for 2010 Standard	**Technology for 2020 Standard**
Description	437 kWh/yr	Same as 2010
Increase in end user installed* ($)	$27	$23
Annual energy savings* (kWh)	48	48
CCE (¢/kWh)	4.9	4.2
Decrease in LCC* ($)	$17	$21

* Relative to baseline technology.

Notes:

Source(s): U.S. Department of Energy (DOE)-Office of Codes and Standards. 1995. "Technical Support Document: Energy Efficiency Standards for Consumer Products: Refrigerators, Refrigerator-Freezers, & Freezers." Washington, DC. DOE/EE-0064. July, 1995.

Sector: Residential
End Use: Water heating
Product: Electric water heater
Lifetime (years): 14

Baseline Technology: 90 Energy Factor (EF), 50 gallon nominal
Baseline Installed Cost in 2010: $491
Baseline Annual Energy Consumption: 3275 kWh
Baseline Life Cycle Cost in 2020: $1,046

	Technology for 2010 Standard	**Technology for 2020 Standard**
Description	None	Heat pump
Increase in end user installed cost* ($)	N/A	$753
Annual energy savings* (kWh)	N/A	2097
CCE (¢/kWh)	N/A	3.9
Decrease in LCC* ($)	N/A	$865

* Relative to baseline technology.

Notes:
Heat PumpWater Heater Price - D & R International - ENERGY STAR Labeling Potential for Water Heaters - DOE April 4, 2003.

Source(s): U.S. Department of Energy (DOE)-Office of Codes and Standards. 2001. "Technical Support Document: Energy Efficiency Standards for Consumer Products: Residential Water Heaters." Washington, DC. January, 2001.

Sector: Residential
End Use: Dishwashing
Product: Dishwasher
Lifetime (years): 12.6

Baseline Technology: 2.14 kWh/cycle
Baseline Equipment Cost in 2010: $332
Baseline Annual Energy Consumption: 535 kWh
Baseline Life Cycle Cost in 2010: $620

	Technology for 2010 Standard	**Technology for 2020 Standard**
Description	1.96 kWh/cycle	Same as 2010
Increase in end user first cost* ($)	$17	$15
Annual energy savings* (kWh)	52	52
CCE (¢/kWh)	3.6	3.1
Decrease in LCC* ($)	$8	$10

* Relative to baseline technology.

Notes:
Annual energy consumption and savings includes associated water heater energy use assuming gas water heater efficiency of 75% and market share of 55%. Although we present the energy in kWh, the values include gas and electricity use. The CCE includes the energy savings from reduced water heating.

Source: Biermayer, P. Energy and Water Saving Potential of Dishwashers and Clothes Washers: An Update. 1996 ACEEE Summer Study on Building Energy Efficiency.

Sector: Residential
End Use: Lighting
Product: Torchiere
Lifetime (years): 4.5

Baseline Technology: Incandescent lamp
Baseline Equipment Cost in 2010: $17
Baseline Annual Energy Consumption: 209 kWh
Baseline Life Cycle Cost in 2010: $81

	Technology for 2010 Standard	**Technology for 2020 Standard**
Description	Fluorescent lamp	Same as 2010
Increase in end user first cost* ($)	$30	$26
Annual energy savings* (kWh)	123	123
CCE (¢/kWh)	6.8	5.9
Decrease in LCC* ($)	$6	$10

* Relative to baseline technology.

Notes:
Base case assumes that halogen lamps are phased out by 2010. Incremental cost includes purchase of a replacement CFL and replacement of incandescent lamps during the lifetime of the torchiere.

Source(s): Unpublished analysis done by LNBL in 2003. Data inputs were from industry sources.

Sector: Residential
End Use: Other Electricity - Electronics
Product: Audio
Lifetime (years): 7

Baseline Technology: 3 W Standby Rack/Component System and 10 W Standby Compact System
Baseline Annual Energy Consumption**:** 121 kWh

	Technology for 2010 Standard	**Technology for 2020 Standard**
Description	1 W Standby	Same as 2010
Increase in end user first cost* ($)	$2	$2
Annual energy savings* (kWh)	30	30
CCE (¢/kWh)	1.2	1.0
Decrease in LCC* ($)	$12	$12

* Relative to baseline technology.

Notes:
The values given are stock-weighted averages for rack/component and compact audio systems. Incremental equipment cost of $2 is from Clean Energy Futures report – assumes that most savings come from circuit redesign during the normal design phase (at negligible cost) plus an improved power supply.

Audio products included account for an estimated 18% of energy use in Other Electricity category.

Source(s): Usage, power, equipment lifetime and shipments from Rosen and Meier – "Energy Use of Home Audio Products in the U.S.", LBNL-43468. Stock quantities are from DOE FY 2005 Preliminary Priority-Setting Summary Report, Appendix A: FY 2005 Technical Support Document.

Sector: Residential
End Use: Other Electricity - Electronics
Product: Settop Boxes
Lifetime (years): 10

Baseline Technology: High Standby Power
Baseline Annual Energy Consumption: 184 kWh

	Technology for 2010 Standard	**Technology for 2020 Standard**
Description	7W Standby	Same as 2010
Increase in end user first cost* ($)	$2	$2
Annual energy savings* (kWh)	95	95
CCE (¢/kWh)	0.3	0.2
Decrease in LCC* ($)	$55	$55

* Relative to baseline technology.

Notes:

The values given are shipment-weighted averages over digital and wireless settop boxes. Analog settop boxes are assumed to be phased out before 2010. Incremental equipment cost of $2 is from Clean Energy Futures report – assumes that most savings come from circuit redesign during the normal design phase (at negligible cost) plus an improved power supply.

Product accounts for estimated 8% of energy use in Other Electric category.

Source(s): Usage, power, equipment lifetime and shipments from Rosen et al (2001), "Energy Use of Set-top boxes and Telephone Products in the U.S.," LBNL-45305. Stock quantities are from DOE FY 2005 Preliminary Priority-Setting Summary Report, Appendix A: FY 2005 Technical Support Document.

Sector: Residential
End Use: Other Electricity - Electronics
Product: Telephony
Lifetime (years): 8

Baseline Technology: 3W Standby Power
Baseline Annual Energy Consumption: 31 kWh

	Technology for 2010 Standard	Technology for 2020 Standard
Description	1W Standby Power	Same as 2010
Increase in end user first cost* ($)	$2	$2
Annual energy savings* (kWh)	8	8
CCE (¢/kWh)	4.0	3.5
Decrease in LCC* ($)	$2	$2

* Relative to baseline technology.

Notes:
The values given are averages over answering machines and cordless phones. Incremental equipment cost of $2 from the Clean Energy Futures report – assumes that most savings come from circuit redesign during the normal design phase (at negligible cost) plus an improved power supply.
Product accounts for estimated 3.1% of energy use in Other Electric category.

Sources: Energy consumption from Sanchez et al (1998), "Miscellaneous Electricity Use in U.S. Homes", LBNL-40295. Equipment lifetime is from *Appliance,* September 1998 (average of answering machine and cordless phone)

Sector: Residential
End Use: Other Electricity - Electronics
Product: Microwave Oven
Lifetime (years): 12

Baseline Technology: 3W Standby Power
Baseline Annual Energy Consumption: 120 kWh

	Technology for 2010 Standard	Technology for 2020 Standard
Description	1W Standby Power	Same as 2010
Increase in end user first cost* ($)	$2	$2
Annual energy savings* (kWh)	81	81
CCE (¢/kWh)	0.3	0.2
Decrease in LCC* ($)	$53	$54

* Relative to baseline technology.

Notes:
Incremental equipment cost of $2 is from Clean Energy Futures report – assumes that most savings come from circuit redesign during the normal design phase (at negligible cost) plus an improved power supply.
Product accounts for estimated 1.9% of energy use in Other Electricity category.

Sources: Energy consumption is from Sanchez et al. (1998), "Miscellaneous Electricity Use in U.S. Homes", LBNL-40295. Equipment lifetime is from *Appliance,* September 1998.

Sector: Residential
End Use: Other Electricity - Electronics
Product: Miscellaneous Electronics
Lifetime (years): 7

Baseline Technology: Current Practice Standby Power
Baseline Annual Energy Consumption: 42 kWh

	Technology for 2010 Standard	Technology for 2020 Standard
Description	1W Standby Power	Same as 2010
Increase in end user first cost* ($)	$2	$2
Annual energy savings* (kWh)	24	24
CCE (¢/kWh)	1.5	1.3
Decrease in LCC* ($)	$9	$9

* Relative to baseline technology.

Notes:

The values given are weighted averages over battery chargers, shavers, electric toothbrushes, hand-held rechargeables, garage door openers, doorbells, security systems, modems, power strips and timers. Weighting is by estimated total national electricity consumption of each product. Incremental equipment cost of $2 is from the Clean Energy Futures report – assumes that most savings come from circuit redesign during the normal design phase (at negligible cost) plus an improved power supply.
Products account for estimated 6.1% of energy use in Other Electricity category.

Sources: Energy consumption is from Sanchez et al (1998), "Miscellaneous Electricity Use in U.S. Homes", LBNL-40295. Equipment lifetime is average over included appliances from *Appliance,* September 1998.

Sector: Residential
End Use: Other Electricity - Motors
Product: Ceiling Fan
Lifetime (years): 15

Baseline Technology: Typical new fan motor efficiency
Baseline Annual Energy Consumption: 164 kWh

	Technology for 2010 Standard	Technology for 2020 Standard
Description	Energy Star Fan	Same as 2010
Increase in end user first cost* ($)	$10	$9
Annual energy savings* (kWh)	30	30
CCE (¢/kWh)	3.4	2.9
Decrease in LCC* ($)	$14	$15

* Relative to baseline technology.

Notes:

Energy savings are from motor efficiency only.

Product accounts for estimated 4.6% of energy use in Other Electricity category.

Source(s): DOE FY 2005 Preliminary Priority-Setting Summary Report, Appendix A: FY 2005 Technical Support Document. Incremental cost is from Clean Energy Futures report. Equipment lifetime is from *Appliance,* September 1998.

Sector: Residential
End Use: Other Electricity - Motors
Product: Pool Pump
Lifetime (years): 10

Baseline Technology: Single-speed pump motor
Baseline Annual Energy Consumption: 725 kWh

	Technology for 2010 Standard	**Technology for 2020 Standard**
Description	Dual-speed motor	Same as 2010
Increase in end user first cost* ($)	$100	$86
Annual energy savings* (kWh)	363	363
CCE (¢/kWh)	3.7	3.2
Decrease in LCC* ($)	$116	$130

* Relative to baseline technology.

Product accounts for estimated 4.3% of energy use in Other Electricity category.

Source(s): Baseline energy consumption is from Department of Energy, Office of Building Research and Standards – *2002 Priority Setting for New Products*, October 2001. Equipment lifetime, standards energy savings, and incremental cost are from Pacific Gas and Electric Company – *Analysis of Standards Options for Residential Pool Pumps, Motors and Controls*, May 2004.

Commercial Sector Products

Sector: Commercial
End Use: Space Heating
Product: Packaged Boiler, Gas-Fired, Hot Water (400 kBtu/hr)
Lifetime (years): 30

Baseline Technology: 75% thermal efficiency
Baseline Installed Cost in 2010: $4,886
Baseline Annual Energy Consumption: 408 MMBtu
Baseline Life Cycle Cost in 2010: $41,867

	Technology for 2010 Standard	**Technology for 2020 Standard**
Description	79% thermal efficiency	Same as 2010
Increase in end user first cost* ($)	$291	$250
Annual energy savings* (MMBtu)	25.7	25.7
CCE ($/MMBtu)	$1.03	$0.89
Decrease in LCC* ($)	$1581	$1811

* Relative to baseline technology.

Notes: This product accounts for about 7% of the furnaces and boiler market for commercial space heating and covers about 11% of the commercial floor space heating.

Source(s): U.S. Department of Energy (DOE)-Office of Energy Efficiency and Renewable Energy. 2000. "Screening Analysis for EPACT-Covered Commercial HVAC and Water-Heating Equipment, Volume 1 - Main Report and Volume 2 - Appendix Material." Washington, DC. April, 2000. Table 2.4, Table 3.8, Appendix D3-D80.

Sector: Commercial
End Use: Space Heating
Product: Packaged Boiler, Gas-Fired, Hot Water (800 kBtu/hr)
Lifetime (years): 30

Baseline Technology: 75% thermal efficiency
Baseline Installed Cost in 2010: $6,926
Baseline Annual Energy Consumption: 1016 MMBtu
Baseline Life Cycle Cost in 2010: $80,885

	Technology for 2010 Standard	**Technology for 2020 Standard**
Description	78% thermal efficiency	88% thermal efficiency
Increase in end user first cost* ($)	$1405	$8175
Annual energy savings* (MMBtu)	39.1	150.0
CCE ($/MMBtu)	$3.28	$4.97
Decrease in LCC* ($)	$1439	$3853

* Relative to baseline technology.

Notes: This product accounts for about 7% of the furnaces and boiler market for commercial space heating and covers about 12% of the commercial floor space heating.

Source(s): U.S. Department of Energy (DOE)-Office of Energy Efficiency and Renewable Energy. 2000. "Screening Analysis for EPACT-Covered Commercial HVAC and Water-Heating Equipment, Volume 1 - Main Report and Volume 2 - Appendix Material." Washington, DC. April, 2000. Table 2.4, Table 3.8, Appendix D3-D80.

Sector: Commercial
End Use: Space Heating
Product: Packaged Boiler, Gas-Fired, Hot Water (1500 kBtu/hr)
Lifetime (years): 30

Baseline Technology: 75% thermal efficiency
Baseline Installed Cost in 2010: $10,458
Baseline Annual Energy Consumption: 1904 MMBtu
Baseline Life Cycle Cost in 2010: $149,133

	Technology for 2010 Standard	**Technology for 2020 Standard**
Description	88% thermal efficiency	Same as 2010
Increase in end user first cost* ($)	$8354	$7182
Annual energy savings* (MMBtu)	281.3	281.3
CCE ($/MMBtu)	$2.71	$2.33
Decrease in LCC* ($)	$12,132	$15,371

* Relative to baseline technology.

Notes: This product accounts for about 1% of the furnaces and boiler market for commercial space heating and covers about 2% of the commercial floor space heating.

Source(s): U.S. Department of Energy (DOE)-Office of Energy Efficiency and Renewable Energy. 2000. "Screening Analysis for EPACT-Covered Commercial HVAC and Water-Heating Equipment, Volume 1 - Main Report and Volume 2 - Appendix Material." Washington, DC. April, 2000. Table 2.4, Table 3.8, Appendix D3-D80.

Sector: Commercial
End Use: Space Heating
Product: Packaged Boilers, Gas-Fired, Hot Water (3000 kBtu/hr)
Lifetime (years): 30

Baseline Technology: 75% thermal efficiency
Baseline Installed Cost in 2010: $16,894
Baseline Annual Energy Consumption: 3809 kBtu
Baseline Life Cycle Cost in 2010: $294,243

	Technology for 2010 Standard	**Technology for 2020 Standard**
Description	88% thermal efficiency	Same as 2010
Increase in end user first cost* ($)	$10,136	$8714
Annual energy savings* (MMBtu)	562.7	562.7
CCE ($/MMBtu)	$1.64	$1.41
Decrease in LCC* ($)	$30,836	$36,392

* Relative to baseline technology.

Notes: This product accounts for about 0.4% of the furnaces and boiler market for commercial space heating and covers about 0.7% of the commercial floor space heating.

Source(s): U.S. Department of Energy (DOE)-Office of Energy Efficiency and Renewable Energy. 2000. "Screening Analysis for EPACT-Covered Commercial HVAC and Water-Heating Equipment, Volume 1 - Main Report and Volume 2 - Appendix Material." Washington, DC. April, 2000. Table 2.4, Table 3.8, Appendix D3-D80.

Sector: Commercial
End Use: Space Heating
Product: Packaged Boiler, Gas-Fired, Steam (400 kBtu/hr)
Lifetime (years): 30

Baseline Technology: 72% thermal efficiency
Baseline Installed Cost in 2010: $6,715
Baseline Annual Energy Consumption: 529 MMBtu
Baseline Life Cycle Cost in 2010: $45,237

	Technology for 2010 Standard	**Technology for 2020 Standard**
Description	76% thermal efficiency	Same as 2010
Increase in end user first cost* ($)	$1008	$866
Annual energy savings* (MMBtu)	27.8	27.8
CCE ($/MMBtu)	$3.30	$2.84
Decrease in LCC* ($)	$1020	$1366

* Relative to baseline technology.

Notes: This product accounts for about 3% of the furnaces and boiler market for commercial space heating and covers about 5% of the commercial floor space heating.

Source(s): U.S. Department of Energy (DOE)-Office of Energy Efficiency and Renewable Energy. 2000. "Screening Analysis for EPACT-Covered Commercial HVAC and Water-Heating Equipment, Volume 1 - Main Report and Volume 2 - Appendix Material." Washington, DC. April, 2000. Table 2.4, Table 3.8, Appendix D3-D80.

Sector: Commercial
End Use: Space Heating
Product: Packaged Boiler, Gas-Fired, Steam (800 kBtu/hr)
Lifetime (years): 30

Baseline Technology: 72% thermal efficiency
Baseline Installed Cost in 2010: $8,916
Baseline Annual Energy Consumption: 1058 MMBtu
Baseline Life Cycle Cost in 2010: $85,957

	Technology for 2010 Standard	**Technology for 2020 Standard**
Description	76% thermal efficiency	Same as 2010
Increase in end user first cost* ($)	$1783	$1533
Annual energy savings* (MMBtu)	55.9	55.9
CCE ($/MMBtu)	$2.92	$2.51
Decrease in LCC* ($)	$2272	$2931

* Relative to baseline technology.

Notes: This product accounts for about 4% of the furnaces and boiler market for commercial space heating and covers about 7% of the commercial floor space heating.

Source(s): U.S. Department of Energy (DOE)-Office of Energy Efficiency and Renewable Energy. 2000. "Screening Analysis for EPACT-Covered Commercial HVAC and Water-Heating Equipment, Volume 1 - Main Report and Volume 2 - Appendix Material." Washington, DC. April, 2000. Table 2.4, Table 3.8, Appendix D3-D80.

Sector: Commercial
End Use: Space Heating
Product: Packaged Boiler, Gas-Fired, Steam (1500 kBtu/hr)
Lifetime (years): 30

Baseline Technology: 72% thermal efficiency
Baseline Installed Cost in 2010: $15,476
Baseline Annual Energy Consumption: 1983 MMBtu
Baseline Life Cycle Cost in 2010: $159,929

	Technology for 2010 Standard	**Technology for 2020 Standard**
Description	79% thermal efficiency	Same as 2010
Increase in end user first cost* ($)	$6302	$5418
Annual energy savings* (MMBtu)	175.8	175.8
CCE ($/MMBtu)	$3.27	$2.81
Decrease in LCC* ($)	$6498	$8673

* Relative to baseline technology.

Notes: This product accounts for about 1% of the furnaces and boiler market for commercial space heating and covers about 1.6% of the commercial floor space heating.

Source(s): U.S. Department of Energy (DOE)-Office of Energy Efficiency and Renewable Energy. 2000. “Screening Analysis for EPACT-Covered Commercial HVAC and Water-Heating Equipment, Volume 1 - Main Report and Volume 2 - Appendix Material.” Washington, DC. April, 2000. Table 2.4, Table 3.8, Appendix D3-D80.

Sector: Commercial
End Use: Space Heating
Product: Packaged Boiler, Gas-Fired, Steam (3000 kBtu/hr)
Lifetime (years): 30

Baseline Technology: 72% thermal efficiency
Baseline Installed Cost in 2010: $22,173
Baseline Annual Energy Consumption: 3967 MMBtu
Baseline Life Cycle Cost in 2010: $311,079

	Technology for 2010 Standard	**Technology for 2020 Standard**
Description	80% thermal efficiency	Same as 2010
Increase in end user first cost* ($)	$8425	$7244
Annual energy savings* (MMBtu)	396.8	396.8
CCE ($/MMBtu)	$1.94	$1.66
Decrease in LCC* ($)	$20,465	$24,562

* Relative to baseline technology.

Notes: This product accounts for about 0.3% of the furnaces and boiler market for commercial space heating and covers about 0.5% of the commercial floor space heating.

Source(s): U.S. Department of Energy (DOE)-Office of Energy Efficiency and Renewable Energy. 2000. “Screening Analysis for EPACT-Covered Commercial HVAC and Water-Heating Equipment, Volume 1 -

Main Report and Volume 2 - Appendix Material." Washington, DC. April, 2000. Table 2.4, Table 3.8, Appendix D3-D80.

Sector: Commercial
End Use: Space Heating
Product: Warm-Air Furnace, Gas-Fired (250 kBtu/hr)
Lifetime (years): 15

Baseline Technology: 78% thermal efficiency
Baseline Installed Cost in 2010: $7,835
Baseline Annual Energy Consumption: 224 MMBtu
Baseline Life Cycle Cost in 2010: $24,179

	Technology for 2010 Standard	**Technology for 2020 Standard**
Description	80% thermal efficiency	Same as 2010
Increase in end user first cost* ($)	$403	$347
Annual energy savings* (MMBtu)	5.6	5.6
CCE ($/MMBtu)	$6.52	$5.60
Decrease in LCC* ($)	$8	$106

* Relative to baseline technology.

Notes: This product accounts for about 46% of the furnaces and boiler market for commercial space heating and covers about 19% of the commercial floor space heating.

Source(s): U.S. Department of Energy (DOE)-Office of Energy Efficiency and Renewable Energy. 2000. "Screening Analysis for EPACT-Covered Commercial HVAC and Water-Heating Equipment, Volume 1 - Main Report and Volume 2 - Appendix Material." Washington, DC. April, 2000. Table 2.4, Table 3.8, Appendix D3-D80.

Sector: Commercial
End Use: Space Heating
Product: Warm-Air Furnace, Gas-Fired (400 kBtu/hr)
Lifetime (years): 15

Baseline Technology: 78% thermal efficiency
Baseline Installed Cost in 2010: $11,712
Baseline Annual Energy Consumption: 359 MMBtu
Baseline Life Cycle Cost in 2010: $37,863

	Technology for 2010 Standard	**Technology for 2020 Standard**
Description	80% thermal efficiency	Same as 2010
Increase in end user first cost* ($)	$510	$438
Annual energy savings* (MMBtu)	9.0	9.0
CCE ($/MMBtu)	$5.14	$4.42
Decrease in LCC* ($)	$148	$286

* Relative to baseline technology.

Notes: This product accounts for about 30% of the furnaces and boiler market for commercial space heating and covers about 12% of the commercial floor space heating.

Source(s): U.S. Department of Energy (DOE)-Office of Energy Efficiency and Renewable Energy. 2000. "Screening Analysis for EPACT-Covered Commercial HVAC and Water-Heating Equipment, Volume 1 -

Main Report and Volume 2 - Appendix Material." Washington, DC. April, 2000. Table 2.4, Table 3.8, Appendix D3-D80.

Sector: Commercial
End Use: Air Conditioning
Product: 3-Phase, Single-Package, Air-Source AC (<65 kBtu/h)
Lifetime (years): 15

Baseline Technology: 9.7 SEER
Baseline Installed Cost in 2010: $2,618
Baseline Annual Energy Consumption: 10,036 kWh
Baseline Life Cycle Cost in 2010: $11,062

	Technology for 2010 Standard	Technology for 2020 Standard
Description	12 SEER	Same as 2010
Increase in end user first cost* ($)	$785	$675
Annual energy savings* (kWh)	1924	1924
CCE (¢/kWh)	4.2	3.6
Decrease in LCC* ($)	$833	$1008

* Relative to baseline technology.

Notes: This product accounts for about 7% of the air-conditioning market for commercial space cooling and covers about 9% of the commercial floor space cooling.

Source(s): U.S. Department of Energy (DOE)-Office of Energy Efficiency and Renewable Energy. 2000. "Screening Analysis for EPACT-Covered Commercial HVAC and Water-Heating Equipment, Volume 1 - Main Report and Volume 2 - Appendix Material." Washington, DC. April, 2000. Table 2.5, Table 3.8, Appendix D3-D80.

Sector: Commercial
End Use: Air Conditioning
Product: 3-Phase, Split-System, Air-Source AC (<65 kBtu/h)
Lifetime (years): 15

Baseline Technology: 10 SEER
Baseline Installed Cost in 2010: $2,666
Baseline Annual Energy Consumption: 9735 kWh
Baseline Life Cycle Cost in 2010: $10,857

	Technology for 2010 Standard	Technology for 2020 Standard
Description	12 SEER	Same as 2010
Increase in end user first cost* ($)	$960	$826
Annual energy savings* (kWh)	1623	1623
CCE (¢/kWh)	6.0	5.2
Decrease in LCC* ($)	$405	$594

* Relative to baseline technology.

Notes: This product accounts for about 12% of the air-conditioning market for commercial space cooling and covers about 16% of the commercial floor space cooling.

Source(s): U.S. Department of Energy (DOE)-Office of Energy Efficiency and Renewable Energy. 2000. "Screening Analysis for EPACT-Covered Commercial HVAC and Water-Heating Equipment, Volume 1 -

Main Report and Volume 2 - Appendix Material." Washington, DC. April, 2000. Table 2.5, Table 3.8, Appendix D3-D80.

Sector: Commercial
End Use: Air Conditioning
Product: 3-Phase, Single-Package, Air-Source Heat Pump (<65 kBtu/h)
Lifetime (years): 15

Baseline Technology: 9.7 SEER
Baseline Installed Cost in 2010: $3,092
Baseline Annual Energy Consumption: 10,036 kWh
Baseline Life Cycle Cost in 2010: $11,536

	Technology for 2010 Standard	**Technology for 2020 Standard**
Description	12 SEER	Same as 2010
Increase in end user first cost* ($)	$865	$744
Annual energy savings* (kWh)	1924	1924
CCE (¢/kWh)	4.6	3.9
Decrease in LCC* ($)	$753	$940

* Relative to baseline technology.

Notes: This product accounts for about 1.3% of the air-conditioning market for commercial space cooling and covers about 2% of the commercial floor space cooling.

Source(s): U.S. Department of Energy (DOE)-Office of Energy Efficiency and Renewable Energy. 2000. "Screening Analysis for EPACT-Covered Commercial HVAC and Water-Heating Equipment, Volume 1 - Main Report and Volume 2 - Appendix Material." Washington, DC. April, 2000. Table 2.5, Table 3.8, Appendix D3-D80.

Sector: Commercial
End Use: Air Conditioning
Product: 3-Phase, Split-System, Air-Source Heat Pump (<65 kBtu/h)
Lifetime (years): 15

Baseline Technology: 10 SEER
Baseline Installed Cost in 2010: $2,612
Baseline Annual Energy Consumption: 9,735 kWh
Baseline Life Cycle Cost in 2010: $10,803

	Technology for 2010 Standard	**Technology for 2020 Standard**
Description	13 SEER	Same as 2010
Increase in end user first cost* ($)	$1149	$988
Annual energy savings* (kWh)	2247	2247
CCE (¢/kWh)	5.2	4.5
Decrease in LCC* ($)	$741	$978

* Relative to baseline technology.

Notes: This product accounts for about 6% of the air-conditioning market for commercial space cooling and covers about 7.5% of the commercial floor space cooling.

Source(s): U.S. Department of Energy (DOE)-Office of Energy Efficiency and Renewable Energy. 2000. "Screening Analysis for EPACT-Covered Commercial HVAC and Water-Heating Equipment, Volume 1 - Main Report and Volume 2 - Appendix Material." Washington, DC. April, 2000. Table 2.5, Table 3.8, Appendix D3-D80.

Sector: Commercial
End Use: Air Conditioning
Product: Central, Air-Source AC (>65 and <135 kBtu/h)
Lifetime (years): 15

Baseline Technology: 10.1 EER
Baseline Installed Cost in 2010: $6,732
Baseline Annual Energy Consumption: 16,079 kWh
Baseline Life Cycle Cost in 2010: $19,677

	Technology for 2010 Standard	**Technology for 2020 Standard**
Description	11.5 EER	12.0 EER
Increase in end user first cost* ($)	$555	$982
Annual energy savings* (kWh)	1769	2251
CCE (¢/kWh)	3.2	4.5
Decrease in LCC* ($)	$887	$1001

* Relative to baseline technology.

Notes: This product accounts for about 11% of the air-conditioning market for commercial space cooling and covers about 15% of the commercial floor space cooling.

Source(s): U.S. Department of Energy (DOE)-Office of Energy Efficiency and Renewable Energy. 2004. "Commercial Unitary Air Conditioners and Heat Pumps, Energy Conservation Standards Rulemaking, Life Cycle Cost Analysis Spreadsheet Model (Tariff-Based Electricity Prices)." Washington, DC. Product Class: 7.5 tons. <http://www.eere.energy.gov/buildings/appliance_standards/commercial/ac_hp.html>

Sector: Commercial
End Use: Air Conditioning
Product: Central, Air-Source Heat Pump (>65 and <135 kBtu/h)
Lifetime (years): 15

Baseline Technology: 10.1 EER
Baseline Installed Cost in 2010: $6,732
Baseline Annual Energy Consumption: 16,079 kWh
Baseline Life Cycle Cost in 2010: $19,677

	Technology for 2010 Standard	**Technology for 2020 Standard**
Description	11.5 EER	12.0 EER
Increase in end user first cost* ($)	$555	$982
Annual energy savings* (kWh)	1769	2251
CCE (¢/kWh)	3.2	4.5
Decrease in LCC* ($)	$887	$1001

* Relative to baseline technology.

Notes: This product accounts for about 1% of the air-conditioning market for commercial space cooling and covers about 1% of the commercial floor space cooling.

Source(s): U.S. Department of Energy (DOE)-Office of Energy Efficiency and Renewable Energy. 2004. "Commercial Unitary Air Conditioners and Heat Pumps, Energy Conservation Standards Rulemaking, Life Cycle Cost Analysis Spreadsheet Model (Tariff-Based Electricity Prices)." Washington, DC. Product Class: 7.5 tons. <http://www.eere.energy.gov/buildings/appliance_standards/commercial/ac_hp.html>

Sector: Commercial
End Use: Air Conditioning
Product: Central, Water-Source Heat Pump (>65 and <135 kBtu/h)
Lifetime (years): 19

Baseline Technology: 12 EER
Baseline Installed Cost in 2010: $3,984
Baseline Annual Energy Consumption: 11,528 kWh
Baseline Life Cycle Cost in 2010: $13,684

	Technology for 2010 Standard	**Technology for 2020 Standard**
Description	12.5 EER	13.0 EER
Increase in end user first cost* ($)	$324	$644
Annual energy savings* (kWh)	461	887
CCE (¢/kWh)	7.2	7.4
Decrease in LCC* ($)	$64	$132

* Relative to baseline technology.

Notes: This product accounts for about 9% of the air-conditioning market for commercial space cooling and covers about 11% of the commercial floor space cooling.

Source(s): U.S. Department of Energy (DOE)-Office of Energy Efficiency and Renewable Energy. 2000. "Screening Analysis for EPACT-Covered Commercial HVAC and Water-Heating Equipment, Volume 1 - Main Report and Volume 2 - Appendix Material." Washington, DC. April, 2000. Table 2.5, Table 3.8, Appendix D3-D80.

Sector: Commercial
End Use: Air Conditioning
Product: Central, Water-Cooled AC (>65 and <135 kBtu/h)
Lifetime (years): 19

Baseline Technology: 11.5 EER
Baseline Installed Cost in 2010: $4,118
Baseline Annual Energy Consumption: 12,029 kWh
Baseline Life Cycle Cost in 2010: $14,240

	Technology for 2010 Standard	**Technology for 2020 Standard**
Description	12.4 EER	14.0 EER
Increase in end user first cost* ($)	$508	$1445
Annual energy savings* (kWh)	873	2148
CCE (¢/kWh)	5.9	6.9
Decrease in LCC* ($)	$227	$435

* Relative to baseline technology.

Notes: This product accounts for less than 1% of the air-conditioning market for commercial space cooling and covers less than 1% of the commercial floor space cooling.

Source(s): U.S. Department of Energy (DOE)-Office of Energy Efficiency and Renewable Energy. 2000. “Screening Analysis for EPACT-Covered Commercial HVAC and Water-Heating Equipment, Volume 1 - Main Report and Volume 2 - Appendix Material.” Washington, DC. April, 2000. Table 2.5, Table 3.8, Appendix D3-D80.
Sector: Commercial
End Use: Air Conditioning
Product: Central, Air-Source AC (>135 and <240 kBtu/h)
Lifetime (years): 15

Baseline Technology: 9.5 EER
Baseline Installed Cost in 2010: $11,812
Baseline Annual Energy Consumption: 33,953 kWh
Baseline Life Cycle Cost in 2010: $39,356

	Technology for 2010 Standard	**Technology for 2020 Standard**
Description	11.5 EER	12.0 EER
Increase in end user first cost* ($)	$1357	$2173
Annual energy savings* (kWh)	5220	6239
CCE (¢/kWh)	2.7	3.6
Decrease in LCC* ($)	$2879	$3213

* Relative to baseline technology.

Notes: This product accounts for about 8% of the air-conditioning market for commercial space cooling and covers about 11% of the commercial floor space cooling.

Source(s): U.S. Department of Energy (DOE)-Office of Energy Efficiency and Renewable Energy. 2004. “Commercial Unitary Air Conditioners and Heat Pumps, Energy Conservation Standards Rulemaking, Life Cycle Cost Analysis Spreadsheet Model (Tariff-Based Electricity Prices).” Washington, DC. Product Class: 7.5 tons. <http://www.eere.energy.gov/buildings/appliance_standards/commercial/ac_hp.html>

Sector: Commercial
End Use: Air Conditioning
Product: Central, Air-Source Heat Pump (>135 and <240 kBtu/h)
Lifetime (years): 15

Baseline Technology: 9.5 EER
Baseline Installed Cost in 2010: $11,812
Baseline Annual Energy Consumption: 33,953 kWh
Baseline Life Cycle Cost in 2010: $39,356

	Technology for 2010 Standard	**Technology for 2020 Standard**
Description	11.5 EER	12.0 EER
Increase in end user first cost* ($)	$1357	$2173
Annual energy savings* (kWh)	5220	6239
CCE (¢/kWh)	2.7	3.6
Decrease in LCC* ($)	$2879	$3213

* Relative to baseline technology.

Notes: This product accounts for less than 1% of the air-conditioning market for commercial space cooling and covers less than 1% of the commercial floor space cooling.

Source(s): U.S. Department of Energy (DOE)-Office of Energy Efficiency and Renewable Energy. 2004. "Commercial Unitary Air Conditioners and Heat Pumps, Energy Conservation Standards Rulemaking, Life Cycle Cost Analysis Spreadsheet Model (Tariff-Based Electricity Prices)." Washington, DC. Product Class: 7.5 tons. <http://www.eere.energy.gov/buildings/appliance_standards/commercial/ac_hp.html>
Sector: Commercial
End Use: Air Conditioning
Product: Central, Water-Cooled AC (>135 and <240 kBtu/h)
Lifetime (years): 19

Baseline Technology: 11 EER
Baseline Installed Cost in 2010: $9,632
Baseline Annual Energy Consumption: 25,152 kWh
Baseline Life Cycle Cost in 2010: $30,795

	Technology for 2010 Standard	**Technology for 2020 Standard**
Description	11.5 EER	Same as 2010
Increase in end user first cost* ($)	$309	$266
Annual energy savings* (kWh)	1094	1094
CCE (¢/kWh)	2.9	2.5
Decrease in LCC* ($)	$611	$691

* Relative to baseline technology.

Notes: This product accounts for less than 1% of the air-conditioning market for commercial space cooling and covers less than 1% of the commercial floor space cooling.

Source(s): U.S. Department of Energy (DOE)-Office of Energy Efficiency and Renewable Energy. 2000. "Screening Analysis for EPACT-Covered Commercial HVAC and Water-Heating Equipment, Volume 1 - Main Report and Volume 2 - Appendix Material." Washington, DC. April, 2000. Table 2.5, Table 3.8, Appendix D3-D80.

Sector: Commercial
End Use: Air Conditioning
Product: Central, Water-Cooled AC (<65 kBtu/h)
Lifetime (years): 19

Baseline Technology: 12.1 EER
Baseline Installed Cost in 2010: $4,396
Baseline Annual Energy Consumption: 8,045 kWh
Baseline Life Cycle Cost in 2010: $11,165

	Technology for 2010 Standard	**Technology for 2020 Standard**
Description	12.1 EER	12.5 EER
Increase in end user first cost* ($)	N/A	$190
Annual energy savings* (kWh)	N/A	257
CCE (¢/kWh)	N/A	7.5
Decrease in LCC* ($)	N/A	$36

* Relative to baseline technology.

Notes: This product accounts for less than 1% of the air-conditioning market for commercial space cooling and covers less than 1% of the commercial floor space cooling.

Source(s): U.S. Department of Energy (DOE)-Office of Energy Efficiency and Renewable Energy. 2000. “Screening Analysis for EPACT-Covered Commercial HVAC and Water-Heating Equipment, Volume 1 - Main Report and Volume 2 - Appendix Material.” Washington, DC. April, 2000. Table 2.5, Table 3.8, Appendix D3-D80.

Sector: Commercial
End Use: Air Conditioning
Product: Central, Water-Source Heat Pump (<17 kBtu/h)
Lifetime (years): 19

Baseline Technology: 11.2 EER
Baseline Installed Cost in 2010: $876
Baseline Annual Energy Consumption: 1,738 kWh
Baseline Life Cycle Cost in 2010: $2,338

	Technology for 2010 Standard	**Technology for 2020 Standard**
Description	11.2 EER	12.5 EER
Increase in end user first cost* ($)	N/A	$139
Annual energy savings* (kWh)	N/A	181
CCE (¢/kWh)	N/A	7.8
Decrease in LCC* ($)	N/A	$19

* Relative to baseline technology.

Notes: This product accounts for about 1% of the air-conditioning market for commercial space cooling and covers about 1% of the commercial floor space cooling.

Source(s): U.S. Department of Energy (DOE)-Office of Energy Efficiency and Renewable Energy. 2000. “Screening Analysis for EPACT-Covered Commercial HVAC and Water-Heating Equipment, Volume 1 - Main Report and Volume 2 - Appendix Material.” Washington, DC. April, 2000. Table 2.5, Table 3.8, Appendix D3-D80.

Sector: Commercial
End Use: Air Conditioning
Product: Central, Water-Source Heat Pump (>17 and <65 kBtu/h)
Lifetime (years): 19

Baseline Technology: 12 EER
Baseline Installed Cost in 2010: $1,346
Baseline Annual Energy Consumption: 4,867 kWh
Baseline Life Cycle Cost in 2010: $5,442

	Technology for 2010 Standard	**Technology for 2020 Standard**
Description	13.1 EER	Same as 2010
Increase in end user first cost* ($)	$286	$246
Annual energy savings* (kWh)	409	409
CCE (¢/kWh)	7.1	6.1
Decrease in LCC* ($)	$58	$112

* Relative to baseline technology.

Notes: This product accounts for about 1% of the air-conditioning market for commercial space cooling and covers about 1% of the commercial floor space cooling.

Source(s): U.S. Department of Energy (DOE)-Office of Energy Efficiency and Renewable Energy. 2000. "Screening Analysis for EPACT-Covered Commercial HVAC and Water-Heating Equipment, Volume 1 - Main Report and Volume 2 - Appendix Material." Washington, DC. April, 2000. Table 2.5, Table 3.8, Appendix D3-D80.

Sector: Commercial
End Use: Air Conditioning
Product: Packaged Terminal Air Conditioner (PTAC) (<7 kBtu/h)
Lifetime (years): 15

Baseline Technology: 9.4 EER
Baseline Installed Cost in 2010: $734
Baseline Annual Energy Consumption: 1331 kWh
Baseline Life Cycle Cost in 2010: $1,854

Description	**Technology for 2010 Standard** 11 EER	**Technology for 2020 Standard** Same as 2010
Increase in end user first cost* ($)	$110	$95
Annual energy savings* (kWh)	194	194
CCE (¢/kWh)	5.8	5.0
Decrease in LCC* ($)	$53	$75
* Relative to baseline technology.		

Notes: This product accounts for about 4% of the packaged terminal air-conditioning market and covers less than 1% of the commercial floor space cooling.

Source(s): U.S. Department of Energy (DOE)-Office of Energy Efficiency and Renewable Energy. 2000. "Screening Analysis for EPACT-Covered Commercial HVAC and Water-Heating Equipment, Volume 1 - Main Report and Volume 2 - Appendix Material." Washington, DC. April, 2000. Table 2.5, Table 3.8, Appendix D3-D80.

Sector: Commercial
End Use: Air Conditioning
Product: Packaged Terminal Air Conditioner (PTAC) (7-10 kBtu/h)
Lifetime (years): 15

Baseline Technology: 9 EER
Baseline Installed Cost in 2010: $807
Baseline Annual Energy Consumption: 1688 kWh
Baseline Life Cycle Cost in 2010: $2,227

Description	**Technology for 2010 Standard** 10.8 EER	**Technology for 2020 Standard** Same as 2010
Increase in end user first cost* ($)	$105	$91
Annual energy savings* (kWh)	281	281
CCE (¢/kWh)	3.8	3.3
Decrease in LCC* ($)	$131	$
156		

* Relative to baseline technology.

Notes: This product accounts for about 20% of the packaged terminal air-conditioning market and covers 1.4% of the commercial floor space cooling.

Source(s): U.S. Department of Energy (DOE)-Office of Energy Efficiency and Renewable Energy. 2000. "Screening Analysis for EPACT-Covered Commercial HVAC and Water-Heating Equipment, Volume 1 - Main Report and Volume 2 - Appendix Material." Washington, DC. April, 2000. Table 2.5, Table 3.8, Appendix D3-D80.

Sector: Commercial
End Use: Air Conditioning
Product: Packaged Terminal Air Conditioner (PTAC) (10-13 kBtu/h)
Lifetime (years): 15

Baseline Technology: 8.3 EER
Baseline Installed Cost in 2010: $716
Baseline Annual Energy Consumption: 2476 kWh
Baseline Life Cycle Cost in 2010: $2,800

	Technology for 2010	Technology for 2020
Description	**Standard** 10.5 EER	**Standard** Same as 2010
Increase in end user first cost* ($)	$211	$181
Annual energy savings* (kWh)	519	519
CCE (¢/kWh)	4.1	3.6
Decrease in LCC* ($)	$226	$273
* Relative to baseline technology.		

Notes: This product accounts for about 21% of the packaged terminal air-conditioning market and covers 1.5% of the commercial floor space cooling.

Source(s): U.S. Department of Energy (DOE)-Office of Energy Efficiency and Renewable Energy. 2000. "Screening Analysis for EPACT-Covered Commercial HVAC and Water-Heating Equipment, Volume 1 - Main Report and Volume 2 - Appendix Material." Washington, DC. April, 2000. Table 2.5, Table 3.8, Appendix D3-D80.

Sector: Commercial
End Use: Air Conditioning
Product: Packaged Terminal Air Conditioner (PTAC) (>13 kBtu/h)
Lifetime (years): 15

Baseline Technology: 7.9 EER
Baseline Installed Cost in 2010: $887
Baseline Annual Energy Consumption: 3168 kWh
Baseline Life Cycle Cost in 2010: $3,552

	Technology for 2010	Technology for 2020
Description	**Standard** 10 EER	**Standard** Same as 2010
Increase in end user first cost* ($)	$126	$108
Annual energy savings* (kWh)	665	665
CCE (¢/kWh)	1.9	1.7

Decrease in LCC* ($)	$434	$474

* Relative to baseline technology.

Notes: This product accounts for about 9% of the packaged terminal air-conditioning market and covers 0.7% of the commercial floor space cooling.

Source(s): U.S. Department of Energy (DOE)-Office of Energy Efficiency and Renewable Energy. 2000. "Screening Analysis for EPACT-Covered Commercial HVAC and Water-Heating Equipment, Volume 1 - Main Report and Volume 2 - Appendix Material." Washington, DC. April, 2000. Table 2.5, Table 3.8, Appendix D3-D80.

Sector: Commercial
End Use: Air Conditioning
Product: Packaged Terminal Heat Pump (PTHP) (<7 kBtu/h)
Lifetime (years): 15

Baseline Technology: 9.3 EER
Baseline Installed Cost in 2010: $810
Baseline Annual Energy Consumption: 1345 kWh
Baseline Life Cycle Cost in 2010: $1,942

	Technology for 2010 Standard	**Technology for 2020 Standard**
Description	10.8 EER	Same as 2010
Increase in end user first cost* ($)	$107	$92
Annual energy savings* (kWh)	187	187
CCE (¢/kWh)	5.8	5.0
Decrease in LCC* ($)	$50	$71

* Relative to baseline technology.

Notes: This product accounts for about 3% of the packaged terminal air-conditioning market and covers 0.2% of the commercial floor space cooling.

Source(s): U.S. Department of Energy (DOE)-Office of Energy Efficiency and Renewable Energy. 2000. "Screening Analysis for EPACT-Covered Commercial HVAC and Water-Heating Equipment, Volume 1 - Main Report and Volume 2 - Appendix Material." Washington, DC. April, 2000. Table 2.5, Table 3.8, Appendix D3-D80.

Sector: Commercial
End Use: Air Conditioning
Product: Packaged Terminal Heat Pump (PTHP) (7-10 kBtu/h)
Lifetime (years): 15

Baseline Technology: 8.9 EER
Baseline Installed Cost in 2010: $895
Baseline Annual Energy Consumption: 1707 kWh
Baseline Life Cycle Cost in 2010: $2,331

	Technology for 2010 Standard	**Technology for 2020 Standard**
Description	10.6 EER	11.4 EER
Increase in end user first cost* ($)	$93	$164
Annual energy savings* (kWh)	274	374

CCE (¢/kWh)	3.4	4.5
Decrease in LCC* ($)	$138	$164

* Relative to baseline technology.

Notes: This product accounts for about 19% of the packaged terminal air-conditioning market and covers 1.4% of the commercial floor space cooling.

Source(s): U.S. Department of Energy (DOE)-Office of Energy Efficiency and Renewable Energy. 2000. "Screening Analysis for EPACT-Covered Commercial HVAC and Water-Heating Equipment, Volume 1 - Main Report and Volume 2 - Appendix Material." Washington, DC. April, 2000. Table 2.5, Table 3.8, Appendix D3-D80.

Sector: Commercial
End Use: Air Conditioning
Product: Packaged Terminal Heat Pump (PTHP) (10-13 kBtu/h)
Lifetime (years): 15

Baseline Technology: 8.2 EER
Baseline Installed Cost in 2010: $777
Baseline Annual Energy Consumption: 2507 kWh
Baseline Life Cycle Cost in 2010: $2,887

	Technology for 2010 Standard	**Technology for 2020 Standard**
Description	9.7 EER	Same as 2010
Increase in end user first cost* ($)	$108	$93
Annual energy savings* (kWh)	388	388
CCE (¢/kWh)	2.8	2.4
Decrease in LCC* ($)	$218	$246

* Relative to baseline technology.

Notes: This product accounts for about 16% of the packaged terminal air-conditioning market and covers 1.1% of the commercial floor space cooling.

Source(s): U.S. Department of Energy (DOE)-Office of Energy Efficiency and Renewable Energy. 2000. "Screening Analysis for EPACT-Covered Commercial HVAC and Water-Heating Equipment, Volume 1 - Main Report and Volume 2 - Appendix Material." Washington, DC. April, 2000. Table 2.5, Table 3.8, Appendix D3-D80.

Sector: Commercial
End Use: Air Conditioning
Product: Packaged Terminal Heat Pump (PTHP) (>13 kBtu/h)
Lifetime (years): 15

Baseline Technology: 7.8 EER
Baseline Installed Cost in 2010: $944
Baseline Annual Energy Consumption: 3208 kWh
Baseline Life Cycle Cost in 2010: $3,643

	Technology for 2010 Standard	**Technology for 2020 Standard**
Description	10 EER	Same as 2010
Increase in end user first cost* ($)	$326	$280

Annual energy savings* (kWh)	706	706
CCE (¢/kWh)	4.7	4.0
Decrease in LCC* ($)	$268	$338

* Relative to baseline technology.

Notes: This product accounts for about 8% of the packaged terminal air-conditioning market and covers 0.6% of the commercial floor space cooling.

Source(s): U.S. Department of Energy (DOE)-Office of Energy Efficiency and Renewable Energy. 2000. "Screening Analysis for EPACT-Covered Commercial HVAC and Water-Heating Equipment, Volume 1 - Main Report and Volume 2 - Appendix Material." Washington, DC. April, 2000. Table 2.5, Table 3.8, Appendix D3-D80.

Sector: Commercial
End Use: Ventilation
Product: Air Distribution, Large Unitary (10 HP)
Lifetime (years): 15

Baseline Technology: 85% efficiency
Baseline Installed Cost in 2010: not available
Baseline Annual Energy Consumption: not available
Baseline Life Cycle Cost in 2010: not available

	Technology for 2010 Standard	**Technology for 2020 Standard**
Description	92%	Same as 2010
Increase in end user first cost* ($)	$84	$72
Annual energy savings* (kWh)	1795	1795
CCE (¢/kWh)	0.5	0.4
Decrease in LCC* ($)	$1042	$1081

* Relative to baseline technology.

Notes: This product accounts for about 4% of the energy consumption by Air Distribution units.

Source(s): Arthur D. Little. 1999. "Opportunities for Energy Savings in the Residential and Commercial Sectors with High Efficiency Electric Motors." Cambridge, MA. December, 1999. Tables 4-3 and 4-4.

Sector: Commercial
End Use: Ventilation
Product: Air Distribution, Exhaust Fan (0.5 HP)
Lifetime (years): 15

Baseline Technology: 60% efficiency
Baseline Installed Cost in 2010: not available
Baseline Annual Energy Consumption: not available
Baseline Life Cycle Cost in 2010: not available

	Technology for 2010 Standard	**Technology for 2020 Standard**
Description	80%	Same as 2010
Increase in end user first cost* ($)	$13	$12
Annual energy savings* (kWh)	710	710
CCE (¢/kWh)	0.2	0.2

Decrease in LCC* ($)	$432	$444

* Relative to baseline technology.

Notes: This product accounts for about 38% of the energy consumption by Air Distribution units

Source(s): Arthur D. Little. 1999. “Opportunities for Energy Savings in the Residential and Commercial Sectors with High Efficiency Electric Motors.” Cambridge, MA. December, 1999. Tables 4-3 and 4-4.

Sector: Commercial
End Use: Ventilation
Product: Air Distribution, Room Fan Coil (0.17 HP)
Lifetime (years): 15

Baseline Technology: 50% efficiency
Baseline Installed Cost in 2010: not available
Baseline Annual Energy Consumption: not available
Baseline Life Cycle Cost in 2010: not available

	Technology for 2010 Standard	**Technology for 2020 Standard**
Description	75%	Same as 2010
Increase in end user first cost* ($)	$12	$10
Annual energy savings* (kWh)	142	142
CCE (¢/kWh)	0.9	0.7
Decrease in LCC* ($)	$77	$81

* Relative to baseline technology.

Notes: This product accounts for about 2% of the energy consumption by Air Distribution units.

Source(s): Arthur D. Little. 1999. "Opportunities for Energy Savings in the Residential and Commercial Sectors with High Efficiency Electric Motors." Cambridge, MA. December, 1999. Tables 4-3 and 4-4.

Sector: Commercial
End Use: Ventilation
Product: Air Distribution, Central Station Air Handling Unit (10 HP)
Lifetime (years): 15

Baseline Technology: 87% efficiency
Baseline Installed Cost in 2010: not available
Baseline Annual Energy Consumption: not available
Baseline Life Cycle Cost in 2010: not available

	Technology for 2010 Standard	**Technology for 2020 Standard**
Description	93%	Same as 2010
Increase in end user first cost* ($)	$84	$72
Annual energy savings* (kWh)	1516	1516
CCE (¢/kWh)	0.6	0.5
Decrease in LCC* ($)	$868	$902

* Relative to baseline technology.

Notes: This product accounts for about 40% of the energy consumption by Air Distribution units.

Source(s): Arthur D. Little. 1999. "Opportunities for Energy Savings in the Residential and Commercial Sectors with High Efficiency Electric Motors." Cambridge, MA. December, 1999. Tables 4-3 and 4-4.

Sector: Commercial

End Use: Ventilation
Product: Hydronic Hot and Chilled Water Circulation, Centrifugal Chiller (25 HP)
Lifetime (years): 23

Baseline Technology: 90% efficiency
Baseline Installed Cost in 2010: not available
Baseline Annual Energy Consumption: not available
Baseline Life Cycle Cost in 2010: not available

	Technology for 2010 Standard	**Technology for 2020 Standard**
Description	95%	Same as 2010
Increase in end user first cost* ($)	$73	$63
Annual energy savings* (kWh)	1111	1111
CCE (¢/kWh)	0.5	0.5
Decrease in LCC* ($)	$789	$820

* Relative to baseline technology.

Notes: This product accounts for about 14% of the energy consumption by Hydronic Hot and Chilled Water Circulation units.

Source(s): Arthur D. Little.1999. "Opportunities for Energy Savings in the Residential and Commercial Sectors with High Efficiency Electric Motors." Cambridge, MA. December, 1999. Tables 4-5 and 4-6.

Sector: Commercial
End Use: Ventilation
Product: Hydronic Hot and Chilled Water Circulation, Screw Chiller (10 HP)
Lifetime (years): 20

Baseline Technology: 90% efficiency
Baseline Installed Cost in 2010: not available
Baseline Annual Energy Consumption: not available
Baseline Life Cycle Cost in 2010: not available

	Technology for 2010 Standard	**Technology for 2020 Standard**
Description	94%	Same as 2010
Increase in end user first cost* ($)	$84	$72
Annual energy savings* (kWh)	500	500
CCE (¢/kWh)	1.4	1.2
Decrease in LCC* ($)	$304	$335

* Relative to baseline technology.

Notes: This product accounts for about 1% of the energy consumption by Hydronic Hot and Chilled Water Circulation units.

Source(s): Arthur D. Little. 1999. "Opportunities for Energy Savings in the Residential and Commercial Sectors with High Efficiency Electric Motors." Cambridge, MA. December, 1999. Tables 4-5 and 4-6.

Sector: Commercial
End Use: Ventilation

Product: Hydronic Hot and Chilled Water Circulation, Reciprocating Chiller (10 HP)
Lifetime (years): 20

Baseline Technology: 88% efficiency
Baseline Installed Cost in 2010: not available
Baseline Annual Energy Consumption: not available
Baseline Life Cycle Cost in 2010: not available

	Technology for 2010 Standard	**Technology for 2020 Standard**
Description	93%	Same as 2010
Increase in end user first cost* ($)	$84	$72
Annual energy savings* (kWh)	476	476
CCE (¢/kWh)	1.5	1.3
Decrease in LCC* ($)	$286	$306

* Relative to baseline technology.

Notes: This product accounts for about 13% of the energy consumption by Hydronic Hot and Chilled Water Circulation units.

Source(s): Arthur D. Little. 1999. "Opportunities for Energy Savings in the Residential and Commercial Sectors with High Efficiency Electric Motors." Cambridge, MA. December, 1999. Tables 4-5 and 4-6.

Sector: Commercial
End Use: Ventilation
Product: Hydronic Hot and Chilled Water Circulation, Absorption Chiller (25 HP)
Lifetime (years): 23

Baseline Technology: 90% efficiency
Baseline Installed Cost in 2010: not available
Baseline Annual Energy Consumption: not available
Baseline Life Cycle Cost in 2010: not available

	Technology for 2010 Standard	**Technology for 2020 Standard**
Description	95%	Same as 2010
Increase in end user first cost* ($)	$73	$63
Annual energy savings* (kWh)	1250	1250
CCE (¢/kWh)	0.5	0.4
Decrease in LCC* ($)	$897	$930

* Relative to baseline technology.

Notes: This product accounts for about 1% of the energy consumption by Hydronic Hot and Chilled Water Circulation units.

Source(s): Arthur D. Little. 1999. "Opportunities for Energy Savings in the Residential and Commercial Sectors with High Efficiency Electric Motors." Cambridge, MA. December, 1999. Tables 4-5 and 4-6.

Sector: Commercial
End Use: Ventilation
Product: Hydronic Hot and Chilled Water Circulation, Hydronic Heating (10 HP)

Lifetime (years): 23

Baseline Technology: 90% efficiency
Baseline Installed Cost in 2010: not available
Baseline Annual Energy Consumption: not available
Baseline Life Cycle Cost in 2010: not available

	Technology for 2010 Standard	**Technology for 2020 Standard**
Description	94%	Same as 2010
Increase in end user first cost* ($)	$84	$72
Annual energy savings* (kWh)	857	857
CCE (¢/kWh)	0.8	0.7
Decrease in LCC* ($)	$581	$609

* Relative to baseline technology.

Notes: This product accounts for about 70% of the energy consumption by Hydronic Hot and Chilled Water Circulation units.

Source(s): Arthur D. Little. 1999. "Opportunities for Energy Savings in the Residential and Commercial Sectors with High Efficiency Electric Motors." Cambridge, MA. December, 1999. Tables 4-5 and 4-6.

Sector: Commercial
End Use: Ventilation
Product: Cooling Water Circulation, Centrifugal Chiller (25 HP)
Lifetime (years): 23

Baseline Technology: 90% efficiency
Baseline Installed Cost in 2010: not available
Baseline Annual Energy Consumption: not available
Baseline Life Cycle Cost in 2010: not available

	Technology for 2010 Standard	**Technology for 2020 Standard**
Description	95%	Same as 2010
Increase in end user first cost* ($)	$73	$63
Annual energy savings* (kWh)	1235	1235
CCE (¢/kWh)	0.5	0.4
Decrease in LCC* ($)	$870	$902

* Relative to baseline technology.

Notes: This product accounts for about 58% of the energy consumption by Cooling Water Circulation units.

Source(s): Arthur D. Little. 1999. "Opportunities for Energy Savings in the Residential and Commercial Sectors with High Efficiency Electric Motors." Cambridge, MA. December, 1999. Tables 4-7 and 4-8.

Sector: Commercial
End Use: Ventilation
Product: Cooling Water Circulation, Screw Chiller (10 HP)
Lifetime (years): 20

Baseline Technology: 90% efficiency
Baseline Installed Cost in 2010: not available
Baseline Annual Energy Consumption: not available
Baseline Life Cycle Cost in 2010: not available

	Technology for 2010 Standard	**Technology for 2020 Standard**
Description	94%	Same as 2010
Increase in end user first cost* ($)	$84	$72
Annual energy savings* (kWh)	714	714
CCE (¢/kWh)	1.0	0.9
Decrease in LCC* ($)	$462	$486

* Relative to baseline technology.

Notes: This product accounts for about 4% of the energy consumption by Cooling Water Circulation units.

Source(s): Arthur D. Little. 1999. "Opportunities for Energy Savings in the Residential and Commercial Sectors with High Efficiency Electric Motors." Cambridge, MA. December, 1999. Tables 4-7 and 4-8.

Sector: Commercial
End Use: Ventilation
Product: Cooling Water Circulation, Reciprocating Chiller (10 HP)
Lifetime (years): 20

Baseline Technology: 88% efficiency
Baseline Installed Cost in 2010: not available
Baseline Annual Energy Consumption: not available
Baseline Life Cycle Cost in 2010: not available

	Technology for 2010 Standard	**Technology for 2020 Standard**
Description	93%	Same as 2010
Increase in end user first cost* ($)	$84	$72
Annual energy savings* (kWh)	381	381
CCE (¢/kWh)	1.9	1.6
Decrease in LCC* ($)	$207	$226

* Relative to baseline technology.

Notes: This product accounts for about 29% of the energy consumption by Cooling Water Circulation units.

Source(s): Arthur D. Little. 1999. "Opportunities for Energy Savings in the Residential and Commercial Sectors with High Efficiency Electric Motors." Cambridge, MA. December, 1999. Tables 4-7 and 4-8.

Sector: Commercial
End Use: Ventilation
Product: Cooling Water Circulation, Li-Br Water Absorption Chiller (25 HP)
Lifetime (years): 23

Baseline Technology: 90% efficiency
Baseline Installed Cost in 2010: not available
Baseline Annual Energy Consumption: not available
Baseline Life Cycle Cost in 2010: not available

	Technology for 2010 Standard	**Technology for 2020 Standard**
Description	95%	Same as 2010
Increase in end user first cost* ($)	$73	$63
Annual energy savings* (kWh)	1250	1250
CCE (¢/kWh)	0.5	0.4
Decrease in LCC* ($)	$881	$914

* Relative to baseline technology.

Notes: This product accounts for about 8% of the energy consumption by Cooling Water Circulation units.

Source(s): Arthur D. Little. 1999. "Opportunities for Energy Savings in the Residential and Commercial Sectors with High Efficiency Electric Motors." Cambridge, MA. December, 1999. Tables 4-7 and 4-8.

Sector: Commercial
End Use: Ventilation
Product: Heat Rejection, Large Unitary (5 HP)
Lifetime (years): 15

Baseline Technology: 85% efficiency
Baseline Installed Cost in 2010: not available
Baseline Annual Energy Consumption: not available
Baseline Life Cycle Cost in 2010: not available

	Technology for 2010 Standard	**Technology for 2020 Standard**
Description	90%	Same as 2010
Increase in end user first cost* ($)	$46	$39
Annual energy savings* (kWh)	299	299
CCE (¢/kWh)	1.4	1.2
Decrease in LCC* ($)	$164	$176

* Relative to baseline technology.

Notes: This product accounts for about 14% of the energy consumption by Heat Rejection units.

Source(s): Arthur D. Little. 1999. "Opportunities for Energy Savings in the Residential and Commercial Sectors with High Efficiency Electric Motors." Cambridge, MA. December, 1999. Tables 4-9 and 4-10.

Sector: Commercial
End Use: Ventilation
Product: Heat Rejection, Air Cooled Screw Chillers (2 HP)
Lifetime (years): 20

Baseline Technology: 85% efficiency

Baseline Installed Cost in 2010: not available
Baseline Annual Energy Consumption: not available
Baseline Life Cycle Cost in 2010: not available

	Technology for 2010 Standard	Technology for 2020 Standard
Description	92%	Same as 2010
Increase in end user first cost* ($)	$14	$12
Annual energy savings* (kWh)	1667	1667
CCE (¢/kWh)	0.1	0.1
Decrease in LCC* ($)	$1156	$1186

* Relative to baseline technology.

Notes: This product accounts for about 1% of the energy consumption by Heat Rejection units.

Source(s): Arthur D. Little. 1999. "Opportunities for Energy Savings in the Residential and Commercial Sectors with High Efficiency Electric Motors." Cambridge, MA. December, 1999. Tables 4-9 and 4-10.

Sector: Commercial
End Use: Ventilation
Product: Heat Rejection, Air Cooled Reciprocating Chillers (2 HP)
Lifetime (years): 20

Baseline Technology: 85% efficiency
Baseline Installed Cost in 2010: not available
Baseline Annual Energy Consumption: not available
Baseline Life Cycle Cost in 2010: not available

	Technology for 2010 Standard	Technology for 2020 Standard
Description	92%	Same as 2010
Increase in end user first cost* ($)	$14	$12
Annual energy savings* (kWh)	952	952
CCE (¢/kWh)	0.1	0.1
Decrease in LCC* ($)	$654	$672

* Relative to baseline technology.

Notes: This product accounts for about 9% of the energy consumption by Heat Rejection units.

Source(s): Arthur D. Little. 1999. "Opportunities for Energy Savings in the Residential and Commercial Sectors with High Efficiency Electric Motors." Cambridge, MA. December, 1999. Tables 4-9 and 4-10.

Sector: Commercial
End Use: Ventilation
Product: Heat Rejection, Cooling Tower (10 HP)
Lifetime (years): 20

Baseline Technology: 85% efficiency
Baseline Installed Cost in 2010: not available

Baseline Annual Energy Consumption: not available
Baseline Life Cycle Cost in 2010: not available

	Technology for 2010 Standard	**Technology for 2020 Standard**
Description	92%	Same as 2010
Increase in end user first cost* ($)	$84	$72
Annual energy savings* (kWh)	559	559
CCE (¢/kWh)	1.4	1.2
Decrease in LCC* ($)	$309	$330

* Relative to baseline technology.

Notes: This product accounts for about 5% of the energy consumption by Heat Rejection units.

Source(s): Arthur D. Little. 1999. "Opportunities for Energy Savings in the Residential and Commercial Sectors with High Efficiency Electric Motors." Cambridge, MA. December, 1999. Tables 4-9 and 4-10.

Sector: Commercial
End Use: Water Heating
Product: Storage Water Heater, Gas-Fired (120 gallon)
Lifetime (years): 7

Baseline Technology: 78% thermal efficiency
Baseline Installed Cost in 2010: $2,184
Baseline Annual Energy Consumption: 101 MMBtu
Baseline Life Cycle Cost in 2010: $6,181

	Technology for 2010 Standard	**Technology for 2020 Standard**
Description	82% thermal efficiency	Same as 2010
Increase in end user first cost* ($)	$116	$100
Annual energy savings* (MMBtu)	4.9	4.9
CCE ($/MMBtu)	$4.01	$3.45
Decrease in LCC* ($)	$79	$115

* Relative to baseline technology.

Notes: This product accounts for about 11% of the gas-fired water heater market.

Source(s): U.S. Department of Energy (DOE)-Office of Energy Efficiency and Renewable Energy. 2000. "Screening Analysis for EPACT-Covered Commercial HVAC and Water-Heating Equipment, Volume 1 - Main Report and Volume 2 - Appendix Material." Washington, DC. April, 2000. Table 2.4, Table 2.5, Table 3.8, Appendix D3-D80.

Sector: Commercial
End Use: Water Heating
Product: Storage Water Heater, Gas-Fired (199 gallon)
Lifetime (years): 7

Baseline Technology: 78% thermal efficiency
Baseline Installed Cost in 2010: $2,722
Baseline Annual Energy Consumption: 165 MMBtu

Baseline Life Cycle Cost in 2010: $9,260

	Technology for 2010 Standard	Technology for 2020 Standard
Description	82% thermal efficiency	Same as 2010
Increase in end user first cost* ($)	$193	$166
Annual energy savings* (MMBtu)	8.1	8.1
CCE ($/MMBtu)	$4.07	$3.50
Decrease in LCC* ($)	$126	$185

* Relative to baseline technology.

Notes: This product accounts for about 23% of the gas-fired water heater market.

Source(s): U.S. Department of Energy (DOE)-Office of Energy Efficiency and Renewable Energy. 2000. “Screening Analysis for EPACT-Covered Commercial HVAC and Water-Heating Equipment, Volume 1 - Main Report and Volume 2 - Appendix Material.” Washington, DC. April, 2000. Table 2.4, Table 2.5, Table 3.8, Appendix D3-D80.

Sector: Commercial
End Use: Water Heating
Product: Storage Water Heater, Gas-Fired (360 gallon)
Lifetime (years): 7

Baseline Technology: 80% thermal efficiency
Baseline Installed Cost in 2010: $4,828
Baseline Annual Energy Consumption: 284 MMBtu
Baseline Life Cycle Cost in 2010: $16,066

	Technology for 2010 Standard	Technology for 2020 Standard
Description	82% thermal efficiency	Same as 2010
Increase in end user first cost* ($)	$175	$151
Annual energy savings* (MMBtu)	6.9	6.9
CCE ($/MMBtu)	$4.30	$3.70
Decrease in LCC* ($)	$99	$151

* Relative to baseline technology.

Notes: This product accounts for about 23% of the gas-fired water heater market.

Source(s): U.S. Department of Energy (DOE)-Office of Energy Efficiency and Renewable Energy. 2000. “Screening Analysis for EPACT-Covered Commercial HVAC and Water-Heating Equipment, Volume 1 - Main Report and Volume 2 - Appendix Material.” Washington, DC. April, 2000. Table 2.4, Table 2.5, Table 3.8, Appendix D3-D80.

Sector: Commercial
End Use: Water Heating
Product: Instantaneous Water Heater, Gas-Fired (1000 kBtu/hr)
Lifetime (years): 15

Baseline Technology: 80% thermal efficiency
Baseline Installed Cost in 2010: $5,282
Baseline Annual Energy Consumption: 760 MMBtu
Baseline Life Cycle Cost in 2010: $35,392

	Technology for 2010 Standard	Technology for 2020 Standard
Description	83% thermal efficiency	Same as 2010
Increase in end user first cost* ($)	$770	$662
Annual energy savings* (MMBtu)	27.5	27.5
CCE ($/MMBtu)	$4.76	$4.09
Decrease in LCC* ($)	$319	$537

* Relative to baseline technology.

Notes: This product accounts for about 6% of the gas-fired water heater market.

Source(s): U.S. Department of Energy (DOE)-Office of Energy Efficiency and Renewable Energy. 2000. "Screening Analysis for EPACT-Covered Commercial HVAC and Water-Heating Equipment, Volume 1 - Main Report and Volume 2 - Appendix Material." Washington, DC. April, 2000. Table 2.4, Table 2.5, Table 3.8, Appendix D3-D80.

Sector: Commercial
End Use: Water Heating
Product: Instantaneous Tank Water Heater, Gas-Fired (500 kBtu/hr)
Lifetime (years): 15

Baseline Technology: 80% thermal efficiency
Baseline Installed Cost in 2010: $7,069
Baseline Annual Energy Consumption: 382 MMBtu
Baseline Life Cycle Cost in 2010: $22,176

	Technology for 2010 Standard	Technology for 2020 Standard
Description	82% thermal efficiency	Same as 2010
Increase in end user first cost* ($)	$344	$296
Annual energy savings* (MMBtu)	9.3	9.3
CCE ($/MMBtu)	$4.25	$3.65
Decrease in LCC* ($)	$24	$110

* Relative to baseline technology.

Notes: This product accounts for about 1% of the gas-fired water heater market.

Source(s): U.S. Department of Energy (DOE)-Office of Energy Efficiency and Renewable Energy. 2000. "Screening Analysis for EPACT-Covered Commercial HVAC and Water-Heating Equipment, Volume 1 - Main Report and Volume 2 - Appendix Material." Washington, DC. April, 2000. Table 2.4, Table 2.5, Table 3.8, Appendix D3-D80.

Sector: Commercial
End Use: Lighting
Product: Fluorescent Lamp/Ballast
Lifetime (years): 14
Baseline Technology: F40T12/ES lamp with magnetic ballast (15% market share); F32T8RE7 lamp with electronic ballast (85% share)
Baseline Installed Cost in 2010: $22.6
Baseline Annual Energy Consumption: 324 kWh
Baseline Life Cycle Cost in 2010: $219

	Technology for 2010 Standard	Technology for 2020 Standard

Description	High-performance T8 lamps with electronic ballasts and with high-performance electronic ballasts	High-performance T8 lamps with high-performance electronic ballasts
Increase in end user first cost* ($)	3.5	2.5
Annual energy savings* (kWh)	27	37
CCE (¢/kWh)	2	1
Decrease in LCC* ($)	12	20

* Relative to baseline technology.

Notes: Technology mix for 2010 standard assumes a market share of 40% of high-performance T8 Lamp with electronic ballast and 60% of high-performance T8 Lamp with high-performance electronic ballast. Installed costs are aggregated for the technology mix.
To calculate efficiency improvement, Lighting Power Densities for the 2010 and 2020 standards were used in combination with the above market share assumptions; LPDs were calculated by LBNL using adapted ASHRAE/IESNA 90.1 lighting application models.

Source(s): Equipment prices are from www.goodmart.com. Last accessed March 11, 2004.

Sector: Commercial
End Use: Lighting
Product: High Intensity Discharge Lamp (HID), Low Bay
Lifetime (years): 13.5
Baseline Technology: Mercury Vapor (MV) 20%; Metal Halide (MH) 55%; High Pressure Sodium (HPS) 25%
Baseline Installed Cost in 2010: $60
Baseline Annual Energy Consumption: 1140 kWh
Baseline Life Cycle Cost in 2010: $769

	Technology for 2010 Standard	**Technology for 2020 Standard**
Description	Pulse MH 75%; HPS 25%	Pulse MH/SSB 75%; HPS 25%
Increase in end user first cost* ($)	24	32
Annual energy savings* (kWh)	159	196
CCE (¢/kWh)	3.0	2.9
Decrease in LCC* ($)	52	71

* Relative to baseline technology.

Notes: SSB = solid state electronic ballast; installed costs are aggregated for the technology mix.
To calculate efficiency improvement, Lighting Power Densities for the 2010 and 2020 standards were used in combination with the above market share assumptions; LPDs were calculated by LBNL using adapted ASHRAE/IESNA 90.1 lighting application models.

Source(s): Equipment prices are from www.goodmart.com. Last accessed March 11, 2004.

Sector: Commercial
End Use: Lighting
Product: High Intensity Discharge Lamp (HID), High Bay
Lifetime (years): 13.5

Baseline Technology: Mercury Vapor (MV) 20%; Metal Halide (MH) 55%; High Pressure Sodium (HPS) 25%
Baseline Installed Cost in 2010: $70
Baseline Annual Energy Consumption: 1915 kWh
Baseline Life Cycle Cost in 2010: $1249

	Technology for 2010 Standard	Technology for 2020 Standard
Description	Pulse MH 75%; HPS 25%	Pulse MH/SSB 75%; HPS 25%
Increase in end user first cost* ($)	16.3	24.6
Annual energy savings* (kWh)	373	435
CCE (¢/kWh)	1.0	1.0
Decrease in LCC* ($)	193	236

* Relative to baseline technology.

Notes: SSB = solid state electronic ballast; Installed costs are aggregated for the technology mix.

Source(s): Equipment prices are from www.goodmart.com. Last accessed March 11, 2004. Lighting Power Densities for the 2010 and 2020 standards were based on the above assumptions, as calculated by LBNL using adapted ASHRAE/IESNA 90.1 lighting application models.

Sector: Commercial
End Use: Refrigeration
Product: Supermarket Units
Lifetime (years): 10

Baseline Technology: Current Technology (characteristics uncertain)

	Technology for 2010 Standard	Technology for 2020 Standard
Description	16% efficiency improvement*	Same as 2010
Increase in end user first cost* ($)	$21,490	$18,475
Annual energy savings* (kWh)	248,946	248,946
CCE (¢/kWh)	1.2	1.1
Decrease in LCC* ($)	$6918	$7937

* Relative to baseline technology.

Notes:

Source(s): Arthur D. Little. 1996. "Energy Savings Potential for Commercial Refrigeration Equipment." Cambridge, MA. June, 1996. Table 5-10.

Sector: Commercial
End Use: Refrigeration
Product: Beverage Merchandizer
Lifetime (years): 8.5

Baseline Technology: Current Technology (characteristics uncertain)

	Technology for 2010 Standard	Technology for 2020 Standard
Description	61% efficiency improvement*	Same as 2010
Increase in end user first cost* ($)	$344	$295

Annual energy savings* (kWh)	2375	2375
CCE (¢/kWh)	2.1	1.8
Decrease in LCC* ($)	$3	$11

* Relative to baseline technology.

Notes:

Source(s): Arthur D. Little. 1996. "Energy Savings Potential for Commercial Refrigeration Equipment." Cambridge, MA. June, 1996. Table 5-17.

Sector: Commercial
End Use: Refrigeration
Product: Reach-In Freezers
Lifetime (years): 9

Baseline Technology: Current Technology (characteristics uncertain)

	Technology for 2010 Standard	**Technology for 2020 Standard**
Description	52% efficiency improvement*	Same as 2010
Increase in end user first cost* ($)	$465	$424
Annual energy savings* (kWh)	2687	2687
CCE (¢/kWh)	2.5	2.3
Decrease in LCC* ($)	$12	$23

* Relative to baseline technology.

Notes:

Source(s): Arthur D. Little. 1996. "Energy Savings Potential for Commercial Refrigeration Equipment." Cambridge, MA. June, 1996. Table 5-18.

Sector: Commercial
End Use: Refrigeration
Product: Reach-In Refrigerators
Lifetime (years): 9

Baseline Technology: Current Technology (characteristics uncertain)

	Technology for 2010 Standard	**Technology for 2020 Standard**
Description	38% efficiency improvement*	Same as 2010
Increase in end user first cost* ($)	$212	$183
Annual energy savings* (kWh)	1631	1631

CCE (¢/kWh)	1.9	1.6
Decrease in LCC* ($)	$162	$191

* Relative to baseline technology.

Notes:

Source(s): Arthur D. Little. 1996. "Energy Savings Potential for Commercial Refrigeration Equipment." Cambridge, MA. June, 1996. Table 5-19.

Sector: Commercial
End Use: Refrigeration
Product: Ice Machines
Lifetime (years): 8.5

Baseline Technology: Current Technology (characteristics uncertain)

	Technology for 2010 Standard	**Technology for 2020 Standard**
Description	23% efficiency improvement*	Same as 2010
Increase in end user first cost* ($)	$221	$190
Annual energy savings* (kWh)	1141	1141
CCE (¢/kWh)	2.8	2.4
Decrease in LCC* ($)	$15	$30

* Relative to baseline technology.

Notes:

Source(s): Arthur D. Little. 1996. "Energy Savings Potential for Commercial Refrigeration Equipment." Cambridge, MA. June, 1996. Table 5-20.

Sector: Commercial
End Use: Refrigeration
Product: Refrigerated Vending Machines
Lifetime (years): 8.5

Baseline Technology: Current Technology (characteristics uncertain)

	Technology for 2010 Standard	Technology for 2020 Standard
Description	51% efficiency improvement*	Same as 2010
Increase in end user first cost* ($)	$308	$265
Annual energy savings* (kWh)	1540	1540
CCE (¢/kWh)	2.9	2.5
Decrease in LCC* ($)	-$1	$4

* Relative to baseline technology.

Notes:

Source(s): Arthur D. Little. 1996. "Energy Savings Potential for Commercial Refrigeration Equipment." Cambridge, MA. June, 1996. Table 5-21.

Sector: Commercial
End Use: Refrigeration
Product: Walk-In Coolers
Lifetime (years): 10

Baseline Technology: Current Technology (characteristics uncertain)

	Technology for 2010 Standard	Technology for 2020 Standard
Description	46% efficiency improvement*	Same as 2010
Increase in end user first cost* ($)	$1611	$1385
Annual energy savings* (kWh)	19,370	19,370
CCE (¢/kWh)	1.2	1.0
Decrease in LCC* ($)	$13	$85

* Relative to baseline technology.

Notes:

Source(s): Arthur D. Little. 1996. "Energy Savings Potential for Commercial Refrigeration Equipment." Cambridge, MA. June, 1996. Table 5-23.

Sector: Commercial

End Use: Refrigeration
Product: Walk-In Freezers
Lifetime (years): 10

Baseline Technology: Current Technology (characteristics uncertain)

	Technology for 2010 Standard	**Technology for 2020 Standard**
Description	48% efficiency improvement*	Same as 2010
Increase in end user first cost* ($)	$1572	$1351
Annual energy savings* (kWh)	7517	7517
CCE (¢/kWh)	3.0	2.6
Decrease in LCC* ($)	-$44	$69

* Relative to baseline technology.

Notes:

Source(s): Arthur D. Little. 1996. "Energy Savings Potential for Commercial Refrigeration Equipment." Cambridge, MA. June, 1996. Table 5-24.

Sector: Commercial
End Use: Office Equipment
Product: Personal Computers
Lifetime (years): 5

Baseline Technology: Current standby power

	Technology for 2010 Standard	**Technology for 2020 Standard**
Description	Standby power at FEMP Phase 2 level	Not applicable
Increase in end user first cost* ($)	0.5	
Annual energy savings* (kWh)	15	
CCE (¢/kWh)	0.8	
Decrease in LCC* ($)	3.5	

* Relative to baseline technology.

Notes: Products include monitors and laptops used in offices. Values given are averages weighted by current levels of shipments.

FEMP Phase 2 level refers to target levels for Federal Energy Management Program.

We do not consider a 2020 standard due to the expected rapid evolution of technology in this area.

Source(s): Unpublished LBNL analysis done in 2003; data inputs based on industry sources and LBNL estimates. See also: Bertoldi, Paolo, Bernard Aebischer, Charles Edlington, Craig Hershberg, Benoit Lebot, Jiang Lin, Tony Marker, Alan Meier, Hidetoshi Nakagami, Yoshiaki Shibata, Hans Paul Siderius, and Carrie Webber. "Standby power use: How big is the problem? What policies and technical solutions can address it?". In *2002 ACEEE Summer Study on Energy Efficiency in Buildings; Pacific Grove, CA; August 18-23 2002*. ACEEE, 2002. LBNL-50567

Sector: Commercial
End Use: Office Equipment

Product: Other than Personal Computers
Lifetime (years): 5

Baseline Technology: Current standby power

	Technology for 2010 Standard	**Technology for 2020 Standard**
Description	Standby power at FEMP Phase 2 level	Not applicable
Increase in end user first cost* ($)	0.5	
Annual energy savings* (kWh)	12	
CCE (¢/kWh)	0.9	
Decrease in LCC* ($)	2.9	

* Relative to baseline technology.

Notes: Products include printers, copiers, scanners and fax machines. Values given are averages weighted by current levels of shipments.

FEMP Phase 2 level refers to target levels for Federal Energy Management Program.

We do not consider a 2020 standard due to the expected rapid evolution of technology in this area.

Source(s): Unpublished LBNL analysis done in 2003; data inputs based on industry sources and LBNL estimates. See also: Bertoldi, Paolo, Bernard Aebischer, Charles Edlington, Craig Hershberg, Benoit Lebot, Jiang Lin, Tony Marker, Alan Meier, Hidetoshi Nakagami, Yoshiaki Shibata, Hans Paul Siderius, and Carrie Webber. "Standby power use: How big is the problem? What policies and technical solutions can address it?". In *2002 ACEEE Summer Study on Energy Efficiency in Buildings; Pacific Grove, CA; August 18-23 2002*. ACEEE, 2002. LBNL-50567

Appendix 2

Methods and Sources Used for
the Cost-Efficiency Analysis of Building Codes

Residential Sector Building Codes

Residential building codes either specify or result in more energy-efficient practice with respect to shell measures such as insulation, glazing, and infiltration. In new homes, they impact the heating and cooling load that any heating and cooling equipment must meet.

Given variation in climate and construction practices across the country, we conducted analysis for each Census Division. For the baseline levels of insulation and glazing, we rely on values identified as 1980s practice by Huang et al.1 Although typical practice has improved somewhat since that period, these data were the most recent we were able to identify. The baseline levels for infiltration are from Koomey et al.'s 1991 study.2 For each level of improved practice with respect to insulation, glazing, and infiltration, we estimated the incremental cost and energy savings --relative to the baseline-- based on measure costs and heating and cooling load impacts given in Koomey et al.[2]

For the 2010 and 2020 code in each Division, we selected the set of measures that provide the most energy savings while still having a simple payback period of 15 years or less. The selected levels of insulation and glazing are shown in Table 1. For infiltration, we find a payback period less than 15 years to improve infiltration rates to 0.4 ach for all divisions, except for division 3 (East North Central), for which current practice implies an infiltration rate of 0.53 ach. Therefore, the code upgrades have no change in infiltration requirements for this division.

We derived national values from Division values by calculating averages weighted by 2002 starts of single-family homes in each Division. Table 2 shows the national-average values for costs and savings associated with the selected 2010 and 2020 codes.

Table 2: National Average Impacts per House for Upgraded Residential Building Codes*

Measure	Incremental Cost		Annual Operating Savings		Annual Site Energy Savings (MMBtu)	
	2010 codes	2020 codes	2010 codes	2020 codes	2010 codes	2020 codes
Ceiling	$56	$251	$4	$19	0.4	1.5
Wall	$386	$333	$39	$41	3.4	3.4
Floor	$104	$89	$15	$27	1.1	2.6
Infiltration	$231	$199	$63	$66	5.1	5.1
Glazing	$662	$855	$60	$62	4.8	5.4

* Values are relative to the baseline levels. The energy savings combine electricity and natural gas.

We do not present CCE values since the measures were selected on the basis of payback. Furthermore, CCE is affected dramatically by choice of building shell lifetime, which is not well known.

Commercial Sector Building Codes

Commercial building codes either specify or result in more energy-efficient practice with respect to shell measures such as glazing, and a greater proportion of efficient equipment in the case of lighting. Shell measures impact the heating and cooling load.

Shell Measures

We limit our analysis of shell measures to glazing or high-performance windows due to lack of available data for other measures. For the baseline levels of glazing, we relied on the judgment of an expert in the field, and identified values for six building types for two representative cities (Houston and Chicago) for two climate zones broadly categorized as Hot and Cold.* We divided the new construction floor space into these two

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For each set of improved window options, we estimated the incremental cost and energy savings, relative to the baseline. The incremental savings in heating and cooling energy are then weighted by new floor space as forecast by AEO 2004 to arrive at a national average for efficiency improvement.

We based the energy savings on the estimates provided in Carmody et al[4] and the respective costs in Johnson and Edelson.[5]

For the 2010 and 2020 code for each building type in each climate zone, we selected the set of measures that had the minimum life-cycle cost. The levels of glazing for each building type are shown in Table 3; the energy and cost impacts are shown in Table 4. We did not consider building types with Window to Wall Ratio of <0.05, as the glazing impact on heating and cooling loads is insignificant.

Table 3. Levels of Glazing for Upgraded Commercial Building Codes

Building Type	Prototype Used in Analysis	Window to Wall Ratio (WWR)	Climate Zone	Baseline Technology	2010 Building Code Technology	2020 Building Code Technology
Education	**Schools**	**0.15**	**Cold**	**Double glazing clear: U=0.6, SHGC=0.6, VT=0.63**	**Triple glazing 1 low-E layer, clear, U=0.20, SHGC=0.22, VT=0.37**	**Same as 2010**
			Hot	**Double glazing clear: U=0.6, SHGC=0.6, VT=0.63**	**Double glazing bronze tint, U=0.6, SHGC=0.42, VT=0.38**	**Same as 2010**
Food Service	**Office**	**0.15**	**Cold**	**Double glazing clear: U=0.6, SHGC=0.6, VT=0.63**	**Triple glazing 1 low-E layer, clear, U=0.20, SHGC=0.22, VT=0.37**	**Same as 2010**
			Hot	**Double glazing bronze tint, U=0.6, SHGC=0.42, VT=0.38**	**Double glazing reflective coating, U=0.54, SHGC=0.17, VT=0.10**	**Same as 2010**

[*] We did not consider the building types assembly, food sales, retail, and warehouse, as these have average window-to-wall ratios of <0.05, and thus there is little room for energy savings from glazing improvement.

Health Care	**Office**	**0.30**	**Cold**	**Double glazing clear: U=0.6, SHGC=0.6, VT=0.63**	**Triple glazing 1 low-E layer, clear, U=0.20, SHGC=0.22, VT=0.37**	**Same as 2010**
			Hot	**Double glazing bronze tint, U=0.6, SHGC=0.42, VT=0.38**	**Double glazing reflective coating, U=0.54, SHGC=0.17, VT=0.10**	**Same as 2010**
Lodging	**School**	**0.15**	**Cold**	**Double glazing clear: U=0.6, SHGC=0.6, VT=0.63**	**Triple glazing 1 low-E layer, clear, U=0.20, SHGC=0.22, VT=0.37**	**Same as 2010**
			Hot	**Double glazing clear: U=0.6, SHGC=0.6, VT=0.63**	**Double glazing bronze tint, U=0.6, SHGC=0.42, VT=0.38**	**Same as 2010**
Small Office	**Office**	**0.30**	**Cold**	**Double glazing clear: U=0.6, SHGC=0.6, VT=0.63**	**Triple glazing 1 low-E layer, clear, U=0.20, SHGC=0.22, VT=0.37**	**Same as 2010**
			Hot	**Double glazing bronze tint, U=0.6, SHGC=0.42, VT=0.38**	**Double glazing reflective coating, U=0.54, SHGC=0.17, VT=0.10**	**Same as 2010**
Large Office	**Office**	**0.45**	**Cold**	**Double glazing spec. selective low-E clear, U=0.46, SHGC=0.34, VT=0.57**	**Triple glazing 1 low-E layer, clear, U=0.20, SHGC=0.22, VT=0.37**	**Same as 2010**
			Hot	**Double glazing spec. selective low-E tint, U=0.46, SHGC=0.27, VT=0.43**	**Same as baseline**	**Triple glazing 1 low-E layer, clear, U=0.20, SHGC=0.22, VT=0.37**

Table 4. Energy and Cost Impacts from Building Codes for Glazing*

	Standard	Building Types					
		Education	**Food service**	**Healthcare**	**Lodging**	**Small office**	**Large office**
Heating	2010	0.91	0.91	4.00	0.91	4.00	3.18
Energy Savings (kBtu/sf)	2020	0.91	0.91	4.00	0.91	4.00	5.30
Cooling	2010	0.10	0.25	0.49	0.10	0.49	0.05
Energy Savings (kWh/sf)	2020	0.10	0.25	0.49	0.10	0.49	0.16
Heating	2010	10.59	16.29	5.49	10.59	5.49	3.21
CCE ($/MMBtu)	2020	9.11	14.01	5.42	9.11	5.42	5.07
Cooling	2010	0.09	0.06	0.05	0.09	0.05	0.20
CCE ($/kWh)	2020	0.08	0.05	0.04	0.08	0.04	0.17
Increase in End-user	2010	0.11	0.17	0.25	0.11	0.25	0.12
First Cost ($/sf)	2020	0.09	0.15	0.25	0.09	0.25	0.31
Hot Climate	2010	0.01	0.05	0.20	0.01	0.20	-
Decrease in LCC ($/sf)	2020	0.01	0.07	0.24	0.01	0.24	0.02
Cold Climate	2010	3.37	0.04	0.64	3.37	0.64	0.42
Decrease in LCC ($/sf)	2020	3.71	0.10	0.81	3.71	0.81	0.56

* Relative to baseline technology.

Lighting Measures

The analysis of the building code impact on lighting begins with Lighting Power Density (LPD) estimates for the different building types from the draft ASHRAE 90.1-2004 code. These LPDs were mapped onto the CBECS building types using the ASHRAE/IESNA 90.1 lighting application models and supplementary information.* This building code is assumed to come into effect in 2015. The baseline is set at the LPD level as determined by the 2010 equipment standard level. The incremental improvement in LPDs as required by the code is then weighted by the new floor space as forecast by AEO 2004 to come up with a national average for efficiency improvement. The technology mix (beyond the fluorescent and HID equipment standards already assumed to be in place) is then identified such that it meets the efficiency improvement required by the building code and provides life-cycle cost savings. We based technology cost on price information available on the Internet.[6]

* LBNL spreadsheet models adapted from ASHRAE/IESNA lighting application models for ASHRAE/IESNA 90.1-1999 and 2004, and supplementary material from Eric Richman, PNNL, and Michael Lane, Lighting Design Lab (February 2004).

The LPDs by building type are shown in Table 5 and the national average energy and cost impacts from the mix of technologies are shown in Table 6.

Table 5. Lighting Power Density (LPD) by Building Types

Building Type	**Baseline (watt/sf)**	**ASHRAE 90.1 2004, 2015 Code (watt/sf)**	**Incremental Improvement in LPD from 2015 Code**
Education	1.22	1.20	2%
Food Sales	2.25	1.5	33%
Food Service	2.39	1.43	40%
Health Care	1.42	1.13	20%
Lodging	1.88	0.93	51%
Mercantile and Service	1.60	1.5	6%
Office	1.35	1.00	26%
Public Assembly	1.51	1.19	21%
Warehouse and Storage	0.85	0.80	6%
All			17%

Table 6. National Average Cost and Energy Impacts of 2015 Building Code for Lighting

	Technology for 2015 Code
Description*	60-W Incandescent 20%; 15-W CFL 50%; 20-W CFL 30%
Increase in end user first cost** ($/ft2)	$4.19
Annual energy savings** (kWh/ft2)	112
CCE (¢/kWh)	1.5
Decrease in LCC** ($/ft2)	$63

NOTE: Baseline Technology: 60-W Incandescent 95%; 15-W CFL 3%; 20-W CFL 2%*

* The percentages represent the respective market share of technologies.

** Relative to baseline technology.

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Appendix 3
Calculation of Learning Rate Parameter

In this study we employ a parameter to estimate the change in manufacturing costs over time for various products that could be subject to standards. We rely on research by economist Richard Newell that he did for DOE to provide a "sound theoretical and empirical basis" for modeling technological advancement for EIA's National Energy Modeling System (NEMS) forecasts. The premise of this research is the common notion of learning by experience. The central idea is that manufacturers will develop efficiencies of production as the industry as a whole matures. This trend scales with the total historical production of the product in question. Accordingly, an empirical learning curve typically uses cumulative production of the product in question as a measure of experience accumulated. The key impact of the learning is a reduction in input use per product – and thus the price.

Mathematically, the learning relationship is expressed with price varying as a power law in total production:

$$c = aQ^{-b},$$

where c is the cost (or input quantity) required to produce the Qth unit of output, a is the cost of the first unit produced, Q is cumulative production, and b is the learning parameter.

For the purposes of this analysis, we are interested in the rate at which cost can be expected to decline in the future as total production grows. Since a is constant, the annual percentage change in cost is dependent on Q, b and the annual change in cumulative production, ΔQ:

$$\frac{\Delta c}{c} = \left(\frac{\Delta Q}{Q}\right)^{-b}$$

The annual change in production in one year equals the shipments for that year. Thus, the rate of change in cost can be determined with total production, shipments and the learning parameter b.

Newell concentrated on three products for which historical data were available: room air conditioners, central air conditioners and gas water heaters. The learning parameter b is in principle product-specific. Table 1 summarizes the parameters and results of the learning rate calculation. The learning parameter b was found to be close to 0.4 for each of the products studied, with only a slight variation. Annual shipments from 2002 (the most recent year available) are taken to represent ΔQ, and for the purposes of this calculation, annual shipments are assumed constant. Inserting the appropriate values for

Q, ΔQ and b for each product yields an annual price decrease rate of 1.3%, 1.8% and 1.3% for room air conditioners, central air conditioners and gas water heaters, respectively. For simplicity, and because b is not determined for all end uses, we use the shipments-weighted average value of 1.5% for all products.

Table 1. Learning Rate Derivation

	Room Air Conditioner	Central Air Conditioner	Gas Water Heater
Production through 2002, Q (million)	171	122	157
Annual shipments ΔQ in 2002 (million)	6.15	5.26	4.99
Learning parameter b	0.38	0.43	0.41
Annual Percentage Increase in Production $\Delta Q/Q$	3.6%	4.3%	3.2%
Implied Cost Growth Factor $(1+ \Delta Q/Q)^{-b}$	0.987	0.982	0.987
Implied Annual Rate of Decline in Cost $1-(1+ \Delta Q/Q)^{-b}$	1.3%	1.8%	1.3%

Source: Census Data (quoted in Newell) and *Appliance* Magazine
Beginning production dates are first date for which data are available.

Reference

Newell, Richard G. *DRAFT, Incorporation of Technological Learning into NEMS Buildings Modules.* Prepared for Energy Information Administration, Department of Energy, Washington, D.C., September 2000.

Appendix 4
Derivation of Discount Rates

The discount rate is the rate at which future monetary values are discounted to establish their present value. In this study, we applied discount rates in two parts of the analysis. In the estimation of consumer impacts, we used average discount rates that are appropriate for residential and commercial consumers. In the estimation of the net economic impacts from the national perspective, we applied alternative discount rates of 7% and 3.5%.

Discount Rates Used in Consumer Impacts Analysis

Residential sector

For the residential sector, we derived discount rates using an approach similar to that used in DOE's recent analysis of residential central air conditioners.[1]

One way of estimating discount rates involves defining the share of various finance methods that are used for purchasing an appliance and then determining the associated interest rates for each of the finance methods. This method focuses on establishing the type of financing utilized for the purchase. For equipment financed through the purchase of a new home, this approach is reasonable.

Replacement equipment for existing homes is usually purchased using cash or some form of credit. One approach is to identify the types of credit used to purchase a given type of equipment, the associated interest rates, and the shares of each credit type in total replacement purchases. Such information is difficult to come by, and there are reasons to favor an alternative approach.

When a household makes a major appliance purchase, the short-term effect may be an increase in debt if the purchase is financed with a dealer loan or credit card, or a decrease in cash if the product is purchased with cash. However, financial theory suggests that in the medium-term, households should tend to rebalance their overall equity/debt portfolio to maintain approximately the same relative shares of different equity/debt classes. According to this line of reasoning, the appropriate opportunity cost for purchase of long-lived equipment should reflect a household's overall equity/debt portfolio, and not simply the financial or opportunity cost of the debt or equity used to purchase the equipment.

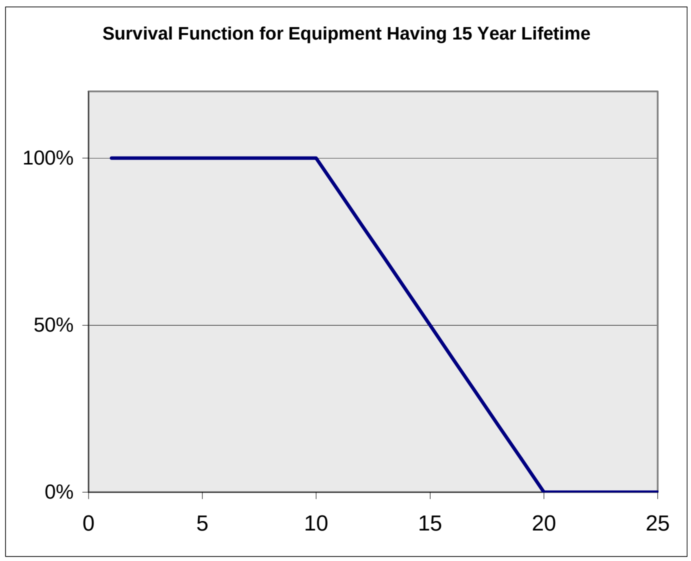
For example, even though the purchase might be financed through a dealer loan or some other short-term financing vehicle, the more probable effect of the purchase is to either cause the consumer to incur additional credit card debt or forego investment in some type of savings-related asset. Cash that was once available to either pay for household expenses or to invest in an asset like the stock market or a savings account now must be earmarked to pay off the equipment purchase, thus causing the consumer to incur additional credit card debt or to lose the opportunity to earn income from assets.

We estimated the discount rate for new-house equipment based on mortgage interest rate data provided in the Federal Reserve Board's *Survey of Consumer Finances* (SCF).[2]

$v < 2/(3L)$ $\quad s = 1$
$2/3\,L <= v <= 4/3\,L$ $\quad s = 2 - 3v/(2L)$
$v > 4/3\,L$ $\quad s = 0$

The retirement function is equivalent to the assumption that a constant percentage of each cohort equal to 3/(2L) is retired each year between two-thirds and four-thirds of the average lifetime. Figure 1 shows the survival function for an equipment type having an average lifetime of 15 years. Application of the retirement function yields a stock factor for replacements, S_R.

Figure 1. Survival Function for Equipment Having an Average Lifetime of 15 Years



New housing and commercial building space are tracked from the year of standard implementation according to the AEO forecast. The ratio of new buildings constructed since the reference year to the building stock in the reference year is denoted S_N. We assume that only new equipment is installed in new buildings, and that equipment type market shares remain constant over time. None of the residential buildings built after 2010 are assumed to be subject to demolition during the forecast period. Energy cost savings benefits are assumed to accrue over the first 30 years of the lifetime of the building shell.

Energy Savings

We calculate a preliminary estimate of total site (delivered) energy use according to existing stock UEC, new equipment UEC, and the stock accounting model described in the previous section. This estimate is refined using the equipment efficiency growth rate incorporated in the AEO forecast. Slight differences between the preliminary estimate and the AEO reference forecast arise due to usage trends (e.g. residential floor space and

This survey indicates that mortgage rates carried by homeowners in 1998 averaged 7.9%. After adjusting for inflation and interest tax deduction (assuming a 28% marginal income tax rate), real after-tax interest rates on mortgages averaged 4.2%.

Equipment installed in new homes is financed as part of the mortgage. The Federal Reserve Board's *Survey of Consumer Finances* (SCF) indicates that mortgage rates carried by homeowners in 1998 averaged 7.9%. Since these mortgages were initiated over a period of many years, we assume that this rate is a reasonable long-term average. Since mortgage interest is tax-deductible, the effective mortgage rate for the average household with a 28% marginal income tax rate is 5.7%. Adjustment for inflation brings the rate to 4.2%.

For equipment purchased to replace old or failed equipment, we estimated the opportunity cost by assuming that households will eventually rebalance their equity/debt portfolio after purchase to maintain approximately the same shares as existed prior to the purchase. Regardless of which type of debt or equity the household actually uses to purchase the appliance, the final opportunity cost is equal to the average rate of return on equity or interest on debt, weighted by the percentage shares of each debt/equity type in the household's total financial portfolio.

We estimated the average household equity and debt portfolio from the 1995 and 1998 *Survey of Consumer Finances*. In considering the household financial portfolio, we exclude highly illiquid types of equity (retirement accounts, life insurance, and other managed assets) and debt on a primary mortgage. We assume that these types of equity are not included in the rebalancing.

We estimated interest or return rates associated with each type of household equity and debt holding from a variety of sources. Rates for second mortgages and credit cards are from 1998 SCF data. We estimated interest rates associated with certificates of deposit (CDs), treasury bills (T-bills), and corporate bonds as an average of the Federal Reserve Board time-series data covering 1977–2001. Based on relative returns to less-liquid assets, we assumed that the interest rate on transactions (checking) accounts averages 2% real. We estimated annual return associated with household stock holdings as an average of data published by the Stern Business School covering the 1977–2001 period.[3] We estimated mutual fund rates as an average of the Standard and Poor's (S&P) 500 stock rate (67% weight) and the T-bill rate (33% weight).

Table 1 summarizes the shares of household equity and debt based on the above sources and the real, after-tax interest rates associated with each type of equity or debt. We assumed a marginal tax rate of 28% and CPI inflation to derive real from nominal values. The weighted-average real, after-tax interest rate across all types of household debt and equity is 6.7%.

Table 6. After-Tax Real Interest or Return Rates for Household Debt and Equity Types

Type	Average Share of Household Debt plus Equity (%)*	Mean Rate (%)
Second mortgage	3.0	5.9
Credit card and installment loans	9.1	12.0
Transaction (checking) accounts	20.0	2.0
CD (6-month)	7.9	2.8
Savings bonds (Treasury)	1.6	3.7
Bonds (Corporate AAA)	8.3	4.4
Stocks (S&P500)	30.2	9.6
Mutual funds	19.8	7.6
Total/Weighted-average discount rate	100	6.7

* 1998 data

In this study, we were not able to separately track equipment purchased with new homes and equipment purchased for replacement. Thus, we derived a weighted-average total discount rate based on the 4.2% rate for new-home equipment and the 6.7% rate for replacement equipment. The weighted-average of 5.6% assumes that two-thirds of total equipment shipments are for replacement equipment. For the analysis of building codes for new homes, however, we used the new-home rate of 4.2%.

Commercial sector

For the commercial sector, we used the discount rates derived for DOE's recent analysis of commercial air conditioners. DOE/LBNL derived the discount rates for this analysis from estimates of the cost of capital of companies that purchase commercial air-conditioning equipment. Most companies use both debt and equity capital to fund investments, so the typical cost of capital is the weighted average of the cost to the firm of equity and debt financing.[4]

The cost of equity financing was estimated using the capital asset pricing model (CAPM). The CAPM, among the most widely used models to estimate the cost of equity financing, assumes that the cost of equity is proportionate to the amount of systematic risk associated with a firm. The cost of equity financing tends to be high when a firm faces a large degree of systematic risk and the cost tends to be low when the firm faces a small degree of systematic risk.

The degree of systematic risk facing a firm is determined by several variables, including the risk coefficient of a firm, the expected return on "risk free" assets (R_f), and the additional return expected on assets facing average market risk (which is known as the equity risk premium or *ERP*). The variable used to measure firm risk is termed the risk coefficient or "beta." Beta indicates the degree of risk associated with a given firm relative to the level of risk (or price variability) in the overall stock market. Betas usually vary between 0.5 and 2.0. A firm with a beta of 0.5 faces half the risk of other stocks in the market; a firm with a beta of 2.0 faces twice the overall stock market risk.

Following this approach, the cost of equity financing for a particular company is given by the equation:

$$k_e = R_f + (\beta * ERP)$$

where:

k_e =	cost of equity for a company,
R_f =	expected return of the risk free asset,
β =	beta of the company stock, and
ERP =	expected equity risk premium.

The cost of debt financing is the yield or interest rate paid on money borrowed by a company (for example, by selling bonds). As defined here, the cost of debt includes compensation for default risk (the risk that a firm will go bankrupt) and excludes deductions for taxes.

We estimated the cost of debt for companies by adding a risk adjustment factor to the current yield on long-term corporate bonds (the risk free rate). This procedure was used to estimate company costs to obtain debt financing. The adjustment factor was based on indicators of company risk, such as credit rating or variability of stock returns.

The discount rate of a company is the weighted average cost of debt and equity financing or the weighted average cost of capital (WACC). It was estimated from the equation:

$$k = k_e \cdot w_e + k_d \cdot w_d$$

Where,

k =	(nominal) cost of capital,
k_e =	expected rate of return on equity,
k_d =	expected rate of return on debt,
w_e =	proportion of equity financing in total annual firm financing, and
w_d =	proportion of debt financing in total annual firm financing.

The cost of capital is a nominal rate, because it includes anticipated future inflation in the expected returns from stocks and bonds. The real discount rate or WACC deducts expected inflation from the nominal rate. We calculated expected inflation (2.3

percent) from the average of the last five quarters' change in gross domestic product (GDP) prices.

We defined the expected return on "risk free" assets, or risk free rate (5.5 percent), by the yield (December 2001) on long-term government bonds.[5] The equity risk premium (*ERP*) represents the difference between the expected (average) stock market return and the risk free rate. The 5.5 percent estimate for the ERP was taken from the Damodaran Online site.[6]

A sample of companies used to represent commercial air conditioner purchasers was pulled from a database of 7,319 U.S. companies included in the Damodaran Online site.[3] This firm database includes most of the publicly traded companies in the United States economy. This database of companies was divided into the categories shown in Table 3 according to their standard industrial code (SIC) code. Financial information was sought for all the retail, property owner, medical service, hotel, and food service firms as well as all of the public for profit and not for profit firms included in the full sample. Financial information was sought for only 10 percent of the industrial and office/service sector firms in the full sample in order keep the data base manageable. The 10 percent sub-sample was chosen by listing the companies alphabetically and drawing every tenth firm on the list. In cases where one or more of the variables needed to estimate the discount rate was missing or could not be obtained, the firm was discarded from the analysis. Overall, about 80 percent of the firms in the full database were discarded for this reason.

Ultimately, a sample of 973 companies was used to represent commercial air conditioner purchasers. For each company, the cost of debt, percent debt financing, and systematic firm risk were drawn from information provided at the Damodaran Online site[6] (Leonard N. Stern School of Business, New York University), Bloomberg Professional,[7] and Federal Regulator Energy Commission (FERC) Form 1 filings.[8*] The cost of debt financing was estimated from the long-term government bond rate (5.5 percent) and the standard deviation of the stock price. Average values for the cost of debt, percent debt financing, and systematic firm risk for companies that purchase commercial air conditioners are shown in Table 2. For the public not-for-profit subsector, we based the cost of capital on average interest rates for Treasury, state, and municipal bonds.

Table 2. Average Values for Variables Used to Estimate Company Discount Rates

Variable	Average	Source
Risk free asset return (R_f)	5.5%	Bloomberg Financial. December 2001
Equity risk premium (*ERP*)	5.5%	Stern Business School, Damodaran Online
Expected inflation (r)	2.3%	Bureau of Economic Analysis
Cost of debt (after tax) (k_d)	5.9%	Stern Business School, Damodaran Online

[*] Percent debt for firms in the property-owning category was estimated using data from Bloomberg Professional. Cost of debt for publicly owned utilities was taken from FERC Form 1 filings.

Percent debt financing (w_d)	44%	Stern Business School, Damodaran Online
Systematic firm risk (β)	0.93	Stern Business School, Damodaran Online

We determined the share of each category in total commercial building square footage with package air conditioning from EIA's 1999 Commercial Building Energy Consumption Survey (CBECS).[9] From these data, we estimated the shares of total commercial sector purchases of commercial air conditioners (Table 3).[**]

Table 3. Estimated Shares of Total Purchases of Commercial Air Conditioners

Category	**Percent**
Property owners and managers	21.2
Retail firms	16.5
Medical services	6.7
Industrial	4.9
Hotels	4.0
Food service	5.3
Office/Service sector	19.4
Public for profit	11.0
Public not for profit	11.0
Total	100.0

Table 4 shows estimates of the real discount rate by category. The weighted average discount rate across all companies is 6.1 percent.

[**] The share of total square footage occupied by property owners is around 40%. However, in some of these buildings the tenants purchase commercial air conditioners. We assumed that this is the case for half of the square footage occupied by property owners. We then allocated the remaining quantity among the other subsectors in proportion to their shares of total square footage.

Table 4. Real Discount Rates by Category for Purchasers of Commercial Air Conditioners

Category	SIC Code	Estimated share of purchases	Mean real discount rate (WACC)	Standard deviation	Number of observations
Retail stores	53, 54, 56	16.5%	7.1%	2.1%	218
Property owners & managers	6720	21.2%	5.2%	0.7%	11
Medical services	8000	6.7%	7.0%	1.7%	115
Industrial	1000-4000	4.9%	6.9%	3.2%	253
Hotels	7000	4.0%	5.6%	1.5%	51
Food service	5400, 5812	5.3%	6.1%	1.4%	88
Office/services	5910-9913	19.4%	6.9%	2.1%	128
Public for profit	7950, 8299	11.0%	7.3%	1.8%	68
Public not for profit	N.A.	11.0%	3.0%	0.7%	41
Weighted Average		N.A.	**6.1%**	1.6%	N.A.
Sources: CBECS, Damodaron Online and LBNL calculations					

Discount Rates in Estimation of National Economic Impacts

In its analyses of the national economic impacts of equipment energy efficiency standards, DOE relies on guidance issued in 1992 by the Office of Management and Budget (OMB) in Circular No. A-94 (Revised), which states (section 8): "In general, public investments and regulations displace both private investment and consumption. … Constant-dollar benefit-cost analyses of proposed investments and regulations should report net present value and other outcomes determined using a real discount rate of 7 percent. This rate approximates the marginal pretax rate of return on an average investment in the private sector in recent years."[*] We apply this "investment discount rate" in this study.

As the OMB guidance notes, regulations such as energy efficiency standards displace both private investment and consumption. Economist Kenneth Arrow notes that "Since consumption is much larger than investment [in the economy], it is reasonable to assume that the appropriate hurdle rate should be closer to the consumption rate… Most estimates of the rate of return on consumption are on the order of 3 or 4 percent."[10] Based on this line of reasoning, we apply a "consumption discount rate" of 3.5%. We note that

[*] See http://www.whitehouse.gov/omb/circulars/a094/a094.html#9. Given the statement that "public investments and regulations displace both private investment and consumption," it is not clear why the OMB elected to base a discount rate only on displacement of private investment.

the OMB later advised Federal agencies to use a 3% discount rate as a sensitivity for calculating the national economic impacts of regulatory policies.*

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Appendix 5

National Impacts Methodology

Overview

We estimate national energy savings from percentage efficiency improvement estimates that we apply to the base case forecast provided by EIA's Annual Energy Outlook (AEO) 2004. EIA gives base case energy consumption for each end use for each year of the forecast. Equipment installed after the standards effective year (2010 or 2020) consumes less energy than in the base case, either due to equipment efficiency standards, which apply to all new equipment, or to building codes, which apply to newly constructed homes or commercial buildings. In order to estimate the fraction of equipment stock for which the standard applies, we use a stock accounting model that tracks equipment retirements, replacements, and shipments to newly constructed buildings. Finally, net consumer financial impacts are derived according to implied utility bill savings and incremental capital expenditures.

Stock Accounting for Equipment

The AEO end use energy consumption forecast represents each appliance's unit energy consumption, multiplied by the number of units in the stock in each year. For each technology, we estimate the average existing stock UEC and the UEC of new equipment in the absence of new standards. In the standards case, equipment shipped after the standard date has a lower UEC. National energy savings is derived from this improvement, according to the accumulation of post-standards stock in each year of the forecast.

New equipment enters the stock either by replacement of retired units or by installation into new buildings. In estimating the amount of new equipment entering the stock due to replacements, we model the retirement of old units, and assume that all retired units are replaced with the same type of equipment. Retirements are modeled with a simple algorithm based on the average lifetime L of each type of equipment, and the vintage v of the existing stock. The survival function $s(L,v)$ gives the ratio of stock in a given year to the total stock in the year of standards implementation. The survival algorithm assumes that no equipment is retired before it has reached two-thirds of its average lifetime, and that all are retired by four-thirds of the average lifetime. In between two-thirds and four-thirds of the lifetime, the survival function is linear. Mathematically, the survival algorithm is given by the following:

fuel switching) not captured in our simplified model. To correct for this, we apply a service growth factor ρ, defined as the ratio of the AEO forecast to our preliminary estimate. Finally, a baseline factor *b* is defined as the percentage of new equipment accounted for by baseline models-- those that are not more efficient than required by standards. For residential appliances, we had data that allowed estimation of the portion of the products in the base case that are more efficient that the upgraded standard, and thus would not be impacted by upgraded standards. We estimated the share of units sold expected to be more efficient than the upgraded standard based on recent market statistics on Energy Star products.

Site energy savings is equal to the product of the following factors: fractional improvement of equipment affected by standards or codes × post-standards stock factor × share of each end use (e.g. electric space heating) claimed by the affected technology (e.g. heat pump) × the unit energy consumption of new units in the base case; or:

$$\Delta E = \rho \times b \times E_0 \times \Delta Eff \times (S_N + S_R) \times MS \times UEC_{N,}$$

where:

ΔE = *Site Energy Savings*
ρ =*Service Growth Factor*
b = *Baseline Percentage Factor*
E_0 = *Base Case End Use Energy Consumption*
ΔEff =*Efficiency Improvement Percentage*
S_N = *New Construction Stock Factor*
S_R × *Replacement Stock Factor*
MS × *Equipment Type Market Share*
UEC_N = *New Equipment Unit Energy Consumption*

Primary energy savings is calculated from site savings using conversion provided by the AEO forecast.

Financial Impacts

Energy savings due to equipment standards and building codes has a direct financial benefit to consumers in the form of decreased utility bills. These are offset, however, by the increased capital expenditure involved in purchasing high-efficiency equipment. Our analysis considers the trade off between utility bill savings and incremental capital costs by calculating life-cycle cost and cost of conserved energy for each technology option. Cost of conserved energy (non-discounted) for each product is given by:

$$CCE = \frac{\Delta EC}{\sum_{1}^{L} \Delta OC}$$

where

CCE	=	Cost of Conserved Energy
ΔEC	=	Incremental Consumer Equipment Cost
ΔOC	=	Annual Consumer Operating Cost Savings
L	=	Equipment Lifetime

Since the CCE provides an incremental cost for higher-efficiency new equipment, the total incremental capital costs in each year are calculated from the incremental site energy savings from one year to the next, which represents additional energy savings due to new equipment. This incremental savings is multiplied by the non-discounted cost of conserved energy of the technology affected by standards. In cases where more than one product in a given end use is affected by standards, a market-weighted average cost of conserved energy is used.

National operating cost savings in each year are equal to delivered energy savings multiplied by the projected price of gas or electricity in that year, as provided by AEO 2004. The net present value (NPV) of financial impacts are calculated using a fixed societal discount rate, applied to each year according to length of time from the reference year (2004).

Supplementary Information on Energy Efficiency for the National Commission on Energy Policy

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Summary

Previous work prepared for the Commission by Resources for the Future (RFF) examined the savings and economics of past energy efficiency programs and policies. A second study by Lawrence Berkeley National Laboratory (LBNL) estimated the additional savings that can be achieved in the future from new appliance and equipment efficiency standards and building codes. In this short paper I review the results of these two studies and address several issues that complement and supplement these two studies. Key findings are as follows:

1. Both studies do an excellent job of laying out the issues and presenting broad estimates for Commission consideration.

2. Research and development programs and building codes were outside the RFF scope, but both are important enough that they merit Commission consideration. In the case of R&D programs, useful data are provided in a recent study by the National Academy of Sciences, which estimated that DOE's energy efficiency R&D efforts are producing about one quadrillion Btus ("quads") per year of energy savings and producing net benefits of about $30 billion (1999$). A study by the President's Committee of Advisors on Science and Technology estimated that even larger savings can be achieved in the future.

3. For building codes, we conduct analyses of both past savings and potential future savings, concluding that past codes saved about 0.54 quads in 2000 while new codes can save about 0.94 quads in 2020. Our estimate of savings from new codes is nearly twice the savings estimated by LBNL since we base our estimates on current voluntary programs for new homes and commercial buildings (e.g., ENERGY STAR® New Homes and E-Benchmark for commercial buildings) while they look at a more limited set of options.

4. LBNL also estimates savings from new appliance and equipment efficiency standards, with cumulative savings over the 2010–2030 period of about 25 quads. A forthcoming analysis by the American Council for an Energy-Efficient Economy (ACEEE) estimates cumulative savings of about 35 quads over the same period. The difference is largely attributable to several residential products where LBNL either did not include new standards or included only modest new standards. On the other hand, in several cases LBNL examined products not covered by ACEEE. When the LBNL estimates for these products are added to the ACEEE estimates, cumulative savings total 48 quads.

5. RFF estimated that past programs reduced U.S. energy use in 2000 by up to 4 quads. When I add in R&D and building code savings but adjust for overlap between programs and for a couple of optimistic savings estimates in the RFF study, I estimate 4–5 quads of savings in 2000. Dividing by the average period of time each program has operated, programs are saving about 0.6 quads for each year of program operation, which works out to an average of about 1.3–1.6% reduction in buildings energy use for each year of program operation (savings are more modest in industry).

6. Several recent studies estimated the achievable and cost-effective energy conservation potential over the next 5–20 years. The median estimate across these studies is that overall U.S. energy use can be reduced by 1.2–1.4% per year, with slightly higher savings in buildings and slightly lower in industry and transportation. These results for buildings are similar to the historical results.

7. Available data indicate that the economics of energy efficiency programs are generally very favorable. RFF found appliance standards to be very cost-effective and a new but not-yet-published RFF analysis finds utility DSM programs to also be quite cost-effective (i.e., average cost of 3.7 cents per kWh saved). I adjust the discount rate used by RFF to be in line with utility and utility regulator practice and find that DSM programs are saving energy at an average cost of 2.9 cents per kWh, which compares favorably with the approximately 5 cents per kWh cost of power from a new coal or gas power plant. Evidence on the cost-effectiveness of R&D and building code programs is also presented.

8. Energy efficiency programs can also exert downward pressure on energy prices when energy markets are tight, a circumstance that is increasingly common. For example, one recent study found that a 5% reduction in natural gas and electricity use can reduce U.S. natural gas prices by about 20%. Energy efficiency programs can also have positive impacts on employment and the gross domestic product.

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Introduction

The National Commission on Energy Policy (NCEP) has previously commissioned two papers on energy efficiency—a *Retrospective Examination of Demand-Side Energy Efficiency Policies* by Resources for the Future (Gillingham, Newell, and Palmer 2004) and *Energy Efficiency Standards and Codes, Residential/Commercial Equipment and Buildings: Additional Opportunities* by Lawrence Berkeley National Laboratory (Rosenquist et al. 2004). The former examined the impacts of many past and present energy efficiency policies while the latter estimated the savings that can be achieved in the future from two specific policies—equipment efficiency standards and building codes.

Both studies did an excellent job of laying out the issues and presenting broad estimates for Commission consideration. The RFF study is probably the most detailed review of energy efficiency accomplishments published in the past decade and presents and discusses the results of dozens of previous studies on the impacts of various energy efficiency programs. It is a Herculean task and the authors have done a commendable job. Their key conclusion is that past programs have saved about 4 quads (quadrillion Btu) of energy, equivalent to a 12% reduction in buildings energy use. The LBNL study is likewise the most comprehensive summary published to date on future savings opportunities from equipment efficiency standards. They have examined dozens of products and concluded that new standards can save more than 25 quads of energy on a cumulative basis by 2030 (about 1.7 quads per year once the equipment stock turns over[1]).

However, while both studies provide a lot of useful information, there are important issues not addressed by either study, or that are only peripherally addressed by one study or the other. In this paper I address several of these issues in an attempt to complement and supplement the previous two papers. Specific issues addressed are:

- Research and development programs
- Building energy codes—past and future savings
- Equipment efficiency standards—additional opportunities for energy savings
- Putting the RFF savings estimates in context
- Overall future savings opportunities
- Economics of energy efficiency

Research and Development Programs

Research and development (R&D) was deliberately excluded from the RFF report.[2] The authors had a large scope of work, and R&D fell outside this scope. However, R&D has been a key policy strategy of the federal government (and of quite a few states) for several decades and thus it is useful to consider both past accomplishments and future potential. Fortunately, a couple of recent major studies have examined these issues in depth.

[1] Details on this calculation are provided later in this paper.

[2] RFF states: "The focus of this review is on adoption of energy efficient equipment and building practices, rather than on energy research and development." (p. 6).

In 2001, the National Academy of Sciences completed a study entitled *Energy Research at DOE: Was It Worth It?* that reviewed DOE's energy efficiency and fossil energy R&D efforts over the 1978–2000 period (National Research Council 2001). A copy of the key table is included as Table 1 in this paper and found that just six energy efficiency R&D successes have produced 4.88 quads of cumulative savings and saved about $30 billion on net. The Academy committee responsible for this report used the assumption that no more than five years of savings should be counted for any R&D success (the assumption being that all of these successes would be achieved without DOE intervention, but five years later). Thus, the 4.88 cumulative savings works out to 0.98 quads saved in any one year (4.88/5). Some of these savings likely overlap with some of the savings cataloged in the RFF report (e.g., improved refrigerators could be credited under standards and under R&D) but given the nature of the energy-saving measures included in the National Academy study, a substantial portion of the R&D savings are not double-counted. Furthermore, the National Academy only looked at six of DOE's most successful projects (the "big winners") but there are hundreds of other projects, many of which contribute some savings. Overall, based on its review, the Academy concluded that "the benefits of these [DOE energy efficiency] programs substantially exceed the programs' costs and contribute to improvements in the economy, the environment, and national security…"

Table 1. Net Realized Benefits Estimated for Selected Technologies Examined for National Academy of Sciences RD&D Case Studies

	Economic Benefits (Cumulative Net Energy Savings and Consumer Cost Savings)				Environmental Benefits (Cumulative Pollution Reduction)				Security Benefits (Oil Use or Outage Reduction)		
Technology	Cost of DOE and Private RD&D (billion $)[a]	Fuel (Q)[b]	Electricity (Q of primary energy)[c]	Net Cost Savings (billion $)[d]	SO_2 (millions of metric tonnes)	NO_x (millions of metric tonnes)	Carbon (millions of metric tonnes)	Damage Reduction (billion $)[e]	Oil and LPG (Q)[f]	Electricity Reliability	Value (billion $)[g]
Advanced refrigerator/freezer compressors	~0.002[h]		1	7[i]	0.4	0.2	20	1-5	0.04		0.02-0.1
Electronic ballast for fluorescent lamps	>0.006[j]		2.5	15	0.7	0.4	40	1-10	0.1		0.05-0.3
Low-e glass	>0.004[k]	0.7	0.5	8[l]	0.3	0.2	20	0.5	0.2		0.1-0.7
Advanced lost foam casting	0.008		0.03	0.1[m]	0.01	0.006	0.5	0.02-0.1			
Oxygen-fueled glass furnace	0.002	0.06		0.3		0.02	1	0.05-0.2			
Advanced turbine systems	~0.356	0.09		~0 by 2005[n]		0.02	1	0.05-0.2		Yes	
Total	~0.4			~30				~3-20			0.2-1

In addition to DOE's R&D efforts, there are many other public sector R&D programs such as those led by states (e.g., the New York State Energy Research and Development Authority and the California Energy Commission's Public Interest Energy Research program) and other research institutes (e.g., the Electric Power Research Institute and the Gas Technology Institute). A few of the major state efforts were profiled in a report prepared for the

Association of State Energy Research and Technology Transfer Institutions (Pye and Nadel 1997). These programs also contribute significant savings.

Looking to the future, in 1997 the President's Committee of Advisors on Science and Technology issued a report on *Federal Energy Research and Development for the Challenges of the Twenty-First Century* (PCAST 1997). The Committee concluded that federal R&D investments in energy efficiency should be nearly doubled from 1997 levels (e.g., from $450 million to $880 million in 1997$) and that such investments could save more than $40 billion per year and reduce annual carbon emissions by 250 million metric tonnes, both by 2010. These potential future savings are substantially larger than the savings achieved over the 1978–2000 period as calculated by the National Academy. PCAST concluded that "[t]his large increase is appropriate because of the high promise of advanced efficiency technologies for relatively quick-starting and rapidly expanding contributions to several important societal goals, including cost-effective reductions in local air pollution and carbon dioxide emissions, diminished dependence on imported oil, and reductions in energy costs to households and firms." While the tight federal budget has resulted in much smaller budget increases than PCAST recommended, the general conclusion from PCAST was that new R&D investments can result in substantial energy and economic savings.

Building Energy Codes

Building energy codes were also excluded from the RFF report.[3] However, building energy codes have also been an important policy strategy since the 1970s and it is important to understand their impacts. My organization, the American Council for an Energy-Efficient Economy (ACEEE), is not aware of any studies that attempted to estimate the national savings from building energy codes, so we have prepared a rough analysis on this issue that is presented in Table 2. For this analysis, we focused on code improvements developed in the late-1980s and early 1990s, improvements that have now been adopted in most states. We looked at new construction during the 1990s and applied savings from model codes to this construction in those states that have adopted these model codes. Overall, we estimate that these codes reduced U.S. energy use by about 0.54 quads in 2000. This estimate is just a "ballpark" estimate as it: (1) ignores any savings from codes adopted in the 1970s or 1980s; (2) ignores savings from codes that exceed the national minimums (e.g., California, Florida, Massachusetts, Minnesota, New York, Oregon, Washington, and Wisconsin have long histories of exceeding national model codes); and (3) assumes all states that presently have adopted the model codes did so as of 1990, even though adoption was gradual throughout the 1990s. Implicitly, we are assuming that the first two factors counterbalance the third factor, an admittedly imprecise assumption.

[3] RFF states: "We further limit the scope of the study by omitting building codes, professional codes, and Corporate Average Fuel Economy (CAFÉ) Standards to focus on the remaining programs (p. 6-7).

Table 2. Estimated National Savings from Building Code Improvements

	Electricity (TWh)	Fuels (Trillion Btu)	Savings from New Code (%)	Proportion of U.S. Construction New Code Applies To (%)	Savings in 2000		
					Electri-city (TWh)	Fuels (Trillion Btu)	Total (Trillion Btu)
Residential	91	725					
Adoption of 1992 CABO MEC or beyond			18%	80%	16.0	127	306
Commercial	122	332					
Adoption of 90.1-1989 or beyond			15%	77%	16.6	45	230
TOTAL					32.6	172	537

Notes:
* Baseline energy use from 2001 Residential Energy Consumption Survey (EIA 2004c) and 1999 Commercial Energy Consumption Survey (EIA 2002). We include space heating, space cooling, water heating and lighting using end-use estimates from these EIA surveys.
* Total energy use numbers in Btu combine direct combustion plus the fuel burned to generate electricity and assume heat rate from Annual Energy Outlook 2003 (EIA 2003) of 1,1181 Btu/kWh in 2000.
* Residential energy savings derived by W. Prindle from Howard and Prindle (1991). Commercial energy savings from Pacific Northwest National Laboratory analysis for DOE.
* Portion codes currently apply to estimated by W. Prindle and S. Nadel based on current code status and residential housing starts and non-residential construction activity by state.

Probably more importantly, there is a very large potential for future energy savings from building codes. LBNL in its report for the Commission attempted to estimate the potential for these future savings. Overall, LBNL estimated potential cumulative energy savings through 2030 from improved building codes to be 5.2 quads. This is equivalent to approximately 0.5 quads in 2030.[4] However, LBNL only examined particular technologies and appears to have missed some significant technical opportunities such as residential duct sealing, reductions in lighting energy use beyond the current ASHRAE standard, and improvements in HVAC equipment efficiency and controls/systems design. In addition, by looking only at individual technologies, a variety of system interaction effects appear not to be included. Much of the remaining savings opportunity is through better systems design and not through use of individual technologies (Johnson and Nadel 2000).

In order to address these limitations, ACEEE prepared an analysis to estimate the energy that can be saved by 2020 by policy interventions to bring energy codes up to the level of today's major voluntary residential and commercial new construction programs, such as the ENERGY STAR New Homes program and the New Buildings Institute E-Benchmark guideline for commercial buildings.

[4] Savings from codes gradually ramp up as buildings are built. The LBNL estimates cover 20 years, but savings start at zero and gradually climb to double the 20-year average. Thus we can estimate annual savings in 2030 by dividing the LBNL cumulative estimate by 20 and multiplying by two.

Specifically, for new homes, we analyzed the savings from bringing codes from current levels to levels needed to achieve the ENERGY STAR Homes designation in states representing 75% of new construction. Depending on region, 15–30% energy savings are needed to go from current code levels to ENERGY STAR levels. We assume average savings of 20%. We further assume that these code improvements are implemented in three stages, corresponding to the 2006, 2009, and 2012 editions of the International Energy Conservation Code (IECC—the major model code). We assume that states on average take three years to adopt the IECC (e.g., some states will adopt the 2006 IECC in 2006, some in 2012, but on average, the 2006 code is adopted in 2009). For the 20% of construction that is not covered by current codes, we assume that these are eventually brought up to current code levels, but that these states will not go beyond current codes. Finally, we also assume that enforcement of existing codes is improved, resulting in 2% savings in those states that improve enforcement. Sources of data that support these assumptions are documented in Table 3.

For new commercial buildings, we made generally similar assumptions, except that the long-term target is set by the E-Benchmark, a level of performance that reduces energy use about 15% relative to the ASHRAE 1999 standard (NBI 2003). We estimate that half these savings are included in the 2004 ASHRAE standard (recently approved), and the other half will be incorporated into a 2012 standard. As with new homes, we limit this advanced code to 75% of new construction, and assume that the other 15% not now using the 1999 standard will only be brought up to the 1999 standard. We also include 2% savings from improved code compliance. Data and sources are documented in Table 3.

Overall, based on these assumptions, we estimate that improved building codes can reduce U.S. energy use by about 0.94 quads in 2020, which represents 2.0% of 2020 residential and commercial primary energy use as estimated by EIA (2004a). In order to adopt these codes, extensive education, training, and promotion efforts will first be needed to build market share for the ENERGY STAR and E-Benchmark specifications (or their equivalent), which will build support for eventually incorporating these specifications into codes.

Additional Opportunities for Equipment Efficiency Standards

RFF conducted an extensive review of past achievements from appliance standards and I have nothing significant to add. LBNL also conducted an extensive analysis of savings available from new appliance and equipment standards. Overall, LBNL estimated that new standards on more than two dozen products can save more than 25 quads of energy on a cumulative basis by 2030, which is approximately 1.7 quads per year once the equipment stock turns over.[5] ACEEE is now completing an analysis of savings available from new

[5] Savings from standards gradually ramp up as equipment is replaced, and then level off once all equipment has been replaced. Assuming a 10-year average equipment life, savings ramp up over 10 years and then are steady for the final 10 years. To approximate annual savings once the equipment stock has been replaced, we take the 20-year savings estimated by LBNL and divide by 15, where 15 is based on 10 years of level savings plus 10 years of gradually growing savings, which can be approximated as half this number of years (10/2) of steady savings.

Table 3. Potential National Savings from Building Code Improvements

Code	2020 Energy Use from Construction in 2006-2020		Savings from New Code (%)	Proportion of U.S. New Code Applies To (%)	Median Date of Enactment	Savings in 2020			Typical Simple Payback
	Electricity (TWh)	Fuels (Tril. Btu)				Electricity (TWh)	Fuels (Tril. Btu)	Total (Tril. Btu)	
Residential	130	1292							
Adoption of 2003 IECC in remaining states			18%	20%	2008	3.8	37	76	8
Adoption of 2006 IECC			5%	80%	2009	3.8	38	78	
Upgrades to IECC circa 2009			7.5%	80%	2012	4.2	41	85	
Upgrades to IECC circa 2012			7.5%	80%	2015	2.6	26	53	
Improved code compliance			2%	60%	2010	1.0	10	21	
Subtotal						15.4	153	312	
Commercial	485	1881							
Adoption of 90.1-1999 in remaining states			6.4%	40%	2008	9.9	39	142	4
Adoption of 90.1-2004			7.5%	77%	2009	20.5	80	293	
Upgrades to 90.1/IECC circa 2012			7.5%	77%	2015	9.3	36	133	
Improved code compliance			2%	60%	2010	3.9	15	55	
Subtotal						43.7	169	623	
TOTAL						59.1	322	935	

Notes:

* Baseline energy use in 2020 from *Annual Energy Outlook 2004* (EIA 2004a). We include space heating, space cooling, water heating and lighting using end-use estimates from EIA's 2001 RECS (EIA 2004c) and 1999 CBECS (EIA 2002) surveys.
* For residential sector, new construction proportion based on 1.518 million housing starts per year (avg. for 1993–2002 from U.S. Census Bureau (2003). For commercial, new construction proportion based on floor area for "new additions" in EIA (2004a).
* Total energy use numbers in Btu combine direct combustion plus the fuel burned to generate electricity and assume heat rate from EIA (2004a) of 10,377 Btu/kWh in 2020.
* Savings for 2004 and 2006 codes estimated by W. Prindle and S. Nadel based on portions of these documents that have been approved. Savings from 2004/2006, 2009, and 2012 codes assume a gradual ramp-up to current ENERGY STAR levels for residential (20% savings) and NBI E-Benchmark levels for commercial (average of 15% savings across different building types (NBI 2003). Code compliance savings assume one-third of the buildings are not in compliance (Smith and Nadel 1995) and that due to non-compliance, one-third of the savings code upgrades are lost.
* Proportion of U.S. new code applies to based on percent of new construction currently covered by relatively up-to-date codes (from Table 2).
* Simple paybacks estimated by ACEEE based on data from a variety of sources on costs and savings.

standards that covers many of the same products, but also additional products. In the ACEEE analysis, like the LBNL analysis, the only standards included are those that are cost-effective to consumers on a life-cycle cost basis. A comparison of the LBNL and ACEEE analyses can be found in Table 4. Where both LBNL and ACEEE analyzed the same products and standards, the results are roughly aligned. However, often ACEEE looked at different products than LBNL, and in some cases ACEEE also looked at stronger standards than LBNL. And in some cases, LBNL looked at products not included in the ACEEE analysis.

Overall, ACEEE found about 10 quads more of cumulative savings than LBNL (38% higher savings). The difference is essentially accounted for by four residential products—residential air conditioning (ACEEE assumes a new standard for central air conditioners in the next decade, LBNL does not include a revision); residential lighting (ACEEE includes consensus standards on ceiling fan light kits and CFLs recently negotiated with industry, LBNL does not include these products); residential refrigerators (LBNL assumes a modest new standard, ACEEE assumes a new standard based on the best current major manufacturer products); and residential furnaces (LBNL includes a modest new standard, ACEEE also includes a standard on furnace fans and a standard requiring condensing furnaces in cold climates).

However, even the ACEEE estimate is probably conservative, as ACEEE did not include several products that are included in the LBNL analysis including additional commercial heating and air conditioning equipment (boilers, chillers, water-source heat pumps, PTACs, and cooling towers), electric heat pump water heaters, miscellaneous residential electronic products, office equipment, and supermarket and walk-in refrigeration systems. When the LBNL savings estimates for these products are added to the ACEEE estimates, the estimated cumulative savings total 48.3 quads (see the "Combined" column in Table 4).[6] This is about 3.2 quads per year once the equipment stock turns over, which is 6.2% of 2025 residential and commercial primary energy use as estimated by EIA 2004a.[7]

Putting the RFF Savings Estimates in Context

As noted above, RFF concludes that previous efficiency policies and programs saved as much as 4 quads of energy in 2004. To this figure, we recommend that our estimates of savings from R&D (0.98 quads) and building codes (0.54 quads) be added. This brings the total to about 5.5 quads, although there is likely some double-counting and optimistic estimates included in these figures (e.g., the estimates cited by RFF for the 1605b registry and DOE Climate Challenge seem optimistic). Overall, I would estimate that actual savings from programs and policies fall somewhere in the range of 4 and 5 quads, which represents between 5.5 and 6.9% of 2000 non-transportation energy use and between 11 and 13% of 2000 buildings energy use (as noted by RFF, a substantial majority of the savings are in

[6] However, there is some overlap between the ACEEE estimate of future savings from building codes and the LBNL estimate of savings from standards, as ACEEE included many types of commercial HVAC equipment under building codes while LBNL included them under standards. Therefore, the ACEEE estimate of savings from building codes and the combined estimate of savings from standards should not be summed.

[7] We use 2025 in this case because it will take this long for the stock to turn over for most of the products affected by these standards.

Table 4. Comparison of LBNL and ACEEE Estimates of Savings from New Standards

End-Use	30 Yr. Cumulative Savings (quads)			LBNL vs. ACEEE	Notes/Explanation of Differences
	LBNL	ACEEE	Combined	Difference	
Residential					
Gas space heating	1.10	2.30	2.30	1.20	ACEEE included condensing furnaces in cold states.
Air conditioning	0.10	5.77	5.87	5.67	ACEEE looked at a new central A/C standard, LBNL only considered room A/C.
Refrigeration	0.92	2.56	2.56	1.64	LBNL assumed standard less stringent than current ENERGY STAR; ACEEE assumed standard based on best mass production units now on the market.
Lighting	1.90	6.65	6.65	4.75	LBNL only included torchieres; ACEEE also included ceiling fan light kits and CFLs per negotiated agreements with manufacturers.
Water heating	2.80	0.00	2.80	-2.80	LBNL examined heat pump water heaters, ACEEE did not.
Dishwashing	0.13	0.46	0.46	0.33	LBNL assumed standard less stringent than current ENERGY STAR; ACEEE used current ENERGY STAR.
Motors	0.48	3.40	3.88	2.92	LBNL examined ceiling fans and pool pumps, ACEEE examined furnace air handlers.
Misc. electronics	4.50	2.29	4.50	-2.21	LBNL included more products such as audio equipment, telephony, and a misc. category.
Subtotal	11.93	23.42	29.01	11.49	
Commercial & Industrial					
Space heating	0.71	0.86	1.57	0.15	Examined different products—LBNL covered furnaces & boilers, ACEEE covered unit heaters.
Air conditioning	3.02	2.67	3.02	-0.36	LBNL included more products such as chillers, water-source equipment, and PTACs.
Ventilation	0.66	0.00	0.66	-0.66	ACEEE did not include in its study.
Water heating	0.25	1.47	1.72	1.22	ACEEE examined pre-rinse spray valves based on pending CEC standards; LBNL did not.
Lighting	3.10	3.77	3.77	0.67	LBNL and ACEEE examined a somewhat different list of products.
Refrigeration	4.52	0.76	4.52	-3.76	LBNL included central systems (e.g., for supermarkets) and walk-ins; ACEEE did not.
Office equipment	1.55	0.00	1.55	-1.55	ACEEE did not include in its study.
Miscellaneous	0.00	0.18	0.18	0.18	ACEEE examined commercial clothes washers, LBNL did not.
Distribution transformers	0.00	2.29	2.29	2.29	LBNL did not include in its study.
Subtotal	13.81	12.00	19.28	-1.81	
TOTAL	25.74	35.42	48.30	9.68	

Notes:
* LBNL estimates from Rosenquist (2004).
* ACEEE estimates from Prindle (2004).
* "Combined" column includes all products looked at by LBNL and ACEEE. Where either LBNL or ACEEE looked at more products, this column shows the savings estimate that includes more products. Where LBNL and ACEEE looked at different products, this column sums the LBNL and ACEEE estimates.

buildings). Many observers would probably characterize these as significant but not dramatic numbers. Please note that these figures are for savings caused by programs and policies and do not include efficiency gains caused by normal market forces. If market-induced efficiency gains were also included, the totals would be higher.

Of perhaps greater importance is what do these savings numbers tell us about the savings that can be achieved in the future? To investigate this question, it is useful to convert the savings achieved in 2000 into incremental savings achieved each year. RFF does for the most part provide the periods covered by each savings estimate. These figures, along with the RFF savings estimates, are summarized in Table 5. If we take the savings in 2000 and divide by the number of years required to achieve these savings, we obtain savings per year for each policy. The net result is up to 0.5 quads saved per year just using the RFF results, and up to 0.6 quads saved per year if we include R&D and building codes. This works out to be about 1.3–1.6% of buildings energy use each year (see Table 5).

These figures imply that if we continue energy efficiency efforts at current levels, we can reduce energy use by about 5 more quads in 10 years and 10 more quads in 20 years, which represents roughly a doubling and tripling, respectively, of the savings from efficiency programs achieved to date.

Table 5. Translating RFF Estimate of Effects of Energy Efficiency Programs into an Incremental Annual Savings Rate

Program		Energy Savings (quads)	% of 2000 Buildings Energy Use	Period Covered	Number of Years		Savings Per Year (quads)	% of 2000 Buildings Energy Use
Appliance standards		1.200		1990-2000	10		0.120	
Utility DSM		0.626		1989-2000	11		0.057	
1605b registry	<	0.411		1993-2000	7	<	0.059	
DOE Climate Challenge	<	0.814		1994-2000	6	<	0.136	
ENERGY STAR	<	0.933		1994-2001	7	<	0.133	
DOE Rebuild America		0.009		1994-2002	8		0.001	
Industrial Assess. Centers		0.019		1976-2000	24		0.001	
Weatherization Assist. Program		0.087		1977-2003	26		0.003	
FEMP	<	0.067		1973-2002	29		0.002	
RFF total	<	4.166	11.1%		8.1	<	0.512	1.36%
Building codes		0.560		1990-2000	10		0.056	
R&D		0.976		1978-2000	22		0.044	
Enhanced total	<	5.702	15.2%		9.3	<	0.613	1.63%

Notes: Energy savings and period covered from Gillingham, Newell, and Palmer (2004) except for building code and R&D figures that come from Tables 1 and 2 of the present paper. Buildings energy use in 2000 from EIA (2003).

Overall Future Savings Opportunities

Of course, projecting from past trends is only one way to estimate the potential for future energy efficiency savings. Many recent studies have also estimated the savings that can be achieved from energy efficiency programs and policies over the next 10–20 years. A report by Nadel, Shipley, and Elliott (2004) summarized the results of 11 recent studies (a copy is attached to this paper). Studies of energy savings potential tend to estimate one or more of three types of potential: technical potential (what can be achieved without considering economics), economic potential (what can be achieved from measures that are cost-effective), and achievable potential (what can be achieved from specific cost-effective programs and policies). Over the different studies examined by Nadel, Shipley, and Elliott (2004), the median technical savings potential was 36%, the median economic savings potential was 21.5%, and the median achievable savings potential was 10.5%. However, the studies also varied in the time frame covered, which makes it difficult to interpret this raw data. To address this problem, the authors also calculated the achievable potential per year and found a median achievable potential of 1.2% per year. In general, savings potentials were found to be somewhat higher than this average for the residential and commercial sectors and somewhat lower than this average for the industrial sector. Overall, these results are consistent with the historic results.

Similarly, in 2001, ACEEE conducted a study that estimated the energy efficiency savings that can be achieved in 2020 if nine key policies were adopted (Nadel and Geller 2001). Specific policies, listed in order of the amount of savings that could be achieved, are:

1. Increase Corporate Average Fuel Economy;
2. Adopt a national system benefit trust fund;
3. Enact new equipment efficiency standards and strengthen existing standards;
4. Enact tax incentives for highly efficient vehicles, homes, commercial buildings, and other products;
5. Expand federal energy efficiency R&D and deployment programs;
6. Promote clean, high-efficiency combined heat and power systems;
7. Voluntary agreements and incentives to reduce industrial energy use;
8. Improve the efficiency and reduce the emissions of the existing power plant fleet; and
9. Greater adoption of current model building energy codes and development and implementation of more advanced codes.

This study estimated that these policies could reduce U.S. forecasted energy use by 34 quads in 2020, a reduction of 26% from forecasted levels. Savings were highest in the commercial sector (31%), lowest for transportation (16%), and in-between for the residential and industrial sectors (25% and 19% savings, respectively). This study also examined the costs and benefits of these policies and found that benefits were 2.2 times greater than costs. The study assumed implementation over an 18-year period, which works out to average savings of 1.4% per year across all sectors, with savings of 1.5% per year for buildings (residential and commercial), 1.1% per year for industry, and 0.9% per year for transportation. The buildings figure is in line with the historic results for the buildings sector from the RFF study.

Economics of Energy Efficiency

RFF reviews the economics of two major policies to reduce energy use—appliance efficiency standards and utility DSM programs. In the case of appliance standards RFF found that standards cost consumers an average of about $2.63 billion per quad of savings, which is less than half of the average 2000 electricity price of $6.34 billion per quad (most of the savings from standards are in electricity). This implies a benefit-cost ratio of about 2.4.

In the case of utility DSM programs, the first two drafts characterized these programs as being of borderline cost-effectiveness, with an average cost of about 6.5 cents per kWh saved. However, in response to comments on the earlier drafts, RFF discovered several errors in its calculations. The latest estimate is that these programs cost an average of about 3.7 cents per kWh saved. This estimate from RFF is provided in Table 6. RFF's estimate of a cost of 3.7 cents per kWh is significantly less than retail electric prices in all sectors, which in 2003 was 7.4 cents per kWh for all customers on average (ranging from 4.95 cents in the industrial sector to 8.71 cents in the residential sector [EIA 2004b]). This DSM cost is also less than the marginal cost of new electric generation (which EIA estimated to be about 5 cents per kWh for both "advanced coal" and "advanced combined cycle" gas in EIA [2004a]). However, even this latest RFF estimate is probably somewhat high as it uses a 9% real discount rate in the calculations, which is higher than the 1.7–7.0% rates now generally used by utilities and state utility commissions when preparing resource plans and evaluating DSM programs (current assumptions for a sample of utilities and states are provided in Table 7). If we take an average value from Table 7, which is a discount rate of about 4.5% real, then the average cost of DSM using the RFF spreadsheet becomes 2.9 cents per kWh, very much in line with other recent assessments of DSM programs (e.g., Kushler, York, and Witte [2004] and Cowart [2001] both found an average cost of DSM of about 3 cents per kWh saved).

Other energy efficiency policies can be equally cost-effective. For example, the National Research Council (2001) study discussed above found that DOE's energy efficiency RD&D efforts have resulted in net energy cost savings of about $30 billion (1999$) at a cost of about $7 billion (also 1999$, including DOE and industry costs), implying a benefit-cost ratio of more than 5:1.[8] And evaluations of building codes have found a typical benefit-cost ratio of 3.0 for residential codes (Howard and Prindle 1991) and even higher for commercial codes (Nadel and Geller 2001).

Furthermore, all of these estimates assume that energy efficiency does not affect energy prices or the economy as a whole. In fact, energy efficiency can often have positive impacts on energy prices and the economy.

Regarding energy prices, basic economic theory holds that when supplies are tight (as they often are for oil, gas, coal, and electricity), reductions in demand will cause prices to decline. To provide just one illustrative example, in 2003, Energy and Environmental Analysis (EEA), Inc. conducted two parallel studies on the U.S. natural gas market, one for the National Petroleum Council (NPC 2003) and one for ACEEE (Elliott et al. 2003). The two studies

[8] They found $30 billion net savings after subtracting the costs. This means benefits total $37 billion, which when divided by the $7 billion in costs is a benefit-cost ratio of 5.3.

used the same EEA model. The NPC study looked primarily as different sources of natural gas supply. The ACEEE study looked at the impacts of energy efficiency programs on natural gas prices. Specifically, the ACEEE study assumed that efficiency programs are operated that reduce natural gas and electricity use by an average of about 5% over a five-year period (with higher savings in states already familiar with such programs and lower savings in states that lack experience with these programs). Electricity savings are important because natural gas is frequently the marginal generation fuel. The EEA model estimated that if such efficiency programs are operated nationally, average natural gas prices would decline about 20% over the five-year period relative to a base case scenario without efficiency programs. Even if efficiency programs are only operated in a single region, the study found that average regional natural gas prices would decline about 5% over the period (Elliott et al. 2003). When these benefits are factored into the calculations, the net costs of efficiency can decline substantially. However, the exact amount of price decline will depend on the markets involved and can only be estimated with sophisticated models, a level of effort beyond both RFF's and my scope.

Table 6. Revised RFF Analysis of National DSM Cost Effectiveness

	Computation of DSM Capital Stock				**Computation of DSM Cost-effectiveness**			
Year	CPI (inflation index)	I(t) (nominal DSM spending $M)	I(t) (DSM spending in $2002 M)	K(t) (DSM capital in $2002 M)	Annual cost of DSM capital ($2002 M)	Total annual energy savings (GWh)	Energy efficiency DSM cost effectiveness ($/KWh)	Energy efficiency DSM cost effectiveness ($B/quad)
1989	124.0	$595	$869	$869				
1990	130.7	$802	$1,112	$1,886				
1991	136.2	$1,229	$1,636	$3,314				
1992	140.3	$1,599	$2,067	$5,016				
1993	144.5	$1,927	$2,418	$6,882				
1994	148.2	$1,918	$2,347	$8,471				
1995	152.4	$1,701	$2,024	$9,563				
1996	156.9	$1,232	$1,424	$9,935				
1997	160.5	$1,084	$1,224	$10,067	$2,013	55,453	$0.036	$3.11
1998	163.0	$883	$982	$9,942	$1,988	48,775	$0.041	$3.50
1999	166.6	$934	$1,016	$9,864	$1,973	49,691	$0.040	$3.40
2000	172.2	$1,061	$1,117	$9,896	$1,979	52,827	**$0.037**	**$3.21**
2001	177.1	$1,234	$1,263	$10,071	$2,014	52,946	$0.038	$3.26
2002	181.3							

Derivation of rental price of capital
□ = depreciation rate
□ = 11% depreciation rate (used to compute DSM Capital)
r = 9% elect. utility cost of capital in 2000 (i.e., discount rate)
□+r = 20% rental price of capital
Source: Newell (2004)

Table 7. Current (July 2004) Utility Discount Rates Used in DSM Filings and Plans

Utility	Rate	Type	Source
National Grid USA			
Mass. Electric	4.41%	nominal	Mass. DTE decision 98-100
	1.86%	real	Same as above and 2.5% inflation
Naraghansett Electric	4.96%	nominal	Per PSC, based on 30 year T-Bill rate on 1/02/03
Granite State Electric	4.25%	nominal	Per PUC, based on prime rate
National Grid average	4.54%		
PacifiCorp (OR & UT)	7.79%	nominal	For cost-of-service regulation, from PacifiCorp Resource Plan, 2000
	9.70%	nominal	For merchant plans, from PacifiCorp Resource Plan, 2000
	8.75%	nominal	Midpoint of above two estimates
PG&E	8.15%	nominal	CPUC decision D-01-11-066
Average of 3 companies	7.15%	nominal	
	4.53%	real	Assuming 2.5% inflation as per Massachusetts

Similarly, many studies have found that efficiency investments generally have a positive impact on the economy, such as increases in GDP and employment (see, for example, Geller et al. 1992; Laitner, Bernow, and DeCicco 1998; Nadel et al. 1997; Prindle et al. 2004). These net benefits can be attributed to several factors including: (a) efficiency investments tend to be more labor-intensive than traditional supply-side energy industries; (b) reductions in energy bills free up money for spending in services and other relatively labor-intensive sectors of the economy; and (c) some of our energy is imported and therefore declines in U.S. imports have positive effects domestically and adverse effects beyond our borders. However, while these impacts can be significant, quantifying them more specifically is beyond the scope of this paper.

Conclusion

The RFF study shows that past energy efficiency programs have achieved significant energy savings, and for appliance standards and utility DSM programs, these savings appear to be very cost-effective (the economics of the other programs weren't examined).[9] Overall, RFF estimated that past energy efficiency programs reduced U.S. energy use by about 4 quads in 2000. In this paper we have shown that significant cost-effective savings have been achieved by R&D efforts and building energy codes, resulting in total savings of as much as 5.5 quads in 2020. However, if we allow for some overlap in savings between programs and also for the fact that a few of the program estimates included in the RFF paper are likely optimistic, total savings in 2000 were most likely in the range of 4–5 quads. If we divide by the weighted average period of time each program has been operating, these savings amount to

[9] Early drafts of the RFF study found DSM to be of borderline cost-effectiveness, but the most recent RFF analysis estimates average costs of about 3.7 cents per kWh saved. Using RFF's methodology and data, but adjusting the discount rate, we estimate average costs of about 2.9 cents per kWh saved.

1.3–1.6% of buildings energy use for each year of program operation (savings in the industrial sector appear to be much less).

There are large opportunities for cost-effective energy savings in the future, which should allow these past trends to continue or even be accelerated. LBNL found the potential for about 25 quads of cumulative energy savings over the 2010–2030 period from new appliance and equipment efficiency standards, which works out to about 1.7 quads per year of savings once the equipment stock has turned over. In this paper we show how the LBNL estimates are likely conservative—we estimate a savings potential from new standards of at least 35 cumulative quads and perhaps as much as 48 quads. The latter works out to about 3.2 quads per year once the equipment stock turns over. LBNL also estimated more modest savings from building codes—about 5 quads of cumulative savings, which is about 0.5 quads per year in the out years. In this paper we do not estimate cumulative code savings but do estimate 0.94 quads in 2020, nearly twice the annual savings derived from the LBNL estimates.

Additional savings can be achieved with continued R&D efforts, continued utility-sector DSM programs, and other programs and policies. Quite a few studies indicate opportunities to achieve savings of 1.2–1.4% per year across multiple sectors over the next 20 or so years, in line with the recent historical experience for the buildings sector.

If these savings are achieved, they can exert downward pressure on energy prices and lead to modest improvements in the economy in addition to the more traditional benefits of energy efficiency such as direct energy bill savings, reduced emissions, reduced dependence on imported energy, and reduced need to develop energy sources in environmentally sensitive areas.

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Report prepared for:
National Commission on Energy Policy

Policy Recommendations for Improving Energy-Efficiency Labeling in the United States

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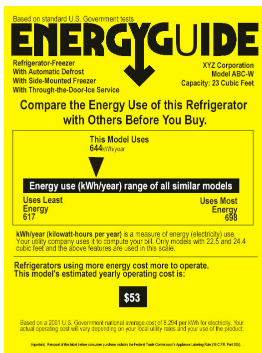
Making a World of Difference

Table of Contents

I. Executive Summary

Energy-efficiency labels are attached to energy-using products or their packaging. They convey standardized, easy-to-understand information about a product's energy efficiency relative to other similar products. The primary goal of an energy efficiency-labeling program is to shift consumer preferences away from inefficient products and towards more efficient products.

This paper recommends ways to improve the overall impact of the two federally funded energy efficiency labels employed in the United States—EnergyGuide and ENERGY STAR.



EnergyGuide is a mandatory program run by the Federal Trade Commission and Department of Energy (DOE). It requires manufacturers of certain appliances and equipment to attach yellow-and-black EnergyGuide labels to their products to inform consumer about the products' energy performance.

ENERGY STAR, administered by the Environmental Protection Agency (EPA) and DOE), is a voluntary partnership among consumers, manufacturers, and government. Partner manufacturers are allowed to display the ENERGY STAR "endorsement" logo on their products that meet energy efficiency guidelines set by the two federal agencies.

Two recommendations for EnergyGuide are:

1. Revise the current EnergyGuide label format to increase clarity and usefulness, employing the categorical rankings that have been proven so effective internationally, and
2. Extend the EnergyGuide label's coverage to a wider range of products.

Organizations such as the International Energy Agency, the Collaborative Labeling and Appliance Standards Program (CLASP), and the American Council for an Energy Efficiency Economy (ACEEE) support these reforms, which could have an estimated savings of close to 100 billion kWh per year.[1]

Changes to a mandatory federal program, however, take time and must go through the federal regulatory process. Political hurdles blocked prior attempts to reform the EnergyGuide label, making it all the more important that the voluntary ENERGY STAR labeling program be as effective as possible.

Recommendations for ENERGY STAR include:

1. Display quantitative information about annual product energy use or efficiency adjacent to the ENERGY STAR label on product packaging or on the ENERGY STAR website.
2. Place more emphasis on products' overall energy use instead of giving precedence to power use in particular modes of operation. This means refining the current test procedures and duty cycle assumptions to develop estimates of annual energy use and operating cost for each labeled product.
3. Establish automatic specification revision processes that update every two years to ensure that no more than 25% of products in a given category qualify for the label.

[1] Estimates cited later in report, from: http://www.aceee.org/buildings/policy_legis/labeling/description.htm and http://www.efficientpowersupplies.org/what_is_it.html.

While mandatory comparative information about products' energy efficiency is clearly preferable, the ENERGY STAR program could achieve some of the same results by providing more information to those who want it.

II. U.S. Energy-Efficiency Labeling Programs

Energy-efficiency labels are attached to energy-using products or their packaging. They convey standardized, easy-to-understand information about a product's energy efficiency. This can be done in a strictly quantitative way, measuring product functionality or performance per unit of energy consumed. It can also be done in a more general way, by grouping products together by approximately equivalent functionality and then simply reporting annual energy usage or costs. In both cases, the primary purpose is to encourage consumers to shift purchases from inefficient to efficient products.[2]

The United States has two primary federally funded labeling programs for consumer products and appliances: EnergyGuide and ENERGY STAR.

- EnergyGuide is a mandatory energy-labeling program administered by the Federal Trade Commission (FTC), which has required manufacturers of certain appliances to attach EnergyGuide labels to their products since 1980. The program's yellow and black labels (Figure 1) provide an estimate of the product's energy consumption and also display the highest and lowest annual energy use estimates of similar appliance models based on test procedures established by the U.S. Department of Energy (DOE).[3]
- ENERGY STAR, introduced in 1992, is a voluntary labeling program operated jointly by the Environmental Protection Agency (EPA) and Department of Energy (DOE). It is designed to reduce greenhouse gas emissions by identifying and promoting energy-efficient products. The program functions as a voluntary partnership between government and various businesses, including manufacturers and various trade allies like retailers, installers, utilities, and energy service companies. The ENERGY STAR logo[4] (Figure 1) is now widely recognized by consumers. Labeled products receive preferential treatment in federal and state procurement processes and in various utility-funded incentive and marketing programs.

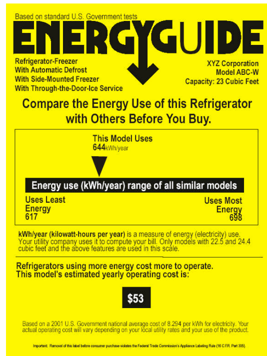
Figure 1 summarizes some additional information about these two programs:

[2] Weil and McMahon, p.7.

[3] www.ftc.gov/bcp/conline/edcams/eande/popups/20yrs.htm

[4] Manufacturers who participate in the ENERGY STAR program are permitted to include the ENERGY STAR logo on their EnergyGuide labels.

Figure 1. EnergyGuide vs. ENERGY STAR

	EnergyGuide	**ENERGY STAR**
Logo/Label		
Program type	Mandatory	Voluntary
Label type	Comparison (Continuous) – label compares the energy use of a given model to other similar models by providing a range (with a low-end and a high-end) of energy use of similar models	Endorsement – label indicates that product meets certain levels of performance.
Year Started	1980	1992
Responsible federal agency	FTC (labeling) and DOE (testing)	EPA and DOE[5]
Underlying legislation	Energy Policy and Conservation Act, 1975; National Energy Conservation Policy Act, 1979; FTC Appliance Labeling Rule, 1980	Voluntary government/industry partnership
Products covered	▪ Refrigerators ▪ Freezers ▪ Dishwashers ▪ Clothes washers ▪ Room air conditioners ▪ Water heaters ▪ Furnaces ▪ Boilers ▪ Central air conditions ▪ Heat pumps ▪ Pool heaters *Other products (e.g., lighting) are required to display energy-efficiency information directly on their product labels/packaging.	Products in more than 40 categories: ▪ Appliances (Clothes Washers, Dehumidifiers, Dishwashers, Refrigerators, Room Air Conditioners) ▪ Heating & Cooling (Air-source Heat Pumps, Boilers, Central AC, Ceiling Fans, Dehumidifiers, Furnaces, Geothermal Heat Pumps, Home Sealing (Insulation), Light Commercial, Programmable Thermostats, Room AC, Ventilating Fans) ▪ Home Electronics (Cordless Phones, Combination Units, DVD Products, Home Audio, Set-top Boxes, Televisions, VCRs) ▪ Lighting (Compact Fluorescent Lamps, Residential Light Fixtures, Ceiling Fans, Exit Signs, Traffic Signals) ▪ Office Equipment (Computers, Printers, Copiers, Faxes, Mailing Machines)

[5] http://www.energystar.gov/index.cfm?c=about.ab_history

EnergyGuide is the second longest-running national energy efficiency-labeling program (after Canada's, which began in 1978). Its legislated goals are to improve energy efficiency and assist consumers in making purchase decisions. However, many U.S. consumers cannot interpret the EnergyGuide label, and most of the credit for energy savings has been attributed to strict minimum efficiency standards, as opposed to labeling efforts.[6]

No systematic federal evaluation of the EnergyGuide program or the efficacy of the current label design has been undertaken in the last 20 years. This runs contrary to the pattern that review cycles in most countries range from three to 12 years.[7] Periodic review "allows the government to adjust test procedures, redesign labels, and adjust or 'ratchet' the stringency of standards upward as new technology emerges and use-patterns change."[8]

Small-scale studies and anecdotal evidence, as well as superior demonstrated results in other countries—in terms of consumer awareness, market impacts, and energy savings—suggest that improvements could be made to the EnergyGuide program.[9]

III. How can we improve EnergyGuide?

This paper discuss two basic ways to increase the impact of the EnergyGuide label:

1. Revise the label format, and
2. Extend the label to more products.

These are not new ideas. A number of organizations, including the International Energy Agency, Collaborative Labeling and Appliance Standards Program (CLASP), and the American Council for an Energy-Efficient Economy (ACEEE), have been pursuing efforts to revise the EnergyGuide label for several years.

There is also growing support to expand EnergyGuide's coverage to a wider variety of products, including consumer electronics, office equipment, and possibly even vehicles. Some of these products are currently covered under voluntary labeling programs, such as ENERGY STAR. Not only is the potential for energy savings in these product categories quite large, but there are also certain characteristics of these products that lend themselves to mandatory energy-efficiency labeling.

A. Redesign the EnergyGuide Label

The design of a label is critical to the success (or failure) of a labeling program.[10] To be successful, labels must effectively communicate with consumers. Recent research has shown that only 20% of the U.S. consumers read the EnergyGuide label at all, and fewer than half of the people who were shown the label were able to correctly interpret it and identify whether that model was more efficient than other models. This clearly suggests that the EnergyGuide label needs to be redesigned to influence consumers more effectively.[11]

[6] http://www.clasponline.org/standard-label/general-info/success-stories/usa.php3

[7] CLASP, p.26.

[8] Ibid.

[9] Thorne, Jennifer and Christine Egan. "An Evaluation of the Federal Trade Commission's EnergyGuide Appliance Label: Final Report and Recommendations." Report Number A021. American Council of an Energy Efficient Economy (ACEEE), August 2002.

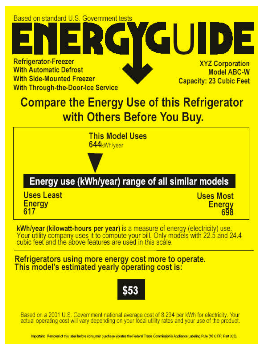
[10] duPont. 4 December, 1997/

[11] http://www.clasponline.org/standard-label/general-info/success-stories/usa.php3

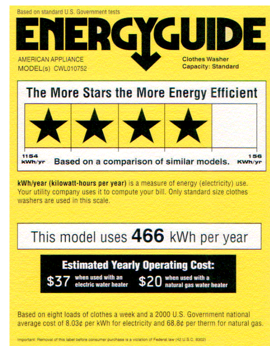
In 2002, ACEEE conducted an in-depth study "to evaluate the efficacy of the current EnergyGuide label and determine the best label format and informational elements for U.S consumers." [12] The study included primary research, focus groups, and interviews with both supply-side actors (e.g., manufacturers, contractors and retail sales staff) as well as consumers. Several rounds of focus groups were used to test consumer reactions to different label designs, content, and interaction with the ENERGY STAR label. Other countries, such as India, have followed similar consumer research processes when designing or redesigning their own labels.[13]

Based on its research, ACEEE proposed a new format of the EnergyGuide label, which is shown in Figure 2.

Figure 2. Current and Proposed EnergyGuide Labels



Current Label



Proposed ACEEE Label

The new label design gives greater attention to quantitative aspects of energy use, like kwh per year and annual operating cost (items which consumers explicitly identified as important), by clearly offsetting this information from rest of the label content. The new label also has a slightly reduced amount of text—to help draw consumers' attention to the primary energy-efficiency message but still provide detailed information for those who want it. Perhaps the biggest overall change in ACEEE's proposed label design is the use of a "categorical" one- to five-star rating system, as opposed to the current label's "continuous" comparison, which shows where a particular model falls along a continuous scale of energy use of similar models.[14]

While continuous comparison labels provide more detailed information on relative energy use, research has shown that they are more difficult for consumers to understand. Categorical labels provide a quick basis for comparison-shopping by ranking different models based on the energy-efficiency (either with stars, numbers, letters, etc.).[15] Categorical comparison labels have been proven highly effective in countries such as Thailand, Australia, Mexico, and Korea, as well as the European Union. Examples of these labels are shown in Figure 3.

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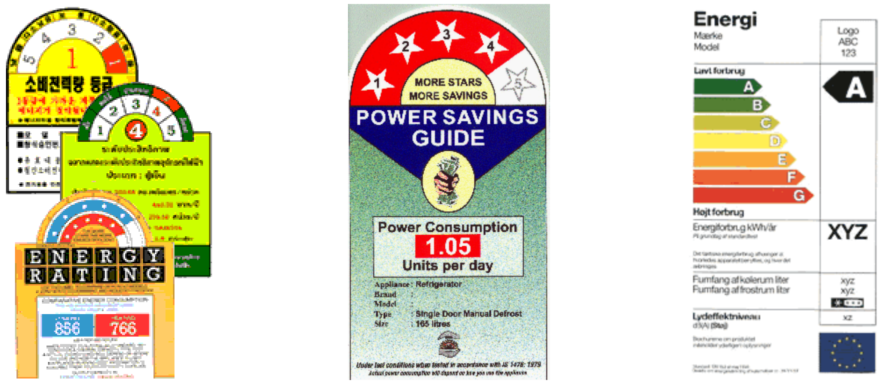
[12] Weil and McMahon, Chapter 5, p. 81-82.

[13] Weil and McMahon, Chapter 5, p. 81-82.

[14] Energy use is usually in terms of kWh or another applicable measure of energy efficiency, such as EER (energy efficiency rating) for air conditioners or HSPF (heating seasonal performance factor) for heat pumps.

[15] ACEEE's study revealed "stars" as the preferred categorical indicator of energy-efficiency; the use of stars was a familiar concept to most people and a natural complement to the ENERGY STAR concept and logo.

Figure 3. Examples of Categorical Labels



Korea, Thailand, and Australia **India** **European Union**

The international trend is clearly towards categorical labels; no country has adopted a continuous label since1986 when Brazil implemented a refrigerator label similar to the U.S. label. In 1997-98, Brazil revised its label to a categorical format, claiming the old one was doing little to influence consumers.[16]

In addition to being more consumer-friendly, categorical labels can have a profound influence on manufacturers. Categorical labels provide the expected positive incentive at the top end of the efficiency spectrum, but also deter manufacturers from selling products with very low ratings.

Thailand is a case in point. Surveys showed that after only three years, more than 60% of Thai consumers ask about or used the label (Figure 3) and 28% reported energy efficiency among their top three purchase priorities.[17] The Thai government implemented a national advertising campaign promoting the label and manufacturers began to increase their production of high-efficiency models or to modify existing models to make them energy-efficient.[18]

> *When [Thailand's voluntary] refrigerator labeling program began in February 1995, only one model earned a "5" rating. Out of the participating refrigerators... 32% were rated at 3, 55% were rated at 4, and 13% were rated at 5. By the end of 1996... 70% of participating models were rated at 5.... The average energy consumption of participating refrigerators dropped by 14% during the first two years.*[19]

More labeling "success stories" can be found on CLASP's website: www.clasponline.org

Australia's energy labeling program has had similar success. It was first instituted in 1986 as a voluntary program, but now all Australian states have mandatory standards for refrigerators, freezers, room air conditioners, dishwashers, clothes washers, and dryers. A 1993 survey showed that nearly 90% of consumers were aware of the energy label and 45% used the information on the label to compare models. It is estimated that Australia's energy labeling program reduced the energy consumption of labeled appliances by about 11%, or 94 GWh, in 1992—about a 1.6% decrease in the total household electricity

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[16] ACEEE, p. 1.

[17] du Pont, Peter. "Label Lessons from Thailand." *Home Energy Magazine Online*, November/December, 1998.

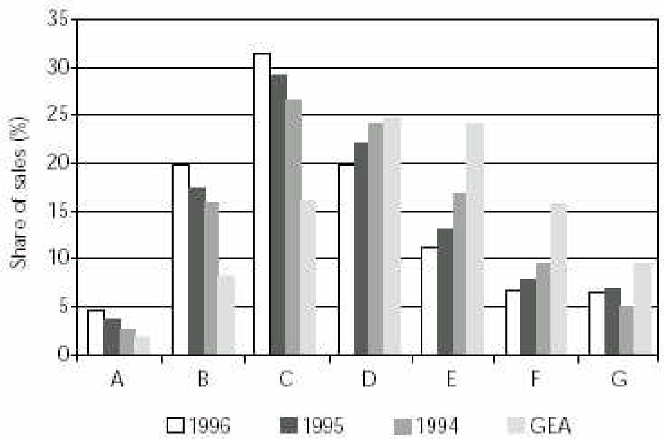
[18] http://www.clasponline.org/standard-label/general-info/success-stories/thai.php3

[19] http://www.clasponline.org/standard-label/general-info/success-stories/thai.php3

consumption in Australia.[20]

Likewise, the first comprehensive evaluation of the EU labeling program showed that the sales-weighted average energy efficiency of refrigeration appliances improved by 29% between 1992 and late 1999, with about one third of the impact due to labeling (the other two-thirds was due to minimum efficiency standards).[21] Figure 4 shows the sale share of EU cold appliances by energy label class for 1994, 1995, and 1996 (GEA indicates the pre-program distribution of appliances calculated by the Group for Efficient Appliances). Over the three years, there is a noticeable shift towards the more efficient models (Category A) and away from the least efficient models (Category F).[22]

Figure 4. Sale Share of EU Cold Appliances by Energy Label Class (1994-1996)



Source: Waide, 1999b.

Current trends in the EU suggest that the labeling program could save 278 TWh by 2020 for refrigerators, freezers, and refrigerator/freezers alone—roughly a 10% decrease in electricity demand for these appliances or more than US$40 billion in avoided electricity spending for consumers.[23] Several Central and Eastern European States, including Hungary and the Czech Republic have started to develop labeling programs similar to the EU.[24]

ACEEE predicts that revisions to the current EnergyGuide label would result in similarly successful results for the United States. A rough estimate of the energy savings achievable by redesigning the EnergyGuide labels is 0.23 quads annually (approximately 67 billion kWh per year), once the existing appliance stock had turned over. Associated CO_2 savings would be approximately 52 million tons per year.[25]

Categorical labels have appeal from an administrative standpoint as well. Typically, they need less frequent revision than do continuous labels. Jennifer Thorne-Amann, Director of ACEEE's

[20] http://www.clasponline.org/standard-label/general-info/success-stories/aus.php3

[21] Bertoldi, 2000, as cited in Weil and McMahon, p. 18.

[22] IEA, p. 89.

[23] http://www.clasponline.org/standard-label/general-info/success-stories/eur.php3

[24] International Energy Agency. Energy Labels and Standards. OECD/IEA, 2000, p. 18.

[25] http://www.aceee.org/buildings/policy_legis/labeling/description.htm, converted to CO_2, based on 1.55 lbs CO_2 per kWh, as cited at: http://www.energystar.gov/index.cfm?c=energy_awareness.bus_energy_use.

FTC Appliance Labeling Project, indicates that the current EnergyGuide design should really be updated annually so that the continuum endpoints accurately reflect the energy usage of models available in the marketplace. In practice, however, this does not happen. The labels are consistently outdated, and consumers can routinely find models that are not even on the current scale.[26] A categorical design would require less frequent calibration—maybe once every three to five years— when the market evolves to the point that models tend to cluster in a few categories. Category labels also fit well with standards programs, since the standard can be set at a point that divides any two of the categories.[27] ACEEE's also believes this design would fit well with the ENERGY STAR program: products scoring "4" or "5" stars, for example, could be eligible for ENERGY STAR status.[28]

B. Extend EnergyGuide to More Products

The mandatory EnergyGuide label applies to a limited range of products including refrigerators, freezers, dishwashers, clothes washers, central and room air conditioners, water heaters, furnaces, boilers, heat pumps, pool heaters, and some lighting and plumbing products.[29] The voluntary endorsement ENERGY STAR label, however, applies to products in over 40 categories—not only appliances, lighting and heating and cooling equipment, but also home electronics, office equipment, and even buildings. Computers and monitors were the first ENERGY STAR labeled products. And, over the past ten years, ENERGY STAR has been a driving force behind the widespread adoption of many energy-saving technical innovations such as LED traffic lights, efficient fluorescent lighting, power management systems for office equipment, and low standby energy use.[30]

Nevertheless, the ENERGY STAR program is voluntary. Experience suggests that mandatory labeling programs are generally more effective than voluntary ones. Voluntary threshold labels like ENERGY STAR can help encourage the sale of labeled products, but consumers choosing the least expensive (and typically most inefficient) product in a given category generally have no way to compare the energy use or operating cost of that choice to an ENERGY STAR choice. Likewise, even among an array of ENERGY STAR labeled products, consumers have no idea that some choices might use 20%, 30%, or even 40% less energy than others. Under voluntary programs, manufacturers of inefficient products simply tend not report energy consumption—resulting in a number of unlabeled products. Some consumers who might have avoided this product, if labeled, will end up buying it. According to CLASP's definitive Standards and Labeling Guidebook, "labeling works best if all products are labeled and if consumers can easily distinguish between poor-, average-, higher-, and highest-efficiency products."[31] In addition, the energy savings under mandatory programs are by and large guaranteed, making them relatively easier to quantify and verify.[32]

Labeling can be more effective for some products than others. Typically, labeling works best for products:

- that use a substantial amount of energy,

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[26] Personal communication with Jennifer Thorne-Amann.

[27] EIA, p. 73.

[28] Personal Communication with Jennifer Thorne-Amann.

[29] Some lighting and plumbing products are not required to display the yellow and black EnergyGuide label. Instead, they carry energy efficiency information directly on their product packaging.

[30] http://www.energystar.gov/index.cfm?c=about.ab_history

[31] Weil and McMahon, Chapter 5, p. 75.

[32] Ibid, pp. 10.

- that are present in most households,
- for which proven energy-efficiency technology exists but has not been widely adopted in the market place,
- for which the purchaser pays the energy bill,
- that are purchased at a retail business (where shoppers can inspect and compare items at the point of sale), and
- for which there could be significant variation in energy use between similar items or models.[33]

There are a growing number of products that meet the criteria listed above and which are, therefore, good candidates for mandatory energy labeling. Among these are consumer electronics (cellular phones, DVD players, etc.) and office equipment (computers, printers, etc) that are all sold with power supplies. Improving the efficiency of the power conversion process in those power supplies can systematically improve overall product efficiency.

Wholesale purchases of consumer electronics by retailers topped $100 billion in 2002, with the top ten retailers, such as Best Buy, Wal-Mart and Circuit City, accounting for nearly two-thirds of total sales.[34]

Consumer electronics accounted for nearly 7% of U.S. residential electricity consumption in 1999.[35] Sales of consumer electronics, particularly new categories of electronics like cellular phones, portable CD and MP3 players, battery chargers, satellite receivers, digital video recorders, and digital cameras are growing rapidly (Figure 6). It seems likely that their share of residential electricity use could now be as high as 15 to 20%, according to California Energy Commission-funded research by LBNL and Ecos Consulting.[36]

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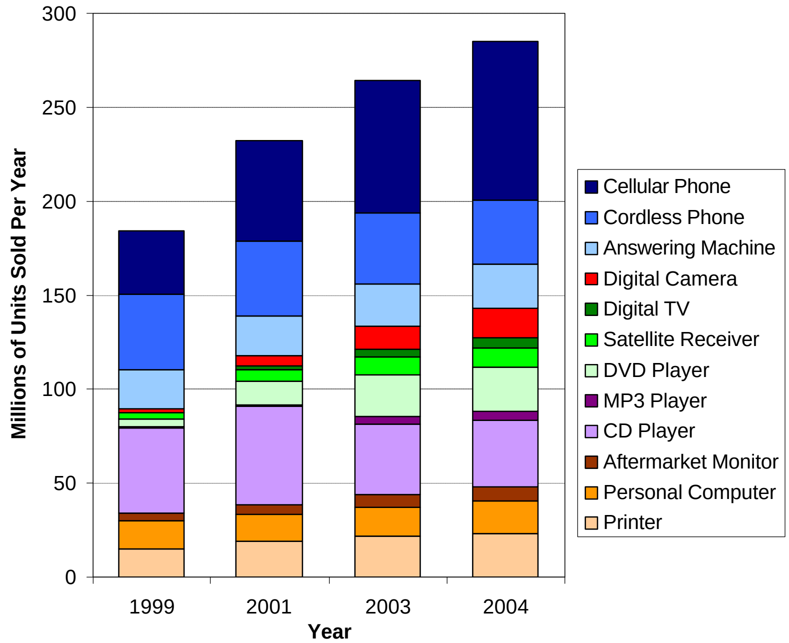
[33] Weil and McMahon, Chapter 5, p. 81-82.

[34] TWICE Market Research. "Top 100 top $100 billion in CE sales." *TWICE , Volume: 18 , Number: 9 , Page: 20 , April 21, 2003.*

[35] DOE statistics, referenced in Rosen, Karen, Alan Meier, and Stefan Zandelin. Lawrence Berkeley National Laboratory. *National Energy Use of Consumer Electronics in 1999*.

[36] Foster, Suzanne, Chris Calwell and Noah Horowitz. *If We're Only Snoozing, We're Losing: Opportunities to Save Energy by Improving the Active Mode Efficiency of Consumer Electronics and Office Equipment*., p. 2, 2004; presentation at ACEEE Summer Study by Suzanne Foster and Chris Calwell, Ecos Consulting, August 26, 2004; Bruce Nordman, Bruce Biermayer, and Gregory Homan, Lawrence Berkeley National Laboratory, *Any Device, Any Mode: Measuring All Residential Low-Power Mode Energy Consumption,* ACEEE Summer Study, August 2004.

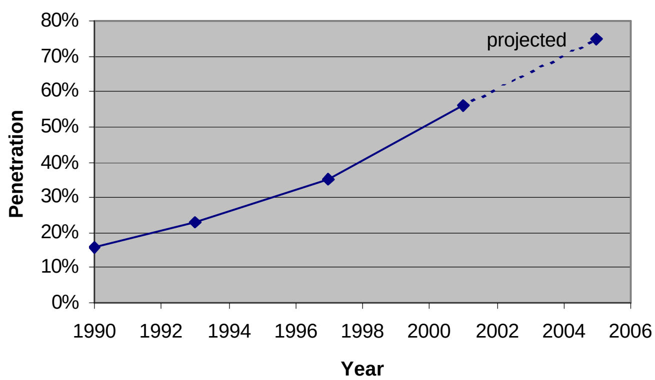
Figure 6. U.S. Sales of Selected Electronic Products, 1999-2004



Source: Consumer Electronics Association 2004.

Increasingly, these electronics are becoming common household items. The DOE's Appliance Reports added personal computers to their list of surveyed appliances in 1990. At that time, the penetration of personal computers in U.S. households was only 16%, but by 2001 (the latest Appliance Report published) the penetration of personal computers had skyrocketed to 56% (Figure 7). Other sources predict it will rise to 75% by 2005. Likewise cell phone ownership grew 29% over the two-year 1999 to 2001 period, with nearly 62% of U.S. adults now owning one.[37]

Figure 7. Penetration of Personal Computers in U.S. Households, 1990-2005



Source: EIA, Appliance Reports, 2001. Jupiter Research, 2005 proj.

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[37] http://www.scarborough.com/scarb2002/press/pr_cellphone.htm

While many types of consumer electronics are covered by the voluntary ENERGY STAR program (Figure 1), it has typically focused on differences in energy consumption when products are in sleep or standby mode. Recent research reveals the need to address active mode as well—by improving test procedures and calculating annual energy use and energy cost information based on a standard duty cycle or hours of use. Such a procedure (similar to the mandatory DOE testing for EnergyGuide) allows consumers to have more accurate information about total energy use and enables them to compare more easily across products.[38] It also highlights the opportunity for energy saving technologies. For example, in a standard benchmark comparison test of a desktop computer performing a series of tasks, simply using a more efficient power supply[39] can yield energy savings of more than 20% with no impact on performance.[40]

Given the effectiveness of mandatory labeling programs, the proliferation of consumer electronics, and the apparent need to establish a better comparative testing procedure for these devices, a natural next step is to expand the EnergyGuide program to include these products. Such a move would accelerate the transformation of markets—as it did for refrigerators and other appliances in the past. Ecos Consulting has estimated the potential energy savings from more efficient power supplies alone at 30 to 60 billion kWh per year. That would cut the annual U.S. energy bill by $2.5 to $5.0 billion, and prevent about 23 to 46 millions tons of CO_2 emissions per year.[41]

IV. Putting Recommendations into Action

Revising the format of the EnergyGuide label and extending the label to more products clear steps that can be taken to improve the U.S. mandatory energy-labeling program. But, what will it take to get there?

The National Energy Conservation Policy Act and the FTC Appliance Labeling Rule authorize the EnergyGuide program. Changes to the program are subject to the federal regulatory rule-making process. The next agency review of the FTC Appliance Labeling Rule is scheduled for 2008, so any triggers before then must come from another source (e.g., legislation, Congressional hearings/reports, court orders, petitions, etc.)[42]

For some time, it looked like that trigger was going to be the Federal Energy Bill. In 2002, shortly after ACEEE published the findings of its research on the EnergyGuide label, work began on the Energy Bill. The bill included language which directed the FTC to evaluate the efficacy of the EnergyGuide program and adopt changes within a very short timeframe. With limited funding of its own for evaluation, the FTC would rely on outside sources (like ACEEE's study) for recommendations. The legislation would provide the impetus needed to execute those recommendations quickly.

Now, however, as the prospects for the Energy Bill are dim, ACEEE is considering filing its own petition outside of the legislative process. Their petition will support the adaptation of the categorical "stars" EnergyGuide label described earlier in this report. Although, Jennifer Thorne-

[38] Foster, Calwell, and Horowitz., p. 4.

[39] A power supply is an electronic power conversion device which converts AC line voltage into the low-voltage DC power that is used by many consumer electronics.

[40] Foster, Calwell, and Horowitz, p. 7.

[41] http://www.efficientpowersupplies.org/what_is_it.html, converted to CO_2, based on 1.55 lbs CO_2 per kWh, as cited at: http://www.energystar.gov/index.cfm?c=energy_awareness.bus_energy_use.

[42] http://www.ftc.gov/os/2004/01/040113frnregulatoryreform.pdf

Amann indicates that without legislative backing, the recommended changes are likely to face greater opposition. Limited funding and key staff changes may cause the FTC to take a more rigid interpretation of the statuary language and be more skeptical about the agency's authority to make major changes to the program. Some of the specific hurdles ACEEE expects to face are:

- How to interpret the "endpoints" of the range— whether they must represent the energy use of actual products in the market or whether they could be "theoretical" values more closely tied to standards,
- How to determine the category levels or divisions and how they will be updated—especially with limited DOE funding and program support,
- How to consolidate similar products on the same rating scale— for example, electric resistance and heat pump water heaters,
- How to coordinate with and maintain political support from the ENERGY STAR program— for example, the categorical "stars' ratings fits well with the ENRGY STAR concept, however, integration of the two programs might require ENERGY STAR to increase the frequency with which it revises ENERGY STAR specifications.

In anticipation of these issues, ACEEE also plans to include a second-choice redesign in their petition. This alternative retains the continuous comparison of the current EnergyGuide label, but improves the label's clarity and visual appeal for customers. ACEEE does not expect much opposition to this less radical proposal.

ACEEE is tentatively planning to file its petition after the elections in November 2004.[43] This will allow time to secure funding, draft the petition, and garner support from the FTC Commissioners and other influential policy groups.

The situation is also complicated because it involves multiple federal agencies and multiple stakeholders. While the FTC handles the labeling and enforcement aspects of the EnergyGuide program, DOE is responsible for developing test procedures test procedures and setting minimum efficiency standards for residential appliances and commercial equipment. DOE sets priority levels for different appliance standards in order to allocate available resources. A public workshop was recently held on June 9, 2004 to discuss the priorities for the appliance standards rulemaking process for fiscal year 2005.[44] Revising current test procedures or creating new ones for additional products will take time, although much work is being done in this area under the ENERGY STAR program or by public interest groups and other consultants.

In addition to governmental agencies, labeling affects a variety of stakeholders— public interest groups, utilities, political organizations, and consumers, as well as supply side actors such as manufacturers, contractors and retail sales staff. Each group has different interests and trade-offs between energy efficiency and other concerns.[45] Any change to the EnergyGuide program would have to offer savings substantial enough to outweigh the impacts on the various actors responsible for implementing it. Each group has its own goals, and some have the ability to exert considerable influence though political lobbies.[46] It will take time to address the needs and concerns of everyone involved to develop an acceptable legislative remedy.

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[43] Personal communication with Jennifer Thorne-Amann.

[44] http://www.eere.energy.gov/buildings/appliance_standards/priority_setting.html

[45] IEA, p.57.

[46] pp. 24

V. Opportunities to Improve ENERGY STAR Labeling

In the interim, a potential solution may lie in revising the Unites States' voluntary labeling program, ENERY STAR. Since ENERGY STAR is a voluntary program, acts of Congress are not required to change it. Changes to the program may face relatively fewer political obstacles and be easier to effect in the short term. In addition, ENERGY STAR's current reach is much broader than EnergyGuide; therefore, changes to the program will be farther-reaching and have more significant impacts in terms of overall energy savings.

Unlike EnergyGuide, which has relatively low public recognition and understanding, ENERGY STAR is arguably the most visible labeling program in the United States, and even overseas. The EPA estimates public awareness of the ENERGY STAR label around 56%.[47] The symbol has gained increasing visibility in the advertising circulars of retailers like Sears, Home Depot and Lowe's and is also promoted heavily by utility efficiency programs. It is recognized internationally as well, especially among electronics and related products.

The ENERGY STAR program now covers more than 40 product categories ranging from consumer products for the home and workplace, to new homes, as well as energy management practices within organizations. The EPA estimates that US consumers have purchased more than one billion ENERGY STAR qualified products. In 2002, with the help of ENERGY STAR, Americans saved more than 100 billion kWh of electricity.[48]

Despite its tremendous impact to date, there are some notable situations where ENERGY STAR could be used more effectively to shift consumer preferences away from inefficient products and towards more efficient products and provide additional information for consumers that want it.

Three specific recommendations to improve the ENERGY STAR program are:

1. Display quantitative information about annual product energy use in addition to the ENERGY STAR endorsement logo,
2. Place more emphasis on products' overall energy use, and
3. Establish an automatic specification revision process to ensure that no more than 25% of products in a given category qualify for the label.

A. Display Quantitative Efficiency Information on ENERGY STAR Products

As a voluntary endorsement or "seal of approval" label, the ENERGY STAR logo indicates that a product meets certain minimum specifications. Thus, while ENERGY STAR can help consumers identify products that are fairly efficient, it is usually designed to recognize uniformly the top 25% or more of products currently available. It is not effective in helping consumers select *the most* energy-efficient ones. Nor, does it explicitly discourage the sale of inefficient products, where the absence of an ENERGY STAR label is not always conspicuous. This is because it offers no comparison or additional information regarding the energy consumption of a product. It also only appears on products made by ENERGY STAR partner manufacturers.

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47 http://www.energystar.gov/index.cfm?c=about.ab_milestones

48 http://www.energystar.gov/ia/partners/downloads/energy_star_report_aug_2003.pdf

While mandatory comparative information about products' energy efficiency is clearly preferable, the ENERGY STAR program could achieve some of the same results by providing more information to those who want it.

One successful example of this approach is the supplemental labeling information that now appears on ENERGY STAR-labeled ceiling fans. Prior to the establishment of the ENERGY STAR labeling program for ceiling fans, each manufacturer measured airflow a different way and made similarly confusing claims about the relative efficiency of their products. Consequently, the guidance they and the retailers provided to fan shoppers about matching particular fan models to particular rooms related only to fan diameter (a poor indicator of utility or performance), rather than to the more useful metric of measured airflow.

In order to develop an efficiency specification for these products, EPA worked with the ceiling fan industry to refine, standardize, and broadly promote a methodology for measuring airflow and power use that had been originally developed at Hunter Fan Company. The ratio of airflow to power use became the metric for efficiency, measured in cubic feet per minute (CFM) per watt. EPA collected data on a wide variety of fans, established a specification corresponding to the top 25% of the market, and then asked its partners to disclose their measured performance on product packaging. An example of that information box appears in Figure 8, allowing customers to choose a product with the airflow they need and to maximize efficiency among a range of competing choices.

Figure 8. Sample ENERGY STAR Ceiling Fan Performance and Efficiency Information

Fan Speed	Airflow	Fan Power Consumption (without lights)	Airflow Efficiency (higher is better)
Low	1,500 CFM	10 watts	150 CFM/watt
Medium	3,000 CFM	30 watts	100 CFM/watt
High	5,000 CFM	65 watts	77 CFM/watt

Major retailers like Home Depot and Lowe's promised EPA that they would require such testing and labeling for all the ceiling fans they sold, whether ENERGY STAR-rated or not. They ultimately decided not to do so, leaving consumers with useful comparative information *among* ENERGY STAR choices, but not *between* ENERGY STAR and non-ENERGY STAR models. The California Energy Commission is now moving to establish testing and listing requirements power use and airflow for all ceiling fans sold in the state, so it can provide comparative efficiency information on its website to all ceiling fan buyers.

EPA considered a very similar quantitative label for computer monitors when recently revising its labeling program for those products to consider active mode power use. Monitor manufacturer NEC-Mitsubishi had begun using the label shown in Figure 9, patterned after the federal EnergyGuide label, to educate purchasers about the energy impacts of their choices. Unfortunately, it suffered from some shortcomings technically and graphically. Power use was not correlated in any way to product performance or features, so the label served largely to call attention to absolute power consumption. The triangular shape also required a substantial area of the product packaging to convey a fairly small amount of information, so could be unpopular with other manufacturers. Finally, its format and color could cause consumers to confuse it with the mandatory EnergyGuide label.

After EPA established a test procedure utilizing monitor resolution as the metric of product performance, it became possibly to characterize monitor efficiency in operation as pixels per watt. Ecos Consulting then proposed a simpler, smaller label providing the key information about monitor resolution (pixels), power use (watts), and efficiency (pixels per watt), as shown in Figure 10. The idea was received favorably by many of the manufacturers, who had been struggling to find a way to fairly compare monitors against each other in their marketing efforts. Unfortunately, EPA ultimately declined to utilize the label, citing concerns that additional information about energy use on the package would confuse consumers or dilute the simplicity and clarity of the ENERGY STAR message.

Figure 9 – NEC-Mitsubishi's Proposed Monitor Efficiency Label

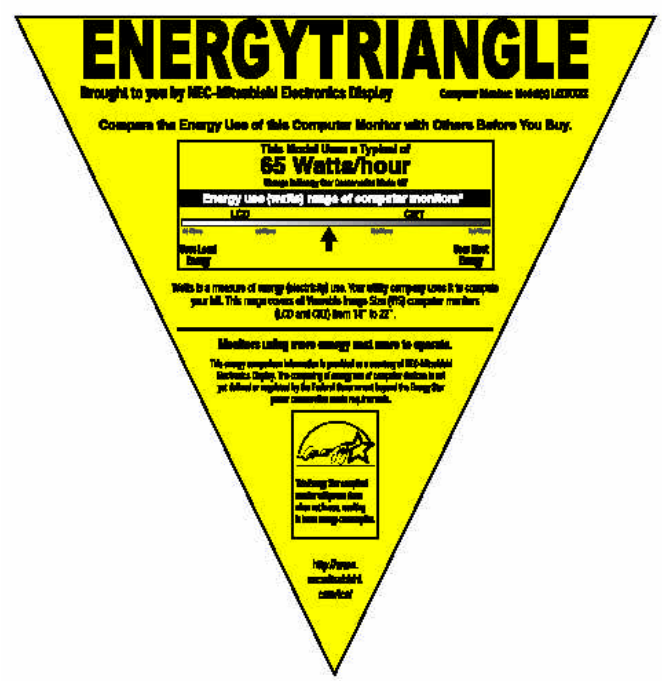


Figure 10 – Ecos Consulting's Proposed Monitor Efficiency Label

<table>
<tr><th colspan="2">Active Power Use</th><th colspan="2">Sleep Power Use</th><th>Off Power Use</th></tr>
<tr><td colspan="2">40 watts</td><td colspan="2">4 watts</td><td>2 watts</td></tr>
<tr><th colspan="3">Resolution</th><th colspan="2">Energy Efficiency</th></tr>
<tr><td colspan="3">1600 x 1200 pixels</td><td colspan="2">48,000 pixels/watt</td></tr>
<tr><td colspan="5">Energy Efficiency measures how much information can be displayed per watt of power used. Higher numbers are better.</td></tr>
</table>

EPA missed an opportunity to help consumers understand key quantifiable differences in monitor performance, power use, and energy efficiency. That same opportunity remains untapped in countless other voluntarily labeled products today, and should be pursued vigorously. Supplemental quantitative information does not undermine the ENERGY STAR message; it reinforces it.

B. Emphasize Annual Energy Use

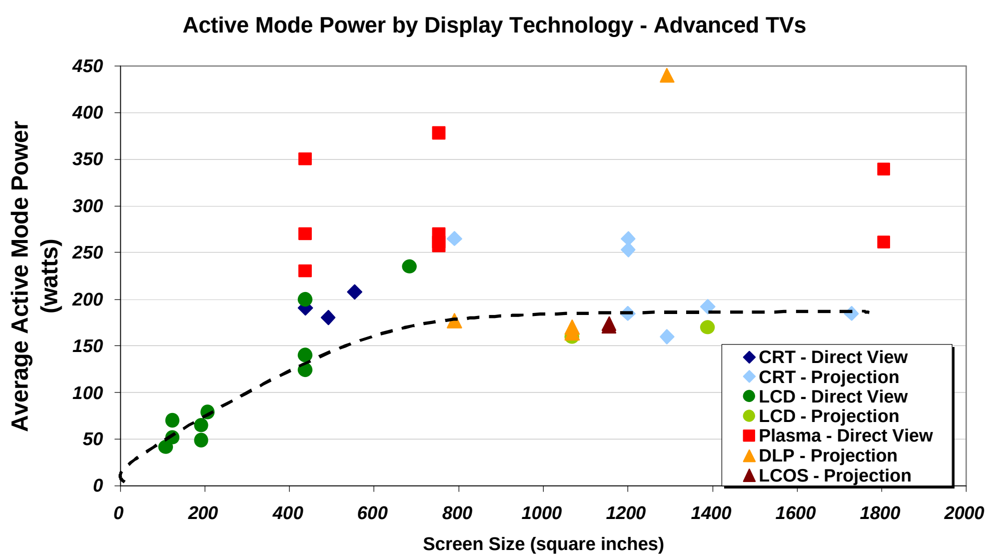
It is also difficult to compare across ENERGY STAR products because ENERGY STAR does not use a standard metric or set guideline for all products that receive the label. In some cases, roughly 20 to 30% of the models on the market comply. In other cases, that percentage can be 80 or even 90%. The translation from percentage of *models* sold to percentage of *units* sold is even more difficult, because good market research data are rarely available regarding total annual unit sales by model. If two or three set top box models account for 50% of sales, for example, it is possible that a specification set at the top 25% of the available models could label the overwhelming majority of units sold.

For refrigerators, annual energy use in all operating modes is considered per cubic foot of interior volume to assess efficiency. It is helpful that all the energy use is being counted, but only relevant if interior volume is also being computed fairly. As *Consumer Reports* has pointed out, the usable volume in different refrigerator geometries (upright, side-by-side, etc.) can be vastly different for units with otherwise comparable nominal volumes.

Similarly, in the ENERGY STAR homes program, only building shell, water heating, and HVAC energy use has been considered for much of the program's history. Differences in home square footage and lighting, appliance, and plug load energy consumption greatly affect a home's total annual energy bill, yet the buyer was not always armed with that information when comparing home options. Recent changes underway at ENERGY STAR are helping to close that gap.

In other cases (virtually all consumer electronics and office equipment except computer monitors and external power supplies), ENERGY STAR specifications are based on power use differences in a single low power mode of operation. Unfortunately, sleep or standby modes are not consistently responsible for the majority of a product's annual energy use.

Figure 11



Televisions, for example, may spend 80% of the *time* in an off or standby mode, but their power consumption when off differs by only a few watts. By contrast, in the 20% of the time they are operating, plasma TVs may draw hundreds more watts than comparable LCD TVs (see Figure 11, summarizing Ecos Consulting's recent TV measurements). Why give the plasmas an ENERGY STAR label for efficiency, when they may use 300 more kwh per year than comparable LCDs that are not labeled because their off mode power use is slightly higher? The ENERGY STAR labeling program is not consistently leading shoppers to the products that can help minimize their annual energy bills.

The EnergyGuide label, on the other hand, takes a more consistent approach: all applicable products are subjected to the same metric, which is annual energy consumption. For many consumer products, this can be a difficult and complex process, as it not only requires power consumption characteristics of products, but also how they are used. For example, for appliances, DOE tests products over all the relevant modes of operation, and then the annual power consumption of the products is computed using an established duty cycle. Establishing test protocols and duty cycle definitions often involves industry involvement and buy-in, which typically takes much longer than the process ENERGY STAR uses to set its specifications.

Nevertheless, a single annual energy consumption number allows the consumer to easily compare one product to another on the basis of kilowatt-hours per year (or more meaningfully, dollars per year), instead of having multiple numbers for each mode of operation. It could become standard practice for magazines like *Consumer Reports* to report the energy efficiency of particular tested products quantitatively, institutionalizing consideration of energy use in a wider range of purchases. It also allows manufacturers to trade off different modes of energy use with each other to achieve the greatest total energy savings at the lowest cost.

C. Establish an Automatic Specification Revision Process

Establishing a single comparison metric with a defined test protocol, as described above, would streamline the ENEGRY STAR specification revision process. Currently, updates are subject to a process that is political, more subjective than necessary, and often protracted. New specifications require the establishment of test procedures, collection of data, proposal of efficiency metrics and specifications, review and response to manufacturer comments, and the issuing of multiple drafts. Revisions of existing specifications may save time with test procedures, but often use more time securing support from overseas partners like the European Union and observing grandfathering periods for existing products. Indeed, revisions to longstanding specification approaches often require even more time persuading manufacturers that the new approach is fair and appropriate. This places an enormous burden on limited staff resources at EPA and DOE, often limiting consideration of meritorious new specifications or greatly delaying the release of those already planned.

One idea worth considering is to revise existing ENERGY STAR specifications automatically every two years, considering half of all the programs on odd years and the other half on even years. The new levels would be set high enough to allow the top 25% of the models for which annual energy use data are available to qualify. ENERGY STAR would supplement self-reported data from manufacturers with data collected independently from laboratories, utilities, and consumers, especially for unlabeled products. Annual energy use data could be posted on the ENERGY STAR website for all labeled product categories and recalculated when individual power consumption levels by mode change, or when new market research today suggests a change in typical consumer usage patterns. This would allow automatic upward "ratcheting" of the ENERGY STAR specification, reducing the amount of time required by ENERGY STAR staff to revise specifications and make updates more scientific, more transparent, and less political.[49]

[49] This idea also dovetails nicely with the proposal to move to ACEEE's proposed categorical EnergyGuide label, and the idea the products rated "4" or "5" stars would be eligible for ENERGY STAR.

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Date: November 8, 2004

Estimates of Cost-Effective Fuel Economy Potential for Passenger Vehicles Based Upon Relevant Data and Analyses Found in *Reducing Greenhouse Gas Emissions from Light-Duty Motor Vehicles*[1]

In September, the Northeast States Center for a Clean Air Future (NESCCAF) released the results of a detailed study assessing the potential for reductions in light duty vehicle greenhouse gas emissions in the 2009-2015 timeframe. Since most of the technologies evaluated in the study can also be used to increase vehicle fuel economy, study results can be utilized to evaluate potentially cost effective increases in average vehicle fuel economy over that same timeframe. However, since there are some technologies included in the NESCCAF study that either do not influence fuel economy, or influence fuel economy through mechanisms that are not captured during the standard U.S. fuel economy testing procedures, it is not possible to use the specific data presented in the NESCCAF study to accurately evaluate fuel economy targets. To evaluate fuel economy potential using the NESCCAF study, it is necessary to remove both the impacts and costs of those technologies that do not influence measured fuel economy under the current CAFE (Corporate Average Fuel Economy) testing procedures.

Generally, NESCCAF evaluated technologies for five specific classes of vehicles,[2] and the results of their evaluation are summarized in Tables 3-4 through 3-8 of the published study report. Specifically, each table presents both estimated greenhouse gas reductions (expressed as change in CO_2 equivalent emissions) and incremental vehicle costs associated with a series of

[1] *Reducing Greenhouse Gas Emissions from Light-Duty Motor Vehicles*, Northeast States Center for a Clean Air Future, September 2004.

[2] Large cars, small cars, large trucks, small trucks, and minivans.

technology packages expected to be available in the 2009-2015 timeframe. Each table also presents, for each technology package, an estimate of the net technology cost over a vehicle lifetime based on the following assumptions:

Gasoline Price:	\$1.58 per gallon
Diesel Fuel Price:	\$1.58 per gallon
Vehicle Lifetime:	12 years
Vehicle Lifetime:	150,000 miles
Vehicle Mileage Declination:	4.5 percent per year
Effective Discount Rate:	5 percent

All impacts are evaluated over the same driving cycles, and using the same weighting factors as are employed for standard U.S. CAFE testing purposes. NESCCAF also performed sensitivity analyses using gasoline and diesel fuel prices of \$2.00 per gallon, but the detailed results for these analyses are not presented in the study report.

As described above, it is necessary to remove both the impacts and cost of technologies that do not influence measured fuel economy before NESCCAF study estimates can be used to evaluate potentially cost effective fuel economy targets. Vehicle air conditioning impacts are the most obvious example of technology impacts and costs that are included in the NESCCAF results, but which do not affect measured fuel economy since: (1) the vehicle air conditioner is not activated during standard U.S. fuel economy testing, and (2) leakage of refrigerant, while important in evaluating overall vehicle greenhouse gas emissions, has no influence on fuel economy. To allow the NESCCAF data to be evaluated from a fuel economy standpoint, Meszler Engineering Services (MES) obtained the data underlying published Tables 3-4 through 3-8 of the NESCCAF study. In addition to the specific data included in the published tables, the data obtained from NESCCAF also included the simulated fuel economy estimates for each technology package over the standard CAFE testing cycles. Therefore, it was not necessary to convert CO_2 equivalent emissions into estimated fuel economy impacts, as both measures were included explicitly in the provided study data.

Using these data, MES removed from the NESCCAF-estimated impacts and costs for each technology package, the impacts and costs of all technologies that do not influence measured fuel economy over the standard CAFE testing procedures. This was performed for each of the five vehicle classes and for each fuel price scenario evaluated by NESCCAF (\$1.58 and \$2.00 per gallon). MES made no other modifications to the NESCCAF data or assumptions, so that the resulting estimates are entirely equivalent to those of the published NESCCAF data, excepting the removal of technologies that do not influence CAFE measurements.

Following these adjustments, the Commission requested that MES calculate the cost effective fleetwide fuel economy for four specific evaluation criteria as follows:

- Evaluation Criteria #1: Assume a fleet made up of gasoline vehicles that include the NESCCAF technology packages for each vehicle class that provide the largest CO_2 emission reductions at the lowest or near lowest cost per ton of CO_2 reduced.

- Evaluation Criteria #2: Assume a fleet made up of gasoline vehicles that include the NESCCAF technology packages for each vehicle class that provide the largest CO_2 emission reductions for a net negative cost per ton of CO_2 reduced.

- Evaluation Criteria #3: Assume a fleet made up of diesel vehicles that include the NESCCAF technology packages for each vehicle class that provide the largest CO_2 emission reductions for a net negative cost per ton of CO_2 reduced.

- Evaluation Criteria #4: Assume a fleet made up of hybrid electric vehicles that include the NESCCAF technology packages for each vehicle class that provide the largest CO_2 emission reductions for a net negative cost per ton of CO_2 reduced.

MES identified the specific technology packages in each of the five vehicle classes that satisfied these criteria. The fleetwide fuel economy associated with each evaluation criteria was then calculated using the normalized class-specific market shares estimated by NESCCAF for 2002. The specific market shares used for this calculation are as follows:

Large car:	26 percent
Small car:	22 percent
Large truck:	21 percent
Small truck:	24 percent
Minivan:	7 percent

Thus, for each evaluation criteria, the estimated fleetwide fuel economy assumes: (1) no change in class specific market shares over time, and (2) homogeneous fleet compositions within each class. The estimates should, therefore, be viewed as indicators of potential fuel economy levels only under these restricted conditions. Finally, it should also be recognized that the underlying impact estimates and cost assumptions employed in the NESCCAF study have been taken as published, except as otherwise described above.

The resulting fleetwide fuel economy estimates are as follows:

<table>
<tr><th rowspan="2">Evaluation Criteria</th><th rowspan="2">Fuel Price</th><th colspan="3">Fuel Economy (mpg)</th></tr>
<tr><th>Cars</th><th>Trucks</th><th>Combined</th></tr>
<tr><td rowspan="2">Gasoline vehicles with high CO_2 reductions and lowest or near lowest cost per ton CO_2 reduced.</td><td>$1.58</td><td rowspan="2">36.7</td><td rowspan="2">27.3</td><td rowspan="2">31.2</td></tr>
<tr><td>$2.00</td></tr>
<tr><td rowspan="2">Gasoline vehicles with highest CO_2 reductions at a negative cost per ton of CO_2 reduced.</td><td>$1.58</td><td rowspan="2">39.2</td><td rowspan="2">28.4</td><td rowspan="2">32.8</td></tr>
<tr><td>$2.00</td></tr>
<tr><td rowspan="2">Diesel vehicles with highest CO_2 reductions at a negative cost per ton of CO_2 reduced.</td><td>$1.58</td><td rowspan="2">40.6</td><td rowspan="2">33.2</td><td rowspan="2">36.2</td></tr>
<tr><td>$2.00</td></tr>
<tr><td rowspan="2">Hybrid vehicles with highest CO_2 reductions at a negative cost per ton of CO_2 reduced.</td><td>$1.58</td><td>42.8</td><td>37.1</td><td>39.2</td></tr>
<tr><td>$2.00</td><td>50.0</td><td>39.9</td><td>44.0</td></tr>
</table>

ENERGY SAVINGS THROUGH INCREASED FUEL ECONOMY FOR HEAVY-DUTY TRUCKS

PREPARED FOR THE NATIONAL COMMISSION ON ENERGY POLICY

Therese Langer
American Council for an Energy-Efficient Economy
February 11, 2004

ENERGY SAVINGS THROUGH INCREASED FUEL ECONOMY FOR HEAVY-DUTY TRUCKS

Summary

Seven percent of energy consumed in the U.S., and 30% of consumption in the transportation sector, is for the movement of freight. While trucks move less than half of all freight ton-miles, they are the preferred mode for short-to-medium distance, time-sensitive goods. Trucks move the bulk of all freight value, and their share is increasing. Trucking is energy-intensive and accounts for 60% of freight energy use, consuming 2.3 million barrels of oil per day in 2000. Hence trucks are an important place to look for energy savings in the transportation sector. Opportunities to reduce trucks' energy consumption include both technological improvements and advances in systems and logistics. This report considers only the potential for vehicle technologies to raise truck fuel economy.

There are fewer than three million medium and heavy trucks (those over 10,000 pounds gross vehicle weight) on U.S. roads, and annual sales are about one percent of passenger vehicle sales. Sales of individual models number in the hundreds or thousands, in contrast to the tens or hundreds of thousands for car models. Truck production is also more modular; engines typically are manufactured by diesel engine companies, then integrated into a vehicle meeting the specifications of the customer and, in many cases, matched with a trailer. Trucks must meet federal pollution emission standards, but they are not subject to fuel economy requirements. Like passenger vehicles, heavy trucks are produced by a handful of companies in the U.S., Europe and Asia.

While truck users are more affected than passenger vehicle users by fuel expenses, the demand for fuel economy is not sufficient to bring all cost-effective efficiency technologies into the market. Manufacturer risk, low fuel prices, lack of fuel economy information on individual models, and undervaluation of fuel economy all limit the introduction of better technologies.

This report estimates the energy savings that could be achieved through cost-effective technology improvements to heavy-duty trucks in the near future and explores candidate policies to realize these savings. The technologies considered are similar to those in DOE's 21st Century Truck Roadmap, but that document contains no cost information. The savings and cost estimates in this report are based largely on two papers by Argonne National Laboratory researchers, one for technologies applicable to tractor-trailers and the other for hybrid technologies for short-haul trucks. The first of these papers has also been used extensively by the Energy Information Administration in forecasting heavy-duty truck energy use in the U.S.

Our methodology for estimating the total fuel economy gain achievable is modeled on the approach used by the National Academy of Sciences CAFÉ panel in its assessment of cars and light trucks in 2001. Truck data throughout this report are derived from the 1997 Vehicle Inventory and Use Study of the U.S. Census Bureau unless otherwise noted.

Findings

Tractor-trailers are the big fuel users among medium and heavy trucks, consuming two-thirds of all truck fuel, or 1.5 million barrels per day. Substantial improvements could be made to their fuel economy through a variety of existing and emerging technologies, including engine improvements, transmission enhancements, and weight reduction: average fuel economy for new tractor-trailers could be raised by 29% starting in 2008 and by 58% in 2015, while providing net savings for the owner based on incremental cost and lifetime fuel savings.

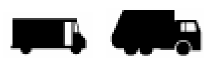
Introducing fuel economy standards for heavy-duty vehicles could help to realize these potential efficiency gains. Standards would present a technical challenge in that they would require a fuel economy test protocol for vehicles that vary widely in aerodynamics, load, and drive cycle. But tractor-trailers are more uniform in these regards than the rest of the fleet, and meaningful standards for these trucks could be set. Alternatively, a standard for CO_2 production for the engine alone could be combined with technology standards for vehicle components.

For trucks other than tractor-trailers, hybrid technologies are promising, because a large fraction of miles driven by these trucks are local and under stop-and-go conditions. Hybridization could almost double fuel economy for Class 3-5 trucks and raise Class 6-7 fuel economy by 71% in city driving, at costs that will decline rapidly in the coming years. For over half of all trucks in classes 3-6 and straight trucks in Classes 7-8, hybridization could bring modest lifetime savings starting in the near future and savings of several thousand dollars for vehicles purchased in 2015 and beyond. Conventional fuel economy improvement technologies similar to those considered for tractor-trailers could be applicable to these vehicles as well, but, in combination with hybridization, they are far less likely to be cost-effective, because the savings per percent increase in fuel economy are lower when the base fuel economy is high.

Because manufacturers will incur expenses in bringing hybrids to market, and because buyers do not purchase vehicles on the basis of net lifetime savings, the cost-effectiveness of hybrids will not in itself translate into market success, and measures to promote hybrids are needed until costs come down. Tax incentives like those proposed in the federal energy bill could contribute to this cost reduction; research and development sponsored by the U.S. Department of Energy could also help.

Combining the cost-effective conventional improvements for tractor-trailers with hybridization of short-haul trucks would yield a 32% reduction overall in fuel consumption for new trucks by 2015. Such an improvement would take a decade to phase into the entire freight truck stock, by which time truck activity will have grown; but the magnitude of potential savings is illustrated by noting that a 32% reduction in freight truck fuel consumption today would save 740,000 barrels of oil per day.

Table S1
Cost-Effective Fuel Savings from Heavy Truck Fuel Economy Improvements Available in 2015

	PICKUP TRUCKS, SUVS, UTILITY VANS 8500 – 10,000 LBS	LOCALLY-DRIVEN TRUCKS 10,000 LBS AND UP	TRACTOR-TRAILERS 33,000 LBS AND UP
			
Potential improvement in fuel economy	33%	71 – 93%	58%
Fuel Use Reduction as Fraction of Total Truck Fuel Use[*]	3%	7%	22%
Technology	Conventional	Hybrid	Conventional
Recommended Policies	Expand CAFE to include these vehicles	Tax Incentives, R&D	Fuel Economy Standards Options: by Vehicle or by Individual Components (engine, body, etc)

Trucks in the 8500-10,000 pound weight range are not considered heavy-duty, nor do they fall under existing passenger vehicle fuel economy regulations. This class, which includes both commercial and personal vehicles, largely pickup trucks, consumes 360,000 barrels of oil daily. While efforts to include these vehicles under fuel economy regulation have encountered resistance based on concerns about farmers and others who need work vehicles meeting certain performance requirements, substantial fuel savings could be achieved in this weight range with no loss of functionality. The findings of the National Academy of Sciences CAFÉ panel provide strong evidence that a fuel economy increase of 33% is feasible for 8500-10,000 lb. vehicles. Applied to today's vehicles, this would translate into savings of 90,000 barrels per day.

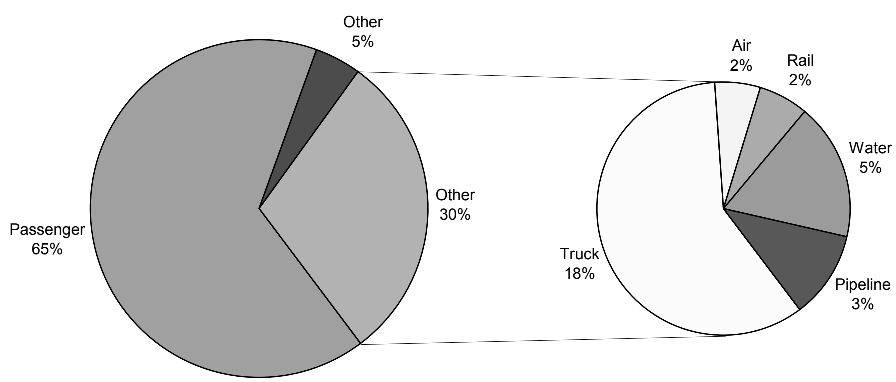
In summary, the fuel consumption of all trucks over 8500 lbs. could be reduced by nearly one-third, as shown in Table S1.

[*] In Table S1 only, "truck fuel use" refers to fuel consumed by all trucks over 8500 lbs. Elsewhere, such phrases refer to trucks over 10,000 lbs. only.

Introduction

Seven percent of energy consumed in the U.S., and 30% of consumption in the transportation sector, is for the movement of freight (Figure 1). While trucks move less than half of all freight ton-miles, they are the preferred mode for short-to-medium distance, time-sensitive goods. Trucks move the bulk of all freight value, and their share is increasing. It is an energy-intensive mode and accounts for 60% of freight energy use, consuming 2.3 million barrels of oil per day in 2000 (Davis 2003).

Figure 1
U.S. Transportation Sector Energy Use in 2000



Data source: Davis 2003

Hence trucks are an important place to look for energy savings in the transportation sector. Opportunities to reduce trucks' energy consumption include both technological improvements and advances in systems and logistics. This report considers the potential to raise truck fuel economy through vehicle technologies only.

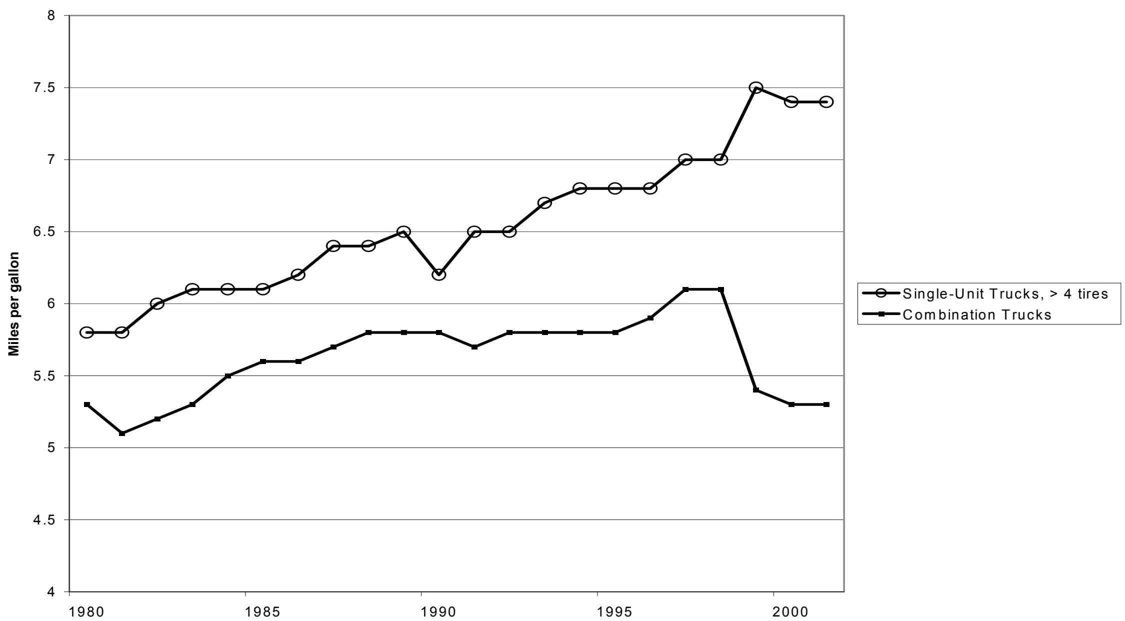
There are fewer than three million medium and heavy trucks (those over 10,000 pounds gross vehicle weight) on U.S. roads, and annual sales are under one percent of passenger vehicle sales. Sales of individual models number in the hundreds or thousands, in contrast to the tens or hundreds of thousands for car models. Truck production is also more modular; engines typically are manufactured by diesel engine companies, then integrated into a vehicle meeting the specifications of the customer and, in many cases, matched with a trailer. Trucks must meet federal pollution emission standards, but they are not subject to fuel economy requirements. Like passenger vehicles, heavy trucks are produced by a handful of companies in the U.S., Europe and Asia.

Trucks fall into eight classes by gross vehicle weight. Classes 1 and 2 (up to 10,000 lbs. gross vehicle weight) are made up of pickups, SUVs, panel trucks and a variety of passenger and small cargo vans. Class 2 is further divided into passenger vehicles and Class 2b trucks (8500-10,000 lbs.) the latter containing mostly "work" pickups (typically

3/4-ton), though an increasing percentage of Class 2b consists of large SUVs and luxury pickups. Classes 3-5 (14,001-19,500 lbs.) include delivery vans, walk-ins, and some specialized vehicles such as bucket trucks. Beverage trucks, rack trucks and school buses are examples of Class 6 vehicles (19,501-26,000 lbs.). Classes 7-8 (26,001 lbs. and over) are largely tractor-trailers, but also include refuse, cement and dump trucks.

Fuel costs are an important consideration for the trucking industry, so truck owners probably value fuel savings more than automobile owners do. Yet the market for fuel economy improvements has serious failings for trucks as well, as discussed below, and cost-effective fuel economy technologies are not necessarily adopted as they become available. Indeed, while fuel economy of the smaller freight trucks has increased slowly over the past 25 years, fuel economy of the energy-intensive tractor-trailer fleet was the same in 2001 as in 1980 (Figure 2).

Figure 2
Fuel Economy of Freight Trucks, 1980-2001



Data source: Davis 2003

Methodology

There is general agreement on the categories of technologies that can contribute substantially to raising truck fuel economy, but estimates of the potential for increases vary widely. DuLeep projected increases in freight truck fuel economy through improved vehicle technologies in 2015, finding an "expected" increase over 1990 levels of 23% and an "optimistic" increase of 33% (DuLeep 1997). A 1992 ACEEE paper found that a tractor-trailer fuel economy increase of 64% over current levels would be feasible (Sachs 1992). DOE's 21st Century Truck Program set as "technical targets" improvements in fuel efficiency of 60% for large trucks and 140% for medium trucks, based on "aggressive development and implementation of technologies currently being considered but not yet commercially viable" (DOE 2000). DOE provided no cost estimates for reaching these targets, however.

The discussion and analysis below of the potential to increase truck fuel economy draw heavily from two papers by Argonne National Laboratory researchers, the findings of which are moderate in the context of the literature. One of these papers (Vyas 2002) is also the basis for the Energy Information Administration's forecasts of heavy-duty truck energy use. The paper estimates fuel economy increases and costs associated with existing and emerging technologies for all truck classes; we use those estimates for some truck classes.
Vyas et al. also project market share for each technology in the year 2025 based on a combination of considerations, including the percentage of each truck class for which the estimated fuel economy gain is valid, the cost of the technology, the date of introduction, and the lag time for adoption. These are considerations best kept separate for purposes of the present analysis, so the market share numbers were not adopted for this report. Instead, we used the fuel economy estimates only for a relatively homogeneous truck population that could get the full benefit of the technologies listed, namely tractor-trailers. We then adopted the costs and dates of introduction from the paper to conduct an analysis of what suite of technologies would be cost-effective for tractor-trailers, using an approach similar to one used in the NAS CAFÉ report on light duty vehicles (NRC 2002).

The second paper we relied upon (An 2000) evaluates benefits and costs of hybridization of heavy-duty trucks. This is the basis for much of our discussion of potential fuel economy gains for short-haul trucks, complementing the tractor-trailer analysis. To calculate cost-effectiveness, we used the average fuel economy percentage improvement found by An et al., together with data on average base fuel economy and annual miles traveled for non-tractor-trailer trucks driven locally. Annual miles are on average close to the figure cited by An et al (14,500 miles), but the base fuel economy we use is substantially higher. This leads to an underestimate of the per vehicle fuel savings. On the other hand, we apply the technology to a broader set of vehicles than seems to be contemplated in the paper, which may result in some overestimate of the effects.

Throughout this discussion, facts appearing without citation are derived from 1997 Vehicle Inventory and Use Survey data. Important shifts may have occurred since then, but this will remain the best data source for many facts about trucks until the data from the 2002 VIUS becomes available later this year.

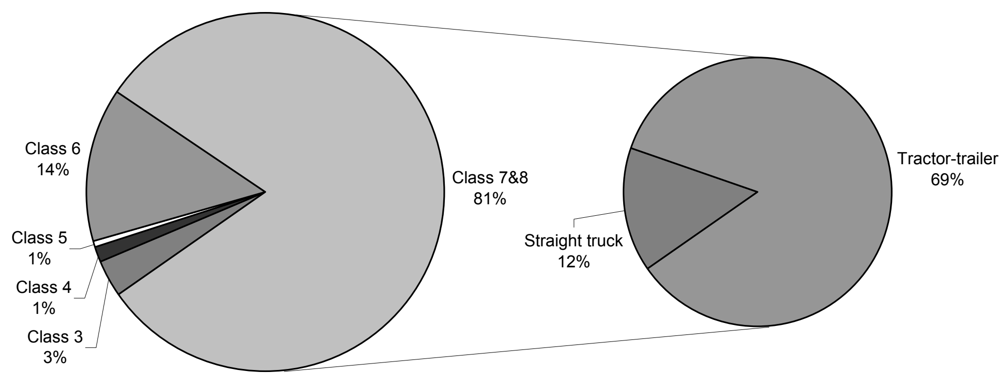
<u>Tractor-trailers</u>

The heaviest trucks (Classes 7 and 8, i.e. greater than 26,000 lbs.) dominate truck energy use, accounting for 81% of the total (Figure 3). These trucks are therefore particularly important to attempts to identify practical ways to improve fuel economy. As discussed above, Vyas et al. provide a list of technologies that could increase the fuel economy of Class 7 and 8 trucks, and the percentage gain and cost associated with each. The applicability of these efficiency technologies depends on truck type and duty cycle, however. In particular, trucks driven at low speeds will not benefit greatly from aerodynamic treatments. Furthermore, the cost-effectiveness of the technologies is related to annual miles traveled, which tends to be low for trucks driven locally.

We therefore analyze the benefits of the technologies only for tractor-trailers, which typically are driven long distances at highway speeds. Since most Class 7 and 8 trucks are tractor-trailers (and in fact tractor-trailers are responsible for 69% of energy consumed by all Class 3-8 trucks (Figure 1)), this simplifying step does not forfeit much of the potential benefit due to these technologies.

Class 7and 8 vehicles that are not tractor-trailers are a diverse group and are discussed further in the section on short-haul trucks below.

Figure 3
Energy Use by Truck Type



Data source: Davis 2003

Technologies to increase fuel economy

Technologies to raise fuel economy considered in the Vyas analysis include engine, aerodynamics and transmission improvements, as well as mass reduction, as shown in Table 1. Noteworthy technologies listed there include:

- *Electric and fuel-cell auxiliaries* – Compressors, pumps and fans now run off the engine could be operated electrically, through an integrated starter-generator, or by fuel cell. A fuel cell could also operate auxiliary systems at rest stops, reducing idling time, but no credit for this is taken below.
- *Thermal management, etc.* – This encompasses reduction of waste heat through increasing the efficiency of turbocharging, for example.
- *Pneumatic blowing* – Aerodynamics can be improved by blowing air through points on the vehicle exterior, a technique already applied to aircraft.

The estimates of fuel economy benefits are in some cases probably conservative; electrical or fuel cell auxiliaries, for example, could be expected to bring higher savings than shown. Other technologies considered may be speculative (e.g. pneumatic blowing). On the other hand, the list omits technology options as well, and it is appropriate that some technologies still under development be included, so as not to underestimate too greatly the potential for fuel economy improvement in the time frame considered here.

Table 1
Fuel Economy Technologies for Class 7 and 8 Trucks

	fuel economy gain	year of introduction	cost
Aerodynamics			
cab top deflector	2.0%	current	$750
gap closing	2.5%	2005	$1,500
trailer edge curvature	1.3%	2005	$500
pneumatic blowing	5.0%	2010	$2,500
rolling resistance			
low RR tires	3.0%	2005	$1,098
super singles	3.0%	2008	$1,098
pneumatic blowing	1.2%	2015	$500
Transmission	2.0%	2005	$1,000
Auxiliaries			
electrical auxiliaries	1.5%	2005	$500
fuel-cell auxiliaries	6.0%	2012	$1,500
Engine			
friction reduction	2.0%	2005	$500
increased peak cylinder pressure	4.0%	2006	$1,000
improved injectors etc	6.0%	2007	$1,500
thermal management, etc.	10.0%	2010	$2,000
vehicle mass	5.0%	2005	$2,000

Source: Vyas 2002

Cost-effectiveness of technology packages

As mentioned above, the approach to determining the cost-effective level of fuel economy follows the light-duty analysis in NAS CAFÉ study. Using average values for annual miles traveled and fuel economy, and various fuel prices and investment payback requirements, we added technologies in declining order of cost-effectiveness until the marginal economic benefit turned negative. This approach is best suited to determining a feasible level for fuel economy standards; it does not predict the behavior of purchasers, even in a perfect market, because it uses average values of important parameters.

Table 2 shows the results under eight different sets of assumptions involving fuel price, discount rate associated with fuel savings, payback period to recover higher capital costs, and deadline for technology introduction. The two diesel fuel prices were $1.41, the average price over the period 2000-2025 according to projections in EIA's Annual

Energy Outlook 2003, and $1.60, which adds a 19 cent-per-gallon externality cost. The two payback requirement options were: 1) a fuel savings discount rate of 12% over an average vehicle life of 14 years, and 2) a discount rate of 8% over 3 years. The two technology horizons were 2008 and 2015.

Table 2
Cost and Savings of Increased Tractor-Trailer Fuel Economy: Eight Scenarios

Baseline fuel economy is 6.2 miles per gallon

Payback/ discount rate	Diesel price per gallon	Fuel economy improvement	New miles per gallon	Cost	Fuel savings	Net savings
Technologies introduced in 2008 or earlier						
14 years/12%	$1.41	29%	8.0	$9250	$21,381	$12,131
3 years/8%	$1.41	18%	7.3	$4750	$7216	$2466
14 years/12%	$1.60	29%	8.0	$9250	$24,262	$15,012
3 years/8%	$1.60	24%	7.7	$6750	$10,363	$3613
Technologies introduced in 2015 or earlier						
14 years/12%	$1.41	58%	9.8	$15,250	$34,576	$19,326
3 years/8%	$1.41	31%	8.1	$6750	$10,791	$4041
14 years/12%	$1.60	58%	9.8	$15,250	$39,236	$23,986
3 years/8%	$1.60	35%	8.4	$8000	$18,588	$10,588

The 14-year payback option was used in the NAS CAFÉ study on light-duty vehicles and is meant to maximize total user benefit, while the 3-year option is meant to reflect the payback requirements of a typical truck purchaser in deciding whether to invest in higher fuel economy when buying a new vehicle. This does not imply that the fuel economy improvements corresponding to the 3-year options would actually materialize in the current market, however. Lack of fuel economy information on vehicles at the time of sale, the manufacturers' risks in investing in new technology, the possibility that manufacturers could apply the same technologies to performance improvements more marketable than fuel economy, and the variety in tractor-trailer duty-cycles all can serve to make fuel economy fall short, in a business-as-usual scenario, of the level predicted by the 3-year payback analysis.

To summarize the result of the cost-effectiveness analysis: Using technologies available before 2008 and allowing a 14-year payback, the cost-effective fuel economy is 8 miles per gallon, 29% above the current average. Adding technologies available by 2015, the cost-effective fuel economy rises to 9.8 mpg, a 58% increase over current levels. Average lifetime savings per truck are considerable: incremental vehicle costs of $15,000 and (discounted) fuel savings of $35,000 give a net savings of $20,000.

Policies to increase tractor-trailer fuel economy

The fact that the gap between highest cost-effective heavy truck fuel economy and existing levels is large raises the question of what policies could reduce that gap. Increasing the price of fuel by the per-gallon externality cost is one candidate. For the particular set of technologies used in the above analysis, an increase of 19 cents per gallon produces little change in the cost-effective level of fuel economy, as Table 2 shows. A second policy option is a fuel economy standard for tractor-trailers. The results in Table 2 indicate that a standard of 9.8 mpg phased in by 2015 would be reasonable,[1] with a baseline of 6.2 mpg for today's fleet.

There are at present no fuel economy standards for vehicles over 8500 lbs. in the US (or elsewhere, for that matter). One reason for this is the huge variety among trucks, both in how they are configured and in how they are used, even within a class. Tractor-trailers are relatively homogeneous, however, making this the best category for which to consider fuel economy standards from the standpoint of feasibility, as well as fuel savings. In particular, because the vast majority of tractor-trailer miles are driven on the highway, the problem of choosing an appropriate test cycle is much simplified. Nonetheless, there is enough variation in performance requirements for these vehicles that a single fuel economy standard does pose a technical challenge.

Given differences among trailer types, an engine bench test such as the one used for emissions testing has the advantage of simplicity. But aerodynamics and other engine-independent features play an enormous role in heavy truck fuel economy, which such a test cannot capture. Among the efficiency technologies listed in Table 1, engine technologies account for only 40% of all potential savings, so standards based on engine performance alone could be expected to yield less than half of the achievable improvement in fuel economy. Combining individual technology requirements for non-engine components with a bench test could recover some of the remaining efficiency opportunities, but could not be expected to match the results of a vehicle fuel economy standard.

The absence of a fuel economy testing and labeling requirement for heavy trucks creates a failure in the current market, in that truck buyers lack the information to choose the most efficient truck. Therefore, one step toward establishment of a fuel economy standard that would have value in itself would be the creation of a testing and labeling program for these vehicles.

Short-Haul Trucks

Trucks that are not tractor-trailers have quite diverse duty cycles, and they are used to a far greater extent for local trips. Indeed, 53% of all miles driven by trucks other than tractor-trailers are driven by trucks that operate primarily locally, i.e. on trips of under 50 miles. The technologies discussed above that provide efficiency gains for tractor-trailers can apply to these smaller trucks as well. Some of the technologies are much less effective for trucks that generally drive at low speeds, however, and therefore have limited applicability. On the other hand, these trucks are the best candidates for hybrid technology, because local trips typically involve a large amount of stop-and-go driving, which permits extensive capture of braking and deceleration energy. Hybridization can offer a larger fuel efficiency gain than any other technology considered here.

[1] These standards in effect assume the availability of certainly technologies as of their date of introduction.

Hybrid vehicles

This section assesses the potential for hybrid technologies to provide cost-effective energy savings. Because hybridization improves efficiency of stop-and-go driving more than efficiency of highway driving, vehicles that operate largely on a city driving cycle would benefit most per mile. On the other hand, many urban vehicles travel comparatively few miles annually, which works against speedy recovery of incremental costs through fuel savings. The best candidates for hybridization are trucks driven many miles on local roads.

The percentage savings that can be expected from hybridization is very sensitive to duty cycle. For this reason, analyses and efforts to promote hybrids often focus on narrow categories of vehicles. The Hybrid Truck Users' Forum, for example, made a preliminary selection of four types as good candidates for hybridization: Class 4-8 Specialty Trucks, including utility and fire trucks; Class 4-6 urban delivery trucks, including package and beverage delivery; Class 7 and 8 refuse collection; and Class 7 and 8 less-than-load urban delivery trucks (WestStart 2002).

Despite the specificity of hybrid gains to duty cycle, some quantitative statements about the fuel economy improvement and cost of hybridization can be made at a general level. Vyas et al., cited in the tractor-trailer discussion above, estimate the fuel economy advantage of a Class 4-6 hybrid-electric to be 40-70%, at a cost of $8000. The 21st Century Truck Roadmap sets a fuel economy goal of three times current levels for Classes 2b and 6, of which a large percent is to come from hybridization; but it does not discuss costs.

As noted above, the analysis here uses estimates of fuel economy improvements and costs associated with hybridization from An 2000. The results of that paper are based on modeling of a Class 3-4 delivery truck and a Class 6-7 truck or bus, and evaluating the effects of hybridization over five urban duty cycles. The average fuel economy increase over the five cycles is 93% for the Class 3-4 truck and 71% for the Class 6-7 vehicle. The incremental cost of the hybrid vehicles depends on the choice of technology and the year, the later being a surrogate for progress towards economies of scale and experience with the technology. The decline in cost over time also reflects expected increases in battery life. For purposes of this discussion, we use the least expensive option, namely a parallel hybrid with a lead-acid battery, for which the cost estimates are shown in Table 3.[2]

Table 3
Estimated Incremental Costs of Parallel Hybrid-Electric Trucks

	2005	2010	2015	2020
Class 3-5	$5,760	$4,472	$3,553	$3,013
Class 6-7	$7,149	$5,371	$4,090	$3,346

Source: An 2000

[2] Given that heavy-duty hybrid trucks are not commercially available in 2004, references to the year 2005 in this section should be read as "near-term".

Work on hydraulic hybrids has yielded similar results. EPA is experimenting with a Class 6 hydraulic hybrid that achieves a fuel economy increase in the vicinity of the hybrid-electric gain cited here and, given "high manufacturing volumes," at similar costs.

Returning to the hybrid-electric case, our conclusions are as follows (Table 4): for purchases at the 2005 cost and under the 14-year-life/12% discount rate scenario, hybrids in Classes 3-5 would bring net cost savings over the life of the vehicle. These savings are $1583 if fuel costs $1.41 per gallon and $2572 at $1.60 per gallon. Using 2015 costs roughly doubles net savings. In the 3-year payback/8% discount rate scenario, hybrids are only cost-effective starting in 2015 (when incremental costs of production will have dropped) and at fuel prices of $1.60. Results for Class 6 trucks are similar, and we assume the same for the larger trucks.

Table 4
Cost-Effectiveness of Hybrid-Electric Trucks

	Base mpg	Fuel economy gain
Class 3-5	9.2	93%
Class 6	7.4	71%

Fuel savings					
Class 3-5	At $1.41 per gallon	At $1.60 per gallon	Class 6	At $1.41 per gallon	At $1.60 per gallon
In 14 years, 12% discount rate	$7,343	$8,332	In 14 years, 12% discount rate	$8,578	$9,733
In 3 years, 8% discount rate	$3,242	$3,679	In 3 years, 8% discount rate	$3,772	$4,280
Net savings at 2005 purchase cost					
Class 3-5	At $1.41 per gallon	At $1.60 per gallon	Class 6	At $1.41 per gallon	At $1.60 per gallon
In 14 years, 12% discount rate	$1,583	$2,572	In 14 years, 12% discount rate	$1,429	$2,584
In 3 years, 8% discount rate	-$2,518	-$2,081	In 3 years, 8% discount rate	-$3,377	-$2,869
Net savings at 2015 purchase cost					
Class 3-5	At $1.41 per gallon	At $1.60 per gallon	Class 6	At $1.41 per gallon	At $1.60 per gallon
In 14 years, 12% discount rate	$3,790	$4,779	In 14 years, 12% discount rate	$4,488	$5,643
In 3 years, 8% discount rate	-$311	$126	In 3 years, 8% discount rate	-$318	$190

Policies to promote hybrids

The 2003 energy bill conference report contains tax credits for purchasers of hybrids, including heavy-duty vehicles. The credit is a percentage of the incremental cost relative to a comparable conventional vehicle, where that percentage is determined by the hybrid's city fuel economy advantage, as shown in Table 5. There is a cap on incremental cost, which depends on vehicle weight.

These credits would be available as of the date of enactment of the bill and last through 2008. Each manufacturer is subject to a cap on the number of vehicles of all types that receive credits in this section of the bill, which include light duty hybrids and diesels.

Consequently some manufacturers, notably those that are far along in their development of light-duty hybrids, may not be motivated to seek heavy-duty hybrid credits. On the other hand, the per-vehicle credits are potentially higher for heavy-duty vehicles, so manufacturers that are in a position to offer heavy-duty hybrids will do so.

Table 5
Energy Bill Tax Incentives for Heavy-Duty Hybrids

Improvement in city fuel economy	**30-40%**	**40-50%**	**>50%**
% incremental cost covered by tax credit	20%	30%	40%

Vehicle weight	**Maximum incremental cost**
<14,000 lbs. (Class 2b-3)	$7,500
14,000-26,000 lbs. (Class 4-6)	$15,000
>26,000 lbs. (Class 7&8)	$30,000

Source: Energy Policy Act of 2003 (H.R.6) Conference Report

The hybrid vehicles considered in the preceding section would be eligible for credits of 40% of incremental cost. The incremental costs projected in An et al. are below the maximum allowed in the energy bill. A comparison of Tables 3 and 5 indicates a lack of consensus on incremental costs, and in particular on its relationship to vehicle size.

Table 4 shows that, while hybrids in all classes considered are cost-effective based on a 14-year payback and 12% discount rate, they are not cost-effective in the immediate future for those demanding a 3-year payback and discounting at 8%. The proposed tax credits could change that picture: at a fuel price of $1.60 per gallon, the credits together with three years' fuel savings would fully offset incremental costs for Class 3-5 hybrids, and would be almost sufficient for Classes 6&7 as well.

Thus the credits seem to be of about the right size to do what they are designed to do, namely to accelerate the viability of hybrids in the vehicle market by providing a temporary subsidy to the consumer.[3] The incentives could also bring about the decline of hybrid costs with time predicted by An et al. Conversely, without the credits or some other incentive, the technology may not materialize at all; the decline of technology costs with time assumed in the study is premised on the growth in experience and economies of scale that would follow from near-term introduction of these vehicles, which the market alone will not bring about.

Funding for hybrid research and development is also a determinant of the rate at which hybrids enter the market. It is not clear that DOE continues to be committed to the

[3] The exact credits in the energy bill, in view of their very short lifetime, are not likely to produce such favorable results as discussed here.

efficiency improvement goals set out in the 21st Century Truck Roadmap, and the FY 2005 budget request for the 21st Century Truck Partnership is 30% below the 2004 appropriation level.

Non-hybrid technologies

A suite of technologies similar to those discussed above for tractor-trailers could also provide substantial fuel economy benefits for Class 3-6 trucks. In most cases, these would not be applied with hybridization because they are better suited to a highway duty cycle, or because technologies' cost-effectiveness drops dramatically when they are combined with hybridization (since the "base" fuel economy for a hybrid is so high). For the 37% of Class 3-6 vehicles that are not used locally and therefore may not be good candidates for hybridization, some of conventional efficiency technologies would be cost-effective. These improvements are not included in our final estimates of potential savings, however. Fuel economy standards for such a diverse group of vehicles would be unwieldy, and no candidate policy is offered here to produce these savings.

Class 2b trucks

Class 2b trucks (8500-10000 lbs. GVW) consume 360,000 barrels of oil annually (Davis 2003), more than any class of medium or heavy truck other than Class 8. A brief discussion of these vehicles is included here because, like the larger trucks, they are subject to no fuel economy standards and are therefore typically excluded from discussions of passenger vehicle efficiency improvements.

Fuel economy standards, feebates, and incentives to promote hybridization all warrant consideration for Class 2b. This class includes a wide range of vehicle types, but 80% are pickups (Davis and Truett 2002), which together with vans, panel trucks and sport utility vehicles make up over 96% of the total. These vehicles have under-8500-lb. counterparts, and bringing them under CAFÉ or a feebate scheme would pose no serious technical obstacles.

Indeed, an increase in the weight limit for vehicles subject to CAFÉ, from 8500 lbs. to 10,000 lbs., has been proposed in recent bills considered by Congress, and DOT has raised this possibility for consideration in its next CAFÉ rulemaking (DOT 2003). One concern voiced repeatedly has been that fuel economy regulation of Class 2b would be a hardship for farmers and others that need a vehicle in this weight range for work. These vehicle owners would benefit at least as much as others by improvements in fuel economy, however, so long as they preserve vehicle functionality. It is nonetheless possible that some will propose to address this issue by creating an exception for work trucks.

Over half of all vehicles in this weight range are used primarily as personal vehicles, but it is difficult to set vehicle standards on the basis of use, rather than vehicle characteristics. EPA's Tier 2 tailpipe regulations approach this problem by defining work vehicles as those that have either a very large seating capacity or a bed of length six feet or more.[4] The emissions rules for heavy-duty vehicles apply to these work vehicles; the remaining vehicles in Class 2b must meet the same standards as light-duty vehicles meet under Tier 2. All pickups and many vans in this weight class will qualify as work vehicles under this definition, leaving large SUVs as the primary Class 2b vehicles brought into the light-duty emissions regime under Tier 2. As noted above, the vast majority of Class 2b vehicles are pick-ups, so this approach would subject only a minority of new vehicles to fuel economy standards. For those that would be subject, though, choosing a test cycle would be relatively straightforward, since these vehicles will already undergo chassis dynamometer testing for Tier 2 compliance purposes in the near future.

Basing fuel economy standards on vehicle attributes such as size, as the Department of Transportation is now considering for light-duty vehicles, could lessen opposition to placing work vehicles under CAFE. At the same time, this approach is likely to yield lower fuel savings than bringing Class 2b vehicles into the present fuel economy regime.

A one-third increase in fuel economy for pickups, SUVs and vans would be feasible. The NAS CAFÉ panel found this level of improvement to be cost-effective for light trucks, and Class 2b trucks are by and large quite similar to their below-8500-lb. counterparts. The NAS concluded that these largest of light-duty vehicles have a higher potential for fuel economy increase than do light trucks on the whole. The 33% improvement estimate for 2bs is in this sense conservative.

<u>Total fuel savings from higher truck fuel economy</u>

Here we estimate fuel savings from all the fuel economy improvements found above to be cost-effective. The efficiency improvement estimates given for tractor-trailers are assumed to apply to all tractor-trailers, even though they are valid only for highway vehicles. A non-negligible fraction of tractor-trailers are driven locally, but they tend to be older trucks. The fact that tractor-trailers travel a smaller percentage of their miles on highways as they age may mean that cost savings of certain technologies are slightly overstated here. Given the high discount rate applied to fuel savings and decline with age of miles traveled, however, this effect is small. For the small percentage of tractor-trailers that are used locally for their entire lives, the analysis is not valid. Life-long local tractor-trailers are candidates for hybridization (although we do not include them in the hybrid discussion), however, which would bring even higher efficiency benefits.

For vehicles other than tractor-trailers, the aggregate potential benefit of hybridization is associated with those that travel primarily locally. In Classes 3-6, local vehicles are responsible for 47% of miles traveled. Among Class 7-8 vehicles that are not tractor-trailers, 56% of miles are traveled by trucks that operate locally.

[4] The definition of "medium duty passenger vehicle" MDPV excludes "any vehicle that (1)has a capacity of more than 12 persons total or (2) that is designed to accommodate more than 9 persons in seating rearward of the driver's seat or (3) has a cargo box (e.g., a pick-up box or bed) or six feet or more in interior length)." Fed Reg Vol. 65, No.28, p.6750.

Table 6 summarizes the fuel savings that would be achieved if each cost-effective fuel economy technology discussed above were to be adopted by the set of vehicles to which it applies. Because the fuel use of trucks is dominated by the tractor-trailers, this is the most important source of fuel savings: a 58% increase in fuel economy increase for tractor-trailers reduces total Class 3-8 fuel consumption by 24%. Hybridization of locally driven trucks in Classes 3-6 and straight trucks in classes 7 and 8 adds another 8%, for a total reduction of 32%.

This represents the potential reduction in *new* truck fuel consumption beginning in 2015. DOE's NEMS model, for example, can be used to project the rate of improvement for the entire truck stock resulting from this level of efficiency improvement in new vehicles. But to place these gains in the context of all highway vehicle fuel use, note that if the Class 3-8 truck stock used 32% less oil today, savings would be 740,000 barrels of oil per day. In addition, if the fuel economy of Class 2b trucks were one-third higher today, their fuel consumption would be 90,000 barrels per day lower.

Table 6
Cost-Effective Fuel Savings from Heavy Truck Fuel Economy Improvements Available in 2015

	Class 2b 8500-10,000 lbs.	**Class 3-5 10,001-19,500 lbs.**	**Class 6 19,501-26,000 lbs.**	**Class 7-8 26,001 lbs. and up**	**Class 7-8 26,001 lbs. and up**	
Technologies	*Assorted conventional*	Hybrid	Hybrid	Assorted conventional	Hybrid	
Policies	*Fuel economy standard, feebate*	Tax incentives and R&D for hybrids	"	Fuel economy and technology standards	Tax incentives and R&D for hybrids	
Applicability	*Pickup, van, SUV*	Local	Local	tractor trailer	Straight, local	
Potential cost-effective improvement in fuel economy	*33%*	93%	71%	58%	71%	
Miles traveled by vehicles to which technology applies (as % of total class miles)	*96%*	53%	44%	85%	9%	
Oil use of class (as % of all Class 3-8 oil use)	*16%*	5%	14%	81%	81%	**Total reduction of Class 3-8 oil use**
Reduction in oil use as % of all Class 3-8 truck oil use	*4%*	1%	3%	25%	3%	32% (36% w/ Class 2b savings)

This discussion summarizes the benefits of all technological improvement found above to be cost-effective. What level of adoption of those technologies the proposed policies would achieve is another question. Fuel economy standards for tractor-trailers and Class

2b trucks would yield a high percentage of the reductions discussed above, though the issue of rebound needs to be considered. In the case of tax credits and R&D funding to accelerate hybridization of the remaining trucks, further analysis needs to be done to determine the extent of incentives and how much investment needed to bring hybrid costs down to levels associated with high volumes.

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NCEP Background Paper –
Congestion Charging: Solutions for the Escalating Problem of Vehicle Miles Traveled

Summary

This paper examines congestion charging as a potential policy mechanism for reducing traffic, pollution, and vehicle miles traveled (VMT) in major U.S. urban areas. Congestion charging involves the imposition of fixed or variable fees for access to certain roadways at certain times of day. As a VMT-reduction strategy, congestion charging is generally best-suited to large, densely populated cities where commuters have access to alternative means of transportation in the form of public transit or carpooling and where the benefits — in terms of reduced air pollution, traffic noise, and congestion — are particularly large.

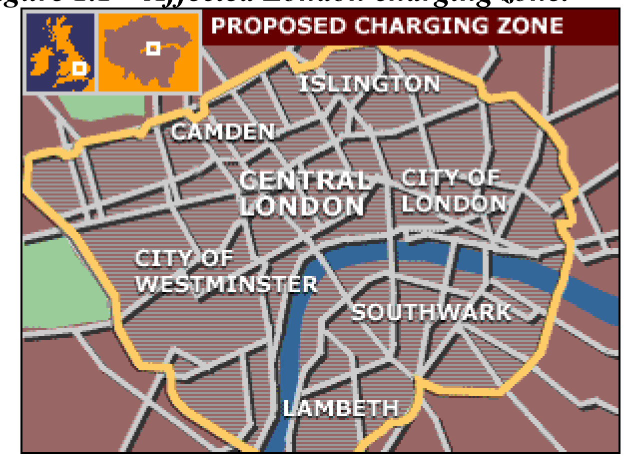
As a starting point, this paper reviews the successful congestion charging program that was launched in London in 2003. The London program imposes a fee on vehicles entering a defined area of downtown and directs resulting revenues towards improving the existing public transportation system. Early evidence from the London program is that it has done more than shift VMT; it has actually reduced VMT in absolute terms. Applying preliminary results from the London program to major U.S. cities with high levels of congestion and air pollution suggests that introducing congestion charging policies in the ten most congested cities in the United States could produce total annual fuel savings of more than 3 million barrels and carbon dioxide (CO_2) reductions of nearly 2 million tons per year. While these reductions are not large relative to total U.S. oil consumption and greenhouse gas emissions, congestion charging could nevertheless offer significant cross-cutting benefits in a number of major U.S. cities.

Background

Congestion charging is one of the few policy tools available for producing large, near-term shifts away from private transport and toward increased use of public transport and carpooling. In many urban areas, continued VMT growth has become a serious problem because it offsets the per-mile improvements that have been achieved in vehicle efficiency and pollution control, while creating chronic congestion problems and stressing highway infrastructure.

On February 17, 2003, London Mayor Ken Livingstone implemented a congestion charging scheme for downtown London. The program requires all vehicles driving in 8 square miles of central London (see Figure 1.1) between 7 am and 6:30 pm to pay a flat rate of £5 (~$8) per day. The policy is enforced by nearly 700 different video cameras located throughout the charging zone using an Automatic Number Plate Recognition (ANPR) computer system. The owners of vehicles caught on the ANPR that have not paid the fee are sent an £80 (~$120) Penalty Charge Notice (PCN) in the mail. London Mayor Livingstone has stated that all revenue raised by the program will be used to improve the existing public transit system. The congestion fee does not apply to emergency vehicles, motorbikes, mopeds, buses, coaches, taxis, firefighters, residents, and National Health Service vehicles. There is also a special exemption for vehicles operating on alternative fuels such as compressed natural gas (CNG) and liquefied petroleum gas (LPG), as well as for electric, hybrid, and fuel-cell vehicles.

Figure 1.1 – Affected London charging zone.

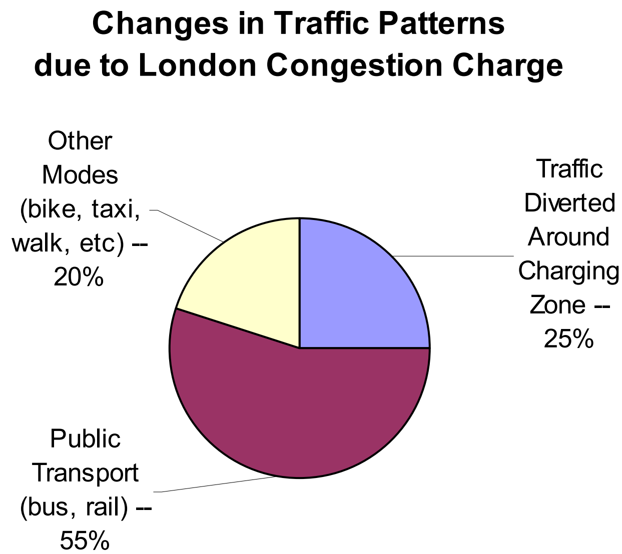


According to a six-month assessment prepared by the organization Transport for London, the number of motor vehicles entering the zone during charging hours was down by 16% and overall congestion during charging hours had fallen by about 30% after the first half year of program implementation. Driving time has also significantly decreased. Based on surveys taken from all over greater London, the time taken for journeys into and out of central London has been reduced by about 14%. Public bus use increased by about 15,000 extra passengers per day during the peak morning period. The program was on course to generate about £68 million for the public transportation system by the end of 2003.

Vehicle Miles Traveled (VMT)

According to the same six-month assessment, about 60,000 fewer vehicles per day entered the charging zone after congestion fees were imposed. It is estimated that 20%–30% of this reduction came from vehicles diverted around the zone, 50%–60% of this reduction came from people who switched to public transport (i.e., bus & tube), and 15%–25% of this reduction came from people who used other modes of transportation (e.g., taxi, bicycle, motorcycle, and walking). Based on these estimates we assume, for purposes of this analysis, that public transportation accounts for 55% of induced VMT reductions, other alternatives (biking walking, carpooling, etc.) account for 20% of induced VMT reductions, and traffic diverted around the charging zone accounts for the remaining 25%. In sum, of the traffic that does not enter the charging zone, three-quarters is assumed to represent people who have found alternative means of reaching their downtown destinations, while one-quarter of commuters are assumed to continue to drive, but go around the charging zone rather than through it. The net result of these assumptions applied to the London program is an estimated decline in total VMT of about 1%. This estimate takes into account an *increase* in VMT for those drivers that choose to travel around the charging zone rather than taking the presumably more direct route through the charging zone. Applying a 1 percent decrease in overall VMT to the 18 billion miles that Londoners are estimated to drive each year suggests annual oil savings of about 100,000 barrels of oil and emissions reductions of 69,000 tons of CO_2 annually.[1]

Figure 1-2



Studies by London-based businesses reinforce the finding that vehicles are diverted by the congestion charging program, but people find other means to reach their destinations in downtown London. A study by an American research firm Georgeson Shareholders & Co. suggests that London businesses are largely in favor of the congestion charge. The study, which was commissioned by the lobbying group London First, surveyed about 500 businesses of different sizes and types. Of those businesses surveyed, nearly 71% said that "congestion charging has had no discernible impact on their bottom line."

Congestion Charging Programs in Other Cities

Besides London, congestion charging programs also exist in Singapore, Melbourne, Toronto, and in three cities in Norway — Trondheim, Bergen, and Oslo. Singapore's program applies different charges to different roads at different times of the day based on traffic volume. Melbourne has implemented a toll road that links three of

[1] These numbers were estimated using the following assumptions: (1) vehicles diverted around the charging zone were assumed to *increase their* overall VMT by 3 miles per vehicle per day; (2) drivers who switched to public transport were estimated to decrease their VMT by 14 miles per vehicle per day while those who switched to other modes of transportation (except taxi) were estimated to decrease their VMT by 2 miles per vehicle per day (taxis do not reduce VMT so they were excluded from the calculation); and (3) Londoners travel were assumed to travel roughly 18 billion miles a year by car (Daily Policy Digest) with an average vehicle fuel economy of about 32 miles per gallon (Walsh). To convert fuel savings to CO_2 reductions, an emissions factor of 28 pounds of CO_2 per gallon of gasoline was applied (ACEEE). See Appendix A.

its arterial freeways. Toronto has an interesting program that charges vehicles on a per kilometer basis so that those who contribute more to the congestion also pay more money. Finally, Trondheim has an electronic toll system that charges vehicles every time they pass through the toll but is designed to give a discount to people who cross the ring multiple times. Most of these programs use overhead gantries which deduct the appropriate fee from either an electronic tag (e-tag) or cash card that is mounted on the vehicle windshield.

All of these programs have succeeded in reducing congestion and improving traffic flow within the charging area as measured by a reduced number of vehicles on the road, increased average vehicle speeds, and an increased number of people per vehicle (suggesting increased carpooling). Air pollution, noise, and safety seem to have improved within these charging zones as well. Apart from some initial technology glitches, all of these programs have been remarkably successful at enforcing the fee.

Candidate Cities for Congestion Charging in the United States

Congestion is a large and growing problem in major and minor U.S. cities. According to the Texas Transportation Institute's (TTI) 2002 Urban Mobility Report, "congestion is growing in areas of every size." With congestion measured as a time delay, the TTI study found that the average annual delay per peak road traveler in the United States increased from 16 hours in 1982 to 62 hours in 2000. To put these figures in perspective, a 62-hour annual delay equates to about 1.2 extra hours of travel each week for commuters. According to the same study, "passenger-miles of travel increased by more than 85 percent on freeways and major streets and by about 25 percent on transit systems." Finally, from an economic standpoint, all of this congestion was estimated to have cost about $67.5 billion in 2000 based on the value of time lost and the 5.7 billion gallons of excess fuel consumed.

According to the Department of Energy's Transportation Energy Data Book, Americans drive about 2.6 trillion miles per year in automobiles, light trucks, and SUVs. The nation's ten most congested cities account for between 0.5% and 2.8% of total national VMT. If charging programs were implemented in all ten of these cities and, similar to the London program, resulted in 1% reductions in VMT for those areas, annual fuel savings would total roughly 3.2 million barrels of oil and associated CO_2 reductions would total roughly 1.9 million tons per year.

Table 1.1 –Top Ten Most Congested U.S. Cities

City	Population (Million)	Annual Person-Hours Delay (Million)
Los Ang. CA	12.6	792
NY - NE NJ	17.1	400
Chicago	8.1	221
San Francisco	4	167
Dallas	3.8	141
DC-MD-VA	3.5	123
Houston TX	3.3	121
Detroit MI	4	101
Atlanta GA	2.9	97
Boston MA	3	85

London's congestion charging program, besides promoting use of alternative means of transportation, is also designed to minimize negative consequences, such as creating more traffic in other areas, encouraging sprawl, and disrupting local businesses. Some cities are more suitable for congestion charging than others. The best candidates have high levels of congestion and air pollution, as well as multiple alternative means of entry other than by single occupancy vehicle. Typically, these conditions are most likely to be met in cities that have compact downtowns and are well served by public transit.

Based on these considerations, the top ten most congested cities in the United States were grouped according to their suitability for congestion charging. Boston, San Francisco, and New York City seem to be the most suitable for charging zones. These cities are all very dense which allows congestion charging to capture a large share of commuting traffic within a well-defined area. Implementing congestion charging in Atlanta, Houston, or Los Angeles, on the other hand, would be more challenging because these city centers are spread out over a larger area. The remaining cities — Chicago, Washington, D.C., Detroit, and Dallas — have a mix of characteristics that are both conducive too, and challenging for, the imposition of congestion charges. For these cities, a congestion charging program may or may not be effective depending on how it is implemented. All of the top ten most congested U.S. cities also have significant air quality problems, particularly with respect to concentrations of ground-level ozone, a pollutant that can lead to severe respiratory and other health problems. Using the criteria noted in Table 1.2 below and detailed maps, Commission staff identified potentially suitable charging zones for each of these cities.

Table 1.2 – Evaluation of top ten congested U.S. Cities.

City	Public Transit?	Centralized Downtown?	U.S. Classification for Non-Attainment of National Ambient Air Quality Standard for Ozone	Size of Proposed Charging Zone[2]
Los Ang. CA	Yes	Un-centralized	Extreme	9 sq. miles
NY - NE NJ	Yes	Centralized	Severe	8 sq. miles
Chicago	Yes	Moderate	Severe	9 sq. miles
San Francisco	Yes	Centralized	Other	8 sq. miles
Dallas	Yes	Moderate	Serious	2.5 sq. miles
DC-MD-VA	Yes	Moderate	Severe	20 sq. miles
Houston TX	Yes	Un-centralized	Severe	2.5 sq. miles
Detroit MI	Yes	Moderate	-	1.5 sq. miles
Atlanta GA	Yes	Un-centralized	Serious	8 sq. miles
Boston MA	Yes	Centralized	Serious	2 sq. miles
London	**Yes**	**Centralized**	**N/A**	**8 sq. miles**

Conclusions

Overall, congestion charging in London has been a success. The number of motor vehicles entering the zone during charging hours has fallen by 16% and overall congestion is down 30%. Public bus use has increased by 15,000 extra passengers per day during the peak morning period, and the program was on course to generate £68 million for the public transportation system by the end of 2003. The program has also been effective at deterring vehicles but not people. Nearly three-quarters of the 500 businesses surveyed within the zone have seen no impact on their bottom line.

A simple analysis by Commission staff based on available data from a six-month assessment of the London program found that it reduced daily VMT in the London area by roughly 1%. Applying this result to the top ten most congested cities in the United States suggests that similar programs in those cities could produce oil savings of roughly 3.2 million barrels of oil per year and CO_2 reductions of roughly 1.9 million tons per year.

[2] See Appendix B

Appendix A – Spreadsheet Analysis

This appendix describes the calculations used to estimate VMT reductions and associated fuel savings and CO_2 reductions from the London congestion charging program.

In the attached spreadsheet, the first section under the bold heading "Charging Zone Data" contains the preliminary data from Transport for London's six-month report indicating that: (1) 60,000 vehicles were reduced from the charging zone each day; (2) 25% (15,000 vehicles) of these vehicles were diverted around the zone (rather than through it); (3) 55% (33,000 vehicles) of the drivers switched to public transport; and (4) 20% (12,000 vehicles) of the drivers switched to other modes (e.g., biking, walking, taxi, carpooling, etc.).

The "Miscellaneous Data" section of the spreadsheet lists other information used in this analysis, including a figure of 50 billion miles per day for baseline VMT in the London area; average vehicle fuel economy of 33 miles per gallon; and an average cost of gasoline of about $3.50 per gallon.

The section labeled "Our Analysis" shows how the effect of the congestion charge on overall London VMT was estimated. First, we assumed that the diverted cars increased VMT by about 3 miles per vehicle. Since the charging zone itself is about 8 square miles, we assumed that a driver driving around the zone (to avoid paying the fee) rather than straight through it would add three miles to his/her commute. Next, we assumed that those drivers who switched to public transport reduced their daily VMT by about 14 miles. Since the majority of the London suburbs are about 25 miles outside of the city, we assumed that the average commute into central London was about 14 miles. Finally, we assumed that drivers who switched to other modes of entry besides public transport or driving, decreased their daily VMT by about 2 miles per day. We assumed that those drivers who decided to walk or ride their bicycle instead of driving probably did not have very far to travel (i.e., it is unlikely that one would walk 14 miles into central London every day). Transport for London's six-month data included taxi as an option for "other modes." Taking a taxi instead of driving a single occupancy vehicle has no impact on VMT. We assumed that 80 percent of the drivers who switched to other modes used non-polluting means such as walking, biking, or carpooling, whereas 20% used taxis with no reduction in VMT. Taking all these assumptions into account we found that the number of vehicles diverted around the zone (15,000) multiplied by their effect on VMT (+ 3 miles per vehicle) has the net effect of increasing VMT by 45,000 miles per day. Using the same calculation for the drivers who switched to public transport, we find that there is a net reduction (thus the negative number) of 462,000 miles per day. Drivers who switched to other modes besides taxi (80% of 12,000 vehicles) multiplied by their effect on VMT (- 2 miles per vehicle per day) were estimated to reduce VMT by 19,200 miles per day. Summing these estimates yields a combined total change in VMT of negative 436,200 miles per day. This reduction represents 0.87% of the estimated 50 million miles of vehicle travel that occurs in the London area each day.

In the "Gas / Oil Impact" section of the spreadsheet, the estimated daily VMT reduction (436,200 miles) is divided by average fuel economy (32.22 MPG) to calculate daily gallons of gasoline saved. At 42 gallons per barrel, this corresponds to about 322 barrels of oil saved per day and 117,653 barrels of oil saved per year. At a cost of $3.50 per gallon, this corresponds to fuel savings of about $47,383 per day and about $17 million per year.

For our final calculations (under the heading "Pollution Reduction") we calculate associated reductions in CO_2 emissions. Every gallon of gasoline consumed releases 28 pounds of CO_2 to the atmosphere (ACEEE). The spreadsheet shows emission reductions in pounds; in the text above, pounds were converted to tons (2000 lbs = 1 ton). Finally, we also convert the £68 million revenue projection from Transport for London into U.S. dollars.

Appendix A - Spreadsheet
Charging Zone Data

	Percentage	*# of Vehicles*
% Diverted	25%	15,000
% Public Transportation	55%	33,000
% Other Modes (bike, walk, taxi, carpool, etc.)	20%	12,000
Total Reduced	100%	60,000

Miscellaneous Data

Daily London VMT (Miles) - Daily Policy Digest	50,000,000
Avg. UK Fuel Efficiency (MPG) - Walsh	32.22
Avg. Gasoline Cost (Per Gallon) - Walsh	$3.50

OUR ANALYSIS:

	VMT Impact (miles / vehicle)	*# of Vehicles*	*VMT (miles)*
Diverted	3	15,000	45,000
Public Transportation	-14	33,000	-462,000
Other Modes (bike, walk, taxi, carpool, etc.)	-2	(.80* 12,000)*	-19,200
		Net VMT Effect	**-436,200**
		Daily % Reduction	**0.87%**

Gas / Oil Impact

Daily Gallons of Gas Saved	13,538.18	(VMT / MPG)
Daily Barrels Oil Saved	322.34	(42 GAL = 1 BARREL)
Yearly Barrels Oil Saved	117,653.19	(365 DAYS = 1 YEAR)
Gas Savings ($/day)	$47,383.61	(GAL * $ PER GAL)
Gas Savings ($/yr)	$17,295,018.62	(365 DAYS = 1 YEAR)

CO2 Reduction

Daily Carbon Dioxide Reduction (pounds)	379,069.04	(GALLONS * 28) - ACEEE
Yearly Carbon Dioxide Reduction (pounds)	138,360,199.60	(365 DAYS = 1 YEAR)

*Taking a taxi instead of driving a single occupancy vehicle has no impact on VMT. So only the percentage (80%) of drivers who switched to other modes besides taxi were considered in our VMT impact calculations.

2003 Charging Zone Revenue Projection

2003 Revenue (U.K.)	£68,000,000
2003 Revenue ($)	$118,789,200

Appendix B - Possible Charging Areas in the Ten Most Congested U.S. Cities

New York City

A charging scheme could possibly be productive in Manhattan from 42nd Street south. This would include the entire southern tip of Manhattan. The primary entry points into this area for vehicles are:

- Queens Midtown Tunnel
- Williamsburgh Bridge
- Manhattan Bridge
- Brooklyn Bridge
- Brooklyn Battery Tunnel
- Holland Tunnel
- Lincoln Tunnel

In addition, charging would need to be implemented at the cross streets (e.g., 1st Ave.) and at all exits off of FDR drive, the Joe DiMaggio highway, and the West side highway. This is an extremely congested area that includes popular tourist attractions such as Greenwich Village, Chinatown, and Canal Street.

Washington, D.C.

A larger charging area of approximately 20 square miles may be effective in DC because the District has so many different points of entry that a small charging zone may lead to additional traffic in other areas as opposed to a reduction in VMT or a switch to public transport as is desired. A smaller area that might work (~9 sq. miles) would encompass the southern tip of downtown Washington below M street. This area includes the central business district, as well as the White House, the Mall, and the Washington Monument.

Los Angeles

In Los Angeles, a downtown area of about 9 square miles could be well-suited for congestion charging. This area is bordered by S. Hoover and S. Virgil Streets and the 2, 101, and 10 freeways (several major arteries that serve downtown LA). Some of the landmarks in this downtown area include Macarthur Park and Lafayette Park.

Chicago

Central downtown Chicago encompasses a roughly 9 square mile area bordered by 47th Street, Western Avenue, Rte. 290 and the lakefront. Major landmarks in this area include Comiskey Park and a significant portion of the Chicago River.

San Francisco

The fact that San Francisco is surrounded on two sides by water suggests a natural boundary for a congestion charging zone that would encompass about an 8-square mile area of downtown. Charges could be levied at off-ramps from most of the major arteries serving this area, including freeways 280, 80, and 101.

Dallas

The Dallas city center is defined by several major highways (including 366, 75, 30, and 35e) that encircle a relatively small, but transit-accessible area of roughly 2.5 square miles.

Houston

Downtown Houston is similarly concentrated in a roughly 2.5 square mile area that is encircled by highways 59, 90, and 45.

Detroit

The area enclosed by highways 375, 75, 10, and Atwater Street is relatively small (1.5 square miles) but forms a natural zone for potential congestion charging.

Atlanta

Atlanta is a relatively sprawling city, but an 8 square mile area of downtown defined by University Avenue, Highway 3, 10th Street, and the Boulevarde could lend itself to congestion charging. Landmarks located within this area include Grant Park, the Georgia Institute of Technology campus, the Georgia State University campus, and the Centennial Olympic Park.

Boston

Downtown Boston comprises a relatively small area of about 2 square miles that is bounded by Storrow Drive and by interstate highways 90 and 93. As with San Francisco, much of the downtown area is also bounded by water. Major landmarks located within this zone include Government Center at Scollay Square as well as the Boston Common and Public Garden. Charges would need to be imposed at the Callahan and Williams Tunnels and at bridge crossings to downtown Boston at Boston Harbor and the Charles River.

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Costs and Benefits of Congestion Pricing Policies in Selected U.S. Cities

A Report to the National Commission on Energy Policy

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Introduction

"Congestion charging" — tolling motor vehicles to drive on congested metropolitan highways and urban streets — is being considered as a potential gridlock-busting and energy-saving policy. Congestion charging can reduce energy use in transportation in two ways: directly by inducing some drivers to make some of their solo trips via other, less fuel-intensive modes of travel such as carpools or transit; and indirectly from the resulting improvement in traffic flow which allows the remaining vehicles in the traffic stream to operate at higher efficiencies, resulting in better gasoline mileage.

At the request of the Commission, we analyzed two different congestion charging schemes: *downtown pricing* and *area-wide pricing*.[1]

In downtown pricing, all vehicles are charged a toll to enter the downtown central business district anytime during the weekday commute and business period. London has successfully implemented downtown pricing in its 22 square-kilometer central district since February 2003.[2] We analyzed downtown pricing for one U.S. city, Chicago, using the 3.3 square-kilometer Loop district as the central charging area. Other than the difference in size, we duplicated the London approach in our Chicago analysis, right down to the $8 daily toll charged to enter downtown and the Monday – Friday, 7 a.m. – 6:30 p.m. tolling period.

Although downtown pricing appears economically feasible in Chicago (see "Results" section further below), it would only pertain to a small fraction of total metropolitan trips and thus would not deliver significant aggregate fuel savings. There are also concerns that some U.S. downtown districts might be too fragile economically to withstand the possible impacts on commerce of a stiff car-entry fee. Thus, we also analyzed a second congestion charging scheme designed to apply across entire metropolitan areas.

Under this alternative approach, known as area-wide pricing, all congested portions of a metropolitan area's existing freeway network would be tolled during the weekday morning and evening peak periods, a total of 6-8 hours per day. Carpools and commercial vehicles would be exempt, but single-occupant vehicles would pay per-mile tolls. The toll

[1] Report author Charles Komanoff may be reached at kea@igc.org or 212-260-5237. Interested parties should contact him to receive a copy of his spreadsheet (1.3 MB) for the analysis.

[2] London's downtown pricing system has received extensive coverage in the U.S. and international press and is briefly summarized further below. Transport for London has posted its report of one-year-after benefits and costs at http://www.tfl.gov.uk/tfl/cclondon/cc_monitoring-2nd-report.shtml.

revenue could finance not only the tolling infrastructure, but also premium bus service in the same corridors, along with discounts for low-income commuters.[3]

Area-wide pricing thus gives drivers four ways to maintain their free commute: ride in a carpool, take transit (perhaps using the newly provided or expanded express bus service), re-route to parallel (untolled) arterial roads, or switch their travel time to off-peak.

We analyzed area-wide pricing for six cities: Atlanta, Chicago, Houston, Los Angeles, New York and Washington, DC. The Chicago area-wide analysis is particularly noteworthy since it provides a direct comparison with downtown pricing.

Analysis Methodology

Our methodology for analyzing both congestion-charging approaches (downtown and area-wide) is based on three cause-and-effect relationships, as follows:

1. Tolls Reduce Traffic: How much drivers must spend to travel by car affects the "demand" for driving. In other words, adding tolls reduces traffic volume. For both types of toll schemes, we estimated the current cost of car trips (i.e., gasoline, applicable parking and tolls, and other incremental costs), and calculated the extent to which new tolls would increase average trip costs. We then applied estimates of "price elasticity" (the readiness of drivers to eliminate some trips in the face of higher driving costs), to calculate the reduction in traffic volume that would be expected due to the tolls.[4]

2. Lighter Traffic Goes Faster: Traffic flow improves as volumes diminish. That is, reducing the amount of traffic enables the "remaining" traffic to go faster. This effect can be striking under congested conditions. For example, removing just 5% of vehicles from a highway filled to capacity produces more than a 15% speed-up of traffic, according to established "volume/speed curves."

3. Faster Traffic Burns Less Fuel: Motor vehicles achieve optimum fuel efficiency when they can avoid both "stop-and-go" driving (which expends braking energy) and very high speeds (which increase air resistance); a range of 40-60 mph tends to be optimum. Thus, under congested highway conditions, i.e., average speeds under 40 mph, increases in

[3] Area-wide pricing is a variation on the widely discussed "HOT lane" concept, discussed further below.

[4] We assumed a (negative) 0.4 price elasticity for trips into downtown, and (negative) 0.75 for trips in the metropolitan area as a whole. The difference reflects the greater variety of new alternatives provided under the area-wide pricing proposal. However, for both cases we assumed a "bounceback" in traffic of 25%, meaning that one-quarter of trips expected to be "tolled off" the road re-materialize when improvements in travel time attract drivers back to the highway.

speed tend to raise fuel efficiency. Here too, the literature allows us to quantify how much higher speeds translate into better mpg. Although the "mph-mpg" sensitivities aren't nearly as dramatic as the "traffic-mph" relationships just noted — a 5% boost in speed from 30 mph engenders just a 2½ -3% improvement in gasoline mileage, for example — the aggregate impact across millions of daily trips can still be significant.

By "chaining together" these three relationships we were able to estimate the extent to which tolling achieves two important objectives: *fuel savings* and *faster travel*. The first objective, saving fuel, is the focal point of our analysis. The second, saving time, turns out to generate most of the social "value" needed to make tolls politically palatable. Time savings made up 70-80% of total driver benefits in the six area-wide pricing analyses, and 90% in our downtown pricing analysis (Chicago).[5] Clearly, gasoline prices would have to rise significantly before fuel savings from congestion charging could defray toll implementation costs. The picture changes radically, however, when motorists' time savings are also counted. ("Selling" congestion pricing primarily on its time-saving benefits is old hat to transportation professionals; the point is worth emphasizing in other contexts such as energy policy.)

Analysis Results

Following is a side-by-side treatment of the two analyses.

Toll Scenario	Area-Wide (6 cities analyzed)	Downtown (Chi. only)
GENERAL INFORMATION + KEY ASSUMPTIONS		
Cities analyzed	Atlanta, Chicago, Houston, Los Angeles, New York, Washington, DC	Chicago
Vehicles tolled	Single-occupant passenger vehicles	All vehicles
Weekday hours covered	Both peaks, e.g., 6-9:30 a.m. and 3:30 - 7 p.m. (7 hrs/day)	7 a.m. - 6:30 p.m. (11½ hrs/day)
Road tolled	All congested portions of highways	All portals to downtown
Toll rate	20¢/mile (except 40¢ in NY), for per-trip cost from $1.17 in Chicago to $2.72 in NY	$8.00 per day to enter downtown
Gasoline price per gallon	$1.70 to $2.10 ($1.80 in Chicago)	$1.80
% incrs in trip cost w/ toll	Range: 44% in Chicago to 72% (Atlanta)	115%
Price elasticity	0.75 (relatively high because of the many new alternatives to toll, e.g., express buses)	0.40 (relatively low due to no new alts. to toll)

[5] Not all of the 30-40% non-time savings are from fuel in the area-wide analyses — some are from reduced parking, insurance and wear-and-tear costs. In the somewhat simplified downtown pricing analysis, all 10% of the non-time savings are from reduced fuel use.

Time value (per person-hr)	Range: \$11.93 - \$19.88 (\$14.58 in Chicago)	\$14.58
TRAFFIC, SPEED & TIME RESULTS		
Toll-paying vehicles / day	1,560,000 – 4,060,000 (2,660,000 in Chi.)	80,000
% reduction in peak VMT	4% to 9% (6% in Chicago)	0.5%
% speed gain (avg'd over all VMT in applicable peak)	Citywide range: 13% to 30% (17% in Chicago)	1% citywide (but 11% within the Loop)
Before / After speeds (mph)	Citywide in Chicago: 34.8 / 40.8	Trips to Loop: 31.5/32.4
Person-hrs saved per yr	27 – 202 million (53 million in Chicago)	8.4 million
Time-savings value per yr	\$360 mill - \$2.8 billion (Chicago: \$770M)	\$147 million
FUEL SAVINGS		
Gasoline saved per year	64 – 327 million gallons (Chi: 112 million)	17 million
Gasoline saved / resident	14 – 54 gallons / year (Chicago: 15)	2.1 gallons / year
Gas saved, % peak usage	16% to 25% (17% in Chicago)	1.1%
Gas saved, % all usage	3% (Chicago) to 13%	0.5%
Gas tax increase to get same	\$0.35 (Chicago) to \$1.70	\$0.04
Saving if ¼ U.S. saved same	65,000 – 260,000 bbl / day (Chi: 70,000)	10,000 bbl / day
% of all U.S. oil so saved	0.3% – 1.3% (Chicago: 0.4%)	0.05%
Gas tax increase to get same	\$0.08 (Chicago) to \$0.31	\$0.01
COSTS & COST-EFFECTIVENESS		
Gross tolling costs (incl. buses, park-ride lots, etc.)	\$243 - \$590 million / yr (Chicago: \$446 M)	\$63 million / year
Per-trip toll cost	Range: \$0.49 - \$0.93 (\$0.67 in Chicago)	\$3.27
Cost / gallon saved (gross)	\$1.80 - \$4.67 (Chicago: \$3.98)	\$3.82
Annualized net benefits	\$217 - \$2800 million (Chi: \$500 M)	\$93 million
Above benefit, w/ avoided externalities (e.g., pollution)	\$400 - \$3400 million (Chi: \$710 M)	\$122 million
Above benefit / yr per capita	\$92 (Chicago) to \$339	\$16
Benefit / gallon saved (net)	\$5.30 to \$10.43 (Chi: \$6.36)	\$7.40
Time savings, % of benefits	69% to 79% (76% in Chicago)	90%

Tolling Implementation

Transport for London, which administers London's downtown pricing system, collects tolls in two complementary ways. The standard method is for drivers to upload their vehicle registration number to TfL via Internet, text-messaging, telephone or retail outlets such as gas stations; the £5 fee is then charged against the driver's pre-paid account. In addition, dedicated cameras installed at 203 entry points record the license plates of each vehicle entering the zone; when a license plate photo cannot be matched with a payment record, vehicle owners are automatically mailed a bill which includes a surcharge to offset the extra administrative cost.

This system is expensive, with estimated per-trip overhead exceeding \$3.00.[6] Applying this rate to the 20 million trips into the Chicago Loop each year during business and commute hours yields annual toll overhead costs of \$63 million. Still, the annualized value of the time savings that downtown charging would bring Chicago-area motorists (not just those driving into the Loop but also many others who would enjoy ripple benefits from the lightened traffic stream) appears to be more than twice as great, an estimated \$147 million, while fuel savings would be worth an additional \$15 million. Moreover, it is possible that tolling costs could be reduced below the London rate by adopting a more streamlined system employing transponders.

Our <u>area-wide pricing</u> scheme would cast a far wider net, tolling all congested portions of a metropolitan area's existing freeway network — typically, highway stretches in which speeds average less than 60 mph — during morning and evening peak periods.[7] Carpools and commercial vehicles would be exempt (whereas all vehicles would be tolled in downtown pricing), and the toll would be in effect only 6-8 hours a day, vs. 11-12 hours for downtown pricing. On the other hand, while downtown charging areas are concentrated and small, area pricing would encompass an entire metropolitan area. In the case of Chicago, the metropolitan area, at 2,780 square miles, is more than 800 times as large as the 3.3-square mile Loop. By our calculations, area-wide pricing in Chicago would toll 300 times as many trips as downtown pricing (roughly 2.7 million per day vs. 80,000), with an almost correspondingly greater potential for saving motorists time, gasoline and money.[8]

Area-wide pricing would use "open road" tolling, deploying transponder readers on overhead gantries to communicate with in-vehicle transponders. As in downtown pricing, vehicles without a compatible transponder would be identified using license plate

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[6] Our estimate of \$3.29 in toll overhead per trip into London's charging zone is based on first-year costs reported in Transport for London's first-year report noted earlier. Lacking a breakout of costs between capital and operating, we arbitrarily assumed that 75% of "scheme operation" costs were capital and amortized these over 10 years at a 6% interest rate.

[7] The leading theorist and advocate of area-wide pricing, Dr. Patrick DeCorla-Souza, envisions using "dynamic" (real-time-varying) pricing to provide highway drivers a guaranteed congestion-free ride. See the next-to-last footnote of this paper for a link to Dr. DeCorla-Souza's work.

[8] We say "almost" because trips removed from highway corridors into the Loop or from within the Loop itself generate the largest per-trip savings, owing to higher existing congestion levels.

recognition technology, and vehicle owners would be invoiced by mail, with a surcharge to cover administrative expenses. (This system has been employed since 1997 on the Highway 407 toll road in metropolitan Toronto.)

To ensure that carpools aren't charged under area-wide pricing, HOV (high-occupancy vehicle) access lanes would be provided near freeway entrance ramps. Carpools going through these lanes would have their vehicle transponder ID numbers recorded, so that no charges would apply to them at all toll-charging points on the freeway. Video technology, supplemented by police enforcement if necessary, would be used at HOV access ramps to prevent their use by solo drivers.

This area-wide pricing system would also include park-and-ride lots at which solo drivers could form carpools or switch to express buses that would operate in the same highway corridors, servicing major destinations such as office parks and satellite downtowns.[9] The system would also incorporate ITS and other improvements to the (untolled) parallel arterial-highway system to ensure that it could accommodate possible increases in traffic while maintaining current levels of service. All of this infrastructure, along with discounts for low-income commuters, would be financed by the toll revenue.[10]

Results: Discussion

Area-wide pricing

The key finding for energy policy, shown in the table above, is that area-wide congestion pricing appears to be a viable tool for making a dent in America's gasoline consumption. For the six cities studied, the expected per capita gasoline savings range from 14 to 54 gallons a year, equivalent to 3% to 13% of the current national rate of gasoline consumption. Even allowing for the fact that gasoline accounts for only a little over 40% of national petroleum usage,[11] our analysis suggests that applying area-wide congestion pricing to just a quarter of the U.S. population would eliminate between 65,000 and 260,000 barrels of petroleum usage a day. This equates to 0.7% to 2.6% of national gasoline use, and 0.3% to 1.3% of overall oil use.

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[9] Capital and operating costs for these facilities, including gantries, operations centers, system management, express buses, park-and-ride lots, HOV access ramps, and arterial road improvements, are included in the cost-benefit analysis of area-wide pricing for all six metropolitan areas studied.

[10] We did not explicitly account for the effect of these discounts on mode-switching, but we believe the impact would be slight.

[11] Our analysis treats all passenger vehicles including so-called "light trucks" and S.U.V.'s, but not freight vehicles, most of which consume diesel fuel.

Put differently, the federal government would have to tax every gallon of gasoline consumed in the 50 states by an additional 8 to 31 cents in order to achieve the same drop in gas consumption as would be expected from applying area-wide congestion pricing to just one-fourth of the U.S. population.

Would area-wide pricing be cost-effective? Apparently so, largely because of the enormous time savings caused by the reduction in traffic volumes. In Chicago, for example, we project a 17% increase in average city-wide speeds during the morning and evening peaks, from 34.8 mph presently to an estimated 40.8 mph. Totaling up the anticipated time and fuel savings, and even netting the considerable infrastructure and tolling costs, the estimated annual net benefits range from $400 million (in Atlanta and Washington, DC) to several billion dollars (in Los Angeles). On a per capita basis, the net benefits range from just under $100 a year, in Chicago, to over $300 a year, in Houston.

Downtown pricing

The fuel-saving benefits from downtown congestion pricing appear to be only modest, owing to its more limited (or targeted) scope. For the one city studied, Chicago, the estimated per capita gasoline savings are just 2 gallons a year, or one-half of 1% (i.e., 0.5%) of the current national gasoline consumption rate. At this savings rate, extending downtown congestion pricing to a quarter of the U.S. population would eliminate just 10,000 barrels a day of use, or 0.05% of total oil use (0.13% of total gasoline use). The same degree of gasoline conservation could be achieved by adding a penny a gallon to the nationwide gas tax.

This isn't to say that downtown congestion pricing couldn't be cost-effective. The estimated net benefits from tolling entry to the Loop are positive, at $120 million a year, or $16 per Chicago-area resident, primarily because of the improvement in traffic speeds. Although the speed gain is relatively diffuse city-wide, averaging just 1% for Chicago as a whole, we estimate that average speeds for weekday trips *into* the Loop would improve by almost 3%, largely due to an estimated 11% increase in traffic speeds *within* the Loop. All told, some 90% of the projected benefits to drivers emanate from time rather than fuel savings, suggesting that downtown pricing is best "sold" as a measure to improve travel efficiency rather than simply a means for saving gasoline.

Differences from "HOT" Lanes

A third method of congestion pricing known as "HOT" lanes is operating on four U.S. highways — I-15 and SR-91 in Southern California, and I-10 and US 290 in Houston. In this system, drivers may opt into high-occupancy vehicle (carpool) lanes by paying a toll, effectively converting HOV into HOT lanes (the "T" denotes tolls). A number of jurisdictions, including Maryland and Virginia, are considering adding new high-occupancy toll lanes to existing suburban freeways as a self-financing means of increasing highway capacity.

HOT lanes have some features in common with the area-wide pricing scheme outlined here. Both exempt carpools from tolls, and both apply to conventional freeways rather than to "portals" into central downtown districts. Some HOT lane schemes also use toll revenues to provide express bus service and finance partial rebates for low-income drivers — elements of our area-wide pricing proposal here. But there are considerable differences as well.

Most importantly, most HOT lane proposals are based on building new lanes which would then be tolled, i.e., adding pavement, whereas area-wide pricing leaves highway capacity unchanged. This difference is potentially crucial, given the expanding consensus that increasing highway capacity cannot offer more than temporary congestion relief. This is because the improved highway speeds "induce" new and longer trips, which uses up the increased capacity, effectively "restoring" congestion and returning speeds to their prior unsatisfactory levels. In contrast, area-wide pricing has built-in immunity to this syndrome because toll rates could be raised over time to keep traffic at free-flow levels; indeed, the essence of area-wide tolling is that it would operate on all congested sections of highways, but only those stretches, thus providing a self-regulating mechanism to keep traffic congestion at bay.

A second key difference is that HOT lanes apply to only one (or at most two) designated travel lanes, whereas area-wide pricing would operate on all freeway lanes. The segmentation of highways into HOT and general-purpose lanes reduces their throughput, since a slower moving vehicle in a HOT lane causes a gap to build up in front of it. In contrast, under area-wide pricing vehicles can move freely from one lane to any other, improving traffic flow and also obviating the need for expensive infrastructure such as flyover ramps to provide connections between separated highway sections. In addition, HOT lanes don't directly discourage trips in single-occupant vehicles, since solo drivers can elect to remain in (untolled) general-purpose lanes and be no worse off than at present.[12]

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[12] A detailed "side-by-side" comparison of area-wide pricing and HOT lanes may be found in a November, 2003 paper by Patrick DeCorla-Souza, "Clearing Existing Freeway Bottlenecks with Fast and Intertwined Regular Networks: Costs, Benefits and Revenues," available at <http://knowledge.fhwa.dot.gov/cops/hcx.nsf/9ba8442069238e44852568fe00708985/a5a934a66798f6aa85256de00000a713?OpenDocument>. The present paper draws heavily on Dr. DeCorla-Souza's ideas, and we are indebted to him for his intellectual guidance and support.

This is not to disparage HOT lanes, which furnished a conceptual "bridge" from the original, downtown-oriented paradigm of congestion pricing to the area-wide system we are proposing here. And HOT lanes are undeniably attractive; certainly, tolling a single, new highway lane is politically more palatable than tolling an entire existing highway network. But in our view, HOT lanes do not qualify as a permanent means of improving traffic flow, and thus should not be credited with improving the average gasoline mileage of highway travel.

Appendix

London's Congestion Pricing Program: Key Results in the Downtown Charging District[13]

- Traffic delays down 30%
- Drop of about ¼ in amount of driver time stationary or at <10km/h
- Bus waiting time down 30%; bus journey time down 14%
- Standard deviation of journey time down 30%, indicating higher reliability
- Increase in average motor vehicle speed from 14.3 to 16.7 km/h
- 10-11% drop in traffic volumes (inside zone)
- 30% fewer passenger cars entering zone
- 26% fewer total vehicles (includes taxis and lorries) entering zone
- Typical 80-minute round-trip to zone is now 10 minutes shorter
- Majority of "tolled-off" car trips have switched to public transport. Of the 60,000 fewer daily trips, 50-60% are on public transport, 15-25% are by other modes (e.g., taxis), 20-30% divert around the zone.
- Bus ridership up 20% in charging zone, 10% in London overall
- Anecdotal evidence that "non-price-constrained" Londoners are now riding buses
- Modest reduction in congestion on district boundary ring road

[13] These results were recorded by the author from a presentation by Jay Walder, Managing Director, TfL Finance and Planning, at a conference on congestion pricing in New York City on Nov. 4, 2003, sponsored by the Eno Foundation and the Urban Land Institute. Mr. Walder's full PowerPoint presentation is available from Transport for London.

ecos CONSULTING

Final Report for:
National Commission on Energy Policy

Dealer Incentives for Fuel Efficiency:
Are They a Cost-Effective Way to Save Gasoline?

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Making a World of Difference

I. Executive Summary

Ecos Consulting, Inc. (Ecos) prepared this report for the National Commission on Energy Policy (NCEP). The purpose of this report is to analyze an Automobile Dealer Fuel-Efficiency Incentive Policy (Dealer Incentive Program), which could assist the NCEP in developing a long-term energy strategy that enhances our national security, strengthens our economy, and protects the global environment and public health.

Twenty years of stalemate on Corporate Average Fuel Economy (CAFÉ) standards has taught policymakers that fuel economy will only improve significantly when those who can build and sell the most fuel-efficient technologies gain a decisive market advantage over their competitors. Absent a move to increase the true cost of fuel or internalize its externalities, such an advantage will likely be conferred through public policies that reward manufacturers or dealers for improvements in the fuel economy of the vehicles they sell. Funding such incentives with fees on the manufacturers or dealers that cannot improve average fuel economy would further accelerate the competitive importance of fuel economy and progress toward national energy-saving goals.

This report examines, develops, and analyzes the concept of a Dealer Incentive Program for fuel efficiency. Unlike manufacturer-focused policies, like CAFÉ standards, or consumer-focused policies, like gasoline taxes, this idea would enlist dealers in the effort to transform the market for more fuel-efficient vehicles by changing their underlying profit structure. Under such a program, auto dealers would be rewarded for selling vehicles with higher gas mileage rating, thereby increasing the fuel economy of the fleet of vehicles they sell. Rewards would be in the form of financial incentives and/or recognition from the state, regional or federal government.

As part of this project, Ecos compiled a data set of 100 top-selling vehicle models in the U.S and used this data set (a total of 1,349 vehicles) to analyze the retail price, dealer profit, and fuel consumption of different vehicles. Ecos also interviewed a handful of auto dealers, located on both the East and West Coasts, to do initial scoping of a Dealer Incentive Program. The goal was to learn more about the factors that drive dealer profitability and sales strategies and to solicit preliminary feedback on the program concept.

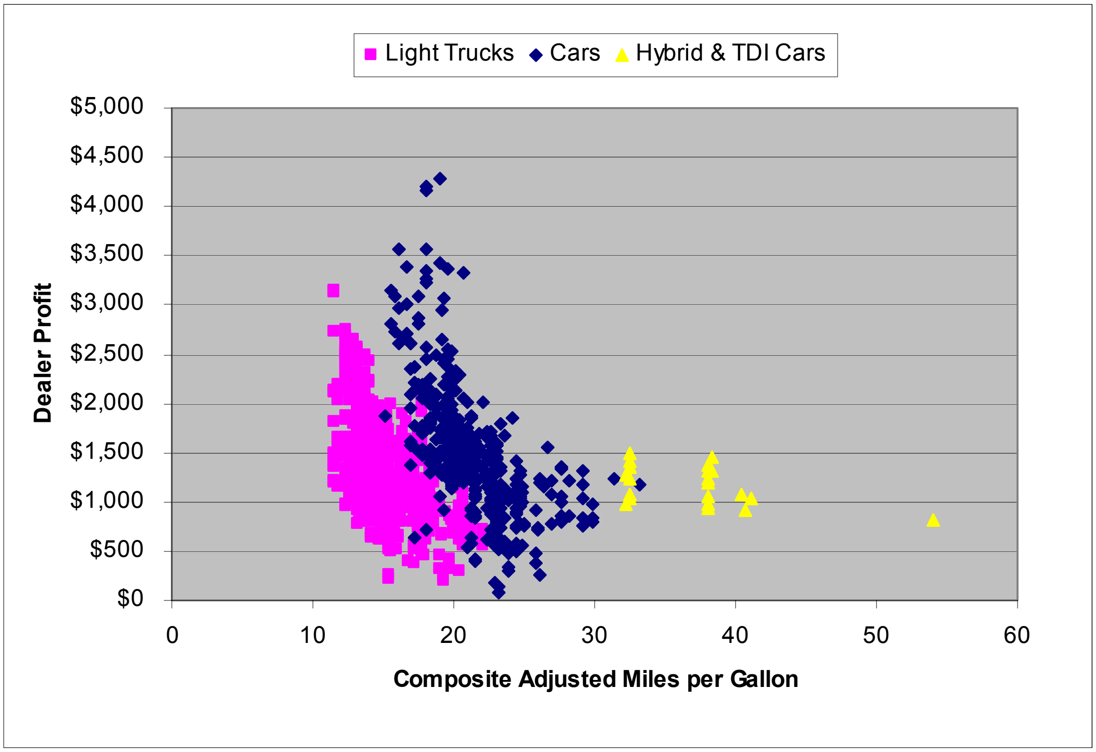
This report summarizes the findings of Ecos' research and makes recommendations to the NCEP on how to proceed towards implementing a Dealer Incentive Program. It also discusses variations in a Dealer Incentive Program meriting further research in order to address vehicle fuel economy. Some of the key findings are:

1. **Auto dealers have strong financial incentives to sell cars that are less fuel-efficient.**

   In a sample of 1,349 top-selling 2003 vehicle configurations, the ten most fuel-efficient cars had an estimated average dealer profit of $1,102, while the ten least-efficient cars had a profit of $2,229. The ten most fuel-efficient trucks had an estimated average profit of $792, while the ten least fuel-efficient trucks had a profit of $1,712. This same inverse relationship between vehicle fuel economy and dealer profit carries throughout the 2003 vehicle fleet (Figure 1).

   When this relationship is coupled with other inherent industry characteristics that tend to promote the sale of high-priced vehicles in large volume (e.g., salesperson/dealer pay structures, factory-to-dealer incentives, etc.), bigger, more powerful vehicles reap financial rewards that dealers cannot afford to ignore.

Figure 1
Cars & Light Trucks (under 8,500 lbs.)
Composite Adjusted MPG vs. Profit



2. **A Dealer Incentive Program that focuses on dealer recognition may be a more effective and cheaper alternative to a program that focuses on monetary incentives.**

   While data analysis suggests that an incentive in the range of $0.25 to $0.65 per gallon of gasoline saved might induce dealers to sell more fuel-efficient vehicles, dealers themselves (who think in aggregate annual profitability terms), often indicate that the number is much higher.

   Some dealers see the primary benefit of a Dealer Incentive Program as a "branding" opportunity to promote themselves as "green" dealers and/or good corporate citizens. These dealers[1] are likely to be attracted to the program for its marketing and public relations awards, which may be less complicated and more economical to deliver than a financial incentive system.

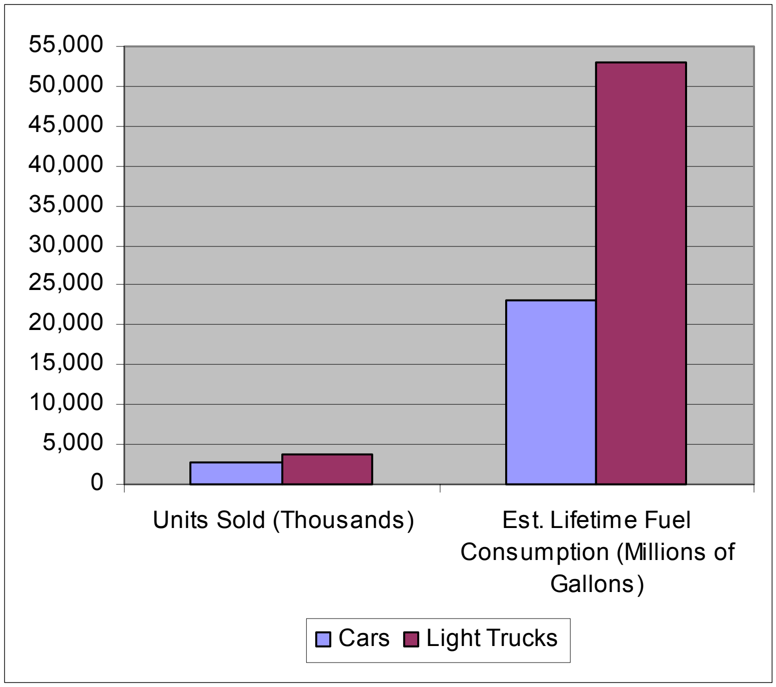
3. **A Dealer Incentive Program might be more cost-effective for trucks than for cars.**

   Light trucks are an especially problematic energy issue and are of growing concern. Trucks are less fuel-efficient than cars, are driven more miles over their lifetimes, and now represent a majority of new vehicle sales.

   In 2003, sales of the ten most popular trucks led the ten most popular cars by 30 percent. These most popular trucks will consume a remarkable 130 percent more fuel over their lifetimes (Figure 2). These vehicles cost significantly more to fuel over their lifetimes than they cost to buy.

[1] In general, these dealers include those who are already involved in "green" marketing, offer hybrid and diesel models, or are located in more progressive areas of the U.S. High-volume dealers indicated limited interest in a Dealer Incentive Program. Dealers who do business solely over the Internet were not interviewed as part of in this study.

Figure 2
Comparison of Units Sold and Estimated Lifetime Fuel Consumption
Top Ten Cars vs. Light Trucks



Data analysis suggests that the monetary incentive level needed to induce the sale of more fuel-efficient trucks is less than half of the incentive required for cars, and might be as low as $0.17 per gallon of gasoline saved (Figure 3).

Figure 3
Estimate of Incentive Level Needed for Vehicles with Various MPG Ratings
(Cost per Gallon Saved)

Cars		
Lifetime Gallons of Gas Consumed	MPG	Dealer Profit
6,000	30.8	$ 445
7,000	26.4	$ 819
8,000	23.1	$ 1,193
9,000	20.5	$ 1,566
10,000	18.5	$ 1,940
11,000	16.8	$ 2,314
12,000	15.4	$ 2,688
Profit per gallon consumed (or cost per gallon saved)		$ 0.37

Light Trucks		
Lifetime Gallons of Gas Consumed	MPG	Dealer Profit
10,000	18.5	$ 879
11,000	16.8	$ 1,049
12,000	15.4	$ 1,220
13,000	14.2	$ 1,391
14,000	13.2	$ 1,561
15,000	12.3	$ 1,732
16,000	11.6	$ 1,902
Profit per gallon consumed (or cost per gallon saved)		$ 0.17

Note: assumes 184,800 lifetime miles for both cars and light trucks.

A Dealer Incentive Program focused on light-duty trucks could be a cost-effective means of reducing new vehicle energy consumption.

4. **It is not clear whether auto dealers are the best policy actor to promote vehicle fuel efficiency.**

   Policymakers have not yet considered the role of auto dealers in their mission to reduce vehicle fuel consumption and resulting greenhouse gas emissions. And, although dealers play a critical link in the vehicle supply chain, it is still difficult to assess whether a Dealer Incentive Program would be more cost effective (or politically achievable) than one focused on manufacturers.

   Dealers' influence over which vehicle and options packages a consumer purchases has declined over time. Consumers are increasingly armed with detailed price and features information from the Internet and have the ability to "shop around" before making a purchase. Most dealers are now in the business of trying to satisfy their customers' stated preferences more cheaply and quickly than their competitors can and may be reluctant to try to shift those preferences too greatly for fear of losing a sale.

5. **Policy efforts should focus on lifetime energy savings and avoid rewarding specific technologies.**

   Technologies continue to enter the new light vehicle fleet. In some instances, these technologies are being used to increase vehicle acceleration performance and engine power, while fuel economy is held constant or even reduced. For example, several new hybrid-electric sport-utility vehicles (SUVs) due to enter the market are expected to deliver only modest fuel economy benefits compared to their standard gasoline counterparts.

   Policies that reward the use of particular technologies, such as hybrid and diesel engines, instead of actual gallons of gasoline saved, run the risk of falling into this trap and promoting technology, not energy savings.

6. **Uncertainties about details of program design should not deter experimentation or progress with a worthy idea.**

   There are a variety of ways to build financial incentives for fuel efficiency into the current marketplace. Some may be more effective or affordable than others, but the most promising options should be pilot-tested soon at the state and federal level. Without this "real-world" experience, all the policy analysis and modeling of hypothetical options will be of limited use in reducing gasoline consumption and reducing the longstanding trend of declining fuel economy.

II. Table of Contents

III. Introduction

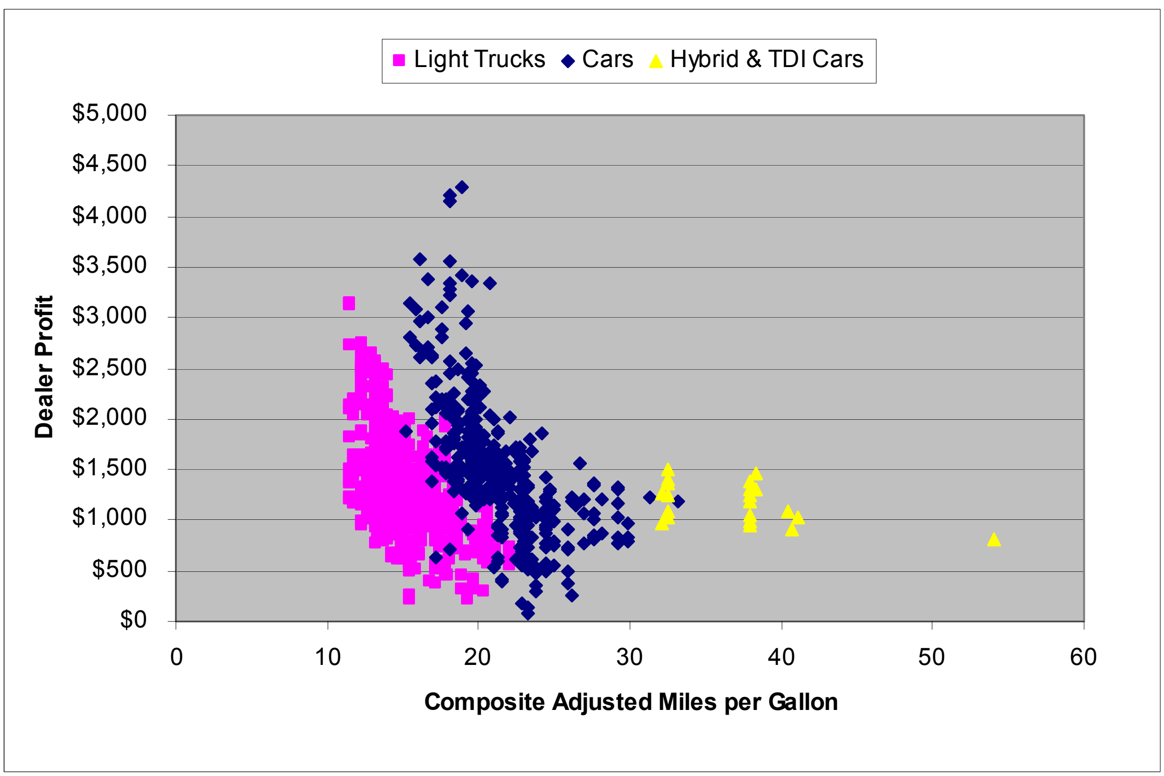
Vehicle fuel economy continues to be a major area of public policy concern for three primary reasons:

1. Light-duty vehicles consume 40 percent of all oil in the U.S.[2]
2. Oil and gasoline prices are volatile, which directly impacts the financial wellbeing of U.S. households, whose demand for these products is relatively stable.
3. Vehicle fuel economy affects the nation's overall energy consumption. Increases in energy efficiency enhance energy security and reduce greenhouse gas emissions.

As a general rule, the more profitable a vehicle is, the less fuel-efficient it is. Vehicles that are larger, heavier, more powerful, and more luxurious are more profitable, yet less fuel-efficient.

Dealer profits for the top 100 vehicle models (representing over 80 percent of the total sales in 2003) increase as fuel economy decreases (Figure 4). As such, the dealer's profit objective runs counter to the societal objective of improving fuel economy and reducing gasoline consumption.

Figure 4
Cars & Light Trucks (under 8,500 lbs.)
Composite Adjusted MPG vs. Profit



Source: Ecos data set.

[2] *U.S. EPA, "Fuel Economy Trends Report", 2003, http://www.epa.gov/otaq/cert/mpg/fetrends/r03006.pdf*

In most cases, light trucks are less fuel-efficient and exhibit a wider range of profits than cars. In general, smaller light trucks have lower profit margins while larger, more luxurious light trucks. Figure 5 shows average gross dealer profit by vehicle type, as reported by J.D. Power and Associates.[3]

Figure 5
Average Dealer Profits by Market Segment, with Vehicle Examples

Segment	Average Gross Profit	Sample Vehicles	Composite Adjusted MPG Range
Cars			
Entry Compact Car	$732	Toyota Corolla, Chevy Cavalier	27 - 36
Premium Compact Car	$934	VW Jetta, Mazda Millennium	24 - 26
Lower Midsize Car	$1,066	Honda Accord, Dodge Stratus	22 - 26
Basic Large Car	$1,076	Ford Taurus, Chrysler Concorde	19 - 24
Upper Midsize Car	$1,195	Nissan Maxima, VW Passat	17 - 21
Luxury Car	$3,276	BMW M5, Cadillac Seville	16 - 22
Light Trucks			
Compact Pickup Truck	$1,187	Ford Ranger, GM S10	17 - 24
Mini SUV	$1,248	Toyota RAV4, Isuzu Rodeo	16 - 26
Compact SUV	$1,478	Nissan Xterra, Honda CR-V	16 - 25
Compact Van	$1,732	Dodge Caravan, Honda Odyssey	19 - 22
Full-size Pickup Truck	$1,785	Nissan Frontier, Ford F150	14 - 18
Full-size SUV	$2,194	Chevy Tahoe, Ford Explorer	14 - 17
Luxury SUV	$3,029	Ford Expedition, GM Suburban	12 - 14

Sources: Profits - J..D. Power and Associates, The Power Report, December 1999. Luxury car profit data and sample vehicles from Ecos data set. Sample vehicles and mpg ranges - U.S. EPA, Fuel Economy Trends Report, 2003, Appendix B, http://www.epa.gov/otaq/cert/mpg/fetrends/r03006.pdf

From January to December 2003, Ward's data (Figure 6) indicate that the ten best-selling trucks outsold the ten best-selling cars by over 850,000 units or 30 percent.[4] The most popular truck in the U.S.—the Ford F-Series—sold more than twice as many units as the most popular car—the Toyota Camry.

[3] A later version of this data was not available from J.D. Power and Associates.

[4] *Ward's AutoInfoBank*, "Ward's 10 Best Selling Cars and Trucks, 12 Months 2003," December 2003.

Figure 6
Ward's 10 Best Selling Cars and Trucks, 12 Months 2003

Cars				
	Model	Units (000s)	Avg MPG	Est. Lifetime Fuel Consumption (Gallons, 000s)
1	Camry	413	20.9	3,650,020
2	Accord	398	22.9	3,216,204
3	Taurus	300	18.5	2,995,484
4	Civic	300	30.1	1,841,833
5	Corolla	269	28.7	1,731,758
6	Impala	268	20.5	2,419,191
7	Cavalier	257	23.8	1,988,549
8	Focus	229	24.0	1,767,178
9	Altima	201	20.8	1,789,101
10	Malibu	173	19.8	1,615,341
Total		**2,809**		**23,014,660**

Trucks				
	Model	Units (000s)	Avg MPG	Est. Lifetime Fuel Consumption (Gallons, 000s)
1	Ford F-Series*	846	14.1	12,301,795
2	Silverado*	684	13.9	10,128,505
3	Ram Pickup*	449	13.0	7,097,152
4	Explorer	373	14.4	5,304,153
5	TrailBlazer	261	14.9	3,604,352
6	Caravan	233	16.9	2,834,531
7	Ranger	209	16.1	2,659,888
8	Grand Cherokee	207	13.9	3,065,233
9	Tahoe	199	13.0	3,146,245
10	Sierra*	197	14.2	2,837,255
Total		**3,659**		**52,979,107**

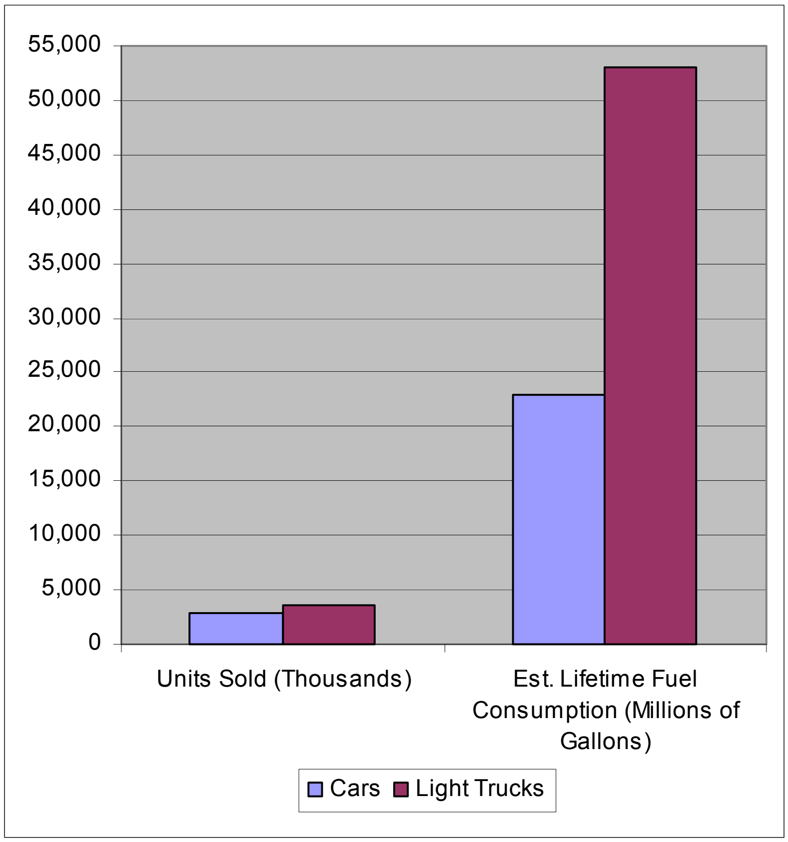
Notes: Assumes 205,000 lifetime miles for trucks and 184,800 lifetime miles for cars. See: Oak Ridge National Laboratory, "Transportation Energy DataBook, Edition 22," 2002, Tables 6.6 and 6.7.
Estimated Lifetime fuel consumptions = Lifetime miles/mpg*Annual Unit Sales
Table combines imports and domestics.
The same models have been in the top ten consistently for the past three years.
*These truck models are also offered above 8,500 lbs. gross vehicle weight (i.e., Ford F-250/350), which are exempt from fuel economy ratings. MPGs for these heavier sub-models are unknown.
Source: Ward's AutoInfoBank. "Ward's 10 Best Selling Cars and Trucks, 12 Months 2003," December 2003. Average MPG data from Ecos data set.

Vehicles in the light truck category, on average, are driven 11 percent more cumulative miles over their lifetimes than passenger cars.[5] Consequently, when consumers purchase a light truck, minivan, or SUV instead of a car, their impact on overall national fuel consumption is even greater.

[5] Cars are driven a estimated total of 184,800 miles over their lifetimes and light trucks (SUVs, vans, pickups) are driven a total of 205,000 miles over their lifetimes. Assuming See: Davis, Stacy, U.S. Department of Energy, Oak Ridge National Laboratory, "Transportation Energy Data Book, Edition 22, 2002, Tables 6.6 and 6.7.

As calculated in Figure 6, the total estimated lifetime fuel consumption of the ten most popular trucks is more than double—130 percent—that of the most popular cars (Figure 7).

Figure 7
Comparison of Units Sold and Estimated Lifetime Fuel Consumption
Top Ten Cars vs. Light Trucks



Source: Figure 6.

Moreover, many popular trucks (e.g., Ford F-Series, Chevrolet Silverado, Dodge Ram, and GMC Sierra) are each offered in configurations over 8,500 pounds gross vehicle weight rating (GVWR), the weight at which CAFÉ standards do not even apply and mileage stickers are not provided on the dealer showroom floor. The heavier versions of these popular trucks are even less efficient than their lighter counterparts. The Dodge Ram, for example, is configured in the range of 6,300 to 11,500 pounds GVWR. The heaviest configuration (Ram Quad Cab 3500), though not reported to consumers, is estimated to achieve only 7 MPG.[6]

The more powerful, feature-laden versions of a given vehicle model, in almost every case, will have lower fuel economy than the base model. This relationship is illustrated in Figures 8 and 9 for cars and light trucks, respectively. This situation can motivate dealers to try to "up-sell" consumers to less fuel-efficient vehicles and respond to manufacturers' incentives to sell more profitable models in greater quantities.

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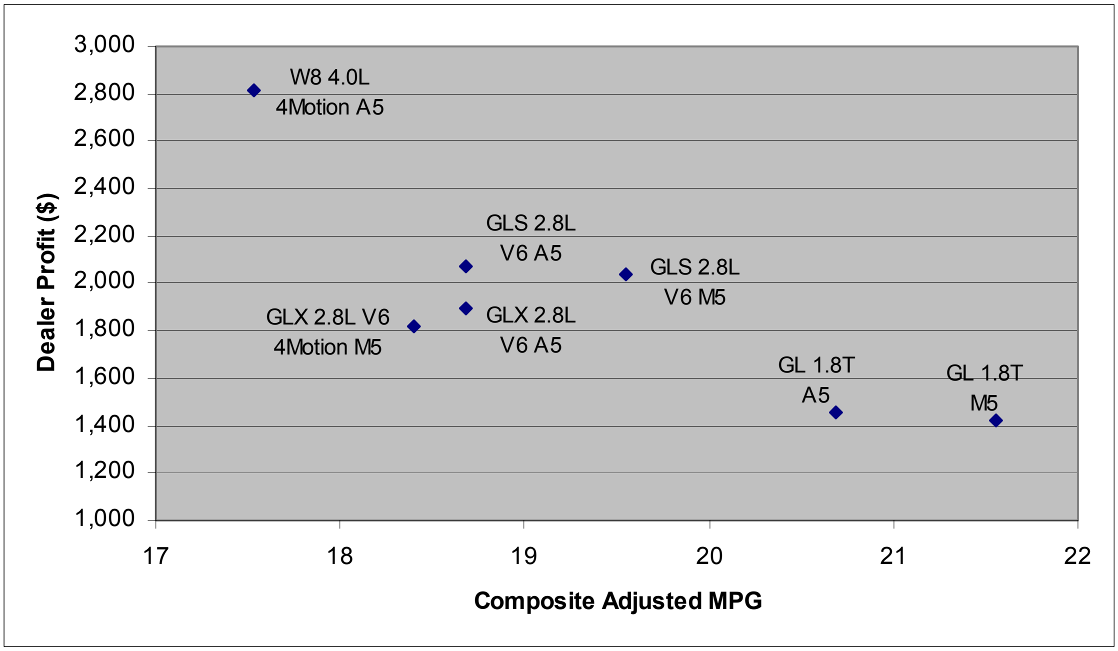
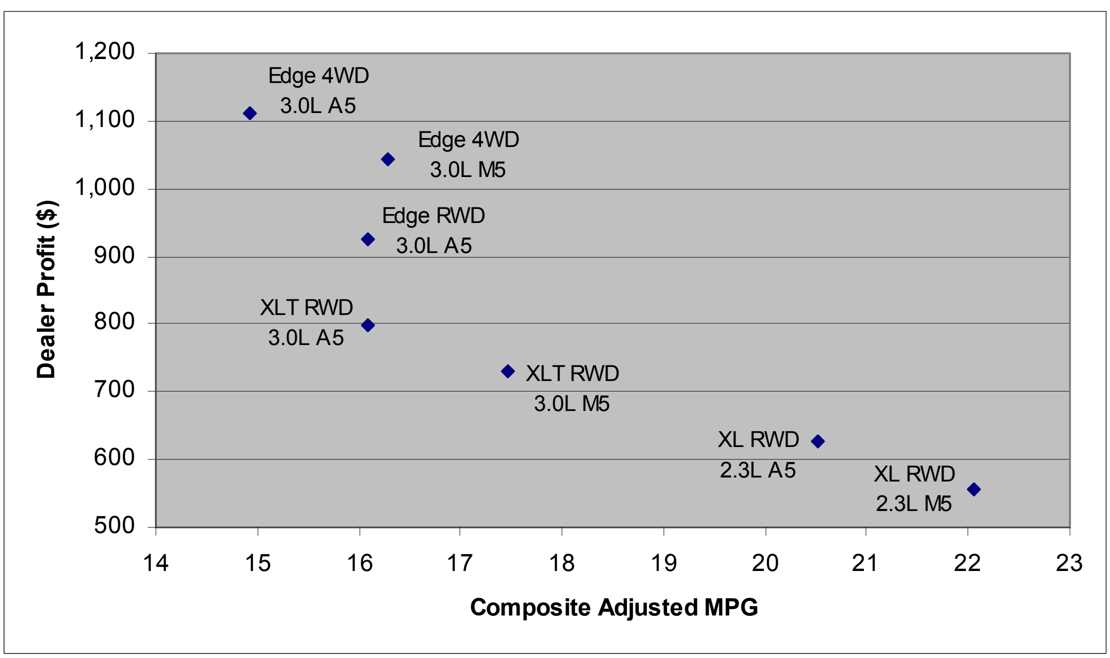
[6] Ecos calculations based on factor of a 6.6 percent reduction in fuel economy per 10 percent increase in weight. See: John DeCicco, Feng An, and Mark Ross, "Technical Options for Improving the Fuel Economy of U.S. Cars and Light Trucks, 2010-2015," American Council for an Energy Efficient Economy, June 2001.

Figure 8
2003 Volkswagen Passat
Dealer Profit and Miles per Gallon of Different Sub-models



Source: Wards and Fighting Chance, 2003 and Ecos calculations.

Figure 9
2003 Ford Ranger Regular Cab Pickup
Dealer Profit and Miles per Gallon of Different Sub-models



Source: Wards and Fighting Chance, 2003 and Ecos calculations.

A policy mechanism that rewards dealers for increases in the average fuel efficiency of the vehicles they sell could supplant the existing structural and financial incentives dealers face to promote gas-guzzling vehicles. Such a policy could better align private incentives with societal goals.

The federal government has historically focused energy policy on vehicle manufacturers through the Corporate Automotive Fuel Economy (CAFE) standards. These standards have not been substantially increased since their adoption in 1975. In fact, in real terms, the in-use fuel economy of new vehicles has fallen due to many factors, including the widespread introduction of light-duty trucks into the car market and increases in less-efficient driving patterns.

In more recent years, the federal and some state governments have turned to consumers, offering financial incentives for particular, narrow subsets of the marketplace, such as electric and hybrid vehicles. At the same time, new incentives for business owners of extremely heavy SUVs have been added to the tax code, likely counteracting the fuel savings achieved from promoting the limited number of hybrid vehicles sold to date.

Today, dealers have to compete on price with nearby dealers and various Internet sources of identical vehicles. Consumers armed with detailed information are forcing dealers to accept lower margins than ever before. Thus, the real profit future in the U.S. automotive market is based on selling, in volume, V-8 engines, SUVs and pickups.[7] Other profit opportunities exist in promoting upgrades from basic models to those with larger engines, automatic transmissions, and four-wheel drive. Each of these option choices tends to reduce vehicle fuel economy at the margin.

[7] The Wall Street Journal, "Toyota's Prius Hybrid Named Motor Trend's 'Car of the Year,' November 26, 2003.

IV. Major Vehicle Trends

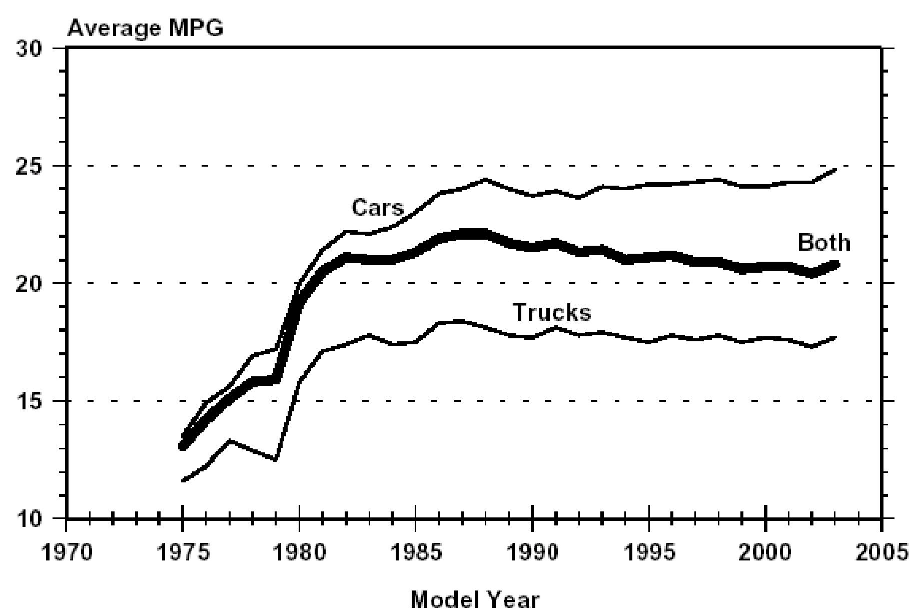
Four major trends in the new vehicle fleet point to the role of auto dealers in addressing concerns of increasing fuel consumption and greenhouse gas emissions. The concept for a Dealer Fuel Efficiency Incentive Program arose from recognition of these trends:

1. There has been a general downward trend in new light-duty vehicle fuel economy since 1988. This downward trend is expected to continue as less-efficient light-duty trucks replace car sales.
2. Manufacturers and consumers have historically been the target of fuel efficiency policies.
3. Much of the fuel economy technology and marketing focus has been applied primarily to a small number of small car models with relatively low market shares, even though the aggregate gasoline savings potential is greater with trucks, SUVs, vans, and large cars.
4. Fuel-efficiency technologies have been used primarily to increase power and performance instead of fuel economy.

A. Declining U.S. Light-Duty Vehicle Fleet Fuel Economy

New U.S. vehicle fleet fuel economy has trended downward to an adjusted, on-road level of 20.8 MPG in 2003 (Figure 10). This is 6 percent lower than the peak value of 22.1 MPG achieved in 1988. Average model year 2003 fuel economy is 24.8 MPG for cars and 17.7 MPG for light trucks.

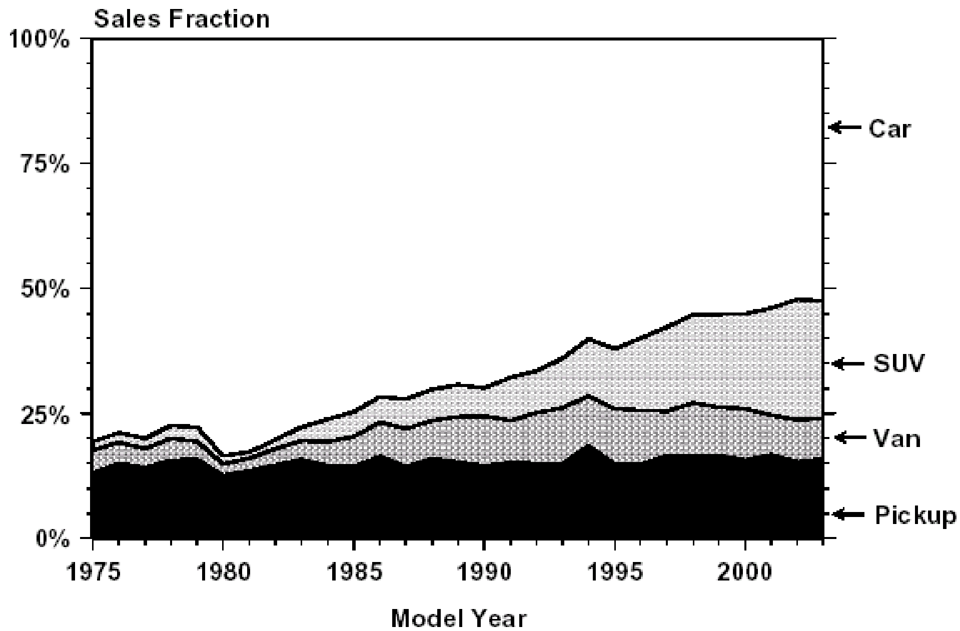
Figure 10
Adjusted Fuel Economy by Model Year



Note: Combined adjusted fuel economy figures are calculated with EPA adjustment factors of 10 percent reduction in city mileage and 22 percent reduction in highway mileage.
Source: Us Environmental Protection Agency, "Light-Duty Automotive Technology and Fuel Economy Trends, 1975 through 2003," April 2003. http://www.epa.gov/otaq/cert/mpg/fetrends/r03006.pdf, p. iii.

New light truck sales are now dominating the market (Figure 11). Nearly half (48 percent) of all new vehicle unit sales today are light trucks, close to twice their market share in 1975 (24 percent). Some estimates put the market share of light trucks at 52 percent or higher, particularly when measuring dollar market share instead of units market share.[8] As market shares of light trucks continue to rise, the new vehicle fleet fuel economy is expected to decline further because CAFE standards are 30 percent lower for trucks than for cars.[9]

Figure 11
Sales Fraction by Vehicle Type



Source: Us Environmental Protection Agency, "Light-Duty Automotive Technology and Fuel Economy Trends, 1975 through 2003," April 2003. http://www.epa.gov/otaq/cert/mpg/fetrends/r03006.pdf, p. iv.

As new light truck sales overtake car sales, the fuel consumed by the new vehicle fleet will continue to rise because trucks are less fuel efficient than cars and are driven more miles over their lifetime. On average, new model year 2003 light trucks will consume 44 percent more fuel over their useful lifetime than new model year 2003 cars.[10]

[8] ORNL, Transportation Energy Databook, Edition 23, Table 4.6.

[9] Note: Use harmonic calculation of percent difference between truck CAFE standard of 21.2 mpg and car CAFE standard of 27.5 mpg.

[10] Ecos calculations. Note: Over an estimated 16-year lifetime of a car and light truck, a truck will log 205,000 lifetime miles at 21.2 MPG compared to 184,800 lifetime car miles at 27.5 MPG. These fuel economy figures are not adjusted for on-road conditions, which represent an estimated 16 percent reduction in fuel economy for cars and trucks combined.

B. Policies Targeted Selectively at Manufacturers and Consumers

Policy research, development, and adoption have focused on eliciting change from manufacturers and consumers. Manufacturers are required to meet certain regulatory standards, such as the CAFÉ standards set by the NHTSA in conjunction with the U.S. Congress. Tax incentives (both state and federal) are available to customers that qualifying advanced technology fuel efficiency vehicles, such as electric and hybrid-electric vehicles.

There is also a federal gas-guzzler tax imposed on consumers who buy automobiles with fuel economy less than 22.5 miles per gallon. In 2001, the IRS collected over $78 million from consumers who purchased these vehicles.[11] This was up $5 million from the $73 million in gas-guzzling tax revenues collected in 2000 (in constant 2001 dollars).[12]

Historically, there has been a policy void in the role that car dealers can play in marketing and selling more fuel-efficient vehicles. As of the beginning of 2000, there were 22,250 franchised light duty vehicle dealerships in the U.S.[13] These businesses tend to have a smaller political role than manufacturers at the federal level, but tend to be much more significant than manufacturers at the state level. As such, fuel economy policies targeted toward dealers have particular appeal for states.

C. High Fuel Economy Focused on Small Cars

High fuel economy has be applied almost exclusively to small cars with relatively low market shares. Consumers shopping for high fuel economy vehicles have very few choices in today's market. In a sample of 1, 349 vehicles, which includes 100 top-selling models, there are only 42 vehicle configurations (7 different models) that exceed the 27.5 MPG CAFÉ standard (Figure 12). The largest of these models is a compact size vehicle that seats four or five people. Nearly all high fuel economy models come with a manual transmission. If purchased with an automatic transmission option, fuel economy will typically be reduced by at least 2 MPG,[14] rendering even fewer high-efficiency vehicles models to choose from.

Figure 12
Light-Duty Vehicle Models with
Fuel Economies that Exceed CAFE Standards

Make	Model	Body-Style	Cyl & Type	Liter	Valves per Cyl	Fuel Sys Inj	Trans	Composite Adj MPG
Honda	Insight	2-dr. htbk	SOHC I-3	1.0	4	SFI	M5	54.0
Honda	Civic Hybrid	4-dr. sedan	SOHC I-4	1.3	4	SFI	M5	41.1
Toyota	Prius	4-dr. sedan	DOHC I-4	1.5	4	SFI	CVT	40.7
Honda	Civic Hybrid	4-dr. sedan	SOHC I-4	1.3	4	SFI	CVT	40.4
VW	Jetta GL 1.9L TDI	4-dr. wagon	SOHC I-4	1.9	2	DI	M5	38.3
VW	Jetta GLS 1.9L TDI	4-dr. wagon	SOHC I-4	1.9	2	DI	M5	38.3
VW	Beetle GL 1.9 TDI	2-dr. sedan	SOHC I-4	1.9	2	DI	M5	38.0
VW	Beetle GLS 1.9 TDI	2-dr. sedan	SOHC I-4	1.9	2	DI	M5	38.0

[11] Note: This tax does not apply to light trucks such as pickups, minivans, sport utility vehicles, and vans.

[12] ORNL, http://www-cta.ornl.gov/data/tedb23/Edition23_Chapter04.pdf. Table 4.22.

[13] ORNL, from National Automobile Dealers Association, *Automotive Executive Magazine*, 2001.

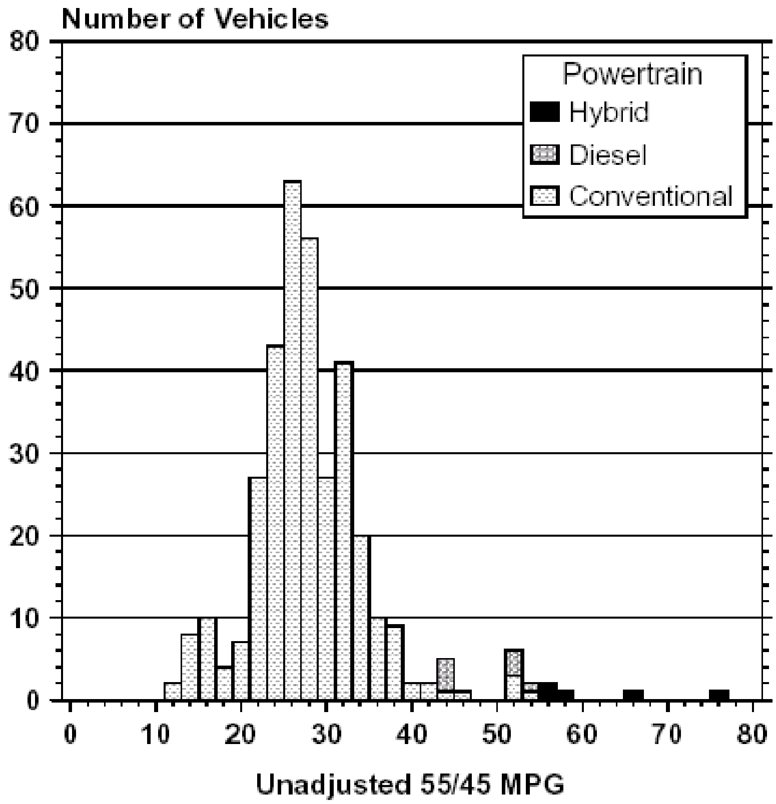
[14] U.S. EPA and U.S. DOE, "Fuel Economy Guide," DOE/EE-0236. www.fueleconomy.gov

Make	Model	Body-Style	Cyl & Type	Liter	Valves per Cyl	Fuel Sys Inj	Trans	Composite Adj MPG
VW	Golf GL 1.9LTDI	2-dr. htbk	SOHC I-4	1.9	2	DI	M5	38.0
VW	Golf GL 1.9LTDI	4-dr. htbk	SOHC I-4	1.9	2	DI	M5	38.0
VW	Golf GLS 1.9L TDI	4-dr. htbk	SOHC I-4	1.9	2	DI	M5	38.0
VW	Jetta GL 1.9L TDI	4-dr. sedan	SOHC I-4	1.9	2	DI	M5	38.0
VW	Jetta GLS 1.9L TDI	4-dr. sedan	SOHC I-4	1.9	2	DI	M5	38.0
Honda	Civic HX	2-dr. coupe	SOHC I-4	1.7	4	SFI	M5	33.2
VW	Golf GL 1.9LTDI	2-dr. htbk	SOHC I-4	1.9	2	DI	A4	32.5
VW	Golf GL 1.9LTDI	4-dr. htbk	SOHC I-4	1.9	2	DI	A4	32.5
VW	Golf GLS 1.9L TDI	4-dr. htbk	SOHC I-4	1.9	2	DI	A4	32.5
VW	Jetta GL 1.9L TDI	4-dr. sedan	SOHC I-4	1.9	2	DI	A4	32.5
VW	Jetta GL 1.9L TDI	4-dr. wagon	SOHC I-4	1.9	2	DI	A4	32.5
VW	Jetta GLS 1.9L TDI	4-dr. sedan	SOHC I-4	1.9	2	DI	A4	32.5
VW	Jetta GLS 1.9L TDI	4-dr. wagon	SOHC I-4	1.9	2	DI	A4	32.5
VW	Beetle GL 1.9 TDI	2-dr. sedan	SOHC I-4	1.9	2	DI	A4	32.2
VW	Beetle GLS 1.9 TDI	2-dr. sedan	SOHC I-4	1.9	2	DI	A4	32.2
Honda	Civic HX	2-dr. coupe	SOHC I-4	1.7	4	SFI	CVT	31.4
Toyota	Corolla S	4-dr. sedan	DOHC I-4	1.8	4	SFI	M5	29.8
Toyota	Corolla CE	4-dr. sedan	DOHC I-4	1.8	4	SFI	M5	29.8
Toyota	Corolla LE	4-dr. sedan	DOHC I-4	1.8	4	SFI	M5	29.8
Honda	Civic DX	2-dr. coupe	SOHC I-4	1.7	4	SFI	M5	29.2
Honda	Civic DX	4-dr. sedan	SOHC I-4	1.7	4	SFI	M5	29.2
Honda	Civic EX	2-dr. coupe	SOHC I-4	1.7	4	SFI	M5	29.2
Honda	Civic EX	4-dr. sedan	SOHC I-4	1.7	4	SFI	M5	29.2
Honda	Civic LX	2-dr. coupe	SOHC I-4	1.7	4	SFI	M5	29.2
Honda	Civic LX	4-dr. sedan	SOHC I-4	1.7	4	SFI	M5	29.2
Honda	Civic EX	2-dr. coupe	SOHC I-4	1.7	4	SFI	A4	28.1
Honda	Civic EX	4-dr. sedan	SOHC I-4	1.7	4	SFI	A4	28.1
Honda	Civic DX	2-dr. coupe	SOHC I-4	1.7	4	SFI	A4	27.6
Honda	Civic DX	4-dr. sedan	SOHC I-4	1.7	4	SFI	A4	27.6
Honda	Civic LX	2-dr. coupe	SOHC I-4	1.7	4	SFI	A4	27.6
Honda	Civic LX	4-dr. sedan	SOHC I-4	1.7	4	SFI	A4	27.6
Toyota	Corolla S	4-dr. sedan	DOHC I-4	1.8	4	SFI	A4	27.6
Toyota	Corolla CE	4-dr. sedan	DOHC I-4	1.8	4	SFI	A4	27.6
Toyota	Corolla LE	4-dr. sedan	DOHC I-4	1.8	4	SFI	A4	27.6

Notes: TRANS: M5 = manual 5 speed; A4 = automatic 4-speed; CVT = continuously variable transmission.
FUEL SYS (INJECTION): MFI = multipoint (port) fuel injection; SFI = sequential fuel injection (a specifically timed version of MFI); DI = Direct injection (used on diesel engines).
ENGINE TYPE: SOHC is single overhead camshaft (one cam per cylinder bank on V-type engines). DOHC is double overhead camshaft (two cams per cylinder bank on V-type engines).
COMPOSITE ADJ MPG is that reported by the EPA for cars equipped with engines meeting 49-state emissions regulations and may differ from cars with engines meeting California standards and is based on the EPA's formula for composite adjusted MPG =1/(0.55/(0.9*City MPG)+0.45/(0.78*Hwy MPG)).
Source: Ecos data set, compiled from Ward's, 2003 Model U.S. Car Specifications and Prices -- FINAL 3/18/03 ©Copyright 2003, Ward's Communications, a division of PRIMEDIA Business Magazines & Media Inc.

Sales of these small, high-efficiency cars are low. As Figures 13 shows, the hybrid and diesel technologies present in the most fuel-efficient, 50+ MPG vehicles, represent only a small portion of the cars sold. The majority of small car models cluster between 25 and 35 MPG, while the majority of the overall light vehicle fleet falls between 17 and 24 MPG. Merely shifting the peak of the distribution in Figure 10 from 26 mpg to 30 mpg could have a significant fuel economy impact.

Figure 13
Distribution of Unadjusted 55/45 MPG
Model Year 2003 Small Cars



Source: Us Environmental Protection Agency, "Light-Duty Automotive Technology and Fuel Economy Trends, 1975 through 2003," April 2003. http://www.epa.gov/otaq/cert/mpg/fetrends/r03006.pdf, p. 30.

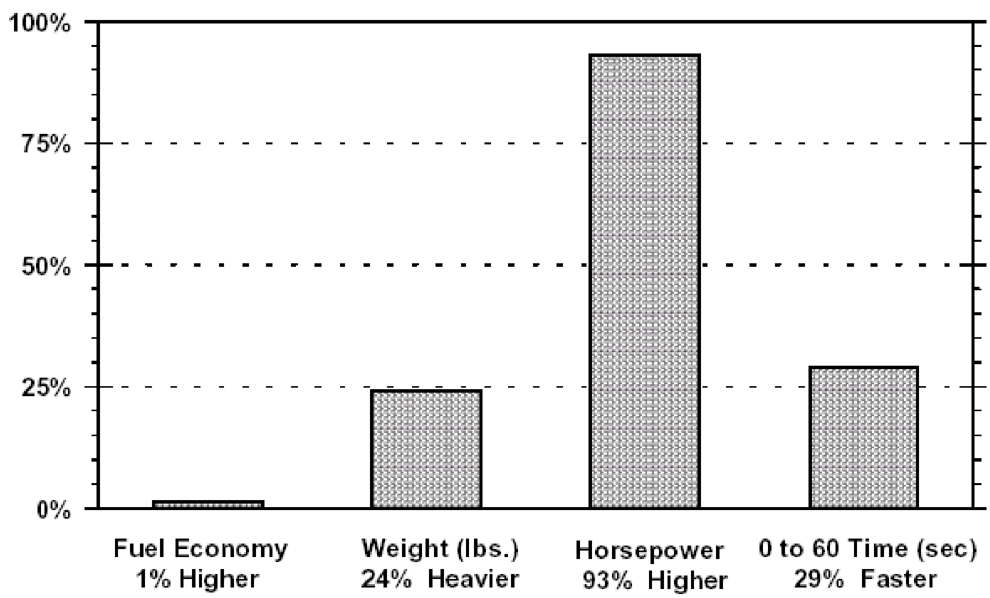
Manufacturers spend millions of dollars on research of advanced technologies, such as hybrid power trains, fuel cells, and electric vehicle technologies. While this research is important, full commercialization of these technologies is still a long way off. Sales of hybrid vehicles are increasing, but still represent only a fraction of the vehicles sold in the U.S. today. Policy options that focus on larger sized, higher sales vehicles are likely to have more overall impact than ones focusing only on 50+ MPG hybrids.

D. Advanced vehicle technologies increase light vehicle performance instead of fuel economy

Over the past two decades, fuel economy has been relatively constant, while vehicle weight and power have been increasing. Based on accepted engineering relationships, had the new 2003 light vehicle fleet had the same average performance and same distribution of weight as in 1981, it could have achieved about 33 percent higher fuel economy.[15]

Fuel-efficiency technologies, such as engines with more valves and transmissions with extra gears, continue to penetrate the new light vehicle fleet. The trend has clearly been to apply these new technologies to accommodate increases in average new vehicle weight, power, and performance while maintaining a constant level of fuel economy. This is reflected by heavier average vehicle weight, rising average horsepower, and faster average 0 to 60 mile-per-hour acceleration time (Figure 14).

Figure 14
Percent Change from 1981 to 2003 in Average Vehicle Characteristics



Source: Us Environmental Protection Agency, "Light-Duty Automotive Technology and Fuel Economy Trends, 1975 through 2003," April 2003. http://www.epa.gov/otaq/cert/mpg/fetrends/r03006.pdf, p. v.

This trend does not bode well for other vehicle technological advances such as hybrid-electric and diesel engines. Automakers are now announcing plans to boost hybrid vehicles' appeal by making these vehicles bigger and more powerful, thereby compromising on the technology's original selling point: fuel economy.[16] As such, the hybrid SUVs are not likely to provide the dramatic fuel economy improvements that have attracted buyers to hybrid small cars such as the Prius or Insight.

Toyota is designing its new hybrid SUVs (Lexus RX 330 and Toyota Highlander) to deliver V-8 equivalent performance compared to its conventional gasoline SUV models with V-6 engines. Ford is making similar fuel economy-power trade-offs with its Escape hybrid. For consumers shopping for fuel economy, this could be a big disappointment.

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[15] Source: Us Environmental Protection Agency, "Light-Duty Automotive Technology and Fuel Economy Trends, 1975 through 2003," April 2003. http://www.epa.gov/otaq/cert/mpg/fetrends/r03006.pdf

[16] Norihiko Shirouzu, "Gas-Electric SUVs Trade Fuel Economy for Size and Power," Wall Street Journal Online, January 5, 2004.

V. The Concept: Dealer Fuel Efficiency Incentive Program

A Dealer Fuel Efficiency Incentive Program (Dealer Incentive Program) seeks to address the general declining fuel economy trends in the new light-duty vehicle fleet described in the previous section. Specifically, this policy is an attempt to understand the car dealers' incentive structure and harness it to increase fuel efficiency profitability.

Under the Dealer Incentive Program, dealers would be rewarded for selling conventional cars with higher gas mileage ratings, thereby increasing the average fuel economy of the fleet of vehicles they sell. Rewards could come in the form of financial incentives (financed with public funds or revenue-neutral fees) and/or public recognition from the state or federal government (e.g., blue ribbon dealer status, public service announcements, website links, etc.)

The program could be designed as follows:

- Dealers would report last year's total sales and ongoing sales at intervals to a designated agency such as a state energy commission or department of motor vehicles.
- An Average Dealer Fuel Efficiency (ADFE) rating would be calculated by the agency's computer system based on the EPA-rated efficiency of each vehicle sold.
- The dealers would be rewarded financially by the extent to which they saved gasoline from one program period to the next, based on increases in their ADFE and its impact on the lifetime fuel consumption of the vehicles they sold.[17]

A Dealer Incentive Program would most likely be implemented at the regional or state level. However, a national program would maximize benefits and decrease cross-boundary effects. Participation could be voluntary initially and participants would agree to be in the program for one year to test the program in a "pilot" setting. Alternatively, the program could be mandatory from its inception, with incentives to dealers with fuel efficiency gains paid by fees on dealers with stagnant or declining average fuel efficiency. The program could cover cars and light trucks or be targeted at light trucks alone since they pose a more significant energy problem than cars today. In any case, pilot testing the program within a relatively self-contained metropolitan area or portion of a state would be an excellent way to test different program elements and fine tune program design before initiating it at a larger scale.

Some of the program elements may include:

- A payment of X cents per lifetime gallon saved versus previous year's sales
- Some type of salesperson training/promotion
- Promotion and referral on state website
- Financial awards for greatest improvement, most fuel saved, best marketing campaign, most hybrids sold, best salesperson, etc.
- Policymaker public recognition programs (similar to the annual Energy Star awards dinner) for all participating dealers and high-visibility awards for winners
- Local news stories and plaques for showrooms of winners

[17] Ideally, all light-duty passenger vehicles would be included in the program, even though fuel economy is not officially reported for vehicles over 8.500 GVWR (which includes several large pick up trucks and vans).

Cost effectiveness could be assessed similarly to the way states assess the cost effectiveness of programs implemented by electric and gas utilities to save energy: dividing total program incentive and administration costs by the number of verifiable lifetime gallons of gasoline saved. In this case, any dealer incentive program that could save gasoline for less than the untaxed price of fuel (about $0.70 to $0.90/gallon) would be clearly cost effective from a societal standpoint. Even programs less expensive than the retail price of fuel (about $1.50 to $1.80/gallon at present) would be arguably worth pursuing if taxes are assumed to account for at least some of the externality costs of gasoline. Present value calculations with estimates of forecasted changes in the future real price of gasoline could also be employed to fairly compare incentive costs incurred now with the value of future fuel savings.

VI. Vehicle Analysis

A. Data Set

To conduct research on the relationship between dealer profits and fuel efficiency and to estimate the appropriate incentive level for a Dealer Incentive Program, we compiled a data set using data from four primary sources:

- **Ward's Automotive.** Ward's is a widely trusted reporting and data service that has provided global auto industry news and analysis for more than 75 years. Ward's offers magazines, newsletters, subscriptions to database products, and a continually updated website.
- **Fighting Chance**. Fighting Chance is a unique information service founded in 1993 by James Bragg, author of *The Car Buyer's and Leaser's Negotiating Bible*. The company's goal is to arm consumers with information so that they can negotiate the purchase of a new vehicle from a position of strength.
- **Consumer Guide**. Consumer Guide has published books and magazines, written by experts, on automobiles and consumer products for more than 30 years. Each year, millions of people use Consumer Guide reviews to make decisions about which products or vehicles to buy. Consumer Guide has teams of experts and editors who review thousands of products and every new car each year.
- **Kelly Blue Book**. Kelly Blue Book, kbb.com, is one of the top automotive websites in the U.S. According to J.D. Power and Associates' Autoshopper.com studies, 53 percent of Internet new car buyers and 55 percent of used car buyers used kbb.com. Kelley Blue Book serves both the automotive buyer and industry by providing pricing reports and automotive awareness studies, and other vehicle related information.

1. Vehicles

Using Ward's Automotive Yearbook 2003, we identified the best-selling cars and light trucks in 2002—the latest year for which annual sales data was available. We selected the "top 100" vehicles (54 cars and 46 light trucks) as our data set.[18] Together, these 100 models account for 82.7 percent of 2002 sales, in volume. (Figure 15)

Figure 15
"Top 100"Cars and Light Trucks, based on 2002 Sales
(Units)

Rank	Car/Pickup Van/SUV	Make	Model	2002 Sales Volume	% 2002 Sales
1	P	Ford	F-Series	774,037	4.6%
2	P	Chevrolet	Silverado	647,748	3.9%
3	C	Toyota	Camry	434,145	2.5%
4	SUV	Ford	Explorer	433,837	2.6%
5	C	Honda	Accord	398,980	2.4%
6	P	Dodge	Ram	396,934	2.4%

[18] Note: Eight of our top 100 were selected, not on sales volume, but because they represent alternative technologies, such as hybrid, diesel, and continuous variable transmission, which NCEP specifically wished to include in this study. So, in fact, our "top 100" is really the "top 92," plus eight additional vehicle models of interest.

Rank	Car/Pickup Van/SUV	Make	Model	2002 Sales Volume	% 2002 Sales
7	C	Ford	Taurus	332,690	2.0%
8	C	Honda	Civic	313,159	1.9%
9	C	Toyota	Corolla	254,360	1.5%
10	SUV	Chevrolet	TrailBlazer	249,568	1.5%
11	V	Dodge	Caravan	244,911	1.5%
12	C	Ford	Focus	243,199	1.4%
13	C	Chevrolet	Cavalier	238,225	1.4%
14	P	Ford	Ranger	226,094	1.3%
15	SUV	Jeep	Cherokee	224,233	1.3%
16	SUV	Chevrolet	Tahoe	209,767	1.2%
17	C	Nissan	Altima	201,822	1.2%
18	P	GMC	Sierra	200,146	1.2%
19	C	Chevrolet	Impala	198,918	1.2%
20	SUV	Jeep	Liberty	171,212	1.0%
21	C	Chevrolet	Malibu	169,377	1.0%
22	V	Ford	Econoline/ClubWagon	165,085	1.0%
23	C	Buick	Century	163,739	1.0%
24	SUV	Ford	Expedition	163,454	1.0%
25	V	Honda	Odyssey	153,467	0.9%
26	P	Toyota	Tacoma	151,960	0.9%
27	SUV	Chevrolet	Suburban	151,056	0.9%
28	P	Chevrolet	S-10	150,992	0.9%
29	C	Pontiac	Grand Am	150,818	0.9%
30	V	Ford	Windstar	148,875	0.9%
31	SUV	Honda	CRV	146,266	0.9%
32	C	Volkswagen	Jetta	145,604	0.9%
33	SUV	Ford	Escape	145,471	0.9%
34	C	Ford	Mustang	138,356	0.8%
35	SUV	Chrysler	PT Cruiser	138,260	0.8%
36	C	Buick	LeSabre	135,016	0.8%
37	P	Dodge	Dakota	130,712	0.8%
38	C	Pontiac	Grand Prix	130,141	0.8%
39	V	Chrysler	Town & Country	126,378	0.8%
40	C	Dodge	Neon	126,118	0.7%
41	C	Hyundai	Elantra	120,638	0.7%
42	C	Saturn	S	117,533	0.7%
43	C	BMW	3-Series	115,428	0.7%
44	SUV	Toyota	Highlander	113,134	0.7%
45	C	Chrysler	Sebring	112,367	0.6%
46	C	Dodge	Intrepid	111,356	0.7%
47	SUV	GMC	Envoy	110,720	0.7%
48	SUV	Dodge	Durango	106,925	0.6%
49	C	Nissan	Sentra	106,060	0.6%
50	V	Chevrolet	Express	100,983	0.6%
51	P	Toyota	Tundra	99,333	0.6%
52	C	Mercury	Sable	98,998	0.6%
53	C	Nissan	Maxima	98,502	0.6%
54	C	Volkswagen	Passat	96,142	0.6%
55	SUV	Chevrolet	S Blazer	95,937	0.6%
56	C	Oldsmobile	Alero	94,285	0.6%

Rank	Car/Pickup Van/SUV	Make	Model	2002 Sales Volume	% 2002 Sales
57	V	Chevrolet	Ventura	94,056	0.6%
58	C	Dodge	Stratus Sedan	90,189	0.5%
59	P	Chevrolet	Avalanche	89,372	0.5%
60	SUV	Toyota	RAV4	86,601	0.5%
61	C	Subaru	Legacy	85,359	0.5%
62	C	Cadillac	Deville	84,729	0.5%
63	C	Mazda	Protégé	83,367	0.5%
64	C	Saturn	L	81,172	0.5%
65	V	Toyota	Sienna	80,915	0.5%
66	C	Mercury	Grand Marquis	80,271	0.5%
67	SUV	Nissan	Xterra	79,779	0.5%
68	C	Ford	Crown Victoria	79,716	0.5%
69	SUV	Hyundai	Santa Fe	78,279	0.5%
70	SUV	Toyota	4Runner	77,026	0.5%
71	SUV	GMC	Yukon	76,488	0.5%
72	SUV	Saturn	Vue	75,477	0.4%
73	P	Nissan	Frontier	75,207	0.4%
74	C	Mitsubishi	Galant	74,660	0.4%
75	SUV	Lexus	RX300	72,963	0.4%
76	C	Kia	Spectra	72,382	0.4%
77	C	Mitsubishi	Eclipse	72,040	0.4%
78	C	Hyundai	Accent	71,488	0.4%
79	C	Lexus	ES300	71,450	0.4%
80	SUV	Toyota	Sequoia	70,187	0.4%
81	C	Mitsubishi	Lancer	69,007	0.4%
82	C	Hyundai	Sonata	68,085	0.4%
83	SUV	GMC	Yukon XL	67,566	0.4%
84	C	Chevrolet	Monte Carlo	64,771	0.4%
85	SUV	Jeep	Wrangler	64,351	0.4%
86	C	Mercedes	C Class	64,025	0.4%
87	C	Pontiac	Sunfire	62,950	0.4%
88	SUV	Buick	Rendezvous	61,468	0.4%
89	C	Acura	TL	60,764	0.4%
90	C	Lincoln	Town Car	59,312	0.4%
91	SUV	Nissan	Pathfinder	57,384	0.3%
92	C	Kia	Rio	51,195	0.3%
93	C	Volkswagen	Beetle	49,549	0.3%
94	C	Audi	A4	44,319	0.3%
95	C	Volkswagen	Golf	31,482	0.2%
96	C	Mini	Cooper	24,590	0.1%
97	C	Audi	A6	24,372	0.1%
98	C	Toyota	Prius	20,119	0.1%
99	C	Honda	Insight	2,216	
100	SUV	Nissan	Murano	2,054	
				Total	82.7%

Note: C = car; P = pickup truck; SUV = sport utility vehicle; V = van.
Source: Ward's Automotive Yearbook, 2003.

Most of the vehicles listed above have different sub-models (e.g., Honda Civic DX, Honda Civic LX) or different options configurations of the same model (e.g., 4-clyinder vs. 6-cylinder engine, manual vs. automatic transmission, etc.). Since these vehicles frequently have different fuel economy than the base model, we included all vehicle sub-models and options configurations in our analysis, where data permitted.[19] Our final data set consisted of a total of 441 cars and 912 light trucks.

2. Variables

Figure 16 provides a complete list of the variables gathered on each vehicle. Our analysis centers on six of these variables—lifetime gallons, dealer profit, drive type, engine cylinder, transmission, and fuel type.

Figure 16
List of Variables Gathered for Data Set

Variable	Sample Data	Source	Comments
Make	Audi	W	
Series	A4	W	
Model	1.8T Quattro	W	
Body style	4-dr. sedan	W	
Drive type	AWD	W	AWD = all wheel drive
Fuel type	G	W	G = gasoline
Box length (ft.)[a]	-	W	
Wheel base (ins.)	104.3	W	
Size, Length (ins.)	179.0	W	
Size, Width (ins.)	69.5	W	
Size, Height (ins.)	56.2	W	
Curb weight (lbs.)	3,406	W	
Gross vehicle weight (lbs.)[a]	-	W	
Engine, Cylinder & Type	DOHC I-4	W	DOHC = double overhead cam I-4 = 4 cylinder
Engine, size, CID	109	W	
Engine, size, cc	1781	W	
Engine, size, Liter	1.8	W	
Engine, valves per cylinder	5	W	
Engine, Fuel System, Injection	SFI	W	SFI = sequential fuel injection
Engine, Fuel System, Intake	T	W	T = Turbo
Engine, Bore and stroke (ins.)	3.18x3.40	W	
Engine, Bore and stroke (mm)	81.0x86.4	W	
Engine, Compression Ratio	9.3:1	W	
Engine, Net horsepower @ RPM	170@5900	W	
Engine, Torque lbs.-ft.	166@1950	W	
Engine, Torque Nm	225@1950	W	
Transmission	M5	W	M5 = manual (5 speed)
Traction control	S	W	S = standard
Antilock brakes, rear	-	W	
Antilock brakes, 4-wheel	S	W	S = standard

[19] Note: All light trucks sub-models with a Gross Vehicle Weight over 8,500 lbs. were eliminated. These vehicles are exempt from the EPA CAFE standards for reporting estimated MPG; and thus, could not be used in any analysis of fuel efficiency. As these heavy passenger vehicles are of growing concern, Ecos recommends that vehicles between 8,500 – 10,000 GVWR be included in a Dealer Incentive Program, if fuel economy data can be obtained from EPA or other sources.

Variable	Sample Data	Source	Comments
Est. MPG City	21	W, CG, or KBB	
Est. MPG Hwy	29	W, CG, or KBB	
Adjusted Composite MPG	20.4	Calculated	Based on EPA formula: =1/(0.55/(0.9*City MPG)+0.45/(0.78*Hwy MPG))
Invoice	$24,434	FC pricing	
Destination	$660	FC pricing	
MSRP (excluding destination)	$26,850	FC pricing	
Guzzler tax[b]	-	W	
Lowest Transaction	$120	FC make-by-make	Amount above/below invoice of the lowest transaction reported by consumers on this vehicle.[c] If no transaction was reported for a particular vehicle, then the closest comparable transaction was used.
Dealer Holdback percent	0.0 percent	FC make-by-make	Usually a percentage of MSRP or Invoice
Dealer Holdback	$0	Calculated	Dealer Holdback times MSRP (or Invoice)
Manufacturer-to-Dealer Incentive	-	CD	Manufacturer-to-dealer incentives change frequently. This amount represents the incentive amount offered at one point in time (November 18, 2003).
Lifetime Gallons[d]	9,054	ORNL, Calculated	184,800 miles divided by Adjusted Composite MPG
Low Profit	$7	Calculated	Lowest Transaction plus Dealer Holdback plus Dealer Incentive
High Profit	$2,416	Calculated	MSRP (excluding destination) minus Invoice plus Dealer Holdback plus Dealer Incentive
Dealer Profit	$1,212	Calculated	Average of Low Profit and High Profit

[a] Light trucks only.
[b] Cars only.
[c] Sometimes, the lowest transaction was not an actual transaction, but a low target amount set by Fighting Chance.
[d] For the purpose of analysis, we assumed trucks were driven the same number of lifetime miles as cars (184,800). This leads to conservative results because, in fact, trucks are driven 205,000 miles over their lifetimes, on average.
Sources:
W = Ward's, 2003 Model U.S. Car (or Light Truck) Specifications and Prices -- FINAL 3/18/03.
CG = Consumer Guide 2003, New Car Price Guide.
CD = CarDeals, Rebate and Incentive Programs Currently Offered on New Cars and Light Trucks, Vol. 13, No 23, November 18, 2003.
FC pricing = Fighting Chance, 2003 pricing reports.
FC make-by-make = Fighting Chance, make-by-make reviews, 2003.
ORNL = Department of Energy, Oak Ridge National Laboratory, Stacy Davis, Transportation Energy Data Book: Edition 22, 2002, Tables 6.6 and 6.7.

Dealer Profit

Dealer profit represents the average profit that a dealer makes when he or she sells a particular vehicle. Dealer profit is extremely difficult to estimate due to lack of information (as described in section VII-A-1. Dealer Profit Structure). We chose to use a mid-point profit value that was calculated as the average of:

- “High” profit. A high estimate for dealer profit on a particular vehicle, calculated as the difference between MSRP and invoice (excluding destination charges), plus dealer holdback, plus any factory-to-dealer incentives.

- "Low" profit. A low estimate for dealer profit, calculated as the amount above or below invoice of the lowest transaction reported by consumers on this vehicle,[20] plus dealer holdback, plus factory-to-dealer incentives.

While "high" profit was highly correlated with MSRP and invoice prices,[21] "low" profit was more randomly distributed, reflecting customer ability to negotiate on a particular transaction. We felt a mid-point was more representative of typical transactions.

Our profit numbers do not taken into account a number of other items that exist. For example, dealers receive additional incentives from the manufacturer for sales-volume and/or their customer satisfaction ratings. Dealers also make money on "back-end items," such as financing and insurance. We did not consider these additional profit sources in our analysis, in part because they are not fuel economy-related and in part because very little reliable public information is available about them: only dealer themselves are privy to this information. Nevertheless, such additional profit sources are real, and to the extent that they exist, our analysis most likely *underestimates* the amount of total profit that dealers make and potentially *overestimates* the amount of the incentive needed in a Dealer Incentive Program.

Lifetime Gallons

Lifetime gallons represents the total gallons of gasoline that a vehicle consumes over its lifetime. It is calculated by dividing 184,800 miles[22]—the total number of miles a vehicle is typically driven over its lifetime—by the vehicle's composite adjusted miles per gallon.[23] Composite adjusted miles per gallon is a number developed by the U.S. EPA which combines reported city MPG and highway MPG based on a formula that takes on-road driving conditions into account. EPA revises this formula periodically so that fuel economy values reflect the gas mileage drivers get in actual use.

While not as intuitive as MPG, lifetime gallons is a more appropriate variable for this analysis, since any Dealer Incentive Program would be measured in terms of cost (dollars) per gallon saved, so it could be compared to the price of gasoline. Note also that rewarding dealers for improvements in average MPG would pay too much for an improvement from 30 to 32 MPG, for example, and too little for an improvement from 18 to 20 MPG, relative to the actual amount of resulting gasoline savings (385 gallons vs. 1,027 gallons, respectively).

Drive Type, Engine Cylinder,[24] Transmission, and Fuel Type

These four non-numeric variables were identified as having a significant impact on lifetime gallons. Figure 17 shows the different values of these variables that were considered.

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[20] If no transaction was reported for a particular vehicle, then the closest comparable transaction was used.

[21] R^2 above 0.70.

[22] Oak Ridge National Laboratory, "Transportation Energy DataBook," Edition 23, 2003. Note: Trucks' estimated lifetime miles is slightly higher (205,000 lifetime miles) than that of cars; however, for purposes of this analysis we kept lifetime miles constant so that trucks were not unfairly penalized. For example, if a 20 MPG car and a 20 MPG truck are compared, the truck would have a higher lifetime gallons, simply because its lifetime miles were higher (205,000/20 = 10,250 gallons versus 184,800/20 = 9,240 gallons). This makes the choice of switching to a 20 MPG car look favorable, when in actuality, from a pure fuel-efficiency standpoint, these cars are identical.

[23] Note: deteriorating MPG over the course of a vehicle lifetime is not taken into account.

[24] Note: Engine Type (DOHC, SOHC, FF, etc.) was not considered.

Figure 17
Variables Influencing Fuel Economy

Variable	Values
Drive Type	2WD (includes RWD and FWD) 4WD (includes AWD)
Engine Cylinder	4 cylinder (includes 3 cylinder) 6 cylinder 8 cylinder
Transmission	Manual (includes 5- and 6-speed) Automatic (includes 3-, 4-, and 5-speed) CVT (continuous variable transmission)
Fuel Type	Gasoline, diesel, hybrid-electric, and electric

Source: Ecos data set.

B. General Relationships

Using our data set of 441 cars and 912 light trucks, we looked at the overall relationship between lifetime gallons of gasoline consumed and dealer profit.

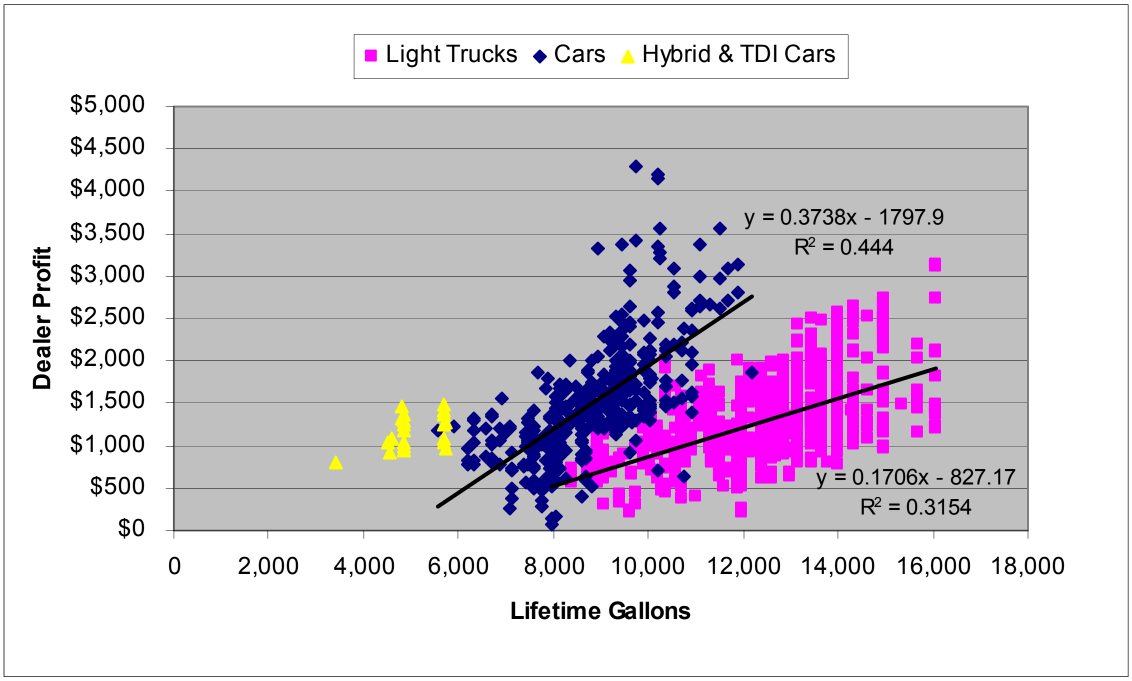
The ten most efficient cars in our data set, averaging 4,564 gallons (approximately 40.5 MPG), have an average retail price (excluding destination charges) of $18,906, while the ten least efficient cars, averaging 11,614 lifetime gallons (15.9 MPG), have an average retail price (excluding destination) of more than twice that—$43,193 per car. For light trucks, the spread is greater. The ten most efficient trucks (averaging 8,548 lifetime gallons or 21.6 MPG) have an estimated retail price of $16,901, while the ten least efficient trucks (averaging 16,075 lifetime gallons or 11.5 MPG) sell for an average of $48,175.

An even more stark difference can be seen when comparing profits. The ten most efficient cars have an average profit of only $1,097 compared to the ten least efficient cars with an average profit nearly three times higher—up to $2,817 per car. The ten most efficient trucks have an estimated profit of only $662 per vehicle while the ten least efficient trucks earn upwards of $2,060 each for the dealer.

We also plotted lifetime gallons versus dealer profits for all the vehicles in our data set.

Figure 18 indicates a clear positive relationship between the two variables (i.e., as gallons of gasoline consumed increases, profit also increases). It also shows a distinct pattern for cars versus light trucks and highlights the fact that hybrid and turbo injection diesel cars are “outliers.”

Figure 18
Relationship between Lifetime Gallons and Dealer Profit



Source: Ecos data set.

Linear regression analysis[25] of this data allows us to estimate the additional profit associated with each additional gallon of gasoline consumed. This is equal to the coefficient (or slope) of the linear regression line, or $0.3738 for cars and $0.1706 for trucks. In other words, if a dealer can sell a customer a car that consumes 10,000 gallons of gas over its lifetime (about 18.5 MPG) instead of one that consumes only 9,000 gallons (about 20.5 MPG), it is predicted that he or she will make an additional $374 in profit (Figure 19). Or conversely, the dealer would need to be paid an incentive of $374 (or $0.37 per gallon saved) to preferentially promote the more fuel-efficient car.

[25] A linear regression provides the best "fit" for the car data. An exponential curve provides a slightly better "fit" than a linear curve for the light trucks (R^2 = 0.3346 versus R^2 = 0.3154); however the results are not as easily interpreted.

Figure 19
Profit Associated with Different Cars and Light Trucks

Cars		
Lifetime Gallons of Gas Consumed	MPG	Dealer Profit
6,000	30.8	$ 445
7,000	26.4	$ 819
8,000	23.1	$ 1,193
9,000	20.5	$ 1,566
10,000	18.5	$ 1,940
11,000	16.8	$ 2,314
12,000	15.4	$ 2,688
Profit per gallon consumed (or cost per gallon saved)		$ 0.37

Light Trucks		
Lifetime Gallons of Gas Consumed	MPG	Dealer Profit
10,000	18.5	$ 879
11,000	16.8	$ 1,049
12,000	15.4	$ 1,220
13,000	14.2	$ 1,391
14,000	13.2	$ 1,561
15,000	12.3	$ 1,732
16,000	11.6	$ 1,902
Profit per gallon consumed (or cost per gallon saved)		$ 0.17

Note: Assumes 184,800 lifetime miles for both cars and light trucks.
Source: Ecos data set.

Thus, the regression coefficients provide initial estimates of appropriate incentive levels for the Dealer Incentive Program.[26] These estimates also show that the incentive for light trucks is less than half of that for cars—$0.17 versus $0.37—since the difference in profit for trucks is less than half the difference for cars for any given change in lifetime gallons (e.g., moving from 11,000 to 10,000 lifetime gallons consumed, profit differential for trucks = $170 and for cars = $374.). Consequently, a policy focused on light trucks might be more cost-effective than one focused on both cars and trucks. This also makes sense when one considers that most light trucks are clustered at the lower end of the fuel-efficiency spectrum, with MPG generally under 20 MPG (or 9,240 lifetime gallons). Small improvements in MPG at the lower end of the spectrum have a larger impact on gallons saved than at the higher end. Figure 20 illustrates this fact, comparing an increase in MPG from 13 MPG to 14 MPG versus one from 20 MPG to 21 MPG. When the estimated incentive amounts are applied, it is obvious that the same amount of incentive money can be stretched further when subsidizing the move from 13 MPG to 14 MPG.

Figure 20
Comparison of MPG Shifts

	MPG	Lifetime Gallons	Gallons Saved	% Gallons Saved	Incentive Estimate per Gallon	Total Incentive
Light Truck	13.0	14,215				
	14.0	13,200	1,015	7.1%	$0.17	$172.62
Car	20.0	9,240				
	21.0	8,800	440	4.8%	$0.37	$162.80

Source: Ecos data set.

[26] We have simplified the analysis slightly by ignoring inflation and discount factors. An actual incentive level would need to take into account the fact that whereas dealer profits are stated in current dollars, gallons saved occurs over the lifetime of the vehicle.

C. A Range of Incentive Levels

Thus far, we have established two key points: (i) as a general rule, the more expensive and profitable a vehicle is, the less fuel efficient it is; and (ii) an incentive might be warranted in order to align car dealers' profit-maximizing objectives with society's environmental objective to reduce fuel consumption.

We then used our data set of 441 cars and 912 light trucks to investigate what an appropriate incentive level might be for the proposed Dealer Incentive Program.

1. Cost (or Dollars) per Gallon Saved

We constructed a new metric—cost per gallon saved—that is used throughout our analysis as a proxy for the appropriate incentive level. Cost per gallon saved is calculated when comparing a higher fuel economy vehicle to a lower fuel economy vehicle by taking the difference in profit a dealer makes on the two vehicles, divided by the difference in the vehicles' lifetime gallons. (Remember, lifetime gallons is the estimated gallons of gasoline that a vehicle consumes over its lifetime or 184,800 miles.) Figure 21 provides an example.

Figure 21
Cost per Gallon Saved Example

Example. A Dodge Stratus SE (automatic) has dealer profit of \$1,203 and lifetime gallons of 8,932 (about 20.7 MPG). A Dodge Neon SE (automatic) has dealer profit of \$830 profit and 7,849 lifetime gallons (23.5 MPG).

The cost per gallon saved on selling a Dodge Neon instead of a Dodge Stratus is:

$$= \frac{(\text{Profit on Stratus - Profit on Neon})}{(\text{Lifetime Gallons of Stratus - Lifetime Gallons of Neon})}$$

$$= \frac{(\$1{,}203 - \$830)}{(8{,}932 \text{ gallons} - 7{,}849 \text{ gallons})}$$

$$= \frac{\$373}{1{,}083 \text{ gallons}}$$

$$= \$0.34 \text{ per gallon}$$

Note that if cost per gallon saved is positive, this means that the vehicle with lower fuel economy carries a *higher* profit potential. The dealer must be paid a financial incentive if he is to sell the other vehicle. The amount of incentive which makes him exactly indifferent to selling one vehicle over the other (i.e., making the profit potential of both vehicle the same) is the cost per gallon saved.[27]

[27] If cost per gallon saved is negative, then the vehicle with lower fuel economy carries a higher profit potential, and no financial incentive is necessary.

In our example, if the dealer who sold the Dodge Neon received an incentive of $0.34 for every gallon of gasoline he saved, he would get a total incentive of $0.34 * 1,083 gallons = $373. Thus, he earns the same amount in either case: he makes $1,203 profit on the Dodge Stratus, or he makes $830 profit + $343 incentive = $1,203 on the Dodge Neon.

2. Buying/Selling Scenarios

Below are three scenarios that demonstrate how an appropriate incentive level might be determined. The scenarios compare vehicles within a given manufacturer only. Although car dealers sometimes offer more than one manufacturer (e.g., Royal Moore Subaru- Nissan, Ron Tonkin Chevrolet-Geo-Kia, or Rey Reeces Oldsmobile-Isuzu-Volkswagen), these "groupings" can vary from dealer to dealer. Also, even when multiple manufacturers are sold at one dealership, the cars are generally located in separate areas on the lot and different salesmen are assigned to each manufacturer. So, the potential for a customer to switch between a VW Jetta and an Oldsmobile Alero is limited without switching at least salesmen, and most likely dealers.

Scenario 1: Customer selecting between different models of the same vehicle

A customer walks into an Audi dealership and wants to buy an Audi A4. The Audi A4 comes in a variety of different models, which the dealer/salesman can sell to this customer. Figure 22 lists 10 models of the Audi A4, along with a few of their salient features, the estimated lifetime gallons of gasoline consumed by each car, and the estimated profit the dealer stands to make on each car.

Figure 22
10 Different Models of the Audi A4

	Model	Body Style	Drive	Cylinder	Trans	Lifetime Gal	Profit
1	A4 1.8T FrontTrak	4-dr. sedan	FWD	DOHC I-4	M5	8,573	$1,508
2	A4 1.8T FrontTrak	4-dr. sedan	FWD	DOHC I-4	CVT	8,587	$1,522
3	A4 1.8T Quattro	4-dr. sedan	AWD	DOHC I-4	M5	9,054	$1,212
4	A4 1.8T Avant Quattro	4-dr. wagon	AWD	DOHC I-4	M5	9,054	$1,563
5	A4 1.8T Quattro	4-dr. sedan	AWD	DOHC I-4	A5	9,454	$1,226
6	A4 1.8T Avant Quattro	4-dr. wagon	AWD	DOHC I-4	A5	9,454	$1,577
7	A4 3.0 Cabriolet FrontTrak	2-dr. convertible	FWD	DOHC V-6	CVT	9,454	$2,366
8	A4 3.0 FrontTrak	4-dr. sedan	FWD	DOHC V-6	CVT	9,454	$1,740
9	A4 3.0 Quattro	4-dr. sedan	AWD	DOHC V-6	A5	10,375	$1,530
10	A4 3.0 Quattro	4-dr. sedan	AWD	DOHC V-6	M6	10,539	$1,516

Source: Ecos data set.

From the dealer's perspective, the best choice is clearly Audi #7, the A4 3.0 Cabriolet FrontTrak, which earns him the most profit, $2,366. However, from a fuel-consumption standpoint the best choice is Audi #1, the A4 1.8T FrontTrak, which consumes only 8,573 gallons of gasoline over its lifetime.

One way to discourage the dealer from trying to "up-sell" the customer from Audi #1 to Audi #7 is to make him indifferent to the two vehicles by paying him a financial incentive that makes up any difference in profit he would collect on each transaction. To determine the amount of incentive needed, we calculate the dealer's cost (or profit lost) per lifetime gallon saved if he sells Audi #1 instead of Audi #7.

In this example, the dealer's cost is $858 ($2,366 - $1,508 = $858). The lifetime gallons saved are 882 gallons (9,454 gallons - 8,573 gallons = 882 gallons). Therefore, the incentive that will make the dealer indifferent between selling these two vehicles is $0.97 per gallon. ($858 / 882 gallons = $0.97 per gallon).

Using the same math described above, we can construct a matrix that shows every valid pair-wise comparison within the Audi A4 line. Comparing a car to itself or comparing a car to another car with the same or higher fuel consumption is not valid. The numbers 1-10 on the matrix represent the different cars listed in Figure 23. Each box in the matrix represents a "switch" to a vehicle with better fuel economy.[28] Note that if a dealer "switches" the customer "to" Audi #1, "from" Audi #7, the cost per gallon saved shown in the matrix is $0.97 (red circle), as calculated previously.

Figure 23
Comparison Matrix for Audi A4
(Cost per Gallon Saved)

		Switch To									
		1	2	3	4	5	6	7	8	9	10
Switch From	1										
	2	$1.00									
	3	($0.62)	($0.66)								
	4	$0.11	$0.09								
	5	($0.32)	($0.34)	$0.03	($0.84)						
	6	$0.08	$0.06	$0.91	$0.03						
	7	$0.97	$0.97	$2.88	$2.01						
	8	$0.26	$0.25	$1.32	$0.44						
	9	$0.01	$0.00	$0.24	($0.03)	$0.33	($0.05)	($0.91)	($0.23)		
	10	$0.00	($0.00)	$0.20	($0.03)	$0.27	($0.06)	($0.78)	($0.21)	($0.09)	

Switch is not applicable (no gallons saved)
Switch is not applicable (same car)

Minimum	($0.91)
Q1 (25th percentile)	($0.08)
Median	$0.03
Q3 (75th percentile)	$0.27
Maximum	$2.88
Average	$0.19

Source: Ecos data set.

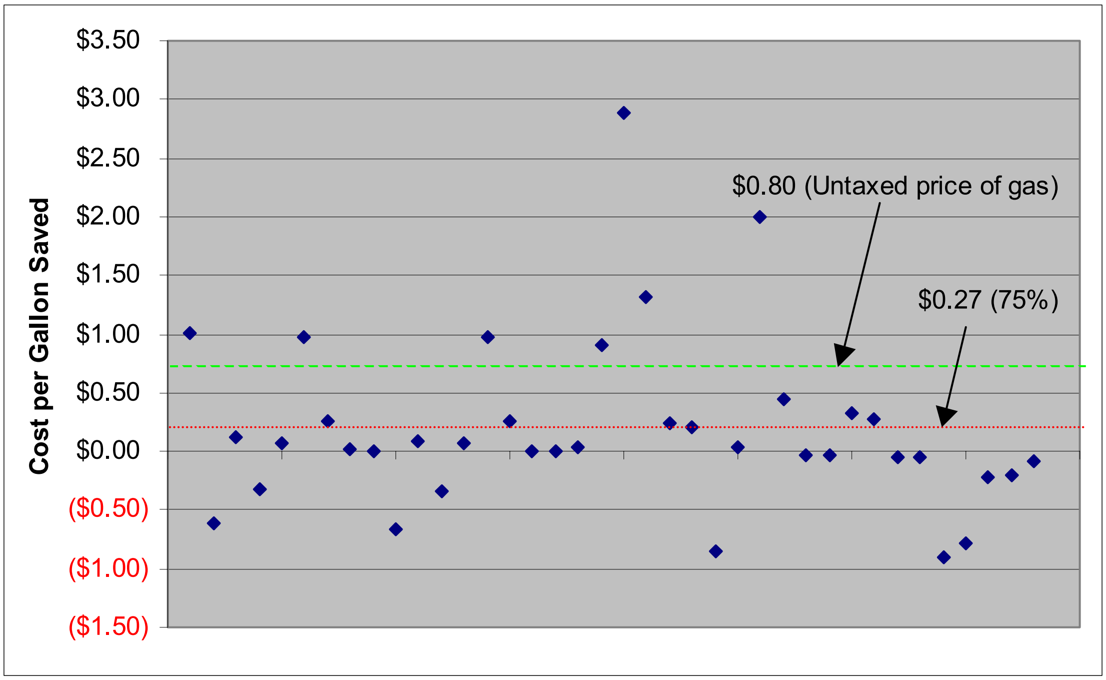
The matrix also shows which "switches" are profitable for dealer even without an incentive. All the negative numbers represent a negative cost (or profit) to the dealer per gallon saved. The summary table at the bottom of Figure 23 indicates that the median value of all "switches" in the matrix is $0.03. This means that 50 percent of the values in the matrix are below $0.03. In other words, if an incentive level were set at $0.03, it would be high enough to cover the profit differential on 50

[28] This "switch" is the equivalent of a "down-sell" to the dealer, if you assume—as our research has found—that vehicles with better fuel economy tend to have lower profits.

percent of all the relevant "switches" the dealer faces in selling a customer one Audi versus another.[29] If the incentive level were set at $0.27, 75 percent of the "switches" would be covered.

We can summarize this information graphically by plotting the matrix values for the Audi A4 (Figure 24).

Figure 24
Plot of Comparison Matrix Values for Audi A4



Source: Ecos data set.

As you can see, if a horizontal line is drawn at $0.27 (the 75th percentile), three-quarters of all possible pair-wise comparisons or "switches" are below this line. If a line is drawn at $0.80 (the untaxed price of gasoline, and thus, the maximum incentive level which is justifiable), all but a handful of points are below this line.

We conducted a similar analysis on other lines of vehicles as well as the Audi A4. Figure 25 presents a summary of the results. Except for the Dodge Caravan, the 75th percentile value for each of these vehicles is between $0.27 and $0.37, with both the Saturn L-series and the Toyota Highlander at $0.33.

[29] At an incentive level of $0.03,the dealer is indifferent to selling Audi #3 versus Audi #5 (i.e., $0.03 is the value is the matrix for this particular comparison). The dealer actual makes money on any "switches" which are below $0.03 and still loses on any "switches" above $0.03.

Figure 25
Summary of Matrices
Dealer Cost per Gallon Saved

	Audi A4	Toyota Higlander	Honda Civic	Dodge Caravan	Saturn L-Series
Number of Models	10	6	17	8	5
Minimum	($0.91)	($1.93)	($3.14)	($0.69)	($0.67)
Q1 (25th percentile)	($0.08)	($0.12)	($0.15)	$0.22	($0.02)
Median	$0.03	$0.08	$0.13	$0.61	$0.18
Q3 (75th percentile)	$0.27	$0.33	$0.37	$1.10	$0.33
Maximum	$2.88	$0.80	$3.79	$2.60	$0.56
Average	$0.19	($0.03)	$0.12	$0.68	$0.10

Source: Ecos data set.

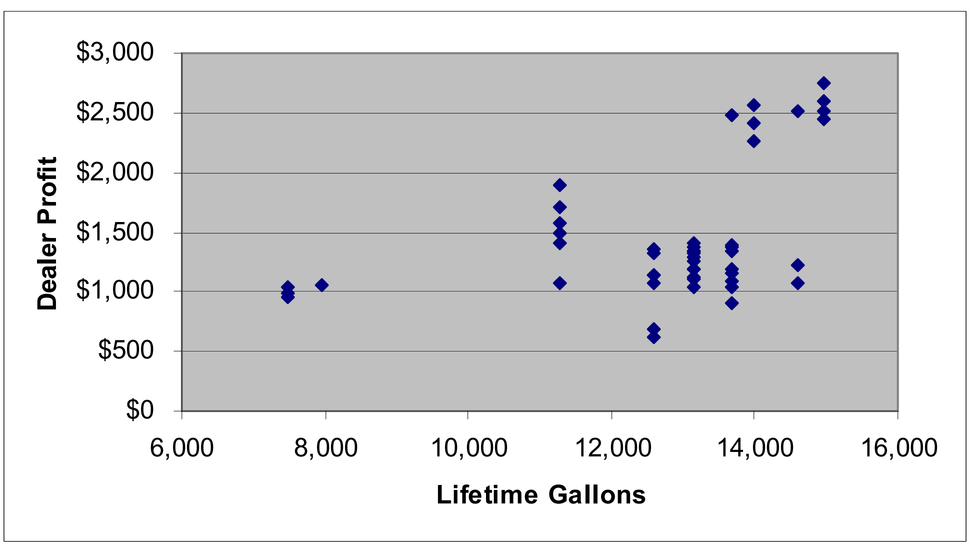
Scenario 2: Customer selecting based on a set of needs

A customer walks into a Ford dealership and wants to buy a vehicle to drive her family around but is not set on any particular model. She needs to transport her children (and their friends) to and from school and after school-activities. She also wants to use the car on weekends for recreational activities and occasional hauling.

There are a variety of Ford models that might satisfy this customer's needs. A dealer might conceivably try to sell her a Ford Focus wagon, a Ford Windstar minivan, a Ford Explorer, or even a Ford Expedition. Within these four series of Ford vehicles, there are many different models—leaving the customer and dealer with about 48 different vehicle choices.

Instead of listing all 48 vehicles in a table, Figure 26 provides a scatter plot of the vehicles' lifetime gallons versus dealer profit. Although a wide range of profit can be seen for vehicles with the same lifetime gallons, in general there is positive relationship between these two variables, indicating the incentive to "up-sell" the customer to vehicles that have higher profits and lower fuel-economy.

Figure 26
Lifetime Gallons vs. Dealer Profit for 48 Ford Vehicles



Source: Ecos data set.

Using the same methodology described above, we constructed a matrix to look at every pair-wise comparison of these 48 vehicles. Figure 27 summarizes these results. The 75th percentile for this matrix—$0.65—is higher than the results obtained from Scenario 1. However, an incentive level of only $0.10 still covers 50 percent of the "switches."

Figure 27
Summary of Comparison Matrix for Ford Focus wagon, Windstar minivan, Ford Explorer and Ford Expedition
(Cost per Gallon Saved)

Number of Models	48
Minimum	($2.40)
Q1 (25th percentile)	($0.07)
Median	$0.10
Q3 (75th percentile)	$0.65
Maximum	$5.29
Average	$0.37

Source: Ecos data set.

Scenario 3: Customer selecting within a specific price range

A customer walks into a Chevrolet dealership and wants to buy a pickup truck, but is not willing to spend more than $21,000 total (including destination charges). While this narrows the pool of suitable vehicles, there are still a number of choices.

Using a matrix, we compared 36 different models of Chevy S10s (Regular Cab and Extended Cab) and Chevy Silverados (Regular Cab) priced below $21,000. Figure 28 summarizes these results. The 75th percentile for this matrix is only $0.06, and the *maximum* value is $0.47.

Figure 28
Summary of Comparison Matrix for Chevy S10 and Silverado
(Cost per Gallon Saved)

Number of Models	36
Minimum	($0.71)
Q1 (25th percentile)	($0.04)
Median	$0.01
Q3 (75th percentile)	$0.06
Maximum	$0.47
Average	$0.01

Source: Ecos data set.

3. Manufacturer Matrices

While the three scenarios discussed above are good examples, their results could be dismissed as arbitrary since they are obviously skewed by which vehicles are included in a particular analysis. For example, in Scenario 2, we might just have easily used a Ford Escape in place of the Ford Explorer and obtained different results. To avoid the "arbitrary" nature of making different comparisons, we developed a more general, consistent methodology for comparing the different vehicles offered by one dealer.

The basic methodology is to create one large matrix for each manufacturer. This "master" matrix contains every possible car that a dealer could sell to a customer and compares the dealer's cost per gallon saved of that car versus every other car in the dealership. Recognizing that some "switches" are absurd—for example, it is unlikely that a customer who comes in wanting a Chevrolet Silverado pickup truck could be persuaded to buy a compact Chevrolet Cavalier—the cells in the matrix corresponding to unlikely "switches" are deleted. In the end, we are left with a "master" matrix containing the most plausible comparisons.

We employed this methodology for each manufacturer that was represented in our data set to estimate a range of incentive levels that would prevent dealers trying to up-sell or "switch" customers to more profitable models. Figure 29 summarizes the results of this analysis.

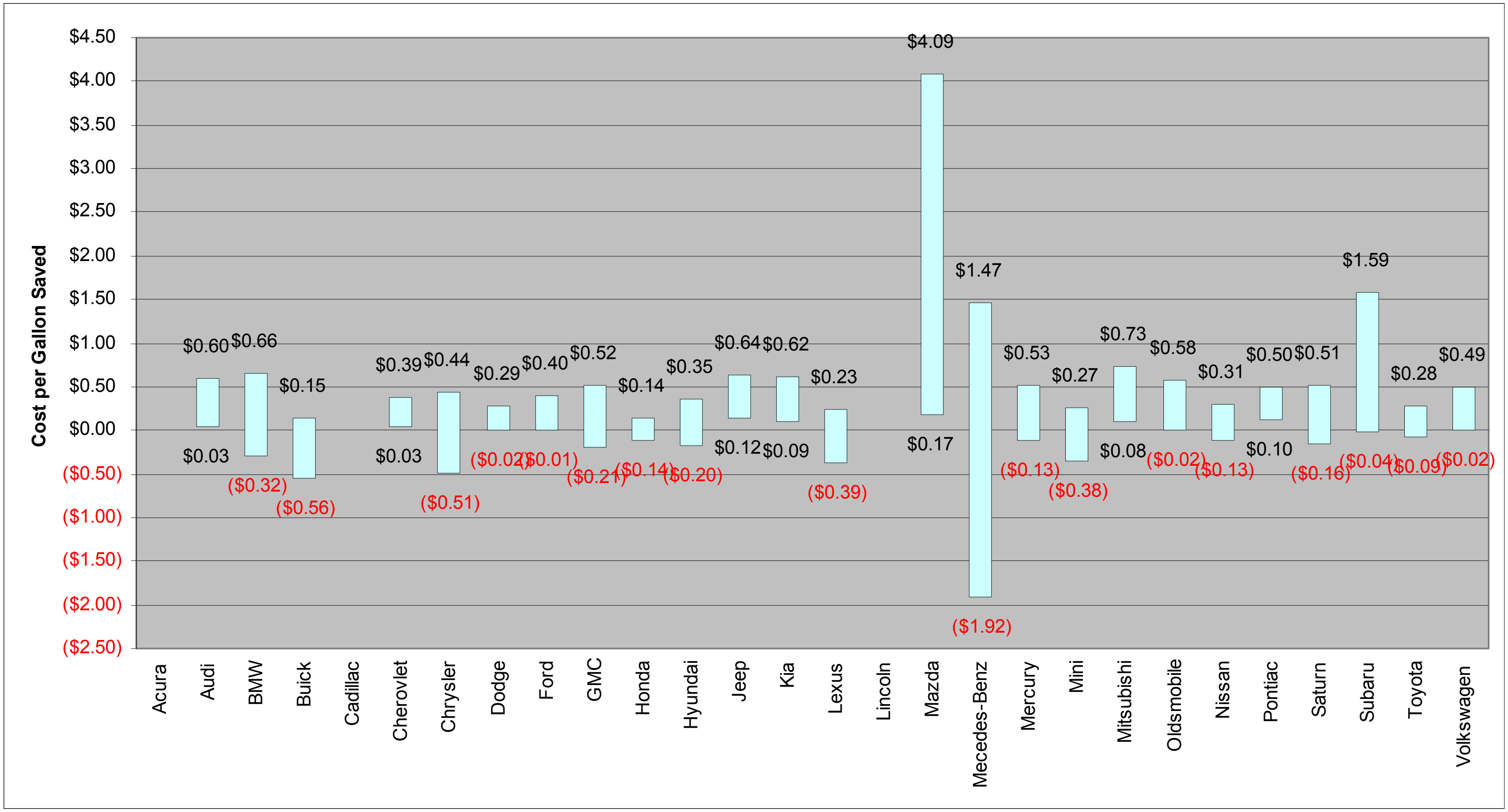
For more than two-thirds of the manufacturers, the bottom end of the inter-quartile range[30] of results (the 25th percentile) is negative, meaning that no incentive is needed: the dealer would actually make more money selling a customer a more fuel-efficient vehicle 25 percent of the time.

The majority of manufacturers exhibit about a 50 to 60-cent range, with the top of the inter-quartile range (75th percentile) falling around $0.50 to $0.60. Mazda and Mercedes-Benz seem to have abnormally wide interquartile ranges. In Mazda's case, this is probably due to the small number of vehicles sampled—only eight vehicles.[31] In Mercedes-Benz's case, it is likely due in part to a small sample—only 13 vehicles—but also, to the tendency of luxury Mercedes-Benz vehicle to have higher-than-average retail price and, hence, a greater variability in profit margins.

It is also the case that many options choices available to the customer are clustered in packages at present. Thus, it is often not possible to purchase the larger engine without also buying leather seats or an improved stereo. The latter two options increase dealer profits without affecting fuel economy, but the dealer incentive in the examples above is being "asked" to compensate the dealer for all of those lost profits, rather than the ones solely attributable to the engine switch. Again, this suggests that our estimates for the amount of dealer incentive needed are high—the real values are likely to be lower.

[30] The interquartile range is a range that represents the middle two quartiles, or middle 50 percent, of the data, from the 25th percentile to the 75th percentile.
[31] Eight vehicles is too small a sample to exhibit any normalizing trends in the distribution.

Figure 29
Potential Range of Incentive Levels by Manufacturer
Interquartile Range (25th to 75th percentile)



Notes: If no interquartile range is shown for a manufacturer, it means that all the vehicles analyzed for this manufacturer had the same fuel economy, and hence no incentive would be relevant. For Chevrolet and Ford the number of vehicle models analyzed was capped at 200.
Source: Ecos data set.

4. Vehicle Options: Drive Type, Engine Cylinder, and Transmission

Any incentive paid under a Dealer Incentive Program should be high enough to offset the profit opportunity associated with an isolated option "up-sell," such as drive type, number of engine cylinders, or transmission type.

As an initial exercise to quantify the link between these "options" and vehicle fuel economy and/or dealer profits, we used our data set to calculate the average MPG, lifetime gallons, and profit of vehicles classified by these different variables, or "options." We also calculated the cost per gallon saved of moving between these different options.

2WD vs. 4WD

Figure 30 confirms that on average 4WD vehicles consume more gallons of gasoline over their lifetime and generate slightly higher profits for dealers.

Figure 30
Average MPG, Lifetime Gallons, and Profit

	# of Models	MPG	Lifetime Gallons	Profit
2WD	920	18.4	10,596	$ 1,328
4WD	429	14.4	13,064	$ 1,517
Total	**1,349**			

Cost per gallon saved (2WD vs 4WD)	$ 0.08

Source: Ecos data set.

4- vs. 6- vs. 8-cylinder

Similarly, as you move up the chain from 4-cylinder to 6-cylinder to 8-cylinder engines, you see corresponding increases in lifetime gallons and dealer profits (Figure 31).

Figure 31
Average MPG, Lifetime Gallons, and Profit

	# of Models	MPG	Lifetime Gallons	Profit
4-cyl.[1]	327	23.2	8,228	$ 1,064
6-cyl.	570	16.3	11,510	$ 1,362
8-cyl.	452	13.8	13,500	$ 1,656
Total	**1,349**			

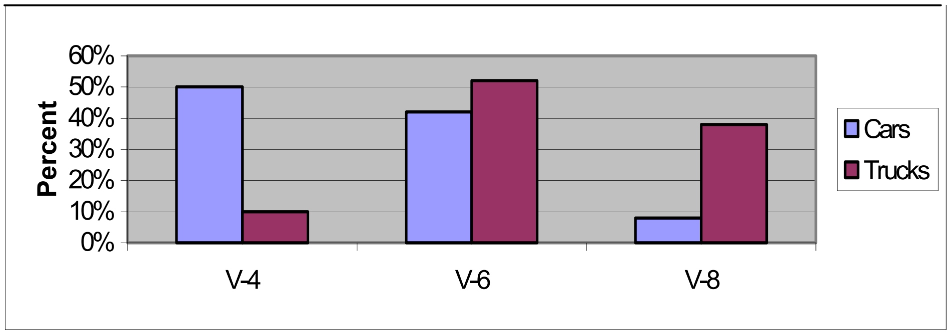
[1]Includes one 3-cyl. Engine.

Cost per gallon saved (4 cyl vs 6 cyl)	$ 0.09
Cost per gallon saved (4 cyl vs 8 cyl)	$ 0.11
Cost per gallon saved (6 cyl vs 8 cyl)	$ 0.15

Source: Ecos data set.

This information is particularly interesting when paired with data on what types of engines are actually sold. In 2002, dealers sold more 6-cylinder trucks than any other engine configuration, with 8-cylinder trucks trailing close behind (Figure 32). The sale of 6-cylinder cars nearly equaled those of 4-cylinder cars. Since the number of cylinders in a vehicle relates directly to its fuel economy, using incentives to reduce the share of V-8 trucks and V-6 cars sold corresponds to the potential for fuel economy improvements.

Figure 32
2002 Sales of Different Engine Configurations (%)



Source: 2003 Ward's Automotive Yearbook, Percent Engine Installations on '02 Model U.S. Cars and Trucks.

CVT vs. Manual vs. Automatic

As one would expect, vehicles with automatic transmissions have, on average, higher lifetime gallons and higher profits than manual transmission vehicles (Figure 33). However, continuously variable transmissions (CVT), which typically have lower lifetime gallons that either manual or automatics, generate higher profits than manuals and only slightly lower profits than automatics. CVT is an example of a vehicle option that not only saves gasoline, but also carries a price premium. This is the ideal combination—a win-win situation—for both dealers and society. However, there are few CVT vehicles on the market today, possibly because they have a higher sales price, or because consumers can't easily compare their extra cost to what they save on gasoline over the vehicle's lifetime.

Figure 33
Average MPG, Lifetime Gallons, and Profit

	# of Models	MPG	Lifetime Gallons	Profit
CVT	14	23.6	8,429	$ 1,369
Manual	405	18.7	10,568	$ 1,204
Automatic	930	16.3	11,780	$ 1,468
Total	**1,349**			

Cost per gallon saved (CVT vs M)	$ (0.08)
Cost per gallon saved (CVT vs A)	$ 0.03
Cost per gallon saved (M vs A)	$ 0.22

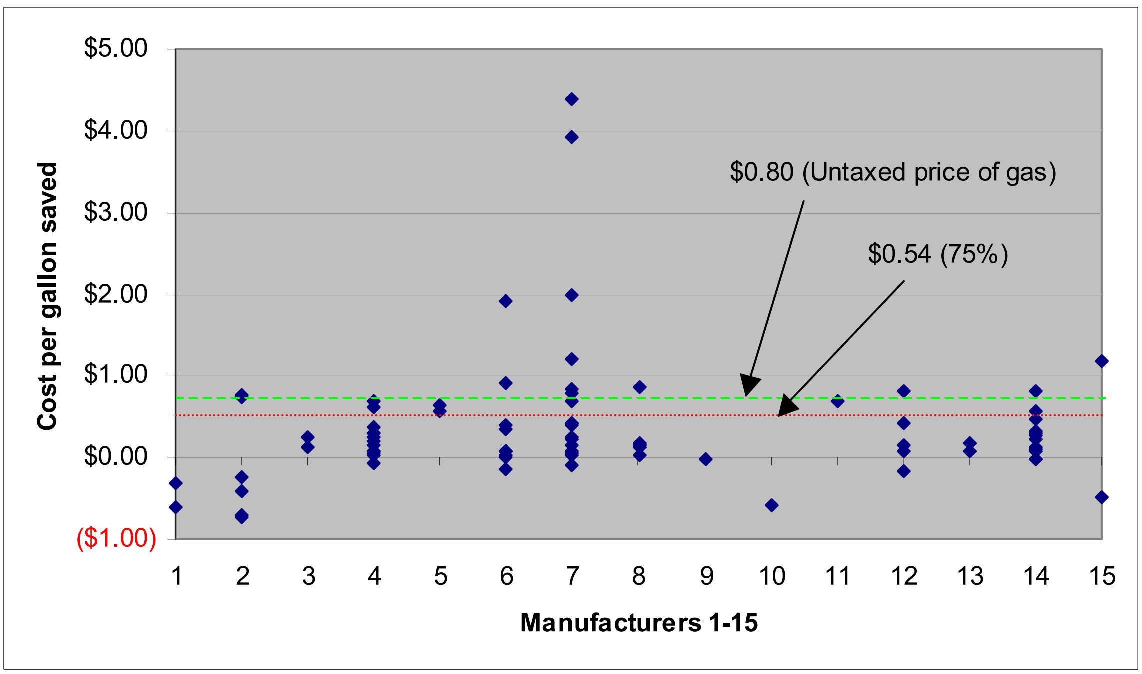
Source: Ecos data set.

Averages vs. Specific Comparisons

While the numbers above give us some idea of an appropriate incentive level or the cost per gallon saved associated with different vehicle options, they have some drawbacks. First, they are based on our entire data set, which contains multiple manufacturers: a dealer (or customer) is generally selecting from a more limited pool of vehicles. Second, they are averages, so they mask some of the variability that might be present when actual pair-wise vehicle comparisons are considered.

Figure 34 plots the cost per gallon saved for 82 pairs of otherwise identical 2WD and 4WD vehicles for 15 different manufacturers. Each dot represents cost of "switching" from a 4WD vehicle to the same vehicle in 2WD. $0.54 is the incentive level at which 75 percent of the "switches" considered would be feasible. This is substantially higher than the $0.08 incentive level calculated for 2WD vs. 4WD using averages. In fact, it is much closer to the $0.35-$0.50 numbers that were derived by our general methodology (see section VI-B. General Relationships).

Figure 34
Cost per Gallon Saved
(2WD. 4WD)



Source: Ecos data set.

5. Hybrids and Diesels

Like CVT transmissions, hybrid-electric and TDI diesel engines, as presently configured, represent rare "up-sell" options that can increase fuel economy and dealer profit potential. Switching to these non-conventional technologies typically yield a negative or near-zero value for dealer cost per gallon saved (Figure 35).

As with CVT, a stumbling block for hybrid vehicles is that they cost more upfront for consumers. Therefore, a Dealer Incentive Program could help motivate consumers to purchase these vehicles if the dealer allocates all or a portion of their incentive toward a customer incentive.

Figure 35
Hybrids and TDIs Compared to Standard Vehicles

Make	Model	Body Style	Drive	Cyl & Type	Trans	Lifetime Gallons	Profit	Cost per Gallon Saved
Honda	Insight	2-dr. hatchbk	FWD	SOHC I-3	M5	3,419	$ 807	
Honda	Civic LX	2-dr. coupe	FWD	SOHC I-4	M5	6,335	$ 1,028	$ 0.08
Honda	Hybrid	4-dr. sedan	FWD	SOHC I-4	M5	4,493	$ 1,037	
Honda	Civic LX	4-dr. sedan	FWD	SOHC I-4	M5	6,335	$ 767	$ (0.15)
Honda	Hybrid	4-dr. sedan	FWD	SOHC I-4	CVT	4,574	$ 1,081	
Honda	Civic LX	4-dr. sedan	FWD	SOHC I-4	A4	6,700	$ 802	$ (0.13)
Toyota	Prius	4-dr. sedan	FWD	DOHC I-4	CVT	4,541	$ 916	
Toyota	Corolla S	4-dr. sedan	FWD	DOHC I-4	A4	6,700	$ 1,006	$ 0.04
VW	Beetle GL 1.9 TDI	2-dr. sedan	FWD	SOHC I-4	M5	4,865	$ 944	
VW	Beetle GL 1.8T	2-dr. sedan	FWD	DOHC I-4	M5	8,145	$ 725	$ (0.07)
VW	Beetle GL 1.9 TDI	2-dr. sedan	FWD	SOHC I-4	A4	5,745	$ 975	
VW	Beetle GL 1.8T	2-dr. sedan	FWD	DOHC I-4	A4	8,587	$ 1,039	$ 0.02
VW	Golf GL 1.9LTDI	2-dr. hatchbk	FWD	SOHC I-4	M5	4,865	$ 1,186	
VW	Golf GL 2.0L	2-dr. hatchbk	FWD	SOHC I-4	M5	8,145	$ 1,089	$ (0.03)
VW	Golf GL 1.9LTDI	2-dr. hatchbk	FWD	SOHC I-4	A4	5,691	$ 1,239	
VW	Golf GL 2.0L	2-dr. hatchbk	FWD	SOHC I-4	A4	8,587	$ 1,120	$ (0.04)
VW	Golf GL 1.9LTDI	4-dr. hatchbk	FWD	SOHC I-4	M5	4,865	$ 983	
VW	Golf GL 2.0L	4-dr. hatchbk	FWD	SOHC I-4	M5	8,145	$ 1,102	$ 0.04
VW	Golf GL 1.9LTDI	4-dr. hatchbk	FWD	SOHC I-4	A4	5,691	$ 1,036	
VW	Golf GL 2.0L	4-dr. hatchbk	FWD	SOHC I-4	A4	8,587	$ 1,134	$ 0.03
VW	Jetta GL 1.9L TDI	4-dr. sedan	FWD	SOHC I-4	M5	4,865	$ 1,307	
VW	Jetta GL 1.8T	4-dr. sedan	FWD	DOHC I-4	M5	8,145	$ 1,215	$ (0.03)
VW	Jetta GL 1.9L TDI	4-dr. wagon	FWD	SOHC I-4	M5	4,821	$ 1,311	
VW	Jetta GL 1.8T	4-dr. wagon	FWD	DOHC I-4	M5	8,145	$ 1,577	$ 0.08
VW	Jetta GL 1.9L TDI	4-dr. wagon	FWD	SOHC I-4	A4	5,691	1,364	
VW	Jetta GL 2.0L	4-dr. wagon	FWD	SOHC I-4	A4	8,587	1,480	$ 0.04
VW	Jetta GLS 1.9L TDI	4-dr. sedan	FWD	SOHC I-4	M5	4,865	$ 1,376	
VW	Jetta GLS 1.8T	4-dr. sedan	FWD	DOHC I-4	M5	8,145	$ 1,497	$ 0.04
VW	Jetta GLS 1.9L TDI	4-dr. wagon	FWD	SOHC I-4	M5	4,821	$ 1,462	
VW	Jetta GLS 1.8T	4-dr. wagon	FWD	DOHC I-4	M5	8,145	$ 1,710	$ 0.07
VW	Jetta GLS 1.9L TDI	4-dr. sedan	FWD	SOHC I-4	M5	4,865	1,376	
VW	Jetta GLS 2.0L	4-dr. sedan	FWD	SOHC I-4	M5	8,145	1,168	$ (0.06)
VW	Jetta GLS 1.9L TDI	4-dr. sedan	FWD	SOHC I-4	A4	5,691	$ 1,408	
VW	Jetta GLS 2.0L	4-dr. sedan	FWD	SOHC I-4	A4	8,587	$ 1,200	$ (0.07)
VW	Jetta GLS 1.9L TDI	4-dr. wagon	FWD	SOHC I-4	A4	5,691	1,494	
VW	Jetta GLS 2.0L	4-dr. wagon	FWD	SOHC I-4	A4	8,587	1,610	$ 0.04

Q1 (25th percentile)	$ (0.06)
Median	$ 0.03
Q3 (75th percentile)	$ 0.04
Average	$ (0.01)

Source: Ecos Data Set.

Some of the profit potential in alternative technologies is probably due to their initial "trendiness," leading to high customer demand and short supply in the short term.[32] However, manufacturers also seem to recognize the long term potential for these vehicles and have plans to add more hybrids, particularly SUVs and trucks, to their vehicle lines in the future (Figure 36).

Figure 36
New Hybrid Models

- **Dodge/Chevrolet:** Dodge has a new electric-hybrid Ram pick-up truck in the pipeline. The U.S. Army will receive the first five of these vehicles, but Dodge expects to offer the truck to the public in 2005. This is part of a larger strategy to produce 10,000 hybrid trucks annually. Chevrolet also plans to introduce a Silverado hybrid in the spring of 2004. Both the Dodge and Chevy trucks will be positioned as "mobile generators." Dodge says their hybrid Ram can provide enough power for a house. It will have both 110-volt and 220-volt outlets. It is intended to serves two distinct markets. Workmen who need off-site power generation and recreational users who need power for camping, hunting, etc.[33]
- **Ford/GM:** Ford plans to introduce a hybrid version of the Escape SUV in 2004 and a Ford Futura hybrid in 2005. GM also plans to introduce hybrid power train vehicles in the U.S. in 2004. GM defends its slow progress in the area of hybrid-electrics by stating that the company is taking a wider "technology" strategy to fuel efficiency and is not solely focused on pushing "hybrids" into the market.[34] Some of the GMC vehicles slated for hybrid technology include Sierra, Yukon, Equinox, Malibu, Tahoe, and (previously mentioned) Silverado. A Saturn VUE hybrid is also due in 2005.
- **Toyota:** Toyota remains the leading seller of hybrids, with the Prius, which has sold over 120,000 units worldwide. Toyota plans to boost Prius production in the U.S. by 31 percent—from 36,000 to 47,000 units—in 2004 due to the popularity of the redesigned 2004 Prius.[35] The new Prius was recently named Motor Trend's "Car of the Year.[36]" Toyota plans to extend its hybrid line by offering a Lexus Rx 330 SUV, followed by a Highlander. Toyota has also recently started selling its hybrid technology to other manufacturers, such as Ford and Nissan.

A Dealer Incentive Program, which rewards dealers for selling fuel-efficient vehicles, serves as a mechanism to help these advanced technologies enter the market sooner. At the same time, it would put competitive pressure on those manufacturers currently lagging behind the hybrid technology leaders. Our data analysis shows that, in some cases, the sale of a hybrid or TDI vehicle is actually *more* profitable to a dealer than the sale of a standard comparable vehicle. In effect, then, a Dealer Incentive Program might initially be subsidizing dealers to push a vehicle they have a financial incentive to sell anyway. While this is not ideal from a policy standpoint, it could be a critical factor in selling such an incentive program to some dealers whose main objective is making money. On the other hand, since these vehicles typically have a higher price tag, dealers who use their incentives to give price breaks to consumers, would still improve the societal outcome.

It is also important to stress that a Dealer Incentive Program cannot just focus on rewarding certain targeted technologies (e.g., hybrid, TDI, etc.). Fuel savings attained from a particular technology can be offset by the higher energy consumption from other technologies and/or vehicle options. For

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[32] A VW dealer in Vancouver, WA indicated that there was a waiting list for Jetta TDI wagons.

[33] Automotive News, Nov 17, 2003, p. 6.

[34] Automotive News, Nov 24, 2003, p. 18.

[35] Automotive News, Dec 8, 2003, p. 1.

[36] http://www.motortrend.com/features/news/112_031120_coy/

example, some manufacturers seem to be trading fuel-economy for size and power in their upcoming hybrid models. The new Ford Escape 4WD, hybrid SUV is estimated to get less than 25 MPG while the regular gasoline Ford Escape FWD, 4-cylinder is expected to get 25 MPG.[37] Therefore, any policy design, vehicle fuel-efficiency program or other strategies need to focus on lifetime energy savings, not the use of particular technologies.

This is particularly important since we do not necessarily know which technologies will be responsible for energy savings in the future. For example, powertrain experts at the Automotive News World Congress agreed that there are still plenty of technologies available to improve the conventional gasoline-powered engine that could improve performance and at the same time increase fuel-efficiency and lower emissions (e.g., turbochargers, direct injection, variable induction systems, adjustable value timing, etc.). These experts do not see advanced technologies, like fuel cells, supplanting the conventional engine any time soon.[38]

6. Incentive Range Summary

Figure 37 summarizes the results of the various methods we used to determine a range of potential incentive levels.

Figure 37
Summary of Incentive Ranges

Method	Approximate Incentive Range
Regression Analysis	\$0.37[a] for cars \$0.17[a] for light trucks
Buying/Selling Scenarios Scenario 1: Different models of the same vehicle Scenario 2: Set of needs Scenario 3: Specific price range	 (\$0.10) – \$0.37[b] (\$0.07) – \$0.65[b] (\$0.04) – \$0.06[b] for pickup truck
Manufacturer Matrices	(\$0.10) – \$0.60[b]
Vehicle Options 2WD vs. 4WD 4- vs. 6- vs. 8-cylinder Manual vs. Automatic vs. CVT	 \$0.08[a] and \$0.05 – \$0.54[b] \$0.09 – \$0.15[c] \$0.08 – \$0.22[c]
Hybrids and Diesels	(\$0.06) – \$0.04[b]

[a] Point estimate.
[b] Approximate interquartile range.
[c] Range of point estimates.
Source: Ecos data set.

In general, vehicle options and trucks exhibit a lower incentive range than cars. In other words, we predict that it will take a lower incentive to induce the sale of more fuel-efficient trucks than more fuel-efficient cars. An incentive level of \$0.25 would be sufficiently higher enough to cover most of these incremental transactions. However, when cars are considered, the top-end of the incentive range is substantially higher—about \$0.35 to \$0.65.

[37] Norihiko Shirouzu, "Gas-Electric SUVs Trade Fuel Economy for Size and Power," Wall Street Journal Online, January 5, 2004.
[38] Truett, Richard. "The conventional engine: Still plenty of life left." *Automotive News*. January 19, 2004, p. 25.

VII. Dealer Analysis

A. Background Research

For most people, the most challenging part of buying a new car is dealing with the car salesman or dealership. Car dealers generally have an uneven reputation resulting from aggressive negotiating tactics and selling the identical vehicle to different customers at different prices.

As part of this project, we tried to understand how car dealerships really work: how their profit structure is designed, what types of sales strategies they employ, and how much influence they really have over customers.

We reviewed several articles and books on this subject, including:

- *Abandon*, "Confessions of an SUV Salesman," Issue 9, November 2, 2003.
- Bragg, James. *Car Buyer's and Leaser's Negotiating Bible, 2nd edition*. Random House: New York, 1999.
- "Confessions of a Car Salesman" http://www.edmunds.com/advice/buying/articles/42962/article.html
- Eskeldson, Mark. *What Car Dealers Don't Want You to Know, 3rd edition*. Technews Publishing: Fair Oaks, CA, 2000.
- Miller, Dan. *Auto Dealers Exposed*. CDI Systems: St. Paul, MN, 2002.
- Ransom, Mark E. *How I Learned to Sell a Lot of Cars*. Protea Publishing, 2002.
- Sutton, Remar. *Don't Get Taken Every Time*. Penguin Books: New York, 2001.

1. Dealer Profit Structure

It is almost impossible to determine how much money a car dealer makes on a sale. Dealers' profit structures are not only extremely complex,[39] they vary quite considerably across dealerships and at different times of the month and year.

One might think that a dealer's profit is simply the purchase price of the new car—manufacturer's suggested retail price (MSRP) or whatever the customer can negotiate—minus the invoice price. However, the invoice price is not always the dealer's true cost for a vehicle. There are a number of items that can affect the dealer's cost:

- Dealer holdback
- Factory-to-dealer incentives
- Carryover Allowances
- Advertising charges
- Floor plan charges

In addition, dealers have other ways—such as "back end sales" and reselling trade-ins—to make additional money on a transaction.

[39] This point was confirmed later in our dealer interviews; most dealers were extremely reluctant to discuss anything to do with profits.

Dealer Holdback

Dealer holdback is a percentage (of invoice or of MSRP) or a specific dollar amount that the manufacturer holds back from the dealer until after a car is sold. After the sale, the dealer holdback is credited back to the dealer's account.[40] Thus, the stated invoice price of a vehicle overstates true dealer cost because it includes the dealer holdback.

Dealer holdbacks are typically in the 1-3 percent range. This can add up. For example, Chrysler's dealer holdback is 3 percent of MSRP, excluding destination charges. On a new Chrysler Sebring LX, 4-dr. sedan—with MSRP, excluding destination charges, of $18,330—the dealer holdback is $550. Figure 38 shows the impact that dealer holdback has on the dealer's profit margin.

Figure 38
Affect of Dealer Holdback on Profit Margin
Chrysler Sebring LX

	Without holdback	With Holdback
MSRP	$18,330	$18,330
Invoice	$17,062	$17,062
	$1,268	$1,268
plus, Delaer holdback (3%)	--	$550
Profit	$1,268	$1,818
Profit (% of MSRP)	7%	10%

Most consumers (and many salesmen, for that matter) do not know what a holdback is, or even that it exists. So, this is pure profit to the dealer that he does not have to share with anyone.

Factory-to-Dealer Incentives

Another reason the invoice might not reflect the dealer's true cost on a car is because of factory-to-dealer incentives. Like holdbacks, factory-to-dealer incentives represent money that is credited to a dealer's account after a sale is made. However, dealer incentives are tied to specific models. They usually have an expiration date, and they may be tied to sales volume. For example, if a dealer sells zero to five of a particular model within the incentive period, he gets $300 per vehicle, but if he sells over five, he gets $500 per vehicle. Thus, a dealer may be willing to sell his sixth vehicle at a steep discount to qualify for incentives.

Factory-to-dealer incentives are different from customer incentives (or customer rebates), which belong to the customer and do not affect dealer profits.

Factory-to-dealer incentives can change frequently, so it is often difficult for consumers to know if one is being offered at the exact time they are purchasing a vehicle. Dealers sometimes publicize factory-to-dealers incentives to stimulate business. And, in some cases the factory-to-dealer incentive may be passed on, all or in part, to the customer. Factory-to-dealer incentives are also published regularly by trade journals, like Automotive News, Consumer Reports, car buying services like CarDeals, and other Internet sources like Kelly Blue Book (www.kbb.com) and Edmunds (www.edmunds.com).

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[40] Eskeldson, Mark. What Car Dealers Don't Want You to Know." 3rd edition. Technews Publishing. Fair Oaks, CA, 2000. pp. 40-41.

Carryover Allowance

A carryover allowance is a year-end factory-to-dealer incentive program, which allows dealer to hold "year-end clearance sales" to clear their lots for new models. Some manufacturers have regular carryover programs. For example, Ford's carryover allowance is 5 percent of MSRP. Many of the programs are publicized, but sometimes the dealer may try to keep a portion of the incentive for himself.[41]

Advertising Charges

Dealers sometime add "national advertising charges" on to the dealer invoice. These can be as much as 1-2 percent of the sales price (MSRP). National advertising charges are a normal cost of doing business, and do not belong on an invoice: this has been the subject of several civil lawsuits.[42]

Floor-Plan Allowance

A dealer does not typically buy the new cars he has on his lot. Dealers "lease" vehicles from the manufacturer and pay interest on them until they are sold. A typical interest rate is 0.6-0.8 percent per month, based on dealer invoice. Floor-plan allowances are the industry mechanism employed to help the dealer cover the interest costs incurred to finance the new cars on his lot.

Sometimes floor-plan allowances are combined with dealer holdback; an additional 1-1.5 percent is held back by the manufacturer and credited to the dealer when the car is sold. Other times, it may appear on the invoice as a cost to dealers, even though the manufacturer may credit a portion of it back to the dealer at a later date. Also, dealers who get reimbursed for floor-plan expenses, collect the full amount each time, regardless of how long the car has actually been sitting on the lot incurring interest charges.[43] Thus, in many cases, floor-plan charges can be an extra source of profit for dealers.

"Back-End" Sales

The term "back-end" sales refers to additional items or services that are sold to the customer after the purchase price of the vehicle has been agreed on. The dealers we spoke to agreed that back end sales are an important, if not THE most important, source of profits for a dealer. Some typical back-end items include:

- Dealer financing
- Extended warranties
- Rust proofing and undercoating
- Paint and fabric protection
- Security systems
- Credit life and disability insurance
- Guaranteed asset protection (GAP) insurance[44]
- Dealer preparation charges

[41] Ibid, p. 45.
[42] Ibid, p. 46.
[43] Ibid. p. 46.
[44] GAP insurance protects consumers against a write-off (e.g., due to a bad accident) or a substantial reduction in the value of your car (e.g., an overvalued lease).

In general, dealers mark-up all these items well above their true cost. Customers can usually purchase these items outside the dealership for much less.[45] For example, a dealer might charge a customer up to $600 for a car alarm system, when one can be purchased and installed by any aftermarket retailer for around $200.[46]

In the case of financing, dealers can also make money by "holding rates" on a loan. This refers to the difference between the interest rate stated on the finance contract versus the "buy" rate from a lender. For example, a contract rate might be 5 percent, the buy rate is 4 percent, so the holding rate is 1 percent. Dealers usually keep a percentage of this difference as profit. For example, if the amount financed is $20,000 and the holding rate is 1 percent, a dealer might keep 75 percent of that amount, which is $20,000 * 1 percent * 75 percent = $150.[47]

The most crucial thing about back-end sales is that profits on these items can only be earned if the dealer actually makes a sale. Therefore, dealers tend to be more interested in selling any vehicle, rather than one particular model. If a consumer is open to different models, then a dealer may promote the one with a higher profit margin, but the overriding goal is to sell a vehicle, any vehicle, as discussed below.

2. Sales Strategies

Advertising is the key to getting customers "in the door." Dealerships offer a variety of sales—Red Tag sales, Labor Day Sales, Year-of-the-End Clearance Sales, etc. Usually, however, the prices available during these sales are available any day of the week to a shrewd customer, so there is no real advantage to shopping during these sales.[48]

Another advertising technique is to advertise an extremely low price, but only on one particular vehicle. Then when the customer walks-in, the salesman can tell them "I'm sorry we just sold our last one of those vehicles, but here's the a slightly different model [with a slightly higher price]."[49]

Arguably, the most important player in a dealer's profit-making system is the car salesman. Most salesmen are paid on a commission basis, usually about 25-30 percent of gross profit (purchase price minus invoice) on every car they sell.[50] Sometimes, sales pay structures are set up similarly to a volume-based factory-to-dealer incentive program, so a salesman's salary is tied to the *number* of vehicles he sells, not necessarily the *price* of each vehicle.[51] Thus, they have an incentive to sell as many as possible and move vehicles off the lot as quickly as possible.

Salesmen receive extensive training on how to make the most out of every sales opportunity. They learn a variety of tactics, from the "hard sell" to the "I'm on your side" / "trusted advisor" approach. Salesmen will often work to convince a buyer that purchases should be made on the basis of potential, perceived, or occasional needs instead of typical ones.[52] Thus, the family that hopes to rent a boat twice a year or drive to the mountains to ski twice a year might be persuaded to buy an oversized four-wheel drive SUV with large towing capacity, even when the vehicle will spend 95 percent of its miles carrying one or two occupants and no cargo on dry, paved roads.

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[45] Eskeldson, Op. Sit., p.53.

[46] Ibid, p. 56.

[47] Miller, Dan. Auto Dealers Exposed. CDI Systems: St. Paul, MN, 2002.

[48] Eskeldson, p. 51-52.

[49] Personal interview with Richard Reeze, former car salesman and subject of article "Confessions of an SUV Salesman."

[50] Eskeldson, p. 50.

[51] Personal interview with Richard Reeze, former car salesman and subject of article "Confessions of an SUV Salesman."

[52] *Abandon*, "Confessions of an SUV Salesman," Issue 9, November 2, 2003. Ecos also corroborated this primary objective in interviews with individual dealers.

Another favored sales strategy is to play on emotional needs, be they status and power or safety. Thus, a young man is convinced to get a super-charged engine, and a mother is convinced to get a heavier, oversized SUV to protect her family in case of an accident. According to a former car salesman, most customers "believe they are making pragmatic decisions, when actually they're grappling to fulfill some deep emotional need."[53]

A former salesman even described tactics used to get customers who are wary of driving an oversized SUV into the driver's seat and purposely distract them from the higher price, interest rate, loan payment, and gas-guzzling nature of the vehicle.[54] Salesmen actively try to avoid discussions about price and car specifications, hoping to make the customer believe these items are not that important.[55]

Most sales strategies and tactics have one objective in mind: *to sell the car*. Essentially, dealers will do anything in their power to prevent a customer from walking off the lot without making a purchase.[56] Losing a sale means losing not only the profit on the new car, but also any "back-end sale" profits, as well as the potential for future business in services/repairs, referrals of friends/family, or repeat purchases.

3. The Saturn Exception

The one real exception to the way most auto dealers do business is Saturn. Since 1991, Saturn has been trying to reshape the way cars are sold. Saturn is a "no-haggle" dealer, where the prices are nonnegotiable; every customer pays MSRP for a Saturn. Saturn can do this because it has a small number of dealers covering exclusive sales territories, so there is no competition. There is also no sales pressure. Saturn salespeople are paid regular salaries, not commissions; therefore, they focus entirely on promoting the vehicle's attributes and making the customer fall in love with it. For their part, Saturn customers do not seem to mind paying a premium (i.e., full retail price): they rate both the "Saturn experience" and their customer satisfaction highly.[57]

B. Dealer Interviews

Having done background research on dealer profit structures, sales strategies, and analysis of appropriate incentive levels, our next step was to discuss the concept of a Dealer Incentive Program with a few willing auto dealers.

We talked with the five car dealerships in the Northeast and Northwest (Figure 39). Some of these dealerships were self-proclaimed "green" dealerships that placed value on their environmental image and used it to differentiate their dealership when marketing to customers. Other dealerships place little value on "green" image. These dealers sold domestic and foreign vehicles as well as low- and high-end priced vehicles.

[53] Ibid.

[54] Ibid.

[55] Ransom, Mark E. "How I Learned to Sell a Lot of Cars." Protea Publishing, 2002, p. 76.

[56] *Abandon*, "Confessions of an SUV Salesman," Issue 9, November 2, 2003.

[57] Eskeldson, p. 100-101.

Figure 39
Dealerships Interviewed

Dealership	Contact Person	Auto Make	Location
Wilsonville Chevrolet	Marn Zeeb, Sales Manager	Chevrolet	Wilsonville, OR
Russ Auto Group	Russ Humberston, Owner/General Manager	Toyota, Saturn, and Chevrolet	Beaverton, Tigard, and Salem, OR
Flow Companies	Tim Zierden, President and General Manager	Audi, Mazda, Volkswagen	Charlottesville, VA
Dayton Automotive	Aaron Winiarz, Chief Financial Officer	Ford, Chevrolet, Toyota, Chrysler, Dodge, Plymouth, Jeep	Dayton, NJ
Colonial Auto Center	Carter Myers	Chevrolet, Pontiac, Cadillac, GM, Nissan	Charlottesville, VA

1. Questions

We spent about 1-2 hours interviewing each dealer. In general, our questions followed seven major themes:

1. Overall reaction to the Dealer Incentive Program concept and role that external incentive and/or public recognition could play in altering the mix of vehicles sold.
2. Relationship between dealer profits and fuel economy
3. Current trends in customer purchases and the importance of fuel economy.
4. Dealer influence over a customer's purchase decision.
5. Value of a "green" image.
6. Relationship between dealers and manufacturers.
7. "Ball-park" incentive levels.

2. Dealer Responses

Overall reactions and the role of external incentives and/or public recognition

In general, the dealers we interviewed reacted favorably to the general concept and intent of a Dealer incentive Program; however, they had reservations about how such a program could be implemented effectively, whether it would be too complicated, and whether the incentive levels offered would be high enough to elicit even "pilot" dealer participation. Most dealers also indicated a desire to stay out of the policy spotlight.

One dealer strongly advocated that it was the responsibility of manufacturers to deal with fuel economy. While he was personally aware of the environmental and energy problems attributed to the cars he sells, he did not want to take this on when he felt that auto manufacturers are the principal actor in the designing and building of vehicles.

Another dealer commented that of the three major market actors in the car industry—manufacturers, dealers, and consumers—he thought that dealers were probably the least effective place to direct incentive funding. In his opinion, customer incentives, such as tax credits for fuel-efficient vehicles, cash-back, and customer financing deals, play a much bigger role in determining which vehicle is actually put on the road. At the same time, he felt it could not hurt to try out the program on a voluntary basis—something Chevrolet does with many of their incentive programs.

Dealers had mixed feelings about the whether financial incentives could work. They had doubts that the incentive levels offered would be high enough to be worth participating. There was also a sense that it would be complicated to add “yet another incentive” to the list of things to remind salesmen about in weekly meetings.

Some dealers felt that a high-profile recognition-based program would be a better option than trying to toy with their financial objectives and bottom line.

A few dealers rejected the entire concept out of hand. This reaction tended to come from the dealers who handle sheer volume and several nameplates under one dealership.

Reactions from dealers appear to be based on who they are (even down to personal ethics) and how they do business. “Green” dealers are the most open for branding opportunities and welcome any type of marketing assistance. They might be the best targets for a pilot Dealer Incentive Program. High-volume dealers, who handle several different nameplates under one dealership, do not want to mix profit signals that demand they sell sheer volume. These dealerships, which are often run in a traditional manner, are probably not good targets. Newer, image-oriented dealerships, often selling higher-end models, are attracted to the public recognition piece of the program because it would help them establish themselves as a good corporate citizen. This is an important branding tool in certain high-socioeconomic markets where environment plays a more prominent role with wealthier consumers. These dealers could also be good targets for a pilot program.

Relationship between dealer profits and fuel economy

Dealers recognized the inverse relationship between fuel economy and profit, but indicated that is merely a function of pricing. Vehicles with lower fuel economy tend to have higher price tags, and since dealers make more money on higher priced cars, there is obviously a relationship.

There was a tendency to point the finger back to the manufacturers to change the skewed relationship between fuel economy and profitability, since the dealers cannot directly control either the fuel economy of the vehicles or their price tag. Some dealers clearly identified the source of the problem, and the solution, as the manufacturers.

Dealers also indicated that cars priced within a few thousand dollars of each other are essentially equivalent to a dealer in terms of profit potential. Dealers are usually focused on making a couple of hundred to a thousand dollars above their cost on each transaction; they are looking for volume, not trying to squeeze as much as they can out of one transaction.

Trends in customer purchases and the importance of fuel economy

Dealers confirmed that consumers are buying SUVs over cars. However, some dealers told us that consumers recently seem to prefer the smaller sport SUVs over larger ones. Also, we were told that while environmentally-conscious consumers are attracted to more efficient diesel vehicles, they are also becoming more concerned about their particulate air emissions. So there appears to be a market segment of “green”, informed consumers who could be influenced by a Dealer Incentive Program. Nevertheless, Marn Zeeb, of Wilsonville Chevrolet, indicated that the Tahoe and Suburban—which both get below 14 MPG—are still by far his most popular selling models.

Consumers do typically ask about the fuel economy of the vehicle they are considering; however, fuel economy is not the deciding factor in which car they ultimately purchase. Usually, by the time the consumer comes into a dealership, they have already narrowed down the range of vehicles they are considering and have self-selected themselves into a fuel-efficiency "range." From that point forward, their selection between different sub-models is usually based on color and other vehicle options, such as stereo, seats, and trim.

One dealer bluntly suggested raising the price of gasoline rather than tinkering with complex policies such as the one we were suggesting. He felt that if the price of gasoline remains as cheap as it has been historically, then the average consumer will continue to ignore fuel economy.

Dealer influence over a customer's purchase decision

All of the dealers we interviewed agreed on the fact that dealers have little or no influence over consumers' purchase decisions. [58] This is largely because the way cars are sold today is dramatically different from just a few years ago.

Consumers now have the ability to shop around, on the Internet, in numerous trade publications, by phone, and in person at dealerships. Dealers reported that over half of their customers have shopped online before they pay a visit to their dealership, and they know exactly what they want. Dayton Ford indicated that 20 percent of their sales are completed over the Internet, with the consumer coming into the dealership merely to sign the paperwork and pick up the car.

Dealers are primarily concerned with making the sale. So, they are hesitant to get too involved in a customer's decision-making and risk losing a sale. They are purely focused on volume, because the way factory-to-dealer incentives and even some salesmen pay structures are set up today, the more cars you move, the more money you make, and the more cars you get in return for the next round of sales. Moreover, high sales volume is so financially rewarding to dealers that some felt the financial incentives contemplated by a Dealer Incentive Program could not be large enough to change their behavior on the showroom floor.

One dealer indicated that if there were incentive money attached to selling a less powerful engine of a particular car, he might make on attempt to get the customer to purchase that particular model, but he would not press the issue if the customer were not interested. Another dealer told us that he would never attempt to down-sell a vehicle for fear of losing the sale.

We were told that consumers have strong preferences for the vehicle they want and need, whether it's a budget-conscious customer or an image-conscious consumer. Most consumers come in to a dealership knowing more about the models they are interested in than the dealers know themselves. Consumers have also compared across different nameplates that a given dealer does not offer. This puts salesmen at a disadvantage in terms of informing consumers, since likely questions and comparisons step beyond their product offerings. This being the case, most dealers just try hard to satisfy their customer's needs. They are essentially uninterested in what model the consumer decides to purchase, as long as they close a deal.

Value of a "green" image

The value of the "green" image to dealerships seems to vary widely depending on where the dealership is located and what types of consumers they serve.

For example, some dealers in Charlottesville, Virginia, a university town with a highly educated population, seem to place value on having an "environmental-friendly" image. Whereas, some Oregon auto dealers were not even familiar with the term "green" image.

Russ Humberston, of Russ Auto Group, says that, to his knowledge, car dealers in Oregon have not tried to use environmental or "green" branding to differentiate themselves from each other: it is

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[58] This point was also confirmed in correspondence with James Bragg, author of *Car Buyer's and Leaser's Negotiating Bible, 2nd edition*. Random House: New York, 1999.

something he is considering in the future, especially for his Toyota dealership in Beaverton. Russ also indicated that whereas "green" branding would potentially benefit a Toyota or a Honda dealership, it may not be as beneficial for other dealerships, such as Chevrolet, which cater to a very different type of consumer who may not be as environmentally-minded or fuel-conscious. In general, it appears that dealers who sell domestic vehicle makes were less interested in the image aspects of the program than were those dealers who sell imported models.

Most dealers felt that "any type of positive publicity is good for business;" be it "green" or otherwise. Preferred types of exposure included various form state or local press—newspapers, TV, billboards, and mass-transit, as well as an award to hang in the dealership and some form of exclusive "green" seal or logo which could be used in advertising.

Relationship between dealers and manufacturers

We heard a mix of reactions as to whether a Dealer Incentive Program would strain the relationship between dealers and manufacturers. Dealers who have flexibility in what models and configurations of vehicles they receive from the manufacturer[59] did not seem to think that such a program would be a problem. In addition, certain manufacturers (e.g. Toyota and Honda) have reputations for being more responsive to customer preferences than others. If a program like this resulted in more demand for certain vehicles, dealers felt confident that manufacturers would provide those vehicles. The response time would only be constrained by production line and existing vehicle stocks.

Other dealers work on an "earn-and-turn" relationship with the manufacturers whereby the more vehicles they sell, the more they get. In volume-based relationships between dealers and manufacturers, only the extremely high volume operations have any real discretion over what models they get. Dealers told us that they are constantly reacting to manufacturers in order to move inventory: they have little time to consider minor details like fuel economy.

Approximate incentive levels

During our dealer interviews we tried to get a sense of what an "attractive" incentive level might be to encourage participation in the Dealer Incentive Program. In most cases, the financial incentives suggested by dealers were much higher than the range derived by our data analysis—$0.25 to $.65 per lifetime gallon.

Some dealers felt that a state or federal government entity could not afford to pay them enough in order to make this program viable. In other words, the incentive level would not be high enough to influence the dealer's selling habits. However, this attitude was generally coupled with support for the public relations aspect of the program, which was described by several dealers as "invaluable."

Other dealers felt that an incentive could definitely be effective. One dealer gave an estimate of $500 per vehicle as being a "ball-park" figure which might entice him to try to sell a smaller engine Chevrolet SUV over a larger one. Figure 40 shows how this $500 incentive translates in terms of cost per gallons saved.

[59] For example, Chevrolet dealers order exactly what they want from the manufacturer.

Figure 40
Comparison of Dealer-Suggested and Data-Estimated Incentive Levels
Chevrolet Tahoe

Vehicle	Engine	MPG	Lifetime Gallons	Dealer Incentive	Cost per Gallon Saved
Chevy Tahoe LS	V-8 4.8 liter	13.7	13,452		
Chevy Tahoe LS	V-8 5.3 liter	13.2	13,990		
Difference in Lifetime Gallons			538		
Estimated Incentive Range, low			538	$ 134	$ 0.25
Estimated Incentive Range, high			538	$ 350	$ 0.65
Dealer Suggestion			538	$ 500	$ 0.93

Source: Calculations based on dealer interviews and Ecos data set.

A Toyota dealer indicated that his "ball-park" amount would be wildly different depending on which model cars were in question. For example, on the Toyota Camry—the most popular car in the U.S. and a model that Toyota heavily advertises—there is a large price differential ($4,000-$5,000) between a 4 cylinder and a V-6, once all option extras and customer incentives are taken into account. This translates into about a $500 to $1,000 profit differential for the dealer or about a $0.41-$0.82 dollar per gallon incentive (Figure 41). However, on a vehicle such as the Toyota 4Runner, the dealer's profit on different engine configurations (e.g., a V-6 versus a V-8) is almost equivalent, so no incentive would be needed, possibly only an award system with public recognition.

Figure 41
Comparison of Dealer-Suggested and Data-Estimated Incentive Levels
Toyota Camry

Vehicle	Engine	MPG	Lifetime Gallons	Dealer Incentive	Cost per Gallon Saved
Toyota Camry LE	I-4 2.4 liter	22.4	8,242		
Toyota Camry LE	V-6 3.0 liter	19.5	9,454		
Difference in Lifetime Gallons			1,212		
Estimated Incentive Range, low			1,212	$ 303	$ 0.25
Estimated Incentive Range, high			1,212	$ 788	$ 0.65
Dealer Suggestion			1,212	$ 500	$ 0.41
Dealer Suggestion			1,212	$ 1,000	$ 0.82

Source: Calculations based on dealer interviews and Ecos data set.

VIII. Conclusions and Recommendations for Future Policy Development

A. Conclusions: Feasibility of a Dealer Incentive Program

Based on the background research and analysis conducted for this report, we conclude that the general concept and intent of a Dealer Incentive Program are sound, and the idea is even well received by some dealers.

Dealers do not dispute a proven inverse relationship between dealer profit and vehicle fuel-economy, and they are surprisingly open to a policy that tries to reverse this trend. They also support the idea that the program would apply to all vehicles and not just advanced technologies, such as hybrids and diesels. Nevertheless, it was apparent from our dealer interviews that certain inherent characteristics of the auto industry might impede the successful implementation of the Dealer Incentive Program, as initially designed.

- Effective monetary incentive levels are difficult to estimate. Not only is there a wide distribution in the profit different dealers make on the same model vehicle, but there are also "hidden" profit sources that are not transparent to policymakers. Initial estimates of financial incentive levels that would close the profit gap between high and low fuel economy vehicles ($0.25 to $0.65 per gallons of gasoline saved) appear to be too low to spark dealer interest in a voluntary program. Changes to current options bundling approaches by manufacturers could also make this program more viable for dealers.
- Although it would be more expensive to implement, if a true profit incentive motive were necessary, the program would have to result in increased dealer profits rather than just making dealers "whole" by closing the profit gap as they sell more fuel-efficient vehicles. This could be achieved by collecting fees from dealers who sell less-efficient fleets and using these non-public revenues to finance incentives for dealers who sell more-efficient fleets.
- Even though a voluntary program is not likely to elicit widespread dealer participation, it may not take the participation of all dealers to achieve vehicle energy savings in a cost-effective manner. A mandatory program will enlist the participation of all dealers, but it may be less politically feasible, at least on a state level, than a voluntary program since many vehicle dealers are involved in local and state politics.
- Most dealers we interviewed reacted favorably to the proposed public recognition aspects of the program, seeing it as a niche "branding" opportunity to promote themselves as "green" or socially-minded. A voluntary program that provides awards and recognition rather than monetary incentives, could be a workable pre-cursor to a full-blown Dealer Incentive Program. Dealers would opt in and help set up the system for measuring their annual fleet-wide fuel economy. Administrative issues could be worked out in advance and the program cost would be extremely inexpensive.
- Trucks are a growing problem in U.S. energy consumption. The opportunities for large decreases in fuel consumption are greater with trucks than with cars. In addition, the incentive levels required to induce the sale of more fuel-efficient trucks are estimated to be lower than for cars. A program that focuses exclusively on trucks may be a cost-effective way to implement the program on a smaller scale. Vehicles over 8,500 GVWR (mostly trucks) are not rated in fuel

economy terms. Some mechanism to rate these vehicles would need to be developed in order to incorporate them into the program.

- Dealers are middlemen. They are constrained on one side by the vehicles which manufacturers promote and give them to sell and on the other by what consumers want to buy. While some dealers have influence over what they receive from the factory, dealers' influence over which vehicle a consumer purchases has decreased in recent years due to the availability of information on the Internet and the ability for consumers to "shop around." In addition, car selling today is mostly about volume and dealers are wary of trying to sway a customer to purchase a more fuel-efficient vehicle, because they may risk losing a sale. For these reasons, it is not clear whether dealers are the best group to use as the policy actor for a vehicle fuel-efficiency program. A similar program that focuses on manufacturers may be more effective, but testing both concepts would be a good way to find out.

B. Recommendations for Future Research

This report answers some questions about the feasibility of a Dealer Incentive Program, but raises others. Some recommendations for future research include:

- **Survey a wider array of dealers throughout the U.S. to test the feasibility of a Dealer Incentive Program.** For this report, Ecos spoke to a few dealers to get some initial feedback on the concept of a Dealer Incentive Program. The responses were mixed, which is to be expected, as actors rarely respond favorably to the implementation of public policy on themselves to address social issues. Surveying a larger sample of dealers, including Internet dealers, dealers who plan to sell a large volume of new hybrid-electric vehicle models, more progressive, "green" dealers, and dealers located in different geographic regions of the U.S. might allow us to better identify some trends and/or common themes of dealer reactions to the program.
- **Evaluate a voluntary versus a mandatory program.** Most dealers we interviewed indicated that as a voluntary program, they did not believe the Dealer Incentive Program would be widely adopted since its main appeal appeared to be in terms of social or environmental publicity—something which is not of interest to all auto dealers. An item that we did not directly address in our dealers interviews was how they would react if a Dealer Incentive Program were mandatory.
- **Analyze different geographic options to implementing the program.** The broader the scale of a Dealer Incentive Program, the greater chance it has of altering manufacturer-driven supply dynamics. Clearly a national program would affect manufacturers' decisions more than a state program. Our initial research did not consider projected differential impacts of a state vs. regional vs. national program. In other words, what is the appropriate geographic scale for this program?
- **Consider revising the program to focus on manufacturers (at the federal level).** The concept of the Dealer Incentive Program assumed implementation at the state level with auto dealers as the main policy actors. However, research indicates that both dealers and manufacturers profit more from vehicles with lower fuel economy. Many dealers point to the manufacturers as the "root" of the problem. This begs the question: are dealers the best place to focus a policy aimed at vehicle fuel-efficiency? Future research might consider a reconfigured regional or national program targeted at manufacturers, as proposed by one of the authors in a 1994 report for NRDC.[60]
- **Explore the viability of staging a Dealer Incentive Program.** Our research seemed to indicate slightly better understanding of and interest in the public recognition piece of the Dealer

[60] Chris Calwell, *Beyond Gridlock: Linking Automakers' Profits to Fuel Efficiency*, Draft Manuscript, NRDC, October 1994.

Incentive Program, than in financial incentives. Dealers were "fuzzy" about how the financial incentives would work and whether they would be larger enough to be attractive. It might be worthwhile to consider a staged approach to a Dealer Incentive Program which starts with recognition and awards, moves to limited, voluntary financial incentives paid through general revenues, and potentially ends up with a mandatory financial incentive program funded through "feebates" on all dealers. Pilot programs are routinely employed in the utility energy efficiency business to test new approaches to saving energy and assess cost effectiveness. If they succeed, they are expanded to broader segments of the marketplace and larger amounts of funding. At the moment, there is neither a comparable funding mechanism nor a formal means of pilot testing promising means of saving gasoline. Testing a Dealer or Manufacturer Incentive Program could be a good place to begin.

- **Develop and pilot test a program that targets dealers who sell hybrid and advanced diesel vehicles.** Our research indicated that "green" dealers and sellers of alternative technology vehicles might be more interested in participating in a Dealer Incentive Program. As the market for more fuel-efficient vehicles is just opening up, this could be an ideal time to induce their sales by a targeted Dealer Incentive Program. As hybrid vehicles or other fuel-efficient product offerings increase in the future, a Dealer Incentive Program could be expanded accordingly.

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Emerging Energy-Efficient Technologies in Industry: Case Studies of Selected Technologies

Prepared for the
National Commission on Energy Policy

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Abstract

Increasingly, industry is confronted with the challenge of moving toward a cleaner, more sustainable path of production and consumption, while increasing global competitiveness. Technology will be essential for meeting these challenges. At some point, businesses are faced with investment in new capital stock. At this decision point, new and emerging technologies compete for capital investment alongside more established or mature technologies. Understanding the dynamics of the decision-making process is important to perceive what drives technology change and the overall effect on industrial energy use. From a policy-making perspective, the better we understand technology developments the more effective we will be in utilizing our future research dollars and in undertaking sound strategy development.

This report focuses on the long-term potential for energy-efficiency improvement in industry. In 2002, the industrial sector consumed 33% of the primary energy and was responsible for 30% of the energy-related greenhouse gas (GHG) emissions in the U.S. Due to the extremely diverse character of the industrial sector, it is not possible to provide an all-encompassing discussion of technology trends and potentials. Instead we focus on a number of key technology areas that illustrate the significant potential energy savings available to industry, given a sustained state, federal and private R&D effort. These include: near net shape casting, membranes, gasification, motor systems, and advanced cogeneration. The discussion of each of these technologies provides a detailed assessment of the potential for future contributions to energy efficiency improvement, economics and performance, as well as the potential development path, including promising areas for research, demonstration or other support. Some of these technologies have particular applications for a specific industry (e.g. near net shape casting in the metal producing sectors and black liquor gasification in the pulp and paper industry), while others can be found in many industries (e.g. advanced motor systems, membranes and advanced cogeneration applications).

The results demonstrate that the United States is not running out of technologies to improve energy efficiency and economic and environmental performance, and will not run out in the foreseeable future. The five technology areas *alone* can potentially result in total primary energy savings of just over 2,600 TBtu by 2025, or nearly 6.5% of total industrial energy use by 2025. The savings are additional to energy savings found in the AEO 2004 reference case forecasts. The technical potential of these technologies in the long term is roughly three times larger, while additional technologies beyond the five covered in this report are currently available or under development.

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1. Introduction

Characterizing industry in the U.S. is difficult since it covers an extremely diverse range of activities. In 2002, the industrial sector consumed 33% of the primary energy and was responsible for 30% of the energy-related greenhouse gas (GHG) emissions in the U.S. (U.S. EIA, 2004a). Over half of this energy was used in energy-intensive industries producing commodities such as steel, cement, paper, and aluminum; the remainder was consumed by light manufacturing industries. Economic development patterns are leading to a shift away from these energy-intensive industries toward lighter, higher value-added industries, which will be responsible for more than half of all manufacturing energy use by 2050 (Interlaboratory Working Group, 2000).

Historically, industrial energy consumption in the U.S. showed an overall decline between 1973 and 1986 when energy prices were relatively high, but has grown annually since then. The U.S. Energy Information Administration's *Annual Energy Outlook* (AEO) for 2004 projects that energy consumption and GHG emissions for U.S. industry will continue to grow and, extrapolating current reference case growth rates, will double by 2050 (U.S. EIA, 2004b). Figure 1.1 and Figure 1.2 show the projected reference case industrial primary energy use by fuel and by sector, respectively, to 2025.

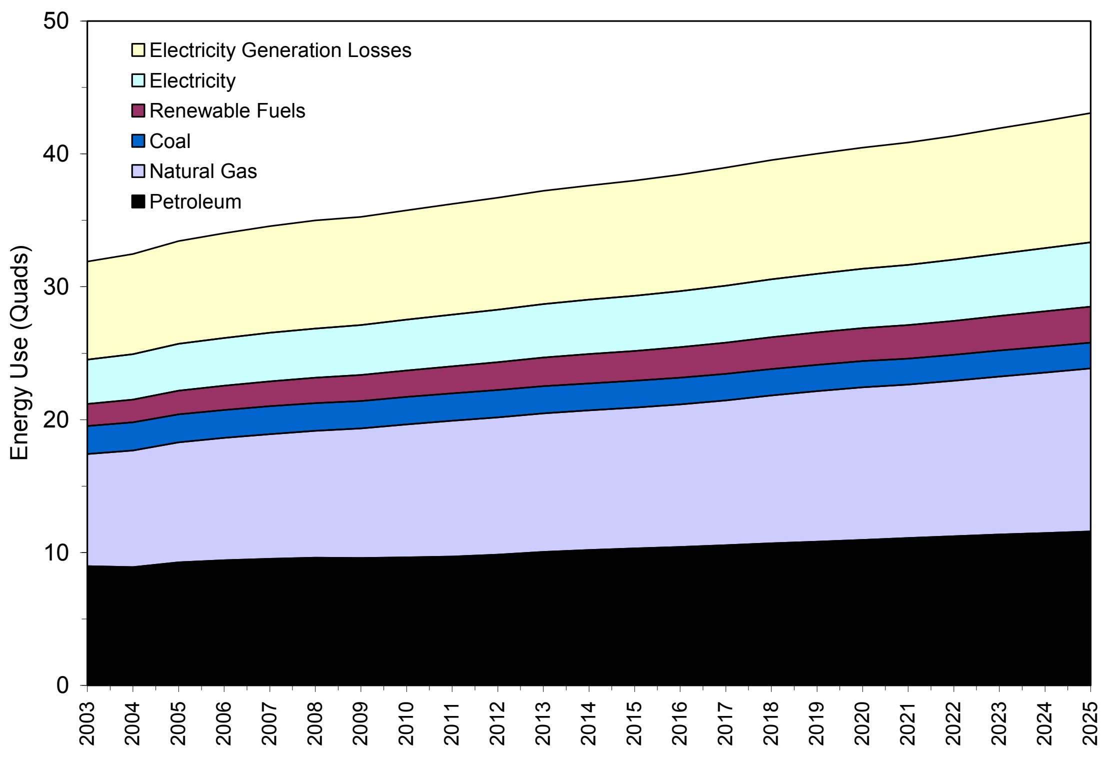

Figure 1.1. AEO2004 Industrial Primary Energy Use by Fuel. Source: U.S. EIA, 2004b.

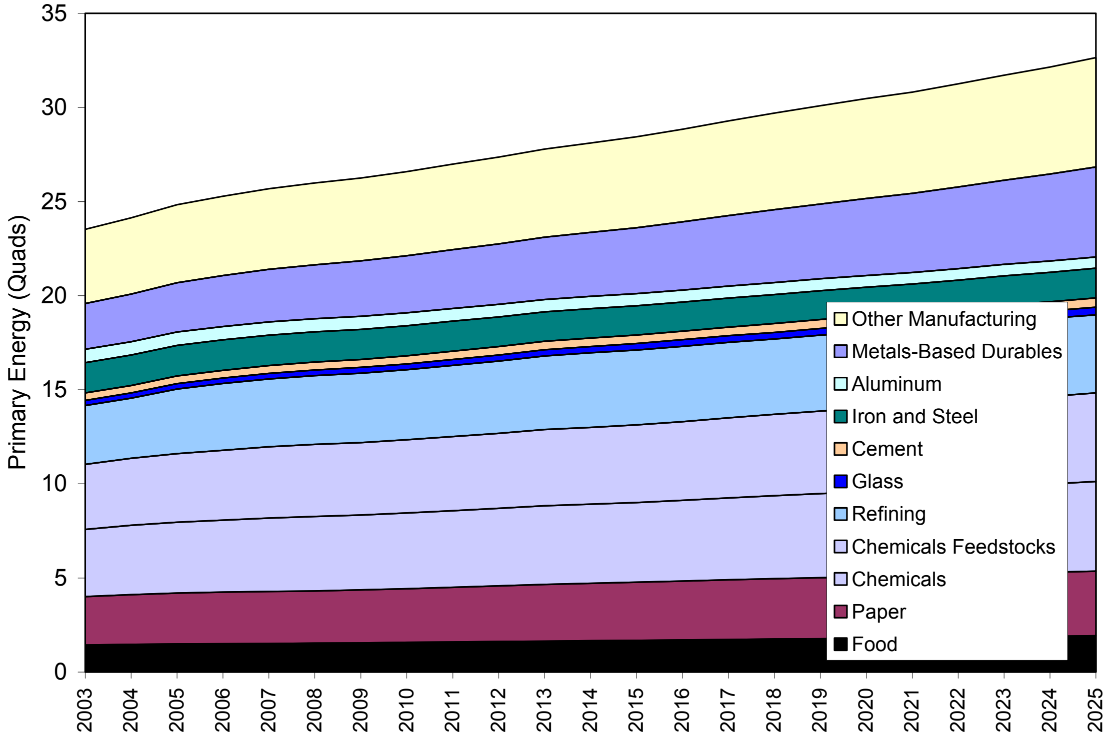

Figure 1.2. AEO2004 Industrial Primary Energy Use by Sector. Source: U.S. EIA, 2004b.

Currently many opportunities exist to improve industrial energy efficiency and there is large potential for future efficiency developments. Improving industrial energy efficiency and reducing energy-related GHG emissions can be accomplished through technological improvements as well as changes in the structure of the overall industrial sector (in response to economic and environmental drivers). In addition, further reductions in emissions due to energy use in industry can be realized through reduction of process-related emissions, fuel switching to lower carbon fuels, and integrated pollution prevention and material efficiency improvement. All of these opportunities are available in the near-term and many will continue to be available in the medium- and long-term.

From a policy-making perspective, the better we understand technology developments the more effective we will be in utilizing our future research dollars and in undertaking sound strategy development. As just one example, few economic models today provide a reasonable characterization of both existing and emerging technologies. But even models with only a limited characterization of technology tend to forecast significantly different energy consumption patterns than those that reflect actual technology choices confronted by consumers and businesses. Inappropriate characterization of technologies can lead to poor analysis and eventually less than optimal policy choices (Worrell et al., 2004).

This report focuses on the long-term potential for energy-efficiency improvement in industry. Due to the extremely diverse character of industry, it is not possible to provide an all-encompassing discussion of technology trends and potentials. Instead, we focus on a number of key technology areas. Martin et al. (2000) provided an in-depth discussion of a larger number of technologies. This report provides a detailed discussion of five major technology areas: near net shape casting, membranes, gasification, motor systems, and advanced cogeneration. Each section provides a detailed assessment on future contributions to energy efficiency improvement, economics and performance, as well as the potential development path, including potential areas for R&D needs Some of these technologies have particular applications for a specific industry (e.g. near net shape casting in the metal producing sectors and black liquor gasification in the pulp and paper industry), while others can be found in many industries (e.g. advanced motor systems, membranes and advanced cogeneration applications).

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2. Near Net Shape Casting/Strip Casting

2.1 Technology

2.1.1 Technology Description

Near net shape casting and strip casting are the most recent developments in metal shaping. Currently, metals are cast in ingots or slabs. The ingots and slabs need to be reheated after casting to roll them in the final shape. Near net shape/strip casting integrates the casting and hot rolling of steel into one process step, thereby reducing the need to reheat the steel before rolling it. Strip casting directly casts a strip of 1–10 mm. This technology leads to considerable capital cost savings and energy savings. It may also lead to indirect energy savings due to reduced material losses.

2.1.2 Specific End-Uses and Applications

Near net shape/strip casting can be used to cast and shape any metal. Since steel is the dominant metal produced in the U.S., this description will focus on steel. The iron and steel industry is one of the largest industrial energy consumers both in the U.S. and globally. The U.S. iron and steel industry is made up of integrated steel mills that produce pig iron from raw materials (iron ore, coke) using a blast furnace and steel using a basic oxygen furnace (BOF) and electric arc furnace steel mills that produce steel from scrap steel, pig iron, or direct reduced iron (DRI) using an electric arc furnace (EAF). After reaching a peak production in the 1990's crude steel production in the U.S. declined to 10 million tons (92.2 million tonnes) in 2002, of which 49% was produced by integrated steel mils and 51% by electric arc furnaces in mini-mills.

Iron and steelmaking is still foremost a batch process. Today, in most steel mills the casting and rolling process is a multi-step process. The liquid steel is first cast continuously into blooms, billets, or slabs in the continuous casting process. About 97% of steel is cast continuously in the U.S., and only 3% is cast as ingots. In continuous casting, liquid steel flows out of the ladle into the tundish (or holding tank), and then is fed into a water-cooled copper mold. Solidification begins in the mold, and continues through the caster. The strand is straightened, torch-cut, then discharged for intermediate storage. Most steel slabs are reheated in reheating furnaces, and rolled into final shape in hot and cold rolling mills or finishing mills.

2.1.3 Current Status

Near net shape casting integrates the casting and hot rolling of steel into one process step, thereby reducing the need to reheat the steel before rolling it. As applied to flat products, instead of casting slabs in a thickness of 120-300 millimeters, strip is cast directly to a final thickness between 1 and 10 mm. (De Beer et al. 1998, Opalka 1999, Worrell et al., 1997). The steel is essentially cast and formed into its final shape without the reheating step.[1] Figure 1 provides a schematic presentation of a strip caster.

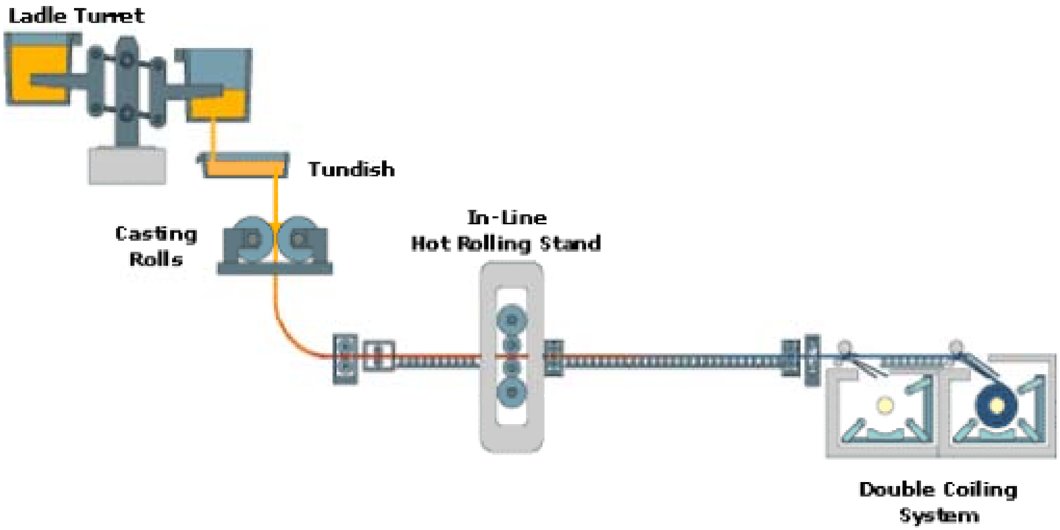

Figure 2.1. Schematic Representation of a Strip Caster. Source Eurostrip

The idea of strip casting was patented by Bessemer in 1856, but technical realization took almost 140 years. Earlier attempts at developing the technology were not successful. Starting in 1975, around 11 clusters of steel producers, technology suppliers, and research groups developing near net shape/strip casting emerged in Europe, Japan, Australia, United States and Canada (Luiten and Blok, 2003).

Since then, three commercial technologies have emerged. All three technologies are based on the same principle as proposed by Bessemer. The steel is cast between two water-cooled casting rolls. This results in very rapid cooling and high production speeds. The major advantage of strip casting is the large reduction in capital costs, due to the high productivity and integration of several production steps. The technology was first applied to stainless steel, and two plants have demonstrated strip casting of carbon steel. The first commercial technologies are:

- **Castrip.** Based on the technology developed by BHP (Australia) and IHI (Japan), the Castrip consortium was formed to commercialize the product. The third partner is Nucor (USA). Nucor is the largest steel producer in the U.S. and was the company to first introduce thin slab casting to the U.S. The first commercial strip caster was constructed at Nucor's Crawfordsville Indiana plant. The plant was commissioned in 2002 and production started in 2003. The plant has a capacity of 500,000 tonnes/year.
- **Eurostrip.** Eurostrip is a consortium of companies from Austria, France and Germany, which merged a number of projects and long-term experience in casting. A first pilot plant was operated in Terni (Italy). The pilot plant is now used to strip cast

[1] An intermediate technology, thin slab casting casts slabs 30-60 mm thick and then reheats them (the slabs enter the furnace at higher temperatures than current technology thereby saving energy). Thin slab casting technology is already commercially applied in the U.S. and other countries.

carbon steel. The first commercial plant opened in 1999 in Krefeld (Germany). The technology is offered at a scale of 500,000 tonnes/year.

- **Nippon/Mitsubishi.** These two Japanese companies commercialized strip casting at Hikari Works of Nippon Steel Corporation (Japan). This is still a relatively small machine (35,000 tonnes per year).

The main challenges for the further development of this technology relate to the quality and usability of the product by steel processors and users, especially in the high-end markets of cold-rolled steels for automobile applications (AISI, 1998; Kuster, 1996). While there is no reason to assume that the quality is lower (Flick and Hohenbichler, 2002), different characteristics may affect processing options. It was feared that maintenance of the rollers would limit the productivity and cost savings, but the first plants in the U.S. and Europe demonstrated that this can be controlled. Furthermore, increased reliability, control and scaling (now limited to a relatively small scale of 500,000 tonnes/year) will benefit the wider application of the technology. Thin slab casters were initially developed at similar scales, but have been scaled up to over 1 million tonnes annual capacity and are used by integrated mills in Germany and The Netherlands.

In the U.S., near net shape casting has so far been applied to the production of beams. This technology was introduced by Nucor at their joint venture company Nucor-Yamato Steel Company in Blytheville, Arkansas and later applied at Nucor's plant in Berkeley County, South Carolina (Worrell et al. 1999, Wechsler 2000). TXI/Chaparral Steel has developed a near net shape casting process for construction steel products like rebar and bar. The process is in use at TXI's plants in Texas and Virginia.

Near net shape/strip casting technologies have been or are being developed for other metals. The most important are aluminum and copper. Steel, aluminum and copper together represent close to 95% of all metals produced in the United States. Together, these industries consume about 11% of all energy used in U.S. industry (1998).

Adoption of near net shape casting will be driven by retirement of existing casters and rolling mills and will be the technology of choice for new greenfield mini-mills.

2.1.4. Research & Development Needs

Further demonstration of the near net shape/strip casting technology at larger scales would make it more attractive to the integrated steel mills. There are three main areas for future R&D to increase the uptake of this technology in the metals industry:

- Improved control of the process and expansion of the capacity of the caster to improve the applicability to large integrated mills (the major producers of flat rolled steel).
- Improved understanding of the casting process to allow the application of the technology to cast different shapes, so to allow use of this technology for all metal products.

- Further development and design of the technology to non-ferrous metals, most importantly aluminum and copper, to directly produce thin film and various shaped castings.

2.2 Cost

2.2.1 Baseline and New Technology

Capital costs for near net shape casting plants are expected to be lower than current practice due to the elimination of the reheating furnaces. Estimates on the reduction of capital costs have ranged from 30-60 percent below current practice (Flemming, 1995; Kuster, 1996; Eurostrip, 2004). Given that this technology is still new, we currently estimate a capital cost 20 percent below conventional continuous casting. However, through learning by doing and multiplication, this is likely to be reduced to 50% of the investments of a typical continuous casting and hot rolling mill.

A strip or near net shape caster is much more compact, reducing the space requirements to about 15-20% of a typical hot rolling mill. This contributes to the large reduction in capital costs (Eurostrip, 2004).

Operations and maintenance costs are also expected to drop by 20-25%, although these reductions will depend strongly on the lifetime of the refractory on the rollers used in the caster and local circumstances.

Baseline costs for construction of a continuous caster and rolling mill are estimated to be \$200/ton annual capacity. The capital costs of the first-of-a-kind strip caster constructed at Nucor's Crawfordville's (Indiana) plant were about \$180/ton. Given this, we estimate the specific capital costs of a strip caster/near net shape caster to be \$160/ton (-20%) within the next 10 years. Eventually, this cost will be reduced to \$110/ton (-45%).

2.2.2 Cost-Effectiveness

Given the lower investment costs of this technology compared to the current technology, the payback period is zero. The cost-effectiveness is driven by new casting and rolling mill construction. In the case of a new greenfield construction of a mini-mill, capacity expansion at an existing mill or replacement of an existing rolling mill, the introduction of a near net shape/strip caster is attractive. However, after the expansion of the steel industry in the 1990's new greenfield plant construction will likely be limited.

Most flat steel products are still produced in large integrated mills. These mills have larger capacities (for which the current capacity of a strip caster is too small) and are typically less innovative. Nucor and TXI are among the most innovative steel companies in the U.S. and have pioneered the commercial application of thin slab casting, and now near net shape/strip casting. Nucor and TXI use "mini-mills" of up to 2 million tons/year. Integrated mills in Europe and Japan, however, use thin slab casters. Further R&D can make this technology more attractive to large integrated mills.

2.3 Energy

2.3.1 Baseline and New Technology

In 1998 the iron and steel industry consumed 1426 TBtu in fuels and 158 TBtu electricity. Total primary energy consumption was equal to 1905 TBtu. Historically, the primary energy intensity of steelmaking has declined from 30.6 MBtu/ton in 1958 to 18.7 MBtu/ton (or 21.8 GJ/tonne) in 1998. This decline is due to a shift towards more secondary or recycled steel production, closing of inefficient plants, and improved energy efficiency, including reduction in material losses.

A study of the industry estimated that casting and rolling consumed 332 TBtu (350 PJ) of primary energy in 1994 (Worrell et al., 1999). The reheating furnaces are usually gas and oil operated and consume roughly 2.6 MBtu/ton (3.0 GJ/t) of energy. Electricity consumption is estimated at 152 kWh/ton (0.67 MBtu/ton). We assume that this has not changed between 1994 and 1998.

Energy consumption of a near net shape/strip caster is significantly less than that for continuous casting. For the intermediate thin slab casting process, energy consumption is 0.8 MBtu/ton (0.9 GJ/tonne) fuel and 39 kWh/ton (43 kWh/tonne) electricity (Flemming 1995). Near net shape casting is expected to consume even less energy. A strip caster is estimated to consume 0.2 GJ/tonne of steel (Eurostrip, 2004). We estimate fuel use at 0.04 MBtu/ton (0.05 GJ/tonne) and electricity use at 39 kWh/ton (42 kWh/tonne).

2.3.2 Potential Energy Savings

The specific primary energy savings for this technology are estimated at 95% compared to the 1994 average energy intensity of casting and rolling. Compared to a state of the art casting and rolling facility, the specific energy savings are estimated at about 90%. Fuel savings are 98% compared to the 1994 average energy intensity and electricity savings are estimated at 74%.

The total energy savings will depend on the penetration rate of near net shape/strip casters into the market. Little new construction is expected in the U.S. steel industry, but the industry will need to re-organize to reduce over-capacity. This will likely happen most in the integrated segment of the industry. Near net shape/strip casters are expected to first penetrate the secondary steel or mini-mill market due to the limited capacity of the current equipment. Mini-mills currently produce 50% of all steel in the U.S.

A recent assessment of multiple emerging energy-efficient technologies assumed a 30% penetration rate by 2015 (Martin et al., 2000). The large benefits of this technology will make this technology an attractive alternative when the current caster and/or rolling mill needs to be replaced. Therefore, in this study we assume a slightly higher penetration rate by 2025. Assuming that by 2025, 40% of steel is cast using near net shape/strip casting technology, this would result in estimated primary energy savings of nearly 160 TBtu, or 10% of total projected primary energy use in the iron and steel industry.

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3. Membrane Technology

3.1. Technology

3.1.1 Technology Description

Membranes selectively separate one or more materials from a liquid or gas and can replace energy-intensive separation processes in a number of industrial sectors including the food processing, chemicals, paper, petroleum refining and metals industries. Membranes can be used to remove dissolved or suspended solids in the wastewater generated by large water-consuming industries. Membranes can also be used to purify product streams or separate gases. Energy savings, however, will depend on the specific application. Figure 3.1 gives a schematic presentation of a membrane unit.

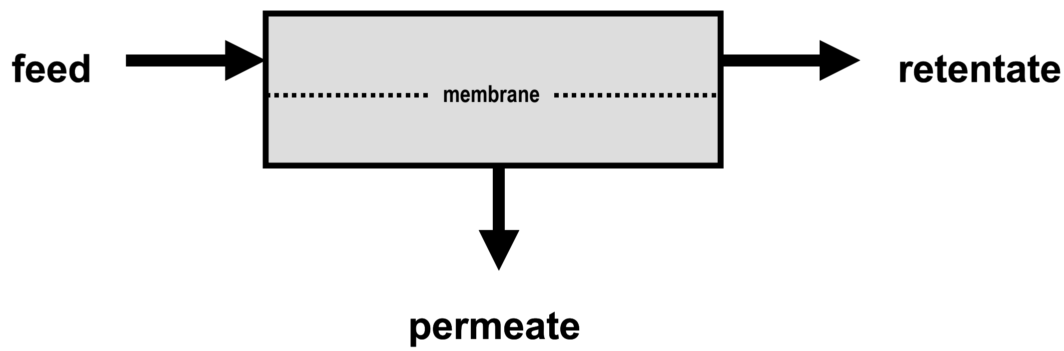

Figure 3.1. Schematic Representation of a Membrane Separation Unit

Membranes can be made from organic or inorganic materials, or can be a hybrid of both. Organic membranes can be used for processes with temperatures below 150°C. Inorganic membranes can be used in high temperature environments, ranging from 500-800ºC using metal membranes to over 1000ºC for many ceramic membranes. Hybrid membranes have organic molecules that allow water and dissolved substances to be filtered by the membrane, and inorganic molecules that provide stability.

Based on the separation principle and the state of feed and permeate streams, different membrane technology categories are distinguished. Typical membrane separation processes include microfiltration (MF), ultrafiltration (UF), nanofiltration (NF), reverse osmosis (RO), electrodialysis (ED), gas separation, and pervaporation. Emerging membrane technologies include microporous membranes for gas separation; ion-exchange membranes for electrodialysis, diffusion dialysis, NF, membrane solvent extraction, and facilitated transport; pervaporation membranes for removing trace organics from water; proton exchange membrane fuel cells for converting chemical energy directly into electrical energy; encapsulating membranes for environmentally-sensitive materials; G-50 UF systems for oily waste streams; supported liquid membranes to selectively extract multiple elements or compounds from a mixed process stream; liquid membranes and emulsion liquid membranes for removal of trace impurities; and a variety of other membrane technologies (Srikanth, 2004).

3.1.2 Specific End-Uses and Applications

Membranes can be used in a wide variety of applications in the automobile, beverage, biopharmaceuticals, chemicals, dairy, electronic, fertilizer, food processing, metal finishing, mining, petroleum refining, pharmaceutical, and textile industries and for cleaning drinking water, cleaning wastewater, de-icing, de-watering, and desalinization. This reports on the food processing and chemicals industries as well as wastewater treatment applications across industries.

In the food processing industry, membranes are used to concentrate, fractionate and purify liquid products. Four types of membrane processes are important: MF, UF, NF, and RO. Gas separation is only used in the fruit and vegetable sector for packaging in a nitrogen atmosphere.

One of the most energy-intensive unit operations in the chemical industry is separation (U.S. DOE, OIT, 2000). Separation technologies include distillation, fractionation, and extraction. Gas membranes to separate organic mixtures and liquid membranes to separate both aqueous and organic mixtures offer an alternative to liquid-liquid extraction that uses much less energy. Membrane separation technology is increasingly being utilized in the chemicals industry for a wide range of applications such as removing water from organics. The membrane-based process of pervaporation is gaining importance and is now routinely used in the chemicals industry for splitting azeotropes.

Wastewater is produced in a variety of industries including the metal, metal plating, food, paper, chemicals, and electronics industries and may contain different contaminants ranging from bio-organic compounds to metal compounds. Such wastewater needs to be cleaned before it can be discharged or recovered for re-use in the plant. Treatment with chemicals (sanitizing, flocculation), biological treatment, ozonation, ultraviolet treatment, gravity settling, flotation and screening are conventional methods used to clean water. Membranes can also be used to remove dissolved or suspended solids, or microbes. The membrane types mostly used in wastewater treatment are UF, NF and RO, while MF is mainly used to stabilize (pre-filter) the water for RO-treatment.

3.1.3 Current Status

The U.S. membrane materials market was over $1 billion in 1997 (Wiesner and Chellam 1999) and forecast to grow to $2.1 billion by 2006 and to $3 billion by 2008 (Freedonia Group, 2004; Business Communications Company, Inc., 2003). In 1997, approximately 40% of the membrane sales were for water and wastewater treatment applications, another 40% was for food and beverage processing combined with pharmaceuticals and medical applications, with the remaining 20% in the area of chemical and industrial gas production (Wiesner and Chellam, 1999). The water and wastewater treatment market accounted for 55% of membrane demand in 2001 (Freedonia Group, 2004). Major suppliers are APV (Denmark) and APV Americas (U.S.), Koch Membrane Systems (U.S.), Osmonics (U.S.), PCI Membrane Systems (U.S.), U.S. Filter (U.S.). MF, UF, NF, and RO membranes account for more than 75% of 2003 sales in the U.S. (Business Communications Company, Inc., 2003).

In 2001, the vast majority of membrane materials were polymeric and these are projected to continue as market leaders because of their flexibility, permeability, and ability to be formed into a variety of membrane modules. By 2006, cellulose membranes are projected to account for over 50% of polymeric membranes. Rapid gains will also be made by non-polymeric materials, including ceramic, metal, and composite types, particularly in specialty uses, such as in extreme temperature or corrosive environments. By process, MF membranes accounted for approximately half of the market in 2001. These membranes are widely used for pretreatment before finer separation processes. Demand for RO membranes is projected to increase rapidly because of their ability to provide the highest level of purity which is a requirement in home water treatment, beverage processing, and wastewater treatment (Freedonia Group, 2004).

The dairy industry is the most important sector using membranes in the U.S. (Dziezak, 1990) and worldwide, and many thousands of m^2 membranes have been installed in this industry. Dairy is the sector with the longest history using membranes, which are used for the desalting of whey[2] and to separate lactose from salt and minerals (NF), the concentration of skim milk for ice cream and of soy proteins (UF), concentrating lactose or whey protein in the waste stream and reclaiming it as value-added concentrates or isolates for other processors (UF), the conversion of milk into cheese and soft cheese, and the preparation of egg white and egg yolk. RO is used to concentrate milk solids prior to evaporation in making concentrated milks and to remove water from whey concentrates, isolates, or lactose in cheese processing (Neff, 1999). Process water can also be recycled or used for boilers if cleaned with RO or can be prepared for discharge using NF (Neff, 1999). Current developments in dairy industry are the reduction of bacteria in milk and the clearing of dairy fluids. The application of membranes in the dairy industry is considered to be in an important phase for implementation on a large scale.

In the beverages industry, while MF is used sometimes for clarification of juices and water purification, UF is more frequently used because it removes a wider range of compounds and can selectively remove certain proteins or sugars. Membranes are used by Coca Cola (in Salina, KS) for juice concentration and for alcohol recovery in the production of non-alcoholic beers (Gach et al., 2000). A number of breweries (e.g. Miller Brewing Co.) already apply membranes for alcohol removal from beer, although potential exists for further application and development. Water treatment is an important application of membranes in the beverages industry (Comb, 1995). Electrodialysis for stabilization of wines is a new application of membranes in the food processing industry (Amon and Mannapperuma, n.d.).

The market for liquid and gas membrane separators will encompass every portion of the chemical industry. The organic chemical industry is forecast to grow by 15 percent between the years 2000 and 2015. The market for membranes remains large because of

[2] By the mid-1990s more than 10,000 m^2 of membranes for the desalting of whey had already been installed in the U.S. dairy industry (Maaskant et al. 1995).

the relatively few processes for which they are currently used for separation. Liquid membranes will first be used in the production of specialty chemicals in the pharmaceutical, agricultural, food, and biotechnology industries and for production of bulk commodity chemicals, processing industrial gases, industrial waste and wastewater (SRI, 1998). Membranes are also an attractive technology for hydrogen recovery in refineries. New membrane applications for the refinery and chemical industry are under development. Membranes for hydrogen recovery from ammonia plants were first demonstrated about 20 years ago (Baker et al., 2000), and are used in various state-of-the-art plant designs. Liquid membranes are highly specific with regards to the compounds that they can separate and therefore differing processes will require differing membranes.

Water is used throughout industry for many applications. Daily industrial water use is estimated at 20 billion gallons/day in 2000 (Hutson et al., 2004). There is no information on water use by sector. Large water users are the food, paper, chemical and metal industries. Wastewater is produced in as many industries and may contain many different contaminants, ranging from bio-organic compounds to metal compounds. The water needs to be cleaned before it can be emitted or can be recovered for re-use in the plant. In 1995 only 110 million gallons/day were reclaimed and re-used by industry (Solley et al., 1998). Treatment with chemicals (sanitizing, flocculation), biological treatment, ozonation, ultraviolet treatment, gravity settling, flotation and screening are conventional methods used to clean water. Membrane wastewater treatment plant design starts with the selection of the membrane. The type of membrane material used determines the contaminant rejection characteristics (i.e. chemicals removed from the water), durability and fouling characteristics (Jacangelo et al., 1998). Most membranes used today are polymer membranes, as these have lower costs. Ceramic membranes are more expensive, but can be used at higher pressures and with longer lifetimes (CADDET, 1994). Two membrane processes (e.g. MF and RO) can be combined to remove different contaminants.

3.1.4 Research and Development Needs

New membranes and membrane applications are under development, expanding the applications to many industries. Federal research programs (e.g. the National Institute for Standards and Technology's Advanced Technology Program) support development of membrane technology, as well as development of specific applications (e.g. DOE, EPA, USDA). Advances in membrane technologies will be driven by the increasing use of membranes in the water and wastewater treatment, and food and beverage processing industries.

One of the principal barriers facing liquid membranes is limited production. More research and development is needed to improve the performance of these technologies. Membranes with varying qualities are continuously being developed for the separation of specific gas mixtures. A large potential market for gas membrane separators is mobile and stationary fuel cells. One type of fuel cells that has promise for mobile applications is the proton exchange membrane (PEM) fuel cell. The U.S.DOE, along with the U.S.

Department of Transportation, has been conducting research and demonstration projects in this area. The U.S. DOE is currently sponsoring research to develop Ion Transport Membrane Technology (ITM) to produce hydrogen from natural gas and Oxygen Transport Membranes (OTM) for oxygen production. These technologies operate at high temperature, providing a higher level of thermal integration with the gasification process and will be increasingly important in the development of fuel cells as well as in the capture of carbon dioxide (Steigel, et al., 2003). An inorganic porous membrane for recovering hydrogen as a by-product of coal burning using Integrated Gasification Combined Cycle (IGCC) technology has recently been developed (U.S. DOE, OFE, 2001). One of the ways in which membranes could be improved is by increasing their lifetime and by decreasing their sensitivities to fouling. Sulfur-resistant membranes, for example, would be a great improvement for many processes in the petrochemical industries. For wastewater treatment, current research aims at new membrane materials and applications, more efficient and longer lasting membranes, and cost reduction.

Growing use of membranes is driven by increasingly strict environmental regulations enacted over the past several decades in addition to improvements in membrane technology, a more competitive market, a broader range of membrane processes, and new materials from which membranes can be fabricated (Freedonia Group, 2004; Wiesner and Chellam, 1999). Barriers to implementation include the lack of information, as well as the need for specific membranes in specific applications.

3.2 Costs: Baseline, New Technology, and Cost-Effectiveness

Economic assessment of membrane applications requires the evaluation of both the capital and operating costs associated with the application as well as the resulting benefits when compared to more traditional alternatives. The economic benefits in process applications include reduced operating costs relative to competitive technology, reduced product waste, recovery of by-products, and savings of water, energy, and chemicals. Economic benefits related to effluent reduction include savings in transport and disposal costs, as well as the ability to increase production in situations where effluent disposal limits are imposed.

Food Processing. In the food processing industry, traditional filtration, separation, and evaporation processes are typically used to separate, clarify, and purify foods and beverages. Membranes can be a cost-effective alternative, especially if they increase by-product recovery. For example, capital costs of $250,000 and annual operating costs of $82,000 for a membrane treatment system were seen at a Dole Raisin Plant, but annual savings of over $500,000 were realized due to recovery of sugar concentrate (Mannapperuma, et al., 1995). At Golden Town Apple Products in Canada, a combination of UF and RO was used for apple juice concentration. The payback period of the combined system is about 2.5 years (CADDET, 1996). Investment costs for a NF unit was installed for whey concentration at a dairy plant in The Netherlands, replacing a two-stage evaporation process were $9.3 ft^2 ($100/m^2). Energy savings, as well as reduced transport costs and emission charges, resulted in a payback period of 1.3 years (CADDET, 1998). Alcohol separation processes in breweries require an additional process step (as opposed to manipulated fermentation) and are done to improve taste. Estimates of utilities costs (energy and water) for RO membranes were \$2.40/barrel (\$2.04/hl) as compared to \$4.10/barrel (\$3.49/hl) for dialysis, while maintenance costs for RO systems are slightly lower than dialysis (\$0.6/barrel as compared to \$0.75/barrel) (Stein, 1993). The Heineken brewery at s'Hertogenbosch (the Netherlands) brewery produces 120,000 hl/year of non-alcoholic beer, by removing alcohol and water from ordinary beer, using a RO filter. In 1997, the filters were replaced by "spiral wound" units, where the filter membranes are shaped like tubes and are configured according to the cross-flow principle. The cost savings are on the order of \$50,000/year (NLG 101,000/year), and the payback period was about 4 years (CADDET, 1999; NOVEM, 1997). A recent study estimated that membranes for food processing cost approximately \$450/Mbtu-s with operating costs savings of \$55/Mbtu-s (varying greatly depending upon the application), resulting in a simple payback period of just over 2 years and an internal rate of return of 45%, given a 15% discount rate (Martin et al., 2000).

Chemicals. One of the most energy-intensive unit operations in the chemical industry is separation, which can account for over 50% of plant operating costs (Tham, 2003). Separation technologies include distillation, fractionation, and extraction. Certain mixtures of chemicals cannot be separated beyond a certain point by standard distillation processes and must undergo extraction. Improved gas separations involving oxygen (O_2), hydrogen (H_2), and carbon dioxide (CO_2) can lead to reduced capital and operating costs, as well as to improvements in thermal efficiency and superior environmental performance. DOE sponsored studies indicate that technologies now in the research and development phase will offer substantial cost reduction compared the cryogenic air separation methods now employed (Steigel, et al., 2003). Liquid and gas membranes for separation offer an alternative to liquid-liquid extraction that uses much less energy. Liquid membrane separators tend to cost about 10 percent less than traditional separation units (Martin et al., 2000). The annual operating costs of membranes tend to run a bit higher than other separators mainly because membranes foul easily and must be replaced rather frequently. In general, gas and liquid membrane applications currently have simple payback times around 10 years with low internal rates of return (Martin et al., 2000), but shorter payback times are seen in many applications.

Wastewater. Traditional wastewater treatment methods include the use of chemicals (coagulants) to remove impurities, flocculation, sedimentation, and fine particle (e.g. sand) filtration. The costs and energy use of wastewater treatment depends heavily on the facility, differences in flow, type of pollutants, as well as type of equipment used. The main driver for membrane application is the cost of wastewater treatment, and not energy use, although membranes can reduce energy use when compared to evaporation. Life-cycle costs of new, relatively small water treatment facilities (less than 20,000 m^3/day) using pressure-driven membrane processes should be less or comparable to those of new facilities using conventional processes for particle removal or reduction of dissolved organic materials (Wiesner and Chellam, 1999). A recent study estimated that membrane technologies for wastewater treatment average about \$30,000 in capital costs and save \$6,400 annually in operating costs, resulting in a simple payback period of just under 5 years and an internal rate of return of about 20% (Martin et al., 2000). In a number of applications, the annual operating cost savings from reductions in wastewater-related fees and associated labor costs lead to simple payback periods of 3 years or less (Nini and Gimenez-Mitsotakis, 1994; Pollution Engineering, 2002). Where the costs of the new membrane technology at a Hunt-Wesson tomato processing plant were greater than the direct benefits, the improved effluent treatment levels enabled the plant to increase production and the resulting increased income outweighed the membrane costs by a significant amount (Mannapperuma, et al., 1995).

3.3 Energy: Baseline, New Technology, and Potential Energy Savings

Food Processing. Primary energy use in the food and kindred products industry (SIC 20) in 1998 was 1573 TBtu (1659 PJ), equivalent to 6.5 percent of total manufacturing energy use in the U.S. Primary energy consumption for this industry in 2025 is estimated to be over 2100 TBtu (2215 PJ), growing at an average annual rate just slightly higher that the manufacturing sector as a whole (U.S. DOE, EIA, 2001; U.S. DOE, EIA, 2004). The main energy-consuming sub-sectors are corn milling, sugar, meat packing, soybean oils, beverages, and dairy. The fruit and vegetable industry has a large potential for improved energy efficiency using membranes. The beverage sector is also an important sector for applying membranes.

Net energy savings of 8.8 MBtu/ton (10.2 GJ/t) of water removed were realized when an NF unit was installed in place of a two-stage evaporation process for whey concentration at a dairy plant (CADDET, 1998). Energy savings of 66% were experienced when a combination of UF and RO were used for apple juice concentration when compared to an evaporation process (CADDET, 1996). Membrane microfiltration for sterilizing and filtration of beer typically uses approximately 0.15-0.25 kWh/gallon (PG&E, 2000). Replacement of plate membranes by new spiral membranes at the Heineken brewery in Den Bosch, The Netherlands, reduced pumping energy and water demand, and resulted in savings of 0.17 kWh/gallon beer (4.6 kWh/100 liter beer). Investigations into the use of oscillatory flow in crossflow microfiltration for beer clarification found energy savings ranging from 15-40% as compared to standard microfiltration due to reduced pumping requirements (Blanpain-Avet et al, 1998).[3] Electrodialysis for stabilizing wines can be used instead of conventional energy-intensive refrigeration, reducing electricity use by 80% (Amon and Mannapperuma, n.d.).

It is challenging to estimate the potential energy savings from implementation of membranes in the food industry without a detailed study. For specific applications, energy savings may be up to 40-55% of the energy needs for distillation and evaporation. Research is aimed at increasing the number of applications, increasing product quality, lifetime, and increasing energy savings. A European study estimated that membranes could be used to replace 15% of fuel using applications in the food industries (Eichhammer, 1995). A recent assessment found that overall primary energy savings (despite an increase in electricity use) using membrane technology instead of existing

[3] Still, some manufacturers believe current cross flow membrane filtration systems may require as much extra energy as they save (Todd, 2001).

separation processes was about 30% and that these savings, when applied to the separation process portion of the food industry, would result in primary energy savings of 27 Tbtu in 2015 (Martin et al., 2000). Assuming increased penetration of membranes in the food industry overall, we estimate savings of about 50 TBtu in 2025.

Chemicals. The estimated total annual consumption of energy (fuels and electricity) and feedstocks by the U.S. chemical and allied products industry was estimated to be over 6500 TBtu in 2000; roughly 40% of that (2600 TBtu) is required for separation processes, including distillation, extraction, adsorption, crystallization, and membrane-based technologies (U.S. DOE, EIA, 2004; U.S. Climate Change Technology Program, 2003). Primary energy consumption (including feedstocks) for this industry in 2025 is estimated to be over 8500 TBtu (U.S. DOE, EIA, 2004). Any process facilitating such separations will result in enormous savings of both energy and waste (U.S. Climate Change Technology Program, 2003). Gas and liquid membranes offer an alternative to liquid-liquid extraction, and use much less energy. This technology can be used to separate both aqueous and organic mixtures. Membrane separation uses 60 percent less fuel than liquid-liquid extraction for separating a mixture of isopropyl alcohol and water. Separation processes account for one quarter of the process energy to produce isopropyl alcohol. A recent assessment found primary energy savings potentials of 20% and 53%, respectively, for specific applications of gas and liquid membranes as replacements in the production of methanol and isopropyl alcohol, respectively, resulting in potential savings of 0.08 TBtu and 0.81TBtu of primary energy in 2015 (Martin et al., 2000). Assuming increased penetration of membranes in these two applications as well as use of membranes in other applications in the chemicals industry, energy savings of about 95 TBtu will be realized in 2025, assuming membranes reduce about 2.5% of total projected chemical industry primary energy consumption.

Wastewater. Water and wastewater facilities operated by U.S. business, industrial, municipal water users, and others consume 75 billion kWh of electricity annually, or about 3% of the total U.S. electricity consumption (U.S. DOE, OIT, 2002a). Most industrial wastewater is pre-treated with physical, chemical or biological means before being disposed to the public sewer system or surface water. Large industrial facilities may need to evaporate water for sludge disposal.

Tri-Valley Growers in Madera, CA installed an UF/RO-membrane system, with help of PG&E and DOE, to reduce wastewater discharge of an olive-oil plant. The system allowed the operation of the plant with zero discharges. The system reduced capital costs and energy costs compared to a biological wastewater treatment system. Gas use was reduced by 55 percent and electricity use by 30 percent, reusing up to 800,000 gallons of water per day (Fok and Moore, 1999). Replacement of polymer membranes by ceramic membranes in an UF-system to clean wastewater from an enameling plant reduced power consumption by 66 percent, due to the reduced silting of the system (CADDET, 1994).

A closed-loop zero-effluent discharge paper mill using pressurized ozone with dissolved air flotation and an ultrafiltration membrane in series allows total dissolved solids in process water to be readily converted to total suspended solids for efficient removal, saving energy through avoiding the cost to heat incoming fresh water. The reduced heating requirements will save an average mill producing 500 tons of paper a day approximately 75 billion Btu/year. Based on 15% market penetration by 2010, annual savings are estimated to be 8.2 trillion Btu. Market penetration of 35% by 2025 is estimated to save almost 20 trillion Btu (U.S. DOE, OIT, 2002b).

It is extremely difficult to estimate the potential energy savings from implementation of membranes for water treatment without a detailed study. For specific applications energy savings may be up to 40-55% of the energy needs for evaporation. Additional production savings are achieved through product quality, reduced water use, lower operation costs, which are site-specific. A recent assessment estimated primary energy savings (accounting for fuel savings and increased electricity use) of about 30% and projected potential primary energy savings of almost 120 TBtu in 2015 for projects with a payback period of 4.7 years or less (Martin et al., 2000). Assuming wastewater energy consumption grows at a rate of 1.2% per year between 2015 and 2025 (slightly slower than the projected 1.4% average annual growth projected for the manufacturing sector as a whole during this period) and the availability of slightly greater savings of 35%, the projected primary energy savings in 2025 are estimated to be almost 160 TBtu.

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4. Gasification

4.1 Technology

4.1.1. Technology Description

Various energy-intensive industries produce low-grade fuels as a by-product of the production process. Currently, these low-grade fuels are combusted in boilers to generate steam or heat. Often, this results in relatively less efficient use of these fuels. Gasification offers opportunities to increase the efficiency of using low-grade fuels. In gasification, the hydrocarbon feedstock is heated in an environment with limited oxygen. The hydrocarbons react to form synthesis gas, a mixture of mainly carbon monoxide and hydrogen. The synthesis gas can be used in more efficient applications like gas turbine-based power generation or as a chemical feedstock. The technology not only allows the efficient use of by-products and wastes, it also allows low-cost gas cleanup (when compared to flue gas treatment). Various industries are pursuing the development of gasification technology, and are at different stages of development. Furthermore, gasification technology can also lead to more efficient and cleaner use of coal, biomass and wastes for power generation. A special gasifier-type is the molten iron bath gasifier, which is the basis for the smelt reduction process. However, this technology would warrant a separate description. This report focuses on industrial uses of gasification technology.

4.1.2 Specific End-Uses and Applications

In this description we highlight two main areas of current gasification development: the pulp and paper industry and petroleum refining. Both are energy-intensive industries that use a considerable amount of the total energy consumed in the U.S.

Pulp & Paper. In standard integrated Kraft mills, the spent liquor produced from de-lignifying wood chips (called black liquor) is normally burned in a large recovery boiler in which the black liquor combustion is used to recover the chemicals used in the delignification process. Because of the relatively high water content of the black liquor fuel (the fuel is usually combusted at a solids content of 65-75 percent), the efficiency of existing recovery boilers is limited. Electricity production capacity is also reduced since recovery boilers produce steam at lower pressures for safety reasons. Gasification allows not only the efficient use of black liquor, but also of other biomass fuels such as bark and felling rests to generate a synthesis gas that after cleaning is combusted in a gas turbine or combined cycle with a high electrical efficiency. This has the potential to increase the electricity production within the pulp mill. The technology is called black liquor gasification-combined cycle (BLGCC, see Figure 4.1). The black liquor gasifier technology produces a surplus of energy from the pulp process, creating the possibility to generate several different energy products for external use, i.e. electricity, heat and fuels. Alternatively, the synthesis gas can be used as a feedstock to produce chemicals, allowing the development of the “bio-refinery.” In Europe, policies focusing on an increasing share of biomass in transportation fuels have led to the increased interest of using black liquor gasifiers for the production of Dimethylether to replace diesel fuel.

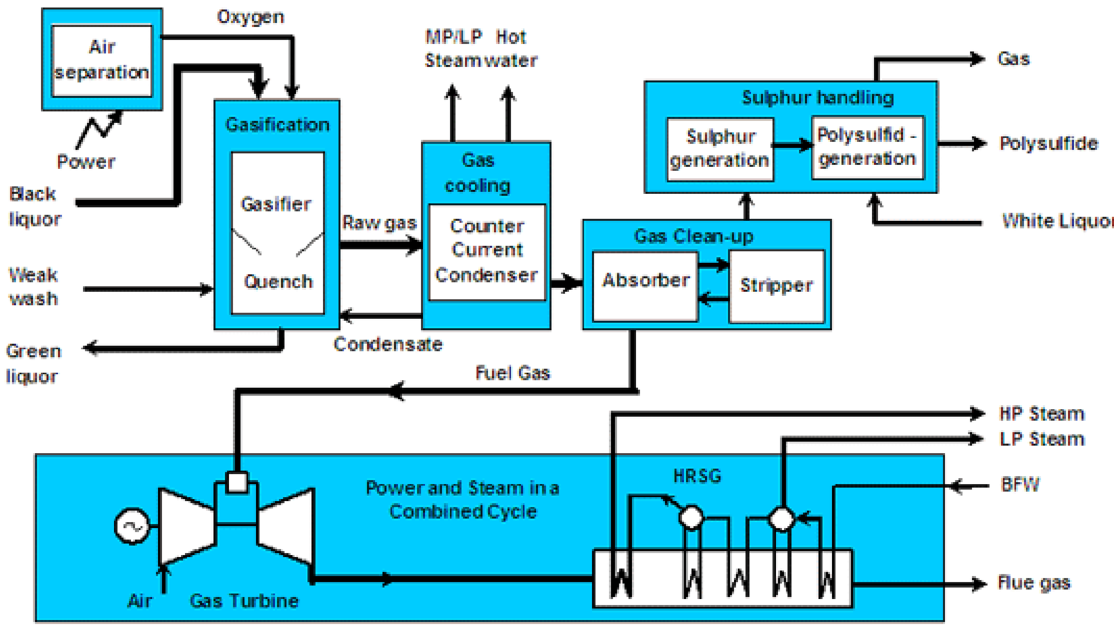

Figure 4.1. Schematic Representation of a Black Liquor Gasifier Integrated with a Combined Cycle (BLGCC). Source: Chemrec, Sweden

Gasifiers can use air or pure oxygen to provide the oxygen needed for the chemical conversions. The advantage of an air-blown gasifier is the reduction in investments. However, the disadvantage is the production of a synthesis gas with a lower heating value. The richer synthesis gas allows easier combustion in a gas turbine. The gas consists of hydrogen, carbon monoxide and hydrocarbons. After cleanup, the gas is well suited as a fuel for gas turbines. The black liquor gasification process can also be divided in different groups based on the form of sodium, i.e., in smelt or solid form. The smelt process is a high temperature process where the sodium is found as molten sodium sulfate and sodium carbonate. The process where the sodium is held in solid form is operated at a lower temperature compared to the smelt process. A natural separation of sulfur from sodium is provided through the gasification process, which allows opportunities for advanced pulping methods. This makes it possible to enhance pulping by modifying conventional pulping liquors (Larson et al., 2000).

Petroleum Refineries. Because of the growing demand for lighter products (e.g., gasoline) and increased use of conversion processes to process a “heavier” crude, refineries will have to manage an increasing stream of heavy bottoms and residues. Gasification of the heavy fractions and coke to produce synthesis gas can help to efficiently remove these by-products. The state-of-the-art gasification processes combine the heavy by-products with oxygen at high temperature in an entrained bed gasifier (see Figure 4.2). Due to the limited oxygen supply, the heavy fractions are gasified to a mixture of carbon monoxide and hydrogen. Sulfur can easily be removed in the form of

H_2S to produce elemental sulfur. The synthesis gas can be used as feedstock for chemical processes. However, the most attractive application seems to be the combination of hydrogen production and generation of power in an Integrated Gasifier Combined Cycle (IGCC). The increased use of conversion processes in the refinery will lead to an increased demand for hydrogen. Hydrogen is removed from the synthesis gas, and the remainder is combusted in a gas turbine (with an adapted combustion chamber to handle the low to medium-BTU gas) generating electricity. The hot flue gases are used to generate steam. The steam can be used onsite or used in a steam turbine to produce additional electricity (i.e. the combined cycle). Steam can also be used onsite when using a backpressure turbine. This technology will result in greater efficiencies in power generation, reduced air pollution (compared to conventional boilers) and reduced solid wastes.

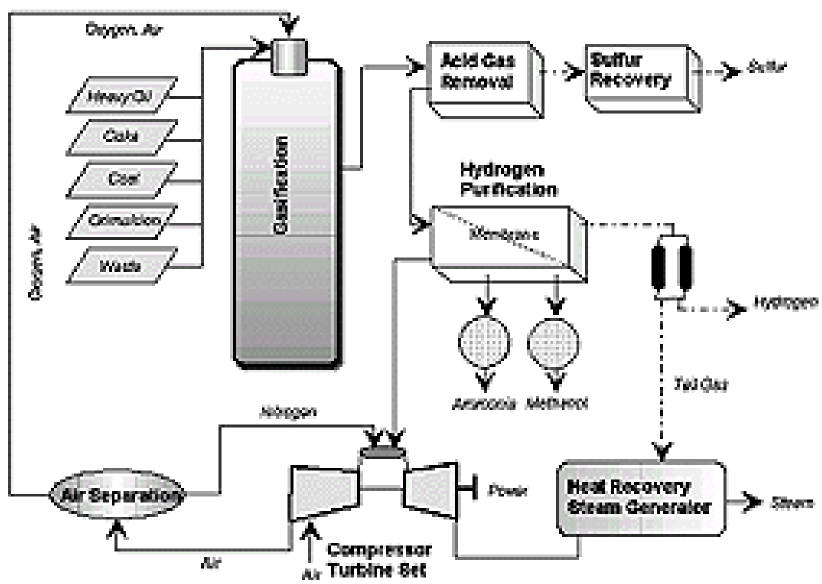

Figure 4.2 Schematic Representation of a Typical Gasification System in a Petroleum Refinery. Source: U.S. Energy Information Administration.

4.1.3 Current Status

In the **pulp and paper industry**, different gasification technologies are being demonstrated at commercial scales. Both air-blown and oxygen-blown gasifiers are being tested and demonstrated. A natural separation of sulfur from sodium is provided through the gasification process. This allows enhanced pulping by modifying conventional pulping liquors (Larson et al., 2000). An increased pulp yield of about 5-7% can be achieved (Larson et al., 2003).

The main developers of black liquor gasification can be found in the U.S. and Scandinavia (Sweden and Finland), and the teams collaborate in the development of the technology. In the U.S., development has focused on both the air and oxygen-based process. The air-based process was originally developed by MTCI, and has been investigated in a small-scale pilot plant at the Weyerhaeuser plant in New Bern (North

Carolina). Georgia-Pacific will build at the Big Island (Virginia) mill, while Boise Cascade also plans to demonstrate a gasifier. International Paper has selected two sites for high-pressure oxygen gasifiers. Weyerhaeuser is now collaborating with Chemrec (Sweden) to design and build an oxygen-based gasifier at its New Bern plant. Chemrec expects the first fully commercial application of its technology by 2006. Both for the low-temperature and high-temperature technologies, there are technical issues that need R&D attention to increase the reliability of the gasifier.

In **petroleum refining**, gasifiers are entering commercial use. Entrained bed IGCC technology was originally developed for refinery applications, but is also used for the gasification of coal. Hence, the major gasification technology developers were oil companies like Shell and Texaco. The technology was first applied by European refineries due to the characteristics of the operations in Europe (e.g., coke was often used onsite). IGCC is used by the Shell refinery in Pernis (The Netherlands) to treat residues from the hydrocracker and other residues to generate 110 MWe of power and 285 tonnes of hydrogen for the refinery. Also, the IPA Falconara refinery (Italy) uses IGCC to treat visbreaker residue to produce 241 MWe of power (Cabooter, 2001). Interest among U.S. refiners has increased, and 3 U.S. refineries currently operate gasifiers, i.e., Motiva (Delaware City, DE), Frontier (El Dorado, KS) and Farmland (Coffeyville, KS). New installations have been announced or are under construction for the Sannazzaro refinery (Agip, Italy), Lake Charles, (Citgo, Louisiana) and Bulwer Island (BP, Australia).

Gasifiers may also provide an attractive option for **food-processing** facilities that produce large amounts of waste, e.g. rice straw, bagasse (from cane-sugar production), shells and others. Regional facilities in areas with food processing plants may provide a cost-effective and energy-efficient way to process these by-products and wastes. However, we have not studied this in detail.

4.1.4 Research & Development Needs

While gasification in petroleum refineries is being implemented in more and more refineries worldwide, demonstration and further development of black liquor gasification is needed to make this technology commercially attractive. After successful commercial demonstration and cost reductions, implementation of BLGCC-technology will be driven by the retirement of current Tomlinson boilers, many of which will be retired over the next decades. However, R&D in oil residue gasification could make this technology more attractive. R&D focuses on improving the reliability, increasing the energetic efficiency, and reducing costs for materials used in the construction. Important areas for R&D are:

- Improved high-temperature gas cleanup systems to remove sulfur, alkali metals, and dust to increase the energetic efficiency of these systems considerably
- Demonstration of advanced pulping and black liquor gasification at near commercial scales to demonstrate the important benefits of integration.
- Improved materials to line the gasification reactor to increase operating hours between maintenance stops.
- Improved combustion turbines for operation on low to mid-calorific gases.

4.2 Cost

4.2.1 Baseline and New Technology

Gasifiers are an attractive way to use low-grade fuels to make a valuable by-product both at refineries and pulp and paper plants.

Larson et al. (2003) performed a cost-benefit analysis of **black liquor gasifier/combined cycle (BLGCC)** for a typical Kraft pulp and paper mill. Over the next 10-20 years, almost all recovery boilers will be retired, providing excellent opportunities to introduce advanced technology. The total capital costs of a BLGCC system are estimated to be about 60-90% higher than that of a standard Tomlinson boiler system. The high-temperature will have relatively lower capital costs than the low-temperature process. The capital costs for a plant with a capacity of 550,000 tons of pulp are estimated at $194 million, compared to $122 million for a Tomlinson system. Annual non-fuel O&M costs are estimated at $10.6 million. BLGCC can have positive macro-economic impacts due to reduced use of imported fossil fuels and maintained or increased regional development.

Petroleum Refining. Marano (2003) studied the efficiencies and costs of gasification processes at refineries. In this study, cost estimates were developed for different configurations. In the base case of the study it is assumed that a gasifier with a capacity of 2000 tons per day would cost $188 million, while the hydrogen plant would cost another $41 million and the combined cycle would cost $159 million (Marano, 2003). In this analysis we assume that the plant is used as an IGCC, with total costs of $347 million for a 178 MW facility. In a more advanced case, the cost of the technology would come down to $286 million. In the more advanced case the specific capital costs are estimated at $408/ton throughput. Gray and Tomlinson (2002) estimated that 40 refineries in the U.S. produce enough byproducts to justify the use of a gasifier. The largest 40 refineries in the U.S. represent over 60% of the refining capacity (O&G Journal, 2003). The baseline is assumed to be a conventional boiler to burn petroleum coke and heavy fuel oil. No cost estimates are available for such a boiler. However, it is likely considerably less than a gasifier system, dependent on the air quality standards to be met.

4.2.2 Cost-Effectiveness

Pulp & Paper. Black liquor gasification is a strategic investment. The IRR of an investment into a BLGCC is estimated at 16-17%, based on electricity sold at 4 cents/kWh. However, if a premium of 2.5 cents/kWh is added to the price of electricity produced from pulp and paper biowaste (as part of a renewable energy policy) the IRR may go up to 24-26% (Larson et al., 2003). The high rate of return is the result of increased pulp production and power sales to the grid, despite the increased capital costs.

Petroleum Refining. The simple payback period of a refinery integrated gasifier system is estimated to be 4 to 5 years (Gray and Tomlinson, 2002), depending on the price of natural gas and oil. Increasing use of gasification units will reduce the perceived risks and lead to further reductions in cost as investments in the technology increase.

4.3 Energy

Energy savings depend strongly on current technology baseline assumptions. We provide estimates of the typical energy savings, as well as an estimate of the technical potential in the U.S. for both applications. Additional energy savings may exist in other sectors or applications. Both applications may result in considerable potential for power production within the two industries. In 1998, industry purchased almost 890 TWh of electricity.

4.3.1 Baseline and New Technology

Pulp & Paper. Existing recovery boilers consume roughly 27 MBtu of black liquor and other biomass per short ton of air-dried pulp. Power production efficiencies using steam turbine systems in current Tomlinson boiler systems are estimated at 10 percent (Consonni et al. 1998, Larson et al. 1997), resulting in the generation of 790 kWh/ton of pulp, sufficient to cover part of the internal power demand in a pulp mill. In 2002 the U.S. pulp and paper industry produced 49.8 million short tons of chemical pulp, producing around 39.4 TWh of electricity from black liquor.

While increased fuel inputs are required for gasification systems, and increased electricity inputs are required (especially for gas compression in the combined cycle system), power efficiencies are much higher, thereby allowing for significant primary energy savings. Based on an electricity production capacity of 1740-1860 kWh/ton, and the performance of a typical Kraft-plant in the Southeastern U.S., a plant will be able to export 220-335 kWh/ton of pulp (Larson et al., 2003). At the 2002 production level of chemical pulp, the U.S. pulp and paper industry could produce around 89.6 TWh of electricity, or double that of the current Tomlinson boiler system, or 50.2 TWh additional to the current power production in the pulp and paper industry.

Petroleum Refining. In 1999, U.S. petroleum refineries produced 96,200 tons of coke per day, virtually all in the 40 largest refineries. A portion of this was burned off in the Fluid Catalytic Cracker to regenerate the catalyst. With increasing production of lighter products the coke production at refineries is expected to increase to 116,000 tons/day in 2010 (Gray and Tomlinson, 2000). Petroleum coke and heavy residues are currently combusted in a boiler or sold as fuel to cement kilns or disposed to a landfill. Currently, a large part of the coke is sold. To allow modeling of the technology, we assume that the petcoke and other heavy residues are combusted onsite. The generated steam is used for power production in a steam turbine. In reality, steam is most likely to be used for process heating. Assuming a power generation efficiency of 28% for a petcoke-fired boiler and steam turbine system, baseline energy use would be 84.4 TWh/year.

The net power production of a refinery based IGCC plant is estimated at 38-45%. Marano (2003) estimates net power production at 3,323 kWh/ton petroleum coke at an efficiency of 38.2%. The efficiency of an IGCC using heavy fuel oil is expected to be around 40% (Marano, 2003). In this assessment we assume that by 2025 the efficiency will increase to 45%, or a net power output of 3,914 kWh/ton petcoke. Based on the 1999 coke production, total power production can be 135.7 TWh/year, or 51 TWh over the baseline.

The above efficiencies are based on operation of the IGCC as a dedicated power production unit. However, the system can also be operated as a trigen-unit, generating electricity, steam and producing hydrogen. The overall system efficiency of such a system is higher, but harder to quantify, as it depends on the efficiency of the current steam reforming facility and of boilers. In practice, we expect the gasifiers to be run as a trigen-unit. However, for this analysis we focus on power production.

4.3.2 Potential Energy Savings

Pulp & Paper. Additional electricity production from black liquor and biomass is estimated at 50.2 TWh, or 1000 kWh/ton of chemical pulp. The primary energy savings (assuming an average efficiency of 32% for power generation) are estimated at 10.3 MBtu/ton of pulp.

Petroleum Refining. The potential energy savings are estimated at 51 TWh (assuming 1999 coke production) or 62.6 TWh in 2010. The specific energy savings are estimated at 1478 kWh/ton coke, equivalent to 18.5 kWh/barrel of oil processed.

For 2025, the combined technical potential in both sectors is estimated at 115 TWh/year. Assuming a penetration rate of 40% (based on stock turnover and age distribution of Tomlinson boilers, and the need for increased residue processing at refineries), we estimate the likely realized potential by 2025 at 45 TWh. This is equivalent to primary energy savings of 461 TBtu additional to the baseline scenario (AEO 2004).

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5. Motor Systems

5.1. Technology

5.1.1 Technology Description

Motor-driven equipment accounts for 64 percent of the electricity consumed in the U.S. industrial sector. Motor systems are made up of a range of components centered around a motor-driven device such as a compressor, pump or fan (see Figure 5.1).

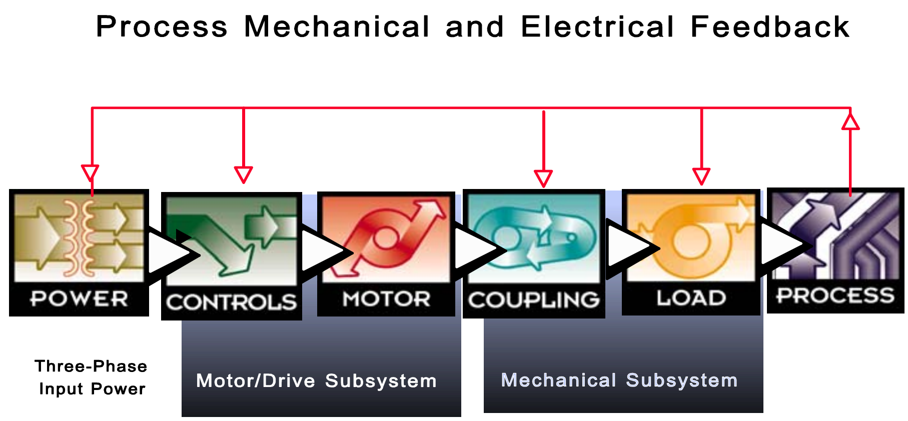

Figure 5.1 Schematic Representation of a Motor System. Source: U.S. Department of Energy

Motor systems performance optimization focuses on optimizing the flows in motor-driven systems to meet end-use requirements. The opportunity for energy savings derives from the fact that the power consumption of the end user varies as the cube of the speed, while output varies linearly. As a result, small changes in motor speed can yield large energy savings, so it is important to closely match output to end-use requirements. Many of these opportunities can be implemented today, but motor operators often fail to do so. However, in the long term new motor technologies may improve the energy efficiency further.

Emerging motor system improvements can be categorized into the following three areas of development opportunities:

1. Upgrades to the motors themselves, for example:
   - superconductive motors,
   - permanent magnet motors,
   - copper rotor motors,
   - switched reluctance (SR) drives,
   - written pole motors, and
   - very low loss magnetic steels; and

2. System design optimization and management, such as:
    - end use efficiency improvements,
    - use of premium lubricants, and
    - advanced system design and management tools; and

3. Controls on existing systems, for example:
    - multi-master controls on compressors,
    - sensor based controls, and
    - advanced adjustable speed drives with improvements like regenerative braking, active power factor correction, better torque/speed control.

New Motors. Superconductivity is the ability of certain materials, when cooled to extremely low temperatures, to conduct electrical current without resistance and with extremely low losses. High temperature superconductor (HTS) motors operate at temperatures between -280 to -320°F (-173 to -195°C), achievable through liquid nitrogen cooling. These motors are expected to exhibit longer operating life, greater safety, higher overload thresholds, reduction in friction, and reduced noise, size, volume and weight.

Permanent magnet (PM) motors either have replaced the stator winding on a motor with a permanent magnet or contain a stator with three windings producing a rotating field and a rotor with one or more permanent magnets that interact with the rotating field of the stator. By switching the direction of current through the stator windings, the polarity of their magnetic field is reversed causing the rotor to rotate. The most common type of PM motor is the electronically commutated permanent magnet motor (ECPMs), also known as the brushless DC motor (Nadel et al., 2002). ECPMs have a rotor with multiple permanent magnets and a stator with electrical windings creating the varying magnetic field. These motors can achieve varying speeds by varying the rate at which the magnetic fields are reversed (or commutated). ECPMs eliminate rotor resistive losses, brush friction, and maintenance associated with conventionally commutated motors. Other advantages include precise speed control, lower operating temperature and higher power factor than induction motors. High speed PM motors are also being developed for the commercial air conditioning market for increased efficiency.

Two new motors have been developed based on identifying the best materials to use in the casting process. Copper rotor motors and magnetic steel motors replace aluminum in the rotor “squirrel cage” structure of the motor since the electrical conductivity of these materials is up to 60% higher than aluminum and hence, produce a more energy-efficient induction motor. In addition, copper reacts with much more stability to changing loads, especially at low speeds and frequencies, operates cooler and has fewer repairs and re-windings, increasing motor life and decreasing maintenance costs (CDA & ICA, 2001).

Written pole (WP) motors are hybrids of induction motors during start-up, and synchronous motors upon reaching full operating speed. The single-phase motor combines the starting characteristics of a high-slip, high-power factor cage motor with the energy-efficiency of an AC permanent magnet motor without power electronics, reduced voltage starters or phase converters. The WP “writes” the number of poles and their locations electronically on the rotor, obtaining higher efficiency and a lower start-up inrush current. Written pole motors can now be used in applications for which only three-phase motors were available in the past.

Switched reluctance drives are simple, compact, brushless, electronically commutated AC motors that offer high efficiency and torque. The stator of the motor consists of steel poles each wound with a series of coils, connected in pairs, while the rotor is just a shape piece of steel or iron forming poles with no magnets or coil windings. Current is switched among the different-phased windings of the stator to rotate it. Their advantages include variable speed regulation and high efficiency in extremely high and low speed ranges (50 to 100,00-rpm), precision control, high vibration tolerance, high power density and simple construction. However, high pulsating magnetic flux cause acoustic noise and large vibrations; therefore, these motors require considerable control to properly switch current, and the specialized design that SR motors require is non-intuitive relative to traditional motors (Paula, 1998).

System Design Optimization and End Users. Designing a system that properly matches supply to demand is crucial to energy efficiency. All components of the motor system, including compressed air, pumps, fans and motors should be optimized to minimize demand and increase efficiency. Experts can be hired to manage the compressed air to minimize leaks, identify inappropriate uses of compressed air and determine proper system pressure level. Likewise, system optimization for pump systems and motors can be outsourced as a service as well, identifying system requirements and selecting the proper motor or end user. While the engineering associated with pump systems is well understood, many engineers are not experienced in conducting the energy efficiency analyses that their system requires (Martin et al, 2000). Pump systems may require slowing pumps, trimming the impellers, or replacing an existing pump. Free software tools are available that can identify system requirements for energy efficiency. One example is from the Motor Challenge Program at the Office of Industrial Technologies (U.S. DOE, OIT, 2004). In addition to system management for motors and motor systems, selecting a premium lubricant for the equipment can reduce friction losses, particularly in end-use equipment like compressors, pumps and gear drives, and increase system efficiency.

Controls. Many controls are available for motors and motors systems and they are continuously being updated. Today, more options are available to meet more system demands, and where one control does not work, another likely does. Still, all types of adjustable speed drives (ASDs) have only penetrated 9% of U.S. motor systems (Easton Consultants, 1999). A new class of ASDs - magnetically-coupled adjustable speed drives (MC-ASDs) offer a greater range of possibilities for ASDs; two particularly promising devices are the MagnaDrive and the PAYBACK drive. In the MagnaDrive, fixed rare earth magnets create an induced electromotive force to transfer torque. The physical connection between motors and loads is replaced with a gap of air, and the amount of torque transferred is controlled by varying the air gap distance between rotating plates in the assembly. The PAYBACK Drive is similar to the MagnaDrive but instead of rare earth magnets, an electromagnet is used to control the speed of the drive. Current is applied to the coil of the electromagnet rotor and speed is controlled by varying the strength of the magnetic field.

Compared to variable frequency drives (VFDs), MC-ASDs have many advantages in addition to greater energy efficiency, including:

- a greater tolerance for motor misalignment,
- little impact on power quality,
- the ability to be used with regular duty motors (instead of inverters),
- expected lower long term maintenance costs, and
- extended motor and equipment lives, due to elimination of vibration and wear on equipment (Chvála, 2002).

Other advanced ASDs include development of different inverter technologies, such as the snubbed inverter or the hybrid secondary uncluttered induction machine (HSU-I) both developed at Oak Ridge National Laboratory. HSU-I adds a section to an existing motor to make it adjustable with simple resistors and other low-cost components, rather than the typical adjustable frequency inverters. Three types of secondary circuits – variable resistance, inverter and magnetic switch can be used in varying combinations. The SR drive can also be used as an ASD (see above).

In addition to ASDs, system controls can be implemented on systems of motors or components to minimize energy consumption, to evenly distribute wear and tear on equipment and to allow for smooth operation of entire systems. For example, advanced compressor controls can handle multiple compressors that communicate with each other. One network boasts the ability to control up to 31 drives together at once (PML Flightlink, 2004). Sensor controls can monitor air quality or other end uses and feedback to the motor for adjustment.

5.1.2 Specific End-Uses and Applications

New Motors. Because of the variety of new motors emerging, many applications have efficient motor options; however, most new motors are best suited for a particular application, range of sizes or flexibilities. Below motors are categorized according to the sizes that are typically seen for each application. Most motors can be applied to a broader range of sizes, but those below are those seen most often (and most economical to manufacture).

Motors > 1000 HP.

Superconductor motors are being developed for a targeted size of 1000 HP and above. Though most motors are very small (1 HP or less), in terms of electricity, large motors of 1000 HP and above convert 30% of all electricity generated in the U.S., of which 70% are well suited to utilize high temperature superconductor technology (Lawrence and Cox, 2002). Xenergy (2000) estimates motors over 200 HP use 45% of the energy used by motors of all sizes (above 1 HP). Superconductor motors will be well suited for standard large motor applications like centrifugal compressors, boiler feed pumps, force draft fans and industrial scrubbers, blowers and belt drives.

Motors <600 HP.
ECPM motors are already in use in HVAC fans, drives and small appliances in the U.S., and can currently be used for applications of up to 600 HP in size (Saskatchewan, 2004). High speed PM motors are being developed for 25 ton or larger compressed air motors used for air conditioning (U.S. DOE, OIT, 2000).

Motors > 200 HP.
The copper rotor motor targets motors of 200 HP and above, although a few smaller specialty purpose motors have been produced when other factors, such as reliability, are more important than costs (Brush et al., 2002). However, if pressure-die casting can be extended to 20,000 shots per die, the economics of motor operation and manufacturing will favor copper in all classes of motors (Peters and Cowie, 1998).

Motors <75 HP.
Written pole motors are available in 15 to 75 HP sizes, and could potentially replace 4% of the integral-horsepower general-purpose motors in service today (Nadel et al., 2002).

All motor sizes.
Like the copper rotor motor, the switched reluctance drive is a good choice when high reliability is required (Paula, 1998). SR motors could potentially replace 20 to 50% of the existing general-purpose motors in service today (Martin et al., 2000).

System Design Optimization and End Users. Motor systems can be optimized for energy efficiency through experts, training programs or computer tools. Sometimes the only barriers to system optimization are a lack of awareness of opportunities or a lack of expertise available for assessment. Capabilities and market demand need to grow at the same rate for system optimization through performance services or experts to expand. We assume about 25 to 50% of the motors, pumps, and compressed air systems can be optimized when hiring experts, using self-assessment tools or completing management training programs to train staff for system optimization. About half of the motors used in industry are eligible for premium lubricants applied by the customer since many smaller motors use sealed bearings that are not user serviceable.

Controls. Today's ASDs are available to a wider range of applications than VFDs. MC-ASDs easily mount on the shaft of any AC motor and therefore can be applied to both new and retrofit motors. The MagnaDrive is well suited for direct-drive loads like fans, pumps and blowers for medium to large sized motors from 20 to 1000 HP. The PAYBACK Drive is best for belt-driven loads and, although in theory can service all motor sizes, today they are only available from 3 to 250 HP. We predict all applications requiring variable speed will have some form of advanced control drive available to them. In addition, we assume about half of the energy used in systems like large multicompressor systems can be optimized using advanced system controls like the multi-master compressor controls for compressed air.

5.1.3 Current Status

New Motors. Rockwell Automation, in partnership with DOE, has successfully demonstrated and tested a cryogenically cooled 1000 HP HTS motor. A prototype 5000 HP HTS motor has been developed by American Superconductor™ (AMSC) that utilizes an off the shelf cryogenic cooling system. The motor successfully passed full load testing at rated voltage, rated current and rated power, sustaining a maximum load of 7,000 HP at rated speed. The current barrier to marketability is costs, particularly wire costs (see below). HTS generators are currently being used in ship propulsion generators (AMSC, 2004).

Over 100,000 PM motors are in used in HVAC fans, drives and small appliances in the U.S. today. ECPMs are currently available from many manufacturers in sizes up to 60 HP. Powertec International and GE produce larger PM motors up to 600 HP in size. PM motors coupled with electronic speed controls are already being used in cordless power tools, residential AC, furnaces and heat pumps (Nadel et al., 2002).

The copper rotor motor is currently four to five years old, but the mold materials today require frequent replacement due to the thermal shock and fatigue experienced during casting. More research is needed on the materials and methods used in pressure-die casting of the copper rotors, their last major hurdle before they can compete in cost.

WP motors are limited to 15 to 75 HP and have been used in less than 100 commercial applications to date. WP motors are currently being used for irrigation pumps, conveyor motors, water pumps, food-processing air dryers and process stirring. At this time, however, only one manufacturer produces WP motors (Nadel et al, 2002).

Switched reluctance drives are currently used in military applications like generators for turbine engines and pump motors for jet fighters that require high reliability (Paula, 1998). However, initial publicity in the late 1990s was overly enthusiastic in its assessment of capabilities, which has hurt the market for SR motors since then (Bartos, 2003). Few engineers today are trained to construct the specialized design that the technology requires, and sensor control is costly (Paula, 1998). However, new high-speed digital signal processors specialized for motion control allows control without mechanical sensors, decreasing costs and increasing reliability (Fedigan and Cole, 1999).

System Design Optimization and End Users. Motor system management tools, experts, training programs are commercially available today. However, a lack of experts available for a particular application or assessment is possible given the overall lack of demand for services in the past. Capabilities and market demand need to grow at the same rate for system optimization through performance services or experts to expand. The only other barrier to system optimization is a lack of awareness of opportunities. Premium lubricants are commercially available to all motors eligible.

Controls. Currently all types of adjustable speed drives have only penetrated 9% of U.S. motor systems (Easton Consultants, 1999) and great potential exists for advanced ASDs. Today's ASDs are available to a wider range of applications than VFDs. MC-ASDs easily mount on the shaft of any AC motor and therefore can be applied to both new and retrofit motors. MC-ASDs are fairly new – less than 10 years old. The MagnaDrive is currently installed in pump, fan and blower installations in the pulp and paper, mining, food processing and raw materials processing industries, as well as in irrigation, power generation, water and wastewater treatment and HVAC systems. It is available in large systems from 20 to 1000 HP. The PAYBACK Drive is currently available from 3 to 250 HP and has been installed in a few applications. Multi-master compressor controls for compressed air are currently commercially available. First cost and lack of appreciation for compressed air inefficiencies are the major barriers.

5.1.4 Research & Development Needs

New Motors. The last hurdles for superconductor motors involve cost, and the drivers for cost are the costs of the wire and the refrigeration. Cryocoolers are used in some applications today but are not universal. More research is needed on the best cooling devices for superconductor motors, as well as ways to produce cheaper wires.

Currently PM motors are easy to manufacture and costs are comparable to conventional ASDs. Barriers that exist for PM motors are not of a research nature but will require information dissemination and demonstrations.

Research on pressure-die casting for the copper rotor motor will enable these motors to compete in costs in the future. Currently, commercialization is cost prohibitive only because of the expensive casting process. Mold materials need to be replaced often due to thermal shock and fatigue experienced during casting. More research on the materials or methods used in pressure-die casting of copper rotors is considered necessary for future cost competitiveness.

WP motors are currently easy to manufacture suffer only from a lack of production volume. Like PM motors, barriers for WP motors are not of a research nature but require information dissemination and demonstrations.

Switched reluctance drives currently require a specialized design and expensive sensor controls to implement. Shaft and bearing systems must be of higher quality than conventional motors, which drives up the price. Research is needed in these areas to develop SR motors that are more mainstream with simpler systems for implementation and control.

System Design Optimization and End Users. Continued research on system optimization will likely always improve efficiency of those systems. However, currently a lack of awareness is the biggest barrier to implementation of optimization techniques, not a lack of knowledge.

Controls. Similar to system optimization, lack of awareness restricts implementation of controls for motor systems. In addition, however, most systems are not evaluated on a life-cycle basis, where long term maintenance, reliability and other long-term costs will affect their cost effectiveness. Improved dissemination of life-cycle costing may help increase penetration of advanced controls whose first costs exceed those of conventional controls.

5.2 Cost

5.2.1 Baseline and New Technology

New Motors. Depending on the new motor, relative costs vary greatly, and each has its own barriers to mass production. Superconductor motors are eventually expected to have lower capital costs due to smaller sizes and compactness and reduced operating costs due to increased energy efficiency (AMSC, 2004). Cost drivers for superconductor motors are the refrigeration and wire costs. Cryocoolers, a mature, highly reliable and relatively low cost "off the shelf" technology, are expected to cool HTS devices (Cox and Hawsey, 2000). Predictions for wire prices at which superconductor motors will be profitable range from $4 to $50 per kA-m (Port, 2002; EIA, 2002; Lawrence and Cox, 2002). Projected wire costs for the near future (after a new production facility is in place) are $10 to $50 per kA-m, compared to copper wires that cost $4 per kA-m (Port, 2002) Several kilometers of wires made up the first 1000 HP HTS motor (Port, 2002).

PM motors are easy to manufacture and costs are comparable to conventional ASDs, about $200 – 400 per HP.

The copper rotor motor commercialization is currently cost prohibitive because of the expensive casting of the rotor. Once this barrier is overcome, potentially lower purchase prices could be achieved due to the motors' reduced size. Operating costs for copper rotor motors are less than conventional aluminum motors. In addition, life expectancy of the motor itself is predicted to be 50% greater, increasing overall cost effectiveness of the motor.

WP motors are simple to manufacture, but costs are still high because of the lack of production volume (Nadel et al, 2002). The installation cost of a 20 HP WP motor and controller package is about 60% higher than for a conventional induction motor. Once the production volume reaches full production levels, the cost premium is expected to drop by 50%, bringing installation costs down to 30% higher.

Switched reluctance motors and their associated controls, starters and enclosures cost about 50% more than comparably sized and equipped induction motors with variable speed controls (Martin et al., 2000). This price is likely to drop to half (25%), if and when SR motors are more widely accepted and with new developments in controls. Currently shafts and bearing systems must be of higher quality than conventional motors, driving up the price.

System Design Optimization and End Users. There are generally no system optimization capital costs because no equipment needs to be purchased. Some fees for staff time or hiring an expert may be required. Many optimization tools are offered free of charge through DOE and require no investment costs. Premium lubricants cost 1.5 to 2.5 times more than conventional lubricants but last three to four times as long.

Controls. MC-ASDs installation costs are comparable to VFDs, when compared over a lifetime. The manufacturers of the MagnaDrive report costs of up to $600 per installed HP: $400 per HP for 25 to 100 HP and $300 per HP for 100 to 500 HP. Conventional ASDs cost between $200 and $400 per HP. However, the life expectancy of the MC-ASDs is longer – 30 years compared to 5 to 10 for conventional ASDs. Long-term maintenance costs are expected to be reduced, and MC-ASD motor systems can be downsized more easily than conventional ASD systems. Advanced ASD designs and advanced compressor controls will cost more up front than conventional ASDs or simpler controls but provide operational savings due to energy efficiency.

Table 5.1. Cost Estimates for Emerging Motor Technologies

Technology	Current Capital Costs	Capital Costs by 2025	O&M Costs	Payback by 2025	Notes
New Motors					
Superconductor	Higher	Lower	Lower	0-1 year	If wire costs decrease, payback will be short to none
Permanent Magnet	Roughly equal	Roughly equal	Lower	12-30 months	High speed PMs will have payback of 12-30 months
Copper Rotor	Higher	Potentially lower	Lower	0-1 year	If die casting costs decrease, payback will be short to none
Written Pole	60% higher	30% higher	Lower		
Switched Reluctance	50% higher	25% higher	Unclear		Controls are more complex but SRs are more efficient. Likely will be driven by reliability
System & End Use Improvements					
Optimization Experts	None	None	Higher initially, then lower	≤1 year	Cost of expert outweighed by energy efficiency savings
Optimization tools	None	None	Higher initially, then lower	≤1 year	Cost of time spent on tools outweighed by energy efficiency savings
Training programs	None	None	Higher initially, then lower	≤1 year	Cost of employee time (training) outweighed by energy efficiency savings
Premium lubricants	50-150% higher	50-150% higher	Lower	≤1 year	Premium lubricants last 3 to 4 times as long
Controls					
MagnaDrive	Higher	Higher	Significantly Lower	<4[4]	Initial capital costs are higher compared to non-ASDs, but more comparable to conventional ASDs
PAYBACK drive	Higher	Higher	Significantly Lower	≤1[4]	Initial capital costs are higher compared to non-ASDs, but more comparable to conventional ASDs
Advanced ASDs	Higher	Higher	Lower	Upon first avoided failure	Advanced ASDs that provide sag control pay for themselves upon first shutdown prevention.

[4] One study estimates payback periods currently at 4 to 5 years for MagnaDrive and 1 to 2 years for PAYBACK drive (Chvála et al, 2002). Costs and payback periods are decreasing for both technologies.

5.2.2 Cost-Effectiveness

Capital costs, operations and maintenance costs and predicted paybacks for particular motor applications are summarized in Table 5.1.

5.3. Energy

5.3.1 Baseline and New Technology

Motor systems are broad cross-cutting technologies that are used by every sector and every industry in the U.S. Motor-driven equipment accounts for 64 percent of the electricity consumed in the U.S. industrial sector, equal to about 6.4 quads (6,400 TBtu) (DOE, 2004). Total energy savings potential for upgrades in motors and motor systems has been estimated to be 15 to 25% (higher when emerging technologies are included) (Nadel et al., 2002). Below we address each of the areas discussed above for energy savings potential[5].

New Motors. Compared to conventional motors, superconductor motors are more efficient at all speeds greater than 5% partial speed up to fully loaded. According to U.S. DOE, current motor efficiency for conventional 500 HP motors is 95 to 96% (U.S. DOE, 1996). Superconductor motors are expected to have half the energy losses (NREL, 2001); at low speeds, AMSC predicts energy efficiency for HTS motors can be increased by 10%. Cryogenic cooling is used to cool the system, but accounts for less than 2% of the total losses in the machine (AMSC, 2004). Net operating efficiency including the cryogenic cooling system is 97.2% for the prototype 5000 HP motor, with expected efficiencies to reach 97.7% for this motor. At one-third to full speed, efficiencies are expected to reach 99%.

Typical induction motor/ASD drive combinations have a range of efficiencies between 85 and 90% at full load. The prototype of the high speed PM motor has an efficiency of 93 to 95% at full load; high speed PMs are predicted to save up to 10 to 15% savings over conventional motors (DOE, 2000). ECPMs are as high as 95% efficient at full load and can maintain their efficiencies better at part load (Nadel et al, 2002). Improved materials may increase efficiencies; a 50 HP PM with a 97% efficiency has been developed.

Copper rotor motors have been shown to reduce total motor losses by 10 to 15%, yielding energy savings of about 1.4% for a 15 HP motor (CDA, 2004), and 1 to 5% for a range of motor sizes from 4 HP to 270 HP (Peters et al., 2002). Energy savings of 1 to 3% are predicted for each motor implementing copper rotors instead of aluminum.

[5] Energy savings comparisons for motors and motor systems should be considered from wire to shaft. Since direct comparisons incorporating wire to shaft efficiencies are not always possible for a *particular* motor based on available data, we have provided the information that is available in this section for each motor type. Conventional motor efficiencies are given where appropriate for a particular comparison.

Larger WP motors are more efficient than small WP motors – maximum efficiencies for motors 40 HP and below are 92%, while efficiencies for motors 60 HP or more are 93 to 94%, for loads of 70% or higher (Nadel et al., 2002). Precise Power Corporation, who manufactures WP motors, claim efficiencies from 92 to 95%, compared to 85% for single phase alternatives (Precise Power, 2004). Small (up to 40 HP) motors efficiencies vary from 72.5 to 93%, the higher efficiencies for larger motors (DOE, 1996). We assume efficiency improvements slightly higher than that of SR motors, about 3 to 4%.

SR motors have flat efficiency curves with maximum efficiencies around 93% in integral-HP models and the low to mid-80% range for fractional HP units (Nadel et al, 2002). If adopted, energy savings relative to conventional motors are estimated to be about 3% (Nadel et al., 2002).

System Design Optimization and End Users. Large savings in energy can result from system design optimization, and this should be the first step taken when evaluating energy efficiency of the motor system. Compressed air management can often yield savings of up to 25% or more. Leaks alone can account for 20 to 30% of compressor output. Pump systems optimization will likely yield slightly lower savings, about 17% are predicted (Martin et al., 2000). Savings of 2 to 30% have been realized in motors and end uses when switching to premium lubricants; however, we conservatively estimate savings to be about 3% on average.

Controls. Compared to non-adjustable speed drives, all ASDs can save large amounts of energy – up to 60% or more where motors are not constantly fully loaded. In some applications, MC-ASDs have shown slightly less efficiency than conventional ASDs, although cooling is no longer required for MC-ASDs at some torques, which will save additional energy[6]. In addition, MC-ASDs can operate at wider speed ranges and can easily be applied to retrofits where conventional ASDs cannot. The Northwest Energy Efficiency Alliance predicts that MC-ASDs will save at least 60% of the energy that typical VFDs save across a range of 50 to 100 HP drives (NEEA, 2004). Applications of the MagnaDrive provided energy savings of 25 to 66%. Advanced ASD designs will save even more energy than ASDs; about 2% is predicted (Nadel et al., 2002). Advanced compressor controls are predicted to save about 3.5% where applied (Nadel et al., 2002).

5.3.2 Potential Energy Savings

Primary specific energy savings for particular motor applications are summarized in Table 5.2. All savings are in electricity; no fuel is used in motor systems.

The total energy savings will depend on the penetration rate of new motors, controls and system improvements into the market. In turn, this rate depends on the success of R&D and the impact of market transformation and technology transfer programs. Depending on the application, some measures can be applied to retrofits of motors and motor systems

[6] Savings comparisons should be considered from wire to shaft. These studies are not available for comparisons of VFDs and MC-ASDs and therefore exact savings potential is not estimated here.

and some can only be applied to new motors (see above). Most systems can be adapted in some way for energy efficiency.

We estimated the total potential for energy savings on detailed assumptions for each individual technology. Assumptions are based on the market forecasts as included in the AEO 2004 and the NEMS motor-module, assumptions on typical energy savings and likely market penetration by 2025. The combined potential energy savings by 2025 are estimated at just below 12% of motor energy use. This is equivalent to additional electricity savings of 67 TWh or 686 TBtu of primary energy.

Table 5.2. Energy Efficiency Estimates for Emerging Motor Technologies

Technology	Energy Savings (%)	Notes
New Motors		
Superconductor	2 to 10	Higher efficiencies at partial load
Copper Rotor	1 to 3	5% has been reported
Switched Reluctance	3	
Permanent Magnet	5 to 10	
Written Pole	3 to 4	
System & End Use Improvements		
Systems Management	17 to 25	Compressed air efficiency improvements are likely greater than pumping systems or motors
Premium lubricants	3	
Controls		
MagnaDrive	Up to 60	Savings are great compared to non-ASDs. Compared to ASDs energy savings will be less.
PAYBACK drive	Up to 60	Savings are great compared to non-ASDs. Compared to ASDs energy savings will be less.
Advanced ASDs	2	Savings are compared to conventional ASDs

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6. Advanced Cogeneration

6.1 Technology

6.1.1 Technology Description

Combined heat and power systems (CHP, also called cogeneration) generate electricity (and/or mechanical energy) and thermal energy in a single, integrated system. This contrasts with the more common practice where electricity is generated at a central power plant, and on-site heating and cooling equipment is used for non-electric energy requirements. Conventional electricity generation is inherently inefficient, converting only about one third of a fuel's potential energy into usable energy. Because CHP captures the heat that would otherwise be rejected in traditional generation of electric or mechanical energy, the total efficiency of these integrated systems is much greater than from separate systems. The significant increase in efficiency with CHP results in lower fuel consumption and reduced emissions compared with separate generation of heat and power. CHP is not a specific technology, but rather an application of technologies to meet end-user needs for heating and/or cooling, and mechanical and/or electric power. Steam turbines, gas turbines, combined cycles, and reciprocating engines are the major current technologies used for power generation and CHP. New technologies, such as fuel cells, are under development, while R&D also contributes to increased efficiencies and new applications of existing cogeneration in industry.

6.1.2 Specific End-Uses and Applications

Large scale (> 10 MW). Currently, most of the installed CHP plants have capacities over 20 MW. The future potential of large-scale conventional CHP systems is estimated at 48 GW (Onsite Sycom, 2000). An increase in turbine-inlet temperature has led to increasing efficiencies in gas turbines. Industrial-sized turbines are available with efficiencies of 40 to 42% (lower heating value, LHV). The current industry "standard" is the GE LM2500 turbine with an efficiency of 34 to 40%. It is expected that the efficiencies of aero-derivative and industrial turbines can increase to 45% by 2010.

The higher inlet temperature also allows a higher outlet temperature. The fluegas of the turbine can then be used to heat a chemical reactor, if the outlet and reactor temperatures can be matched. One option is the so-called *"re-powering"* option. In this option, the furnace is not modified, but the combustion air fans in the furnace are replaced by a gas turbine. The exhaust gases still contain a considerable amount of oxygen, and can thus be used as combustion air for the furnaces. The gas turbine can deliver up to 20% of the furnace heat. The re-powering option is used by a few plants around the world. For example, two of these installations, totaling 35 MW are installed at refineries in the Netherlands.

Another option, with a larger CHP potential and associated energy savings, is *"high-temperature CHP."* In this case, the flue gases of a CHP plant are used to heat the input of a furnace. Zollar (2002) discusses various applications in the chemical and refinery industries. The study found a total potential of 44 GW additional to the conventional CHP potential in these two sectors. The major candidate processes are atmospheric distillation, coking and hydrotreating in petroleum refineries and ethylene and ammonia manufacture in the chemical industry. In 1990, GE filed a patent for the integration of a gas turbine and a steam reformer (used in ammonia manufacture) (Reay, 2002). High-temperature CHP requires replacing the existing furnaces. This is due to the fact that the radiative heat transfer from gas turbine exhaust gases is much smaller than from combustion gases, due to their lower temperature. Two different types are distinguished. The main difference is that in the first type the process feed is directly heated by exhaust gases, where the second uses thermal oil as an intermediate, leading to larger flexibility. In the first type, the exhaust heat of a gas turbine is led to a waste recovery furnace in which the process feed is heated. In the second type the exhaust heat is led to a waste heat oil heater in which thermal oil is heated. The heat content of the oil is transferred to the process feed. The second type is more reliable, because a thermal oil buffer can be included. An installation of the first type is used in Fredericia, Denmark at a Shell refinery. Here, the low temperature remaining heat is used for district heating.

Within the timeframe of this study, large-scale applications of *fuel cells* are expected to consist of parallel smaller systems, which are discussed below. In the long term, integration of industrial processes, such as reforming in the chemical and petroleum refining industries, with high-temperature solid oxide fuel cells (SOFC) is believed to lead to revolutionary design changes and allow direct co-generation of power and chemicals. However, we do not expect SOFC-integrated processes to be commercially available by 2025.

Medium scale (< 20 MW). Both in the U.S. and Europe, research aims at developing medium-scale gas turbines with high efficiencies. In Europe, the development and demonstration of a 1.4 MW gas turbine with a single cycle efficiency of 43% (LHV) is being undertaken, as part of the CAME-GT program. Current turbines of this size have efficiencies of around 25% (LHV).

Steam-injected gas turbines (STIG, or Cheng cycle) can absorb excess steam, e.g. generated due to seasonal reduced heating needs, to boost power production by injecting the steam in the turbine. Steam injection boosts the power output of the turbine. The size of typical STIGs starts around 5 MWe. Currently, over 100 STIGs are found around the world, especially in Japan, as well as in Europe and the U.S. International Power Technology (CA), for example, installed STIGs at Sunkist Growers in Ontario (CA) in 1985. Other industrial U.S. users are Frito Lay (Bakersfield, CA) and Hershey Foods (Oakdale, CA) (IPT, 2004). These systems use a 5.6 MW gas turbine.

CHP Integration allows increased use of CHP in industry by using the heat in more efficient ways. This can be done by using the heat as a process input for drying or process heating (see also above) or through tri-generation through supply of power, heating and cooling. The fluegas of a turbine can often be used directly in a drier. This option has been used successfully for the drying of minerals as well as food products. Although NOx emissions of gas turbines vary widely, tests in The Netherlands have shown that the flue gases do not affect the drying air and product quality negatively, depending on the type of gas turbine selected (Buijze, 1998). To allow continuous operation, bypass of the gas turbines makes it possible to maintain the turbine and run the drying process (Buijze, 1998). A cement plant in Rozenburg, The Netherlands, uses a standard industrial gas turbine to generate power and to dry the blast furnace slags used in cement making to replace clinker. In the food industry, an Avebe starch plant in Gasselternijveen (The Netherlands) uses a steam-injected gas turbine (STIG) installation to provide both power and heat for the plant. The gas turbine was often running at less than full load, reducing the efficiency of the turbine. Another project showed that it is more efficient to use the waste heat (i.e. flue gases) from a gas turbine directly to dry protein rich cattle feed by-product. The excess flue gas is mixed with air and used directly for the drying process. The project was expected to result in savings of 12% of total onsite fuel consumption with a simple payback period of 2.5 years (under conditions in the Netherlands in 1995) (NOVEM, 1995).

Tri-generation has been used at various commercial locations in the U.S., but less so in industry. Bassols et al. (2002) discuss various applications in food processing plants in Europe. Plants that have varying heating and refrigeration loads and that have a large refrigeration load are especially attractive, e.g. margarine and vegetable oils, dairy, vegetable and fruit processing and freezing, and meat processing. Bassols et al. (2002) discuss commercial applications varying from 4 to 9 MW capacity in The Netherlands and Spain, but do not discuss economics.

Pressure recovery turbines are an opportunity to recover power from the decompression of natural gas on industrial sites. Natural gas is transported in pipelines at a pressure of 700 psi, and large industrial facilities receive gas with pressure up to 650 psi. In the U.S. about 3.4% of the gas is used to pressurize the gas. Recovery turbines can recover part of this energy by producing power (Lehman and Worrell, 2001). The reliability of the technology has much improved since the experiments in the U.S. in the 1980s. Industrial facilities are very suitable for this technology as low-temperature waste heat is often available onsite to re-heat the gas during decompression. Many industrial sites have excess low-temperature waste heat that is currently not used due to a lack of suitable uses or due to poor economics. Lehman and Worrell (2001) estimated the technical potential in U.S. industry at 12 TWh, while the payback period depends strongly on the electricity price. With an electricity price of 10 cents/kWh the simple payback period may be as low as 3 years. The Corus iron and steel plant in IJmuiden, The Netherlands, installed a 2 MW power recovery turbine in 1994. Hot water from the hot strip mill is used to reheat the recompressed gas in the system (Lehman and Worrell, 2001).

Small scale (< 1 MW). For small scale industrial applications the major developments are found in improved designs for reciprocating engines, fuel cells, microturbines, and developments in integration of the unit in processes allowing more efficient operation (e.g. tri-generation of power, heat and cooling or drying and other direct process applications, see above). Micro-turbines and fuel cells are the most exciting developments in small-scale CHP technology.

Microturbines (25 – 500 kW) are expected to have an efficiency of 26-30% (Martin et al., 2000). Although this is lower than the efficiency of power generation in large grid-connected power plants, their use as a CHP unit can provide substantial energy savings. Martin et al. (2000) estimate the primary energy savings of a microturbine system at 17%, compared to separate power and heat production. Current development aims mainly at the commercial market, but small-scale industrial facilities may provide a potential application as well. Martin et al. (2000) estimate that up to 5% of the industrial power market by 2015 may technically be suitable for microturbine application, resulting in the power production of up to 40 TWh and 67 TBtu of primary energy savings. However, the high costs of microturbines make the technology less attractive for most industries, and only in cases of high-quality power needs (premium power), microturbines would likely be implemented.

Fuel cells generate direct current electricity and heat by combining fuel and oxygen in an electrochemical reaction. This technology is an advancement in power generation that avoids the intermediate combustion step and boiling water associated with Rankine cycle technologies, or efficiency losses associated with gas turbine technologies. Fuel to electricity conversion efficiencies can theoretically reach 80-83% for low temperature fuel cell stacks and 73-78% for high temperature stacks. In practice, efficiencies of 50-60% are achieved with hydrogen fuel cells while efficiencies of 42-65% are achievable with natural gas as a fuel (Martin et al., 2000). The main fuel cell types for industrial CHP applications are phosphoric acid (PAFC), molten carbonate (MCFC) and solid oxide (SOFC). Proton exchange membrane (PEM) fuel cells are less suitable for cogeneration as they only produce hot water as byproduct. PAFC efficiencies are limited and the corrosive nature of the process reduces the economic attractiveness of the technology. Hence, MCFC and SOFC offer the most potential for industrial applications.

Although PAFC is the most sold fuel cell system, MCFC and SOFC offer the most potential. Currently, several industrial facilities use MCFCs in Japan (Kirin brewery) and Germany (Michelin rubber processing) (Hoogers, 2003). These demonstration systems still cost around $11,000/kW. Stand-alone SOFCs have achieved efficiencies of 47%, and in combination with a gas turbine in a pressurized system, efficiencies of 53% (LHV) have been achieved (Hoogers, 2003). Unfortunately, the production costs of SOFCs are still high. Dow Chemical and GM will collaborate in the installation of a large-scale proton exchange membrane fuel cell (PEMFC) system (up to 35 MW), using hydrogen produced as a byproduct from chlorine production at Freeport, Texas. It is expected that the performance of fuel cells between 100 kW and 5 MW will surpass the efficiency of engine based CHP, and that costs will also come down through improved fabrication techniques, mass production and reduced catalysts loads (in the case of PEMFC).

6.1.3 Current Status

The estimated technical potential for conventional CHP at existing manufacturing facilities is approximately 132,000 MW (Onsite, 2000). Approximately 44,000 MW of CHP-capacity is already in place at existing manufacturing facilities, leaving a remaining potential of 88,000 MW. Much of the remaining potential is found in those industries that have traditionally relied on CHP – paper, chemicals, food, primary metals, and petroleum refining. Most CHP development to date has focused on large systems (20 MW or larger) and 55% of the remaining CHP potential is in systems of this size. However, small systems represent a largely untapped market for CHP. 32% of the remaining potential is in system sizes of 4 MW or less (Onsite, 2000).

6.1.4 Research & Development Needs

Major barriers to implementation of this technology lay in the need for further research and demonstration to improve the performance, demonstrate reliability and reduce investment costs. However, policies aimed at improved acceptance and interconnection of cogeneration are also important to realize the large potential for cogeneration. The major directions for development of advanced cogeneration concepts have been outlined above. For each technology R&D is needed to commercialize the technology, to improve the performance or to bring the costs of the technology down. We summarize the main R&D needs for each of the technologies:

- High-temperature CHP: Increasing the inlet (and outlet) temperatures of gas turbines, as well as the reliability of the turbines to allow long running times.
- Medium-scale applications: STIG and integration of medium-scale turbines needs to be demonstrated at various scales and various industrial settings. Development of integrated technologies to reduce NO_x in flue gases would allow use of process-integrated applications for food industries. Pressure recovery turbines need to be demonstrated at various locations (e.g. industrial sites and power stations).
- Small-scale systems: The efficiency of micro turbines needs to be improved, and the cost brought down through improved manufacturing techniques. Fuel cell research aims at bringing down the costs through improved materials (e.g. lower catalysts needs, improved lifetime) and manufacturing processes.

6.2 Cost

6.2.1 Baseline and New Technology

The capital costs will vary by technology. Also, CHP is a modular technology, and costs are expected to come down as the volume produced increases. We base our estimates on recent studies on these technologies. Costs are expressed as specific costs, or $/kW-capacity. We include the costs of installation in the estimates. The cost estimates provide a general guideline, and will vary over time and by site. Table 6.1 provides an overview of the costs estimates.

6.2.2 Cost-Effectiveness

The cost-effectiveness of CHP will depend strongly on the price differential between electricity and fuels (mainly natural gas). This means that the cost-effectiveness will vary by region, site and over-time. Table 1 provides estimates of the simple payback period, based on an estimated electricity price of 4-5 cents/kWh and a natural gas price of

$3.4/MBtu. It should be noted that smaller industrial sites are likely to pay higher electricity prices.

Table 6.1. Cost Estimates for CHP Technologies in 2015

Technology	Investments ($/kW)	O&M ($/kWh)	Estimated simple payback period (years)	References
Small – gas turbine	915	0.008		Martin et al., 2000
Small – fuel cell	1500	0.005	> 10	Onsite, 2000
Medium- gas turbine	830	0.005	5-7	Onsite, 2000
Large – gas turbine	625	0.004	3-4	Onsite, 2000
Process	650	0.004	3-5	Onsite, 2000; Worrell et al., 1997
Pressure recovery	1300	0.008	5-8	Lehman & Worrell, 2001

Simple payback period estimates are based on an electricity price of 4-5 cents/kWh and a natural gas price of $3.4/MBtu.

6.3 Energy

6.3.1 Baseline and New Technology

In 1998, manufacturing industry consumed 20.7 Quads of fuels and 3.0 Quads of electricity, which is equivalent to a primary energy consumption of 29.6 Quads. Industry generated around 139 TWh of electricity, of which 125 TWh was generated in co-generation units (EIA, 2004). The installed CHP capacity is estimated at 44,242 MW (Onsite, 2000). Table 2 estimates the additional technical potential for cogeneration in U.S. industry at 134,470 MW of power generating capacity. Small applications (< 4 MW) represent approximately 25% of the total potential. Still, a considerable potential remains in the medium to large-scale applications, especially because of process-integrated CHP opportunities.

Table 6.2. Estimated Technical Potential for Cogeneration in U.S. Industries by Major Sectors

	Small (< 1 MW)	Traditional/ Trigen/STIG	Process-Integrated	Pressure Recovery	Total
Food	1,711	6,375	*100*	*140*	8,326
Paper & Allied	880	25,318	0	*151*	26,349
Chemical	619	8,820	9,660	*700*	19,799
Refineries	84	6,704	34,000	*260*	41,048
Minerals	0	1,924	*50*	*115*	2,089
Primary Metals	208	6,733	*50*	*241*	7,232
Other	13,935	15,056	*500*	*313*	29,804
Total	17,437	70,750	44,360	1,920	134,470

Values are given in MW. Own estimates are given in italics. Sources: Onsite, 2000; Zollar, 2002; Lehman and Worrell, 2001.

Only a part of the technical potential will be implemented by 2025. We estimate that approximately 30% of the technical potential given in Table 6.2 can be realized by 2025, additional to existing CHP-capacity. This is equal to 40.3 GW, and could potentially double the existing CHP capacity.

6.3.2 Potential Energy Savings

The primary energy savings are determined on the efficiency of the cogeneration unit used (see above), the efficiency of the boiler or other equipment replaced, and the average efficiency of electricity generation of the public grid. Martin et al. (2000) estimated the primary energy savings at 17% for micro turbine CHP applications to 33% for larger scale systems. Table 6.3 summarizes the estimated primary energy savings for each technology. Table 6.3 provides rough estimates for the potentials of the specific technologies by 2025. The total potential by 2025 is estimated at nearly 1 Quad of primary energy savings. Actual energy savings will vary by site and operational variables.

Table 6.3. Estimated Primary Energy Savings from Cogeneration in 2025

Application	Technical Potential (GW)	2025 Market Potential (MW)	Estimated Running time (hours/year)	Power generated (TWh)	Estimated Energy savings (%)	Primary energy savings (TBtu)
Small - GT	17,437	3,487	5,000	17.4	17%	30.2
Small - FC		670	5,000	3.4	33%	11.5
Medium- GT	17,407	6,615	6,000	39.7	30%	118.8
Large - GT	53,343	20,270	8,000	162.2	33%	534.1
Process	44,360	8,872	8,500	75.4	36%	270.8
Pressure recovery	1,920	385	6,200	1.4	73%	10.2
Total	134,470	40,299		299.5		975.6

Baseline power generation efficiency is 33.4%.

6.4 References

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7. Conclusions

Increasingly, industry is confronted with the challenge of moving toward a cleaner, more sustainable path of production and consumption, while increasing global competitiveness. Technology will be essential for meeting these challenges. At some point, businesses are faced with investment in new capital stock. At this decision point, new and emerging technologies compete for capital investment alongside more established or mature technologies. Understanding the dynamics of the decision-making process is important to perceive what drives technology change and the overall effect on industrial energy use. From a policy-making perspective, the better we understand technology developments the more effective we will be in utilizing our future research dollars and in undertaking sound strategy development.

This report focuses on the long-term potential for energy-efficiency improvement in industry. In 2002, manufacturing industry consumed 33% of the country's primary energy and was responsible for 30% of the energy-related GHG emissions in the U.S. Due to the extremely diverse character of industry, it is not possible to provide an all-encompassing discussion of technology trends and potentials. Instead we focus on a number of key technology areas: near net shape casting, membrane technology, gasification, motor systems and advanced cogeneration. Each section provides a detailed assessment on future contributions to energy efficiency improvement, economics and performance, as well as the potential development path, including potential areas for research, demonstration or other support. Each section also describes ways to model the technology in NEMS (National Energy Modeling System) to aid in further model evaluation of the selected technologies. Some of these technologies have particular applications for a specific industry (e.g. near net shape casting in the metal producing sectors and black liquor gasification in the pulp and paper industry), while others can be found in many industries (e.g. advanced motor systems, membranes and advanced cogeneration applications). Table 7.1 provides a summary of the findings of this report.

Near net shape casting enables the integration of casting and rolling, dramatically reducing the energy demand for rolling, as well as reducing material losses. Assuming that by 2025, 40% of steel is cast using advanced near net shape casting technology, this would result in estimated primary energy savings of nearly 160 TBtu, or 10% of total primary energy use in the iron and steel industry.

Membranes are key development to improve the efficiency of often very energy-intensive separations. Almost all industries use separation processes, although we focus on the food, chemical and wastewater processing industries. In the food industry we estimate energy savings of about 50 TBtu in 2025. In the chemical industry the 2025 energy savings potential is estimated at about 95 TBtu, while in wastewater treatment the savings are likely to be as high as 160 TBtu.

Development of modern *gasification* technology, most notably in the pulp and paper and petroleum refining industries would lead to enhanced energy recovery from by-products in these industries. For 2025, the likely realizable combined potential in both sectors is estimated at 45 TWh. This is equivalent to primary energy savings of 461 TBtu additional to the baseline scenario.

Motor systems are found throughout the industry, and are often inefficient. Motor system improvement is and will remain a major area for energy efficiency improvements. The combined potential energy savings by 2025 are estimated at just below 12% of motor energy use. This is equivalent to additional electricity savings of 67 TWh or 686 TBtu of primary energy.

Finally, *cogeneration* is a technology that has been used by industry for many years. Still, considerable potential remains, while new technology development and cogeneration applications will increase the potential of this technology. The total potential by 2025 is estimated at nearly 1 Quad of primary energy savings.

The report demonstrates that the United States is not running out of technologies to improve energy efficiency and economic and environmental performance, and will not run out in the foreseeable future. The five technology areas *alone* can potentially result in total primary energy savings of just over 2,600 TBtu by 2025, or about 6.5% of total industrial energy use by 2025. Many other technologies will contribute to additional potential for energy-efficiency improvement in industry, while the technical potential of these five technologies on the long term is even larger.

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Table 7.1 Summary of 2025 Achievable Primary Energy Savings from Selected Industrial Sector Technologies.

Technology	Industrial Sector	2025 Primary Energy Use by Sub-Sector (TBtu)*	2025 Technical Potential Primary Energy Savings from Technology (TBtu)	2025 Assumed Penetration (%)	2025 Achievable Primary Energy Savings from Technology (TBtu)	Share of Industrial Sub-Sector (%)	Notes
Near net shape casting/Strip casting	Iron and Steel	1578	400	40%	160	10%	Can also be used for casting in aluminum, non-ferrous metals, and metal casting
Membranes	Food	1931	167	30%	50	3%	Can also be used in the automobile, electronics, metal finishing, mining, paper, petroleum refining, and textile industries
	Chemicals	4756	317	30%	95	2%	
	Wastewater	1020	225	70%	158	15%	
Gasification	Pulp and Paper	3433	1153	40%	461	6%	Can also be used in the food industry
	Petroleum Refining	4157					
Motor Systems	Cross-cutting	32653	2288	30%	686	2%	
Cogeneration	Cross-cutting	32653	3333	30%	1000	3%	
Total Savings	**Manufacturing**	**32653**	**7883**		**2610**	**8.0%**	
	Industry	**40980**				**6.4%**	

*Source: U.S. Energy Information Administration, 2004. *Annual Energy Outlook with Projections to 2025.* Washington, DC: EIA. DOE/EIA-0383(2004). http://www.eia.doe.gov/oiaf/aeo/

Appendix

This appendix provides information related to the possibility of modeling each of the five technologies in the U.S. Energy Information Administration's National Energy Modeling System (NEMS).

Near Net Shape Casting/Strip Casting

Strip/near net shape casting will most likely be introduced due to replacement, production expansion or construction of new plants. In NEMS, this can be achieved by modeling it as new technology.

In the **steel industry**, casting and hot rolling are modeled as separate technologies. Strip casting can be modeled by letting the UECs go to zero for hot rolling and the specific energy consumption for strip casting, respectively. This assumes that all new casters by 2025 will be strip/near net shape casters. This is a reasonable assumption as strip and long products, which can all be processed in a near net shape caster, are the majority of steel products in the U.S. steel industry. However, this is only feasible assuming active policy to further support the use of this technology in all kind of steelmills (see section 2.1.3).

NEMS does not model the casting of any of the non-ferrous metals. The **aluminum sector** includes primary smelting alone. However, a substantial amount of gas use is reported in these. It is likely that this figure may include ingot casting, which will be abolished by near net shape casting. Hence, near net shape casting may be introduced in NEMS by reducing the natural gas use and electricity use for new technology by a relatively small amount.

Other metal production and casting activities are incorporated in the NEMS sector **Metals-based Durables**. It is unclear how casting is included in the technology modeling. However, near net shape casting may be introduced by reducing the fuel and electricity UECs for new equipment, based on the share of casting energy use that can be replaced by this technology.

Membrane Technology

NEMS only models process/assembly energy use in eight energy-intensive industries. Of these, only food and kindred products and bulk chemicals have potential for application of membranes in the manufacturing process. In the **food and kindred products industry**, membranes can reduce process heating energy use by replacing evaporation and distillation processes and they can reduce process cooling requirements by replacing refrigeration. Reduced energy use for machine drives in the food processing industry can be seen when membrane use results in reduced pumping demand. In the **bulk chemical industry**, membranes will reduce energy use in the process heating when membranes are used for distillation or drying.

Energy use for water and wastewater treatment in paper manufacturing is accounted for in both the paper-making and the pulping steps of the **paper and allied products industry** in the NEMS model. Membrane use for water and wastewater treatment in all of the other industrial sectors does not appear to be explicitly included in the NEMS model.

Two types of membranes are included in NEMS. The first, the hollow fiber membrane air separation process, is considered an advanced melting/refining technology in the glass industry. The other, the novel membrane-based process for producing lactate esters, is considered an advanced synthesis technology in the chemicals and generic technologies sector.

Membranes typically have 5-year warrantees, but a properly operated facility may easily exceed 10 years (Wiesner and Chellam, 1999).

Gasification

Pulp & Paper. Kraft and chemical pulping are separate processes in the NEMS industrial module. We propose to adapt the TPCs for electricity and steam consumption of both processes for a new plant and old plant to simulate the gradual uptake of this technology. A gasifier can both be added to an existing pulp mill and to a new one. Over the next 20 years the majority of the Tomlinson boilers are expected to be replaced. Gasification is expected to penetrate earlier in chemical pulping due to the reduced sulfur loads. Based on the development plans for both the low- and high-temperature gasifiers we expect commercial application to start in 2006 for chemical pulping and 2008 for kraft pulping.

Petroleum Refining. Marano (2003) has performed a study co-funded by the Energy Information Administration on characterizing gasification to allow inclusion in the Petroleum Marketing Module (PMM) of NEMS. It may be that EIA has included gasification in the PMM for the AEO 2004 model. In that case, we propose that only the efficiency of power generation should be gradually increased to 45% by 2025, compared to 38%, as assumed by Marano (2003).

EIA has not included gasification in the PMM of the AEO 2004 NEMS model. Close collaboration with EIA is recommended to determine how NEMS can be modified to include the development and market penetration of gasification in petroleum refining.

Motor Systems

Currently, in the NEMS model, motor systems energy use is separated out of the energy use of each of the industrial sectors and motors are modeled as a separate subroutine "MOTORS." There are five sections to this motor stock model: (1) determining the purchases of new motors and percentage of motors that are rewound for each size group within each industry; (2) determine the cost differential, energy savings and payback period for premium motors versus EPACT minimum efficiency motors; (3) estimating the fraction of premium motors and EPACT motors purchased based on the above; (4)

calculating average energy efficiency of the set of motors at year's end (including premium motors, EPACT motors, rewound motors and surviving motors); and (5) calculating the total electricity consumption of machine drive and the effects of system efficiency improvements. Systems are broken down into three types: pump systems, fan systems and compressed air systems, which are set to sum to 100%.

In addition to the premium motors now considered in NEMS, additional new motors should be considered in the model, including superconductor motors, copper rotor motors, switched reluctance motors, permanent magnet motors and written pole motors. New motors will be added by increasing both the share of "premium" motors (or eventually, if warranted, establish a new category of efficient motors in addition to premium motors) and increasing the efficiency of machine drive. Hence, the percentage of new motors purchased will increase (part of item #1, above). The efficiencies of premium motors should be increased over time (on a per year basis for the current model), to account for increased efficiency due to continuing research on the new motors. In addition, currently only motors up to 200 HP can be set to be premium motors; however, depending on the motor type, emerging motors discussed in this report can be applicable a range of motors including sizes greater than 200 HP (e.g., superconductor motors will be used for motors greater than 1000 HP). Furthermore, basing the total percentage of "premium" or high efficiency motors that are installed each year on energy efficiency and payback period alone will inevitably underestimate total high efficiency motors installed because of the following: many motors are chosen based not only on installed capital costs or energy savings potential but also on reliability or other cost factors such as long term maintenance requirements. Currently NEMS does not include an option to address these considerations for buyers.

System design optimization obviously must be included in system efficiency improvement potentials of the motor stock model (item #5, above). Likewise, controls, such as magnetically – coupled adjustable speed drives, must also be included in the system improvements section of the motor stock model. The three variables that define the system improvement efficiency savings - $PumpSavPct_{i,s}$, $FanSavPct_{i,s}$ and $CompSavPct_{i,s}$ which define motor system efficiency savings for pump systems, fan systems and compressed air systems, must all be increased to include system improvements and controls. Specific end use improvements like slowing pumps, trimming the impellers, or replacing an existing pump should be applied only to the applicable system (in these cases, $PumpSavPct_{i,s}$).

Advanced Cogeneration

The latest version of NEMS includes a cogeneration module. The module allocates steam demand to cogeneration and boilers based on technology and economic characteristics. This module is not suitable to model the potential contribution of cogeneration technologies that do not produce steam. It may not be suitable to model technologies that provide cooling or a varying heat to power-ratio (such as STIG), as it underestimates the amount of power that can be generated given a set steam demand (and allocation). Hence, changes to the NEMS model may need to be made to the:

- cogeneration module
- technology characteristics of modeled cogeneration equipment (including heat to power ratio and economics)
- individual sectors in the industrial demand module to reflect process integrated CHP opportunities and pressure recovery turbines.

Cogeneration Module: Within the cogeneration module the following "levers" are available to increase penetration of CHP: improving the profitability by decreasing the investments of the various CHP units (see below), changing the payback acceptance rate to increase the share of companies accepting a specific payback criterion, or changing the penetration rate (reflecting the annual uptake of cogeneration, currently set at 5%).

Technology Characteristics: The investment (total installed cost) can be changed to reflect a decrease in specific investments. The current costs are relatively high (Onsite, 2000), and are based on current costs. Reflecting the effects of R&D and increased penetration will lead to lower investments. The performance of the CHP units can be changed in the module by changing the power to steam ratio, allowing for increased power consumption for a given thermal output.

Industrial Module. For those sectors that have a considerable potential for alternative CHP options, i.e. chemicals, petroleum refining (see table 2), the technology characteristics, i.e. the UEC and TPC, may be changed to reflect the additional savings of the advanced CHP technologies. This approach would be valid because many of these technologies would be integrated with modeled processes, through pre-coupling of a gas turbine or use of waste heat from processes to allow pressure recovery from natural gas.

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Emerging Energy-Efficient Technologies in Buildings: Technology Characterizations for Energy Modeling

May 2004

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ENGINEERING SCIENCE AND TECHNOLOGY DIVISION

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National Commission on Energy Policy

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Abstract

The energy use in America's commercial and residential building sectors is large and growing. Over 38 quadrillion Btus (Quads) of primary energy were consumed in 2002, representing 39% of total U.S. energy consumption. While the energy use in buildings is expected to grow to 52 Quads by 2025, a large number of energy-related technologies exist that could curtail this increase. In recent years, improvements in such items as high efficiency refrigerators, compact fluorescent lights, high-SEER air conditioners, and improved building shells have all contributed to reducing energy use. Hundreds of other technology improvements have and will continue to improve the energy use in buildings. While many technologies are well understood and are gradually penetrating the market, more advanced technologies will be introduced in the future. The pace and extent of these advances can be improved through state and federal R&D.

This report focuses on the long-term potential for energy-efficiency improvement in buildings. Five promising technologies have been selected for description to give an idea of the wide range of possibilities. They address the major areas of energy use in buildings: space conditioning (33% of building use), water heating (9%), and lighting (16%). Besides describing energy-using technologies (solid-state lighting and geothermal heat pumps), the report also discusses energy-saving building shell improvements (smart roofs) and the integration of multiple energy service technologies (CHP packaged systems and triple function heat pumps) to create synergistic savings. Finally, information technologies that can improve the efficiency of building operations are discussed.

The report demonstrates that the United States is not running out of technologies to improve energy efficiency and economic and environmental performance, and will not run out in the future. The five technology areas alone can potentially result in total primary energy savings of between 2 and 4.2 Quads by 2025, or 3.8% to 8.1% of the total commercial and residential energy use by 2025 (52 Quads). Many other technologies will contribute to additional potential for energy-efficiency improvement, while the technical potential of these five technologies on the long term is even larger.

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1. Introduction[1]

There are a large number of technologies that have the potential to improve energy efficiency in U.S. buildings. In recent years high efficiency refrigerators, compact fluorescent lights, high-SEER air conditioners, and improved building shells have all contributed to reducing energy use. Various reports such as the *Clean Energy Futures* study (Interlaboratory Working Group 2000) and *Emerging Energy-Saving Technologies and Practices for the Building Sector* (Nadel et al. 1998) have identified many other technology improvements. This paper describes just five of the many technologies that may be deployed to give an idea of the potential available.

The Department of Energy's (DOE's) Energy Information Administration (EIA) annually provides forecasts of energy use over the next twenty to twenty-five years, with their most recent being the *Annual Energy Outlook 2004* (*AEO2004*) (EIA 2003). They use their National Energy Modeling System (NEMS) to calculate the amounts of energy supplied and demanded by different sectors. Figure 1 and Figure 2 show the amount of total primary energy required for various end-uses in the residential and commercial (buildings) sectors.

Figure 1. *AEO2004* Reference case residential primary energy use (EIA 2003)

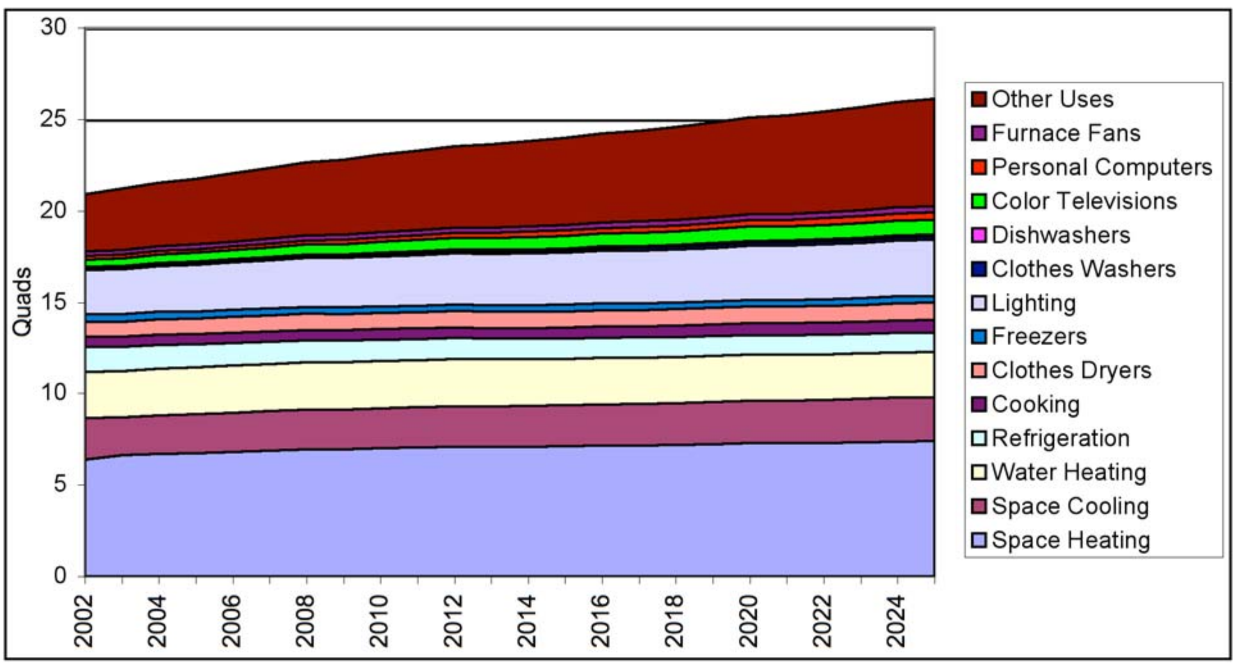

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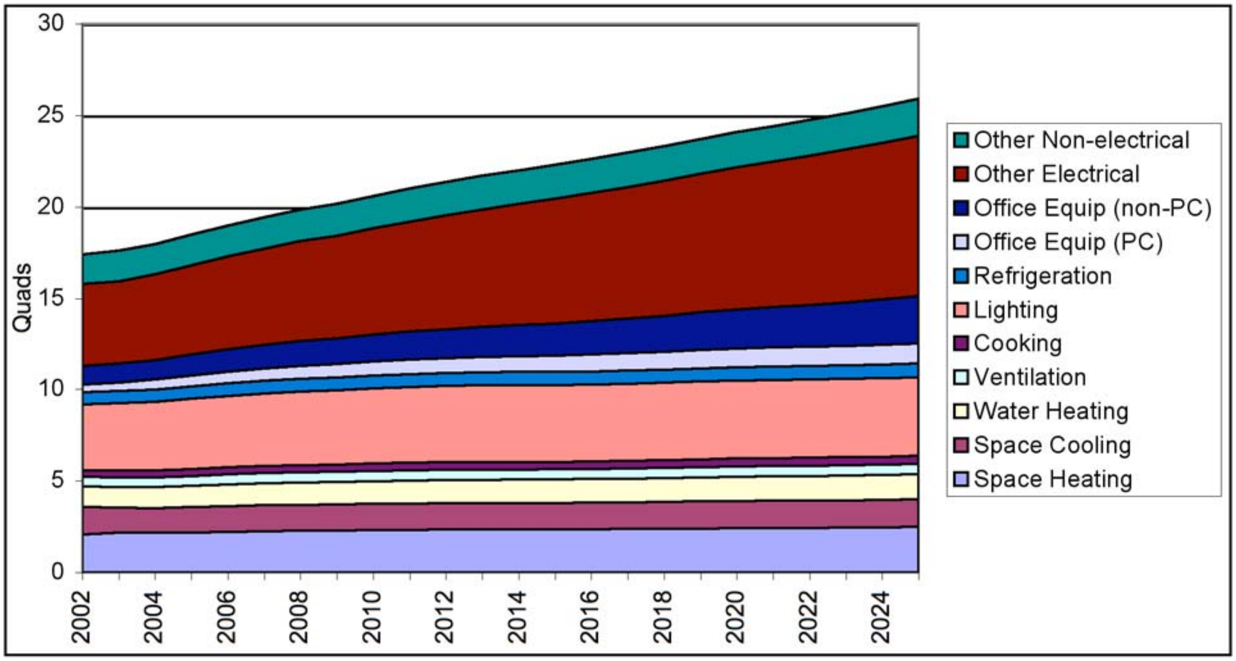
Figure 2. ***AEO2004*** **Reference case commercial primary energy use (EIA 2003)**



In the residential sector, the largest current demands are in space heating and cooling, water heating, and lighting. These are also the largest single end-uses in the commercial sector. The Other categories cover the multitude of other energy uses in homes and businesses, from toasters to swimming pool heaters, ATMs to elevators. Combined heat and power is included in the commercial other non-electrical use. As modeled in NEMS, these "Other" end-uses are less responsive to efficiency improvements and come to dominate each sector's energy use.

The five technologies described in this paper and achievable energy savings by 2025 are:

- **Solid state lighting**
  - Inorganic and organic light emitting diodes that replace incandescent and fluorescent lighting in a broad variety of end-uses (1.2-3.5 Quads),
- **Advanced geothermal heat pumps**
  - Selective water sorbents and other technologies that greatly reduce the capital cost and land requirements for geothermal heat pumps in residential and commercial sectors (0.2 Quads),
- **Integrated energy equipment**
  - Multi-function (cooling, heating, hot water, dehumidification) and packaged combined heat and power technologies that integrate multiple energy services into single pieces of equipment to lower cost and increase efficiency (0.3 Quads),
- **Efficient operations technologies**
  - Information technologies to improve the functioning of energy-using equipment on an ongoing basis within buildings (0.1 Quads), and
- **Smart roofs**
  - Nano- and micro-technologies that change the reflectance and infra-red emissivity of roof materials as a function of temperature to retain heat in winter and reflect heat in summer (0.1 Quads).

Summing these achievable savings gives a total of 1.9-4.2 Quads, which represents 4%–8% of projected 2025 residential and commercial demands of 52 Quads. The technical potential by 2025 from these technologies is much higher, 9.6 Quads, but does not factor in the time necessary for penetration of the market. The calculations of energy savings are only rough estimates using different methodologies. Many of the needed advances have not been developed yet and require further research. To some extent, these technologies will overlap and so savings may be less, but also the calculations only consider a subset of the possible market. The actual energy savings that will come will take time to achieve and are dependent on the amount of research and market penetration that occurs. It is hoped that through research and policy initiatives, these and other energy efficient technologies can play a major role in reducing the energy needs of our country.

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2. Solid State Lighting

2.1 Technology

Solid-state lighting (SSL) has the potential to revolutionize the lighting market through the introduction of highly energy efficient, longer-lasting and more versatile light sources. Advancements in SSL technology over the last two decades have contributed to a gradual market penetration in colored and some specialty white-light markets. As industry and government investment continues to improve the performance and reduce the costs associated with this technology, SSL is expected to start competing with conventional light sources for market share in general illumination applications. The scientific and research communities forecast that as the performance of light emitting diodes (LEDs) and organic light emitting diodes (OLEDs) improves, their costs will simultaneously decrease. Energy savings will result from consumers choosing SSL sources in general illumination (white-light) applications such as offices, retail establishments and homes.

2.1.1 Brief description

SSL uses the emission of semi-conductor diodes to directly produce light, rather than resistance heating of a wire as in incandescent lamps or excitation of a gas as in fluorescent lamps. Electrons and holes are injected into a solid-state semiconductor material. When these recombine, light is emitted at around the wavelength corresponding to the energy bandgap of the material. Once the light is created internally, a high fraction of it must reach the surface and escape rather than be absorbed; this is done either through the shape of the LED or the type of material used. Because these lights can concentrate their emissions in the visible spectrum, they can be very efficient. Different wavelengths can be easily created by using different materials. However, SSL faces the problem that a single LED does not fill the full spectrum and appears colored. Creating a white, general-purpose light causes additional complexity and/or lower efficiency.

There are two main categories of lights: LED and OLED. LED lighting uses inorganic semiconductor material such as InGaN (ultra-violet), AlGaN (blue or green), AlInGaP (red-orange), or AlGaAs (red), as well as others. It was first discovered in 1907 and the first commercial devices were introduced in 1968. OLED lighting uses organic polymers and provides a more diffuse lighting that may be more useful for displays for computers, televisions, or cell phones.

2.1.2 End-uses

Lighting has a wide variety of end-uses, from high-quality task lighting in residential buildings, to factory lighting for a large area, to street lighting, to warning signals and headlights in transportation, among others. There are a number of lighting attributes that define the attractiveness of a technology.

- Color Rendering Index (CRI) – how broad a spectrum the light provides for color rendition,
- Luminous efficacy (lm/W) – how much light (lumens) is provided for the power used,
- Lifetime (khr) – how long the lamp lasts,
- Flux (lm/lamp) – how much light each lamp provides,

- Cost ($/klm) – Cost to consumer.

The CRI segregates end-uses by the quality of light required; e.g., street lighting does not need to provide good rendition of colors, but must provide sufficient low-cost light to make roadways visible. Navigant conducted two energy savings studies: one of general-purpose lighting (Navigant 2003a) and one of niche applications (Navigant 2003b). The general-purpose lighting study considered alternative SSL investment scenarios and compared the SSL to a variety of conventional lighting sources. They segregated the markets into four CRI bins as shown in Table 1 with typical lamps and purposes for each. While CRI is not the sole distinguishing characteristic, it does capture the fundamental differences in lighting services.

Table 1. CRI Bins and typical lamps and end-uses for each (Navigant 2003a)

CRI Bin	CRI Range	Example Lamps	Example Purposes
Low CRI	0 – 40 CRI	Mercury Vapor, High Pressure Sodium	Street lighting
Medium CRI	41 – 75 CRI	T12 four foot, T8 greater than 4 foot, Circline	Warehouse, factory
High CRI	76 – 90 CRI	T8 four foot, Compact Fluorescent Lamps	Office, commercial
Very High CRI	91 – 100 CRI	Incandescent, Halogen	Residential

Other attributes, such as energy use or total cost per lamp, are shown in Table 2. These come from the Optoelectronics Industry Development Association Technology Roadmap (OIDA 2002a). They show current values and targets for LED lighting as well as representative values for some forms of incandescent and fluorescent lighting. The last two columns do not represent all forms of incandescent and fluorescent lighting; these can have a wide array of values depending on the specific purpose.

Table 2. SSL-LED Lamp Targets (OIDA Technology Roadmap Tutorial 2002)

TECHNOLOGY	SSL-LED 2002	SSL-LED 2007	SSL-LED 2012	SSL-LED 2020	Incandescent	Fluorescent
Luminous Efficacy (lm/W)	25	75	150	200	16	85
Lifetime (khr)	20	>20	>100	>100	1	10
Flux (lm/lamp)	25	200	1,000	1,500	1,200	3,400
Input Power (W/lamp)	1	2.7	6.7	7.5	75	40
Lumens Cost ($/klm)	200	20	<5	<2	0.4	1.5
Lamp Cost ($/lamp)	5	4	<5	<3	0.5	5
Color Rendering Index (CRI)	75	80	>80	>80	95	75
Lighting Markets Penetrated	Low-flux	Incandescent	Fluorescent	All		

Initial end-uses for LED lighting have been in areas where long life has been especially desirable while high flux is not necessary (i.e., the light needs to be visible itself, but not necessarily illuminate other objects.) Examples include traffic lights, exit signs, and automobile taillights. In addition, these end-uses are generally single-color applications rather than white light so that CRI is not important.

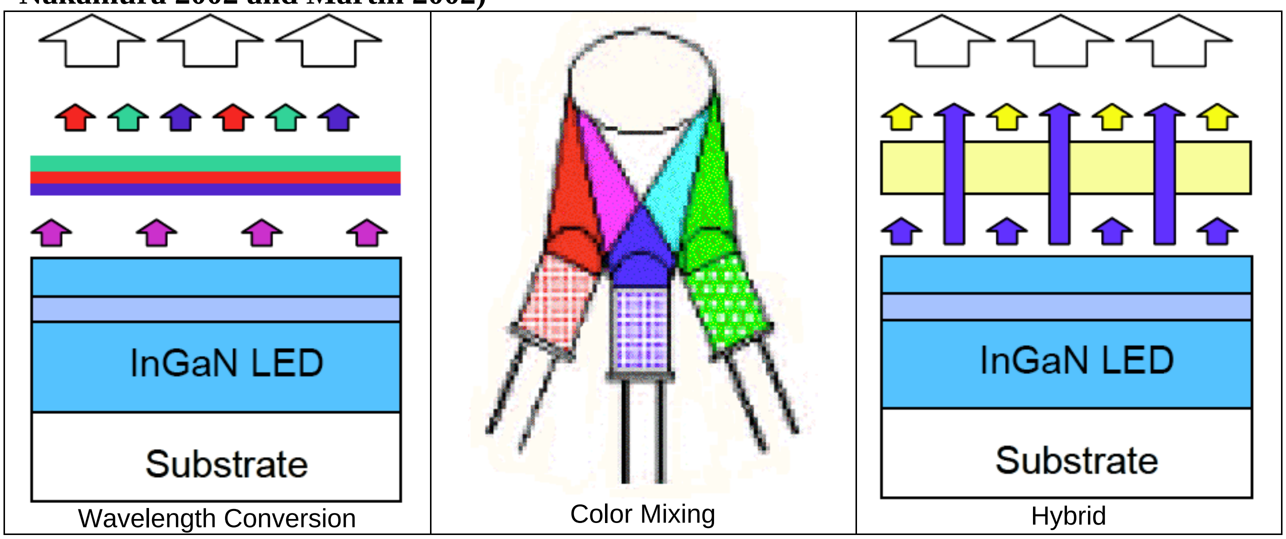
Future applications will expand as the technology provides increased brightness, better CRI, longer life, and lower cost, as shown in Table 2. Initial applications will likely be in areas with little requirement for a high CRI such as outdoor and warehouse lighting. As the technology develops, with improved lighting quality and lowered cost, additional end-uses will be feasible. Eventually, most major end-uses could be supplied by LEDs.

OLEDs are most suitable in the near term for displays such as computer monitors or televisions. They may also be used for commercial accent lighting such as signs. In the longer term, they may be replacements for area lighting such as ceiling lights. However, the research priorities for the near-term end-uses (brightness, responsiveness) do not necessarily match the improvements needed for broader markets (efficiency, cost).

2.1.3 R&D needed

A key difficulty that LED lighting faces is that it is inherently monochromatic. Different colors of LED's have been produced: red, green, yellow, orange, blue, and even ultra-violet. Three methods to produce white light have been developed, each with its advantages and disadvantages (Figure 3).

Figure 3. Possible approaches to white light production (Roadmap Update Tutorial / Nakamura 2002 and Martin 2002)



- Wavelength conversion involves using an ultra-violet LED with a three-color phosphor to down-convert the wavelength to a mixture of colors giving a white spectrum, similar to a fluorescent lamp. It is likely to be lowest cost of the three methods since it uses only one LED and colors are created together, easing engineering. However, it is also the most inefficient because of the losses during the down-conversion.

- Color mixing involves using three separate LEDs to provide white light, similar to television displays. It provides color flexibility by adjusting the output of each LED and has higher efficiency since no filters are needed. However, the three different LEDs add to the complexity and cost.

- A hybrid system uses a blue LED that has part of its light downshifted to its complement color of yellow, resulting in a perceived white light. However, the quality of the light is poor. Using only two colors gives a poorer CRI, and a "halo" effect occurs where the light directly from the lamp looks blue because it is directional while the yellow is more diffuse. Variations on this approach may improve the quality by using a two-color phosphor (from blue to red and green) or a green phosphor plus an additional red LED. The hybrid approach will have costs, complexity, and efficiencies in between the other two approaches.

For SSL to succeed in the market place there are a number of issues requiring research. The DOE/OIDA roadmapping exercise has identified additional long-term research in eight main areas (OIDA 2002b):

Materials research and the physics of light generation – Long term research should focus on the development of new experimental techniques, complete characterization of materials and devices, detailed first principles modeling, and the development of new semiconductor materials and device structures.

Substrate materials – There are at least three different substrate materials used: sapphire, GAN, and SiC. Each has its pros and cons but none provide a large area, defect-free substrate with good lattice match and at a reasonable cost

Reactor design – The current epitaxial reactors are not very efficient or reliable. A better understanding of the chemical reactions for the growth of nitride materials and reactor fluid dynamics should enable more efficient and robust reactors.

Light extraction – Due to the high refractive index of LED material a large fraction of the light is trapped inside the LED. Research in materials, architecture, and modeling of light extraction are necessary.

Photon conversion materials – Conversion of ultraviolet to visible light and compatibility of phosphors under LED lighting conditions should be explored. Novel wavelength conversion materials and encapsulents that are insensitive to radiation would help in the production of long-lived LEDs.

Novel concepts of solid-state light emission – Research can expand the types of SSL beyond LEDs. These could include novel device structures, super luminescent diodes, edge emitters, or other concepts such as quantum dots or photonic lattices.

Packaging – This topic was identified as having an enormous impact on the efficiency, life, and cost of LED devices, but must first be led by the final LED design strategies.

Lighting infrastructure – Only a third of the $40 billion in lighting represents light bulbs. The larger market includes lighting fixtures, powering, distribution, etc. Research in these other aspects of the industry so that they better utilize SSL will help SSL succeed in the market.

Understanding materials issues with both the semiconductor and the substrate are crucial to improving efficiency and lowering cost. These research areas over the next five years should help to make SSL into a commercially viable industry.

2.2 Cost

The cost of LED technologies is currently too high to compete with general service types of lighting, but with accelerated investment in R&D, future penetration could occur. Table 2 from the OIDA Technology Roadmap Update shows an estimate of present and future costs for SSL-LED. While the initial lamp cost is expected to stay higher than for incandescent or fluorescent lighting, the longer life and higher efficiency should lower the lifecycle cost per lumen-hour (Table 3, OIDA 2002a). The table shows that on an over-all ownership cost per lumen-hour, SSL could surpass incandescent lighting by 2007 and fluorescent lighting by 2012. However, on an initial cost per lumen (ignoring the lifetime of the lamp) the SSL cost remains higher (Table 4). Quality aspects such as CRI only determine where SSL can compete, cost objectives determine if it will compete. Total costs include the capital costs and operating costs of the technology. The cost comparisons should also include such factors as maintenance and replacement costs to equalize the total lighting service over its lifetime.

Table 3. Purchase and operating costs associated with traditional lamps and SSL-LED target lamps (OIDA Technology Roadmap Tutorial 2002a)

COST OF LIGHT	SSL-LED 2002	SSL-LED 2007	SSL-LED 2012	SSL-LED 2020	Incandescent	Fluorescent
Capital Cost ($/Mlm-hr)	12.00	1.25	0.30	0.13	1.25	0.18
Operating Cost ($/Mlm-hr)	4.00	1.33	0.67	0.50	6.25	1.18
Total Cost ($/Mlm-hr)	16.00	2.58	0.97	0.63	7.50	1.35

Navigant conducted two energy savings studies: one of general-purpose lighting and one of niche applications. The general purpose lighting study (Navigant 2003a) considered alternative SSL investment scenarios and compared the SSL to a variety of conventional lighting sources. They segregated the markets into the four CRI bins of Table 1 and four sectors: residential, commercial, industrial, and outdoor. For these markets they proposed a moderate and accelerated investment in SSL R&D. Table 4 shows the lamp price, efficacy, and life of the four LED market segments, along with expected values for some of the conventional commercial lights.

The steps involved in the Navigant general-purpose lighting study included:

1. Determine lighting demand converting data from DOE on the lighting market into lumen hours of lighting service;

2. Group similar lighting types as shown in Table 1;

3. Project lighting demand using new building construction projections from the *Annual Energy Outlook 2003* (EIA 2003a);

4. Create an adjustable stock-model to determine lighting "turn-over";

5. Estimate improvements in cost, efficacy and operating life of conventional technologies;

6. Estimate improvements in cost, efficacy and operating life of SSL technologies;

7. Project lighting costs based on current markets and anticipated cost improvements in installation and operation;

8. Develop an economic model of the U.S. lighting market to calculate SSL market penetration based on relative costs;

9. Calculate energy savings based on SSL performance and market penetration.

Table 4. Projected price, efficacy, and life for SSL with accelerated investment compared to conventional lighting (Navigant 2003a)

Light and CRI	Lamp Price ($/klumen)		Efficacy (lumens per watt)		Life (thousand hours)	
	2005	2025	2005	2025	2005	2025
Low CRI LED, 0-40	32.8	1.2	90.3	225.6	30.8	99.9
Med CRI LED, 41-75	81.2	2.5	65.5	181.5	18.6	99.9
High CRI LED, 76-90	145.9	3.3	47.1	162.3	15.7	99.8
Very High CRI LED, 91-100	230.8	5.8	24.7	142.3	12.4	99.6
General Service Incandescent, 100 CRI	0.86	0.72	14	15	2.5	2.8
T8 Fluorescent, 68 CRI	0.73	0.60	83	91	17.5	21
High Pressure Sodium, 22 CRI	0.85	0.63	100	120	20	24

While initial lamp cost is higher per thousand lumens, the LEDs have a target life of over four times the life of efficient competitors and thirty times the life of incandescents.

2.3 Energy

2.3.1 Energy consumption and comparison to existing

Energy use of SSL lighting will depend on the application and type of SSL used. The Navigant general purpose lighting study (Navigant 2003a) considered alternative SSL investment scenarios and compared the SSL to a variety of conventional lighting sources. Their accelerated investment scenario assumed a national investment of ~$100 million per year, which is high but achieved significantly improved performance and reduced cost (Table 4). Their moderate investment scenario did not advance technologies as much, with medium CRI LEDs achieving 93 lm/W and $4.3/klm by 2025.

Monochromatic, niche end-uses show great efficiency savings compared to existing technologies and their long life greatly reduces maintenance costs. To create single color lighting from incandescent lights requires filtering out of most of the output. For example, in a 12” traffic signal, an 11W LED red signal head replaces a 140 W reflector lamp resulting in a 92% reduction in energy consumption (Navigant 2003b). This is why LEDs have penetrated most significantly in niche markets such as exit signs, traffic lights, and large truck and bus lights (Table 5, Navigant 2003b). Total primary energy savings in the niche markets in 2002 were 0.116 Quads (116 TBtu), and the potential savings if all niche lighting changed to LED was estimated at 0.554 Quads.

Table 5. Energy Consumption and Savings in 2002 of Niche Markets Evaluated (Navigant 2003b)

Application	Annual Energy[1]	LED Market Penetration	Electricity Savings 2002	Primary Energy Savings 2002[2]
Mobile Transportation Applications				
Automobile Lights	12.95 TWh	1–2%	0.17 TWh	41.3 Mgal gasoline (4.9 TBtu)
Large Truck and Bus Lights	11.80 TWh	5–7% / 41%	1.07 TWh	142.1 Mgal diesel (19.9 TBtu)
Aircraft Passenger Lights	0.003 TWh	0%	0.0 TWh	0.0 gal jet (0.0 TBtu)
Stationary Transportation Applications				
Traffic Signals	3.41 TWh	30%	1.48 TWh	16.2 TBtu
Railway Signals	0.025 TWh	3–4 %	0.001 TWh	0.007 TBtu
Airport Taxiway Edge Lights	0.06 TWh	1–1.5 %	0.001 TWh	0.007 TBtu
Other Stationary Applications				
Exit Signs	2.57 TWh	80%	6.86 TWh	75.2 TBtu
Holiday Lights	2.22 TWh	0%	0.0 TWh	0.0 TBtu
Commercial Advertising Signs	10.06 TWh	0%	0.0 TWh	0.0 TBtu
Total	43.1 TWh	-	9.6 TWh	116.1 TBtu

2.3.2 Potential energy savings

The lighting demands for the four CRI segments in each sector (in teralumen-hours) are shown in Table 6. Annual growth rates are expected in the 1% to 1.5% range.

Table 6. Sector and CRI Bins of Teralumen-hours Lighting Demand in 2005 (Navigant 2003a)

CRI Bin	Residential	Commercial	Industrial	Outdoor	CRI-Bin Total
Low CRI	33	1,021	711	4,145	5,910
Medium CRI	1,336	12,451	3,755	572	18,113
High CRI	62	7,932	4,258	64	12,316
Very High CRI	2,632	1,956	41	88	4,717
Sector Totals	4,062	23,361	8,765	4,868	41,056

Lighting services are most demanded in the commercial sector, especially for medium and high CRI lighting such as that provided by fluorescent lighting. According to the *AEO2004* (EIA 2003b), lighting is the largest electrical end-use for both residential and commercial sectors, and the largest single energy use in the commercial sector (Figure 1 and Figure 2 in the Introduction.)

Energy savings projections in the general illumination markets using Navigant's investment scenarios are shown in Table 7. As much as 33% of reference energy use for lighting could be saved in the accelerated investment scenario by 2025. Navigant calculated these values using the methodology described in Section 2.2 above.

Table 7. Primary energy used and savings for moderate and accelerated LED R&D investment, Quads (Navigant 2003a)

	2010	**2015**	**2020**	**2025**	**Cumulative**
Reference case energy used	9.24	9.68	10.08	10.47	n/a
Moderate Investment savings	0.00	0.04	0.39	1.23	5.44
Accelerated Investment savings	0.01	0.34	1.67	3.51	19.9

2.4 NEMS approach

NEMS models lighting in both the residential and commercial modules, but to different levels of detail. In the residential module, NEMS contains parameters for three standard lighting and two torchiere technologies. The capital cost for 2001, 2010 and 2020, wattage, and efficiency are built into the FORTRAN coding of the model, in the source code resd.f. Torchiere penetration rates over time are also built in. In the *AEO2004*, the values are shown in Table 8. The capital costs are not well-described but based on their use in the model they include the non-energy costs for six years' worth of bulbs as well as the lamp.

Table 8. Residential lighting parameters in NEMS for *AEO2004* (EIA 2003b)

Technology	Wattage	Efficiency, lm/W	Capital Cost 2001, $/lamp	Capital Cost 2010, $/lamp	Capital Cost 2020, $/lamp
Standard 1	75	18	5.6	5.6	5.6
Standard 2	20	50.625	75	65	60
Standard 3	10	88	10000	10000	10000
Torchiere 1	300		10	10	10
Torchiere 2	78		75	70	65

For standard lighting wattage is used for calculating operating costs and market share is determined by ratios of operating to capital costs logit parameters. Energy use is comparing the efficiency of the lighting relative to a base efficiency of 18. Torchiere energy use is based on the relative wattage of the two types of torchiere, with market share dependent on relative costs. SSL lighting could be put in through modification of the Standard 3 lighting technology, reducing the capital costs to roughly that of Standard 2, although this does not truly capture the differences over time in efficiency, lifetime and other characteristics of SSL.

In the commercial sector, lighting is modeled in more detail and with more flexibility. NEMS currently has 24 different lighting technologies, and can handle more. Efficiency, capital cost, operating cost, lifetime and state of technology all help to define the technologies over time. The commercial sector also only has costs change over time, not efficiency or other parameters. However, a start and end year for availability of each technology allows improvements to be introduced. Also, CRI market segments are not observed. Table 9 shows values for some of the representative technologies in the *AEO2004*.

Table 9. Example commercial lighting parameters in NEMS for the *AEO2004* (EIA 2003b)

Technology	Efficiency lm/W	Capital Cost, $/klm	O&M Cost, $/klm	Life	Tech Type	Cost Decline
Incandescent 1150 lumens, 75 watts	15.3	15.3	15.3	12	Mature	0.0
High Pressure Sodium	89.7	19.6	0.6	15.0	Mature	0.0
F32T8 -Electronic -Reflector	88.3	27.0	0.7	13.9	Adolescent	0.1
CFL 1200 lumens, 20 watts	67.1	61.5	7.2	12.0	Adolescent	0.1

SSL can be represented by adding these technologies into the mix, using values from Table 2 or Table 4. Multiple SSL can be added with staggered windows of availability to represent changes in efficiency, cost, or life.

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3. Advanced Geothermal

3.1 Technology

Space heating and cooling are provided by a variety of technologies across the United States. Cooling is provided largely through central or room air conditioning systems while heating is provided largely through direct combustion of natural gas, LPG, or oil. Heat pumps are also used for heating (and cooling), but provide less than 10% of the heating needs in the country. A heat pump works on the same principle as an air conditioner except that it allows the functions of the evaporator and condenser (which absorb and reject heat) to be exchanged depending on whether heating or cooling is required.

Heat pumps have been around for many years, and the technology is quite robust. However, they suffer from one problem. The efficiency and capacity of heat pumps depends on the temperature difference across which the heat is to be pumped: the greater this temperature difference, the lower the efficiency and the lower the capacity. For an air-source heat pump, the temperature difference corresponds to the difference between outside air temperature and the desired indoor air temperature. Thus in the cooling season, both the cooling capacity and the cooling efficiency decrease as the outdoor air temperature rises. Likewise, in the heating season, both the heating capacity and the heating efficiency decrease as outdoor air temperature falls. In most applications, supplemental heating is required during the winter.

A geothermal heat pump (GHP) solves the problem of decreasing efficiencies due to temperature extremes by eliminating the outdoor coil altogether, and replacing it with a heat exchanger that is coupled to the earth. Unlike outdoor air temperatures – which can vary by more than 100°F over the year – the temperature of the earth just a few feet below the surface is fairly constant. Absorbing and rejecting heat to the earth results in a heat pump with higher efficiency and more stable capacity throughout the year. Most applications do not require supplemental heating. The main disadvantages of the conventional GHP systems relative to air-to-air heat pumps are the extra expense of burying heat exchangers in the earth and the difficulty of locating and making repairs, if needed.

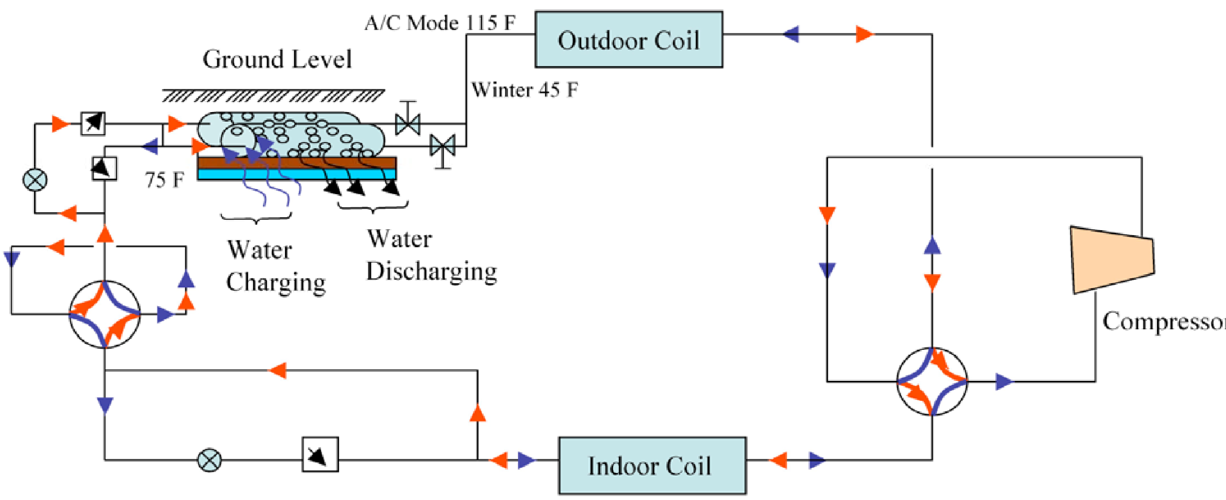
Several near- and long-term technologies could improve the cost-effectiveness of GHP systems. One way of reducing the cost of GHPs is to use a supplemental heat rejecter such as a dry fluid cooler. In this type of system – known as a hybrid – the ground heat exchangers are typically sized to meet the heating load only. During the cooling season, some of the heat that would have been rejected to the ground is rejected to the atmosphere through the fluid cooler.

Recent research has identified a process that can overcome more of the shortfalls in conventional ground-coupled heat pumps and offer even higher efficiencies and peak load reduction capability for residential and small commercial heat pumps. The expense of large underground heat exchangers is bypassed by a revolutionary new process of heat recovery that enables a small heat exchanger with a special desiccant-like material to exchange water naturally present in the environment either in the form of humidity or as adsorbed water. The process is termed selective water sorbents (SWS).

By absorbing water from the ambient surroundings (ground or air) during off-peak periods and desorbing water during peak periods, the overall energy profile can be changed to accomplish higher cooling efficiencies and simultaneously reduce peak electric demand. In a ground-coupled situation, the system would use a small, buried container that can rapidly exchange heat through a reversible process of exchanging water between the SWS and its environs (Figure 4). Since water has a large heat of vaporization, small quantities of water transport can move large amounts of energy across small thermal gradients.

Since water is environmentally benign, SWS technology offers both energy efficiency and environmental benefits. The dynamic sequence of water exchange reduces the footprint and physical size of a ground-coupled heat exchanger, lowering its initial and operating costs and increasing the potential market. Additional improvements may increase the likelihood of expansion of this energy efficient and green technology as the SWS technology is further developed.

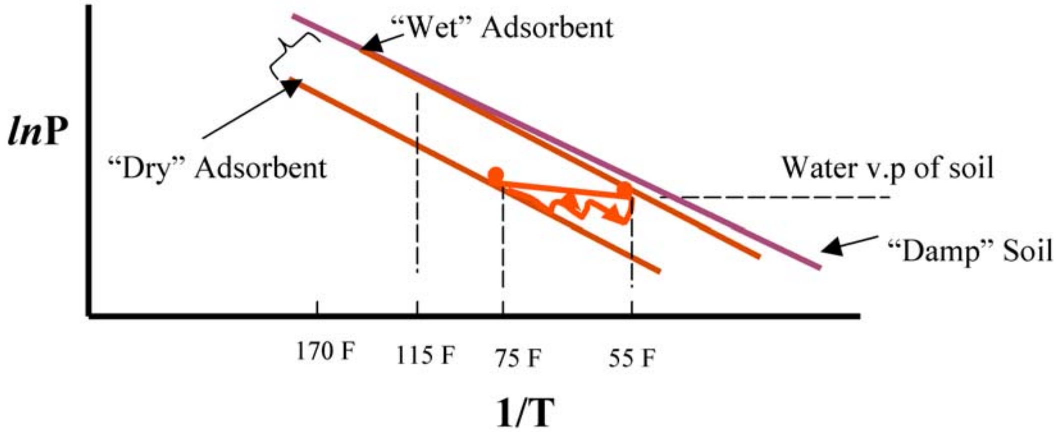
Figure 4. Schematic of SWS geothermal heat pump



3.1.1 Brief description

SWS technology uses the difference in water vapor pressure between itself and the environment (ground or air) to transport water with a high latent heat of vaporization (Figure 5). SWS materials researched recently include open-pore mesoporous matrix substrate filled with a hygroscopic substance or a hydrated salt (Atistov, et al., 2002, Levitskij, et al, 1996). These materials are inexpensive, widely available, and manufactured in bulk quantities for a variety of industrial and commercial applications. An example of an open matrix substrate is Type A or RD silica gel and a typical hydrated salt is calcium chloride present as a tetra- or hexahydrate. Other SWS materials would be those that absorb up to 350 times their dry weight of water. These are also produced in bulk amounts and sold commercially.

Figure 5. Enthalpy of wet and dry adsorbent as a function of temperature



SWS also has the added property of being able to absorb about 7 to 8 times its own weight of water, thereby making water storage very efficient. Water is released when the temperature of the SWS is such that its water vapor pressure is slightly above the environment. Water is absorbed by the SWS when its temperature is slightly below that of its environment, or if it comes into contact with condensed water. European research has shown that these properties of SWS materials can be exploited for engineering a new generation of highly cost-effective and more efficient ground-coupled heat pumps that can also offer peak electricity demand reductions.

3.1.2 End-uses

For residential customers, the cost of a ground-coupled heat pump is about 4 times greater than the same-size air-to-air heat pump. In 1991, TVA initiated a program that offered customers of participating power distributors "free" ground loops. Two years later, only 219 customers were participating. The customer costs for a 3-ton heat pump unit was $5400; TVA cost was $435 and the distributor cost was $870. Thus, the total cost for the ground-coupled heat pump system was $6705 (or $2235/ton) (Kavanaugh et al., 1995). These costs do not include any overhead and profit for the loop installation component since it was subsidized by the utility. A 3-ton air-to-air system would cost $4000. At an estimated savings of $300/year, simple payback was 4.7 years with the utility supplement and 9.0 years without. Kavanaugh et. al (*ibid*.) states that, "Many customers are very reluctant to participate in the program even with the 4.7 year payback. Since little activity has occurred without supplements, it is likely that very few customers would be eager to participate with the 9-year payback."

It is estimated that ground-coupled systems comprise less than 2% of HVAC sales in the United States. The main market impediments relate primarily to a lack of awareness and knowledge about the technology, its benefits and the high initial costs. Other barriers include lack of reliable installation and service infrastructure and its perception as an innovative and unconventional HVAC choice. For these reasons, ground-coupled systems constitute a higher risk decision for purchaser and seller, alike.

Development of the SWS would address many technical barriers facing ground-coupled heat pumps. With some investment incentives and the readiness of architectural and engineering communities to offer this energy saving and environmentally friendly technology as an option could enable greater market penetration in the future. Market penetration might be assisted with incentive plans for adopting environmentally friendly technologies and options offered by architects and builders.

3.1.3 R&D needed

SWS technology is being hotly pursued throughout Europe [Aristov et al., (2002); Gordeeva, (1998a, 1998b); Cacciola (1994); Meunier, 1992; Shelton, (1992)], because of its potential use in ground-coupled, solar and sorption cooling/heating technologies and because it is completely consistent with the requirements of the Montreal Protocol of 1988 and with the Kyoto Protocol of 1997. Research and development is starting to address the following issues that will improve the viability of SWS as a phase change material (PCM) for use in heat pumps:

- Energy density of 1200 Btu/lb is possible, compared to 60-200 Btu/lb for known phase change materials.
- Phase transition at a sliding temperature between $-15^{o}C$ up to $110^{o}C$, which can fit any practical HVAC application.
- Not limited to one fixed temperature or to a narrow range of temperatures like traditional PCM blends. This adds flexibility to design and improved performance.
- Issues related to incongruent melting are non-existent. This is a significant drawback to traditional PCMs.
- Does not require energy to restore initial phase. This is the main limitation of the thermal ice storage concept.
- Improve the design of heat pump equipment using the SWS concept to fulfill DOE's objective of achieving SEER >20 for a 1 ton unit, with no maintenance for the SWS over the twenty year life of the equipment.

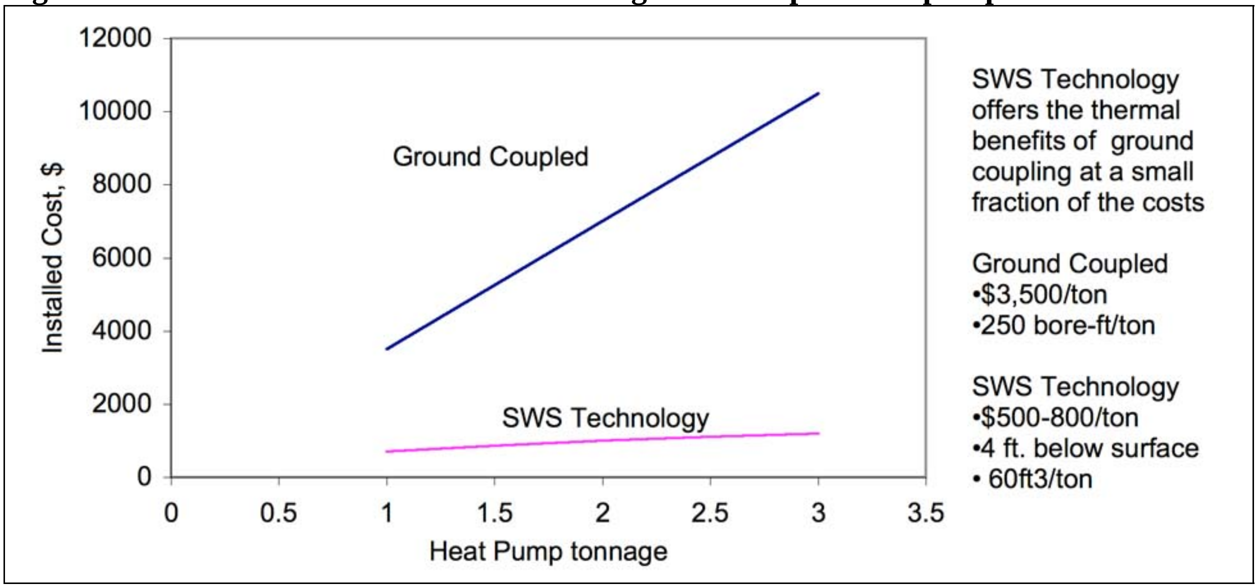
A prototype system can be ready for testing by FY 2006 with sufficient funding. Long-term, additional research is needed in the following three areas:

- The physics of SWS materials and types of chemical precursor materials that can be used for storage of water in condensed form;
- Routes of synthesis suitable for mass production;
- Improved understanding of physico-chemical processes and influence of aging on material properties.

3.2 Cost

Fortunately, the cost of SWS precursor materials is low and therefore from a material inventory standpoint the economics appear favorable. Some SWS materials are commercially available and can easily be modified to suit ground-coupled heat pump applications. Other SWS materials require synthesis and hence the costs associated with these steps need to be factored in the price. Figure 6 below shows the cost advantage of the ground-coupled portion of an SWS heat pump system compared against conventional ground-coupled systems available to the consumer. (Kavanaugh, et al., 1995) and preliminary in-house calculations on SWS based on literature. (Saha, et al. (2003); Chua et al, (1999); Chua, et al. (2004)). Since SWS precludes extensive excavation, it offers a very attractive installed cost structure to the consumer. Full-cost of a system would also include the

Figure 6. Installed cost of SWS vs. traditional ground-coupled heat pumps

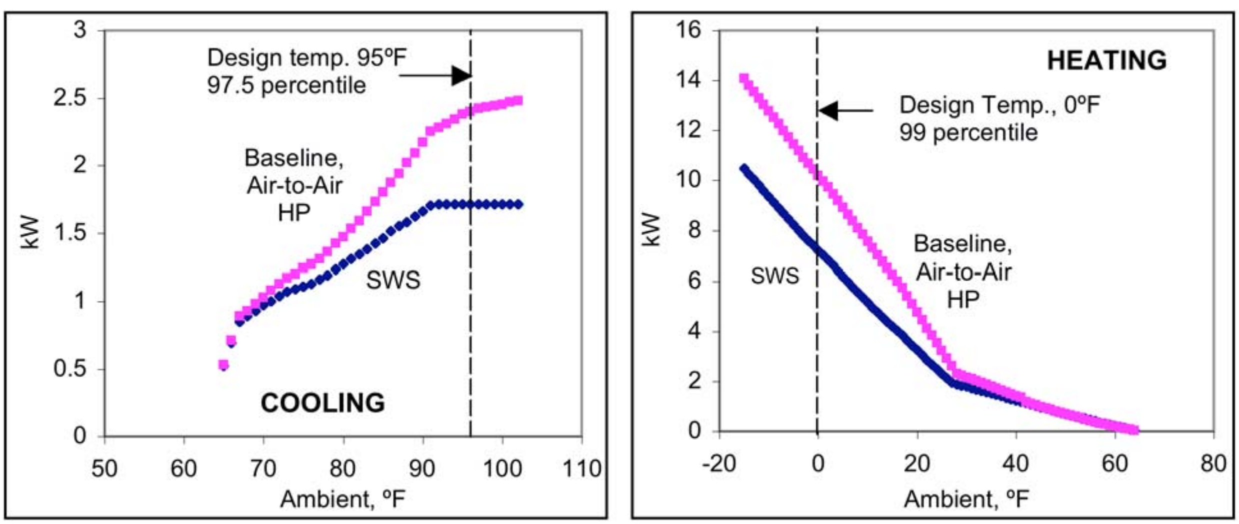


3.3 Energy

3.3.1 Energy consumption and comparison to existing technology

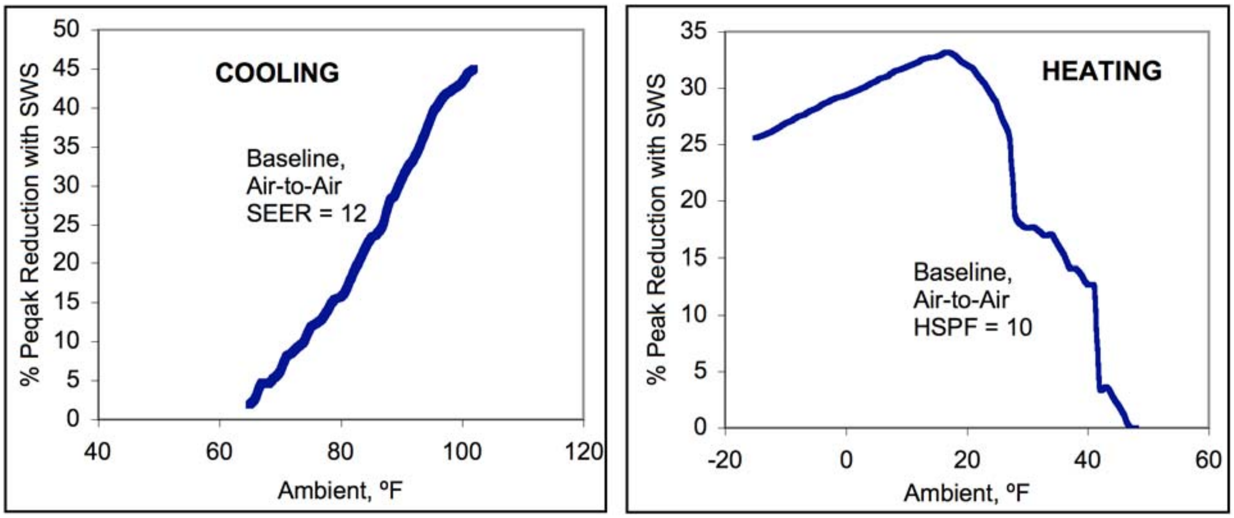
Simulation studies indicate energy as well as peak electric demand reduction using SWS in a ground-coupled heat pump in residential applications. A comparison of the aggregate electric demand in DOE's Region III, (the Mid-Atlantic states of New Jersey, Pennsylvania, Delaware, Maryland, Virginia, and West Virginia) depicting electricity savings during the summer (daytime cooling) and winter (night time heating) as a function of the ambient temperature is shown below (Figure 7) (Rice, 2004). These calculations were made using the DOE/ORNL Heat Pump Design Model for DOE Region III. (DOE 2004)

Figure 7. Comparison of aggregate demand between SWS and Air-to-Air HPs: Heating (nighttime) and Cooling (daytime)



Comparison of aggregate electricity demand of SWS versus conventional air-to-air heat pump technology shows substantial electricity savings during summer and winter months when outdoor temperatures are hot and cold, respectively. Aggregate peak electricity demand may be reduced as much as 45% and 35% during the summer and winter months, respectively, using SWS as shown below (Figure 8) (Rice 2004).

Figure 8. Aggregate percent peak savings with SWS: Cooling (daytime) and Heating (nighttime)



3.3.2 Potential energy savings

The ORNL heat pump model analysis between a conventional air-to-air heat pump and an SWS ground-coupled heat pump installed in DOE's Region III shows annual electricity savings of 36%. Other regions with broader air temperature extremes should see greater savings. The *AEO2004* reports 11 million air-to-air residential heat pumps and only 88 thousand geothermal residential heat pumps in 2003. Even with a 9.1% growth rate for geothermal, this still represents only 550 thousand residential geothermal heat pumps by 2025. Development and deployment of SWS heat pumps will improve energy savings two ways. By making these projected geothermal heat pumps more efficient, there will be savings over those that are projected to be used. Secondly, and perhaps more importantly, the lowered cost and increased flexibility of the SWS heat pumps could greatly expand their market penetration into the air-to-air heat pump market. By 2025, the *AEO2004* reports the average geothermal heat pump cooling efficiency at 14.82 SEER, while air-to-air heat pumps have a SEER of 13.08. If the SWS can improve efficiency by 35%, this could represent an average SEER of 17.7. Of course, more detailed analysis of market potential (such as with NEMS) could distinguish the amount of market that SWS may capture. Commercial market penetration would need to be explored as well.

As a very rough approximation of potential savings, the residential electrical consumption for space heating in 2025 totals 1.4 Quads in the *AEO2004*. Assuming conservatively based on 1999 ratios that one third of the heat is provided by heat pumps (versus resistance heating) and there is an equal amount of energy used for cooling from heat pumps, a 35% savings from SWS heat pumps over air-to-air heat pumps would equal 0.32 Quads. In the commercial sector, 0.5 quad of primary energy for electric space heating converts into 0.11 Quad potential saving, using the same factors as for residential. In the *AEO2004* reference case, geothermal heat pumps provide only 0.01 Quads of energy. It is unknown how rapidly SWS could penetrate (and possibly expand) the heat pump market. Assuming through a combination of penetration and expansion it could take 50% of the expected heat pump market, this would be equal to savings of 0.21Quads.

For a detailed analysis of market energy savings, the heat pump model must be run for each of six regions in the continental USA along with information on residential population density and potential commercial applications as well as heat pump size distribution. For a rough analysis, the seven air-conditioning and heat pump manufacturers in the U.S shipped 6.2 million air-to-air and geothermal heat pump units in 2001(DOE 2003). In addition, heat pumps have an average lifetime of 14 years and 124,000 units were replaced in 2003. If the SWS heat pump's economics proved highly attractive, greater savings could be achieved through increased shares of the natural gas and other heating fuel markets.

3.4 NEMS approach

The NEMS commercial module includes ground source heat pumps as an option for heating and cooling. It only allows them in the Assembly, Education, Food Sales, Food Service, Small Office, and Merchandise/Service sectors, not in the Health Care, Lodging, Large Office, Warehouse, or Other sectors. The decision methodology for heat pumps to compete against other sources recognizes the separate heating and cooling they provide. By subtracting the cost of central air conditioners from the heat pump cost before it competes in the heating category, its incremental heating cost is compared to other heating sources.

The NEMS commercial module places cost values in terms of $/output capacity. Using an SWS cost of $5,200 for a three-ton (36,000 Btu/hr) heat pump, this equals $144/1000 Btu/hr. This makes it more expensive than the typical air-to-air heat pump but less than the high efficiency or other geothermal heat pumps.

Table 10. NEMS example commercial heat pump parameters from the *AEO2004* (EIA 2004) and corresponding SWS values

	Efficiency (Btu out/Btu in)	Capital Cost (2001$/ 1000 Btu out/hr)	O&M Cost (2001$/ 1000 Btu out/hr)	Lifetime (years)
Geo HP 2005 typical	3.4 (heat) 3.96 (cool)[1]	$166.67	$1.46	20
Geo HP 2010 high	4.3 (heat) 6.15(cool)[1]	$208.33	$1.46	20
Air-to-Air HP 2005 typical	2.2 (heat) 3.52 (cool)	$97.22	$3.33	14
Air-to-Air HP 2010 high	2.87 (heat) 5.28 (cool)	$155.56	$3.33	14
SWS	3.22 (heat) 4.0 (cool)	$144.44	$1.46	20

The NEMS residential module also includes ground-source heat pumps, but in a different format than the commercial module. Key factors include the start year, end year, efficiency, capital cost, and retail (replacement) cost for heating and cooling. The inputs allow a change in efficiency or cost by setting different years when equipment can be installed, with improved equipment available in later years. Table 11 shows values for two of the air-source and geo-source heat pumps available 2006-2019, along with representative values for the SWS. While the SWS technology is not as efficient as the other geothermal heat pumps, its cost is much less.

Table 11. NEMS example residential heat pump parameters from the *AEO2004* and corresponding SWS values

	Efficiency (Btu out/Btu in)	Capital Cost (2001$)	Replacement Cost (2001$)
Geo HP #1	3.4 (heat) 13.5 (cool)[1]	$6,760 (heat) $3,640 (cool)	$4,000
Geo HP #2	4.3 (heat) 21 (cool)[1]	$7,891 (heat) $4,249 (cool)	$4,800
Air-to-Air HP #1	2.2 (heat) 3.52 (cool)	$2,345 (heat) $1,155 (cool)	$2,000
Air-to-Air HP #2	2.38 (heat) 3.81 (cool)	$2,580 (heat) $1,271 (cool)	$2,333
SWS	3.22 (heat) 4.0 (cool)	$3,200 (heat) $2,000 (cool)	$3,200

[1] NEMS values for cooling efficiencies for Geo-HP are inconsistent with other heat pump values in the same input file, (appear to be SEER values so should divide by 3.412). However, source code refers to different mechanisms for calculating Geo-HP energy use in which case SWS values should be multiplied by 3.412.

3.5 References

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4. Integrated Energy Equipment

4.1 Technology

Integration of systems is a powerful method to improve the functions provided by multiple systems. It can lower costs, improve efficiency, reduce space requirements, and make services that are otherwise unavailable attractive to users. Integration occurs in a large number of fields, from combined inventory control/checkout in businesses, to cell phones with built-in cameras for consumers.

A major concept for improving energy efficiency is recognizing the synergy between energy forms needed by different energy end-uses or types of equipment. Integrating the equipment allows the exhaust of one to be supplied to another, lowering the overall energy losses. In addition, integrated systems allow the common use of components for multiple purposes, which can result in lower first costs for systems.

There are a number of examples of integration of energy systems that have been proposed, are under development, or are in current use. Solar photovoltaics on rooftops combine electricity generation and building shell weatherization. This concept has been modified to include solar collectors for piping light indoors or powering bioreactors that produce hydrogen. Integration of hybrid electric or fuel cell vehicles with distributed microgrids could mean electric generation that travels along with people and their consequent demand. On a much larger scale, high-temperature superconducting transmission lines could be cooled by liquid hydrogen produced at the same generation facility, resulting in the distribution of both electricity and gaseous fuels as part of a “supergrid”.

Industry has long used integration of energy equipment through cogeneration, providing both steam and electricity to manufacturing processes on the factory floor. The first generating plants in the country provided steam or hot water as well as electricity. Today, cogeneration provides over 9% of the electricity used in this country (EIA 2003). As equipment has improved, smaller sizes of equipment have become economic, but other factors besides cost begin to enter the decision process when energy is not a major factor for a business or consumer. Improved integration can lower these barriers and foster the acceptance of high efficiency technologies.

4.1.1 Brief description of the emerging technology

This chapter will discuss in more detail some ways that integrated energy equipment could be improved so that more commercial and residential consumers can take advantage of the cost and efficiency benefits that they can provide. Possibilities in the residential and commercial sectors include:

- Combined heat pump space heating, cooling, water heating, and dehumidification
- Cool air from heat-pump water heating used for space cooling
- Exhaust heat from refrigeration and freezing used for space heating and/or hot water
- Exhaust heat from distributed electricity generation used for space heating, water heating, and other thermal energy needs

Several of these concepts are already being implemented, most notably the use of thermal exhaust from distributed generation as combined heat and power (CHP). Further expansion of these concepts will occur as equipment manufacturers progress from simply routing the energy between equipment to integrating the different pieces of equipment during design. This optimization should lower the cost and improve the overall utilization of energy.

4.1.2 End-uses

Integrated Appliances: Some energy needs, such as water heating and space heating, serve to raise temperatures while others, such as refrigeration and space cooling, lower them. Surplus or exhaust heat or cool air from these appliances can be provided to others, boosting the overall efficiency. As a simple example, exhaust air from a domestic clothes dryer could be filtered and ducted to provide heat and humidification to a home during the winter. The end result is an appliance that performs several functions (drying, humidification and heating) that would otherwise require several individual appliances. In a more complex approach, the condenser heat from a domestic refrigerator could be captured and used to provide domestic hot water. Appliances such as air conditioners, heat pumps, refrigerators and dehumidifiers that use compressors and therefore provide heating and cooling at the same time, provide opportunities as integrated appliances that perform dual functions.

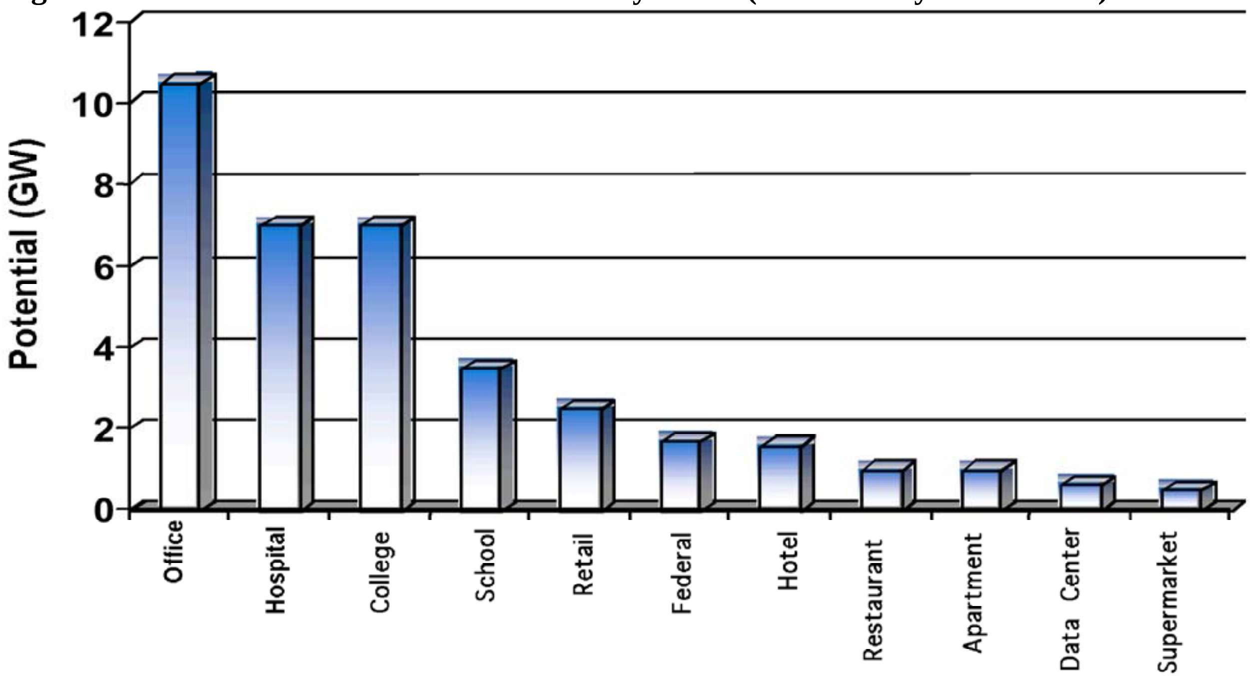
There are a number of ways in which appliances may be integrated to perform heating, cooling, humidity control and water heating efficiently, and some products are in the market as shown in Table 12 below. Combined equipment for space heating and water heating are available for residential applications. These commercially available systems use natural gas as a fuel and accomplish space heating and water heating at the efficiency of the gas burner. Relatively little technology exists in terms of residential integrated appliances where heat pumping could be used to significantly reduce overall energy consumption. There are only three manufacturers of the residential heat pump water heater (which also provides space cooling and dehumidification), and they are trying to expand the current market at present. With commercial buildings, heat recovery chillers are available where space conditioning coincides with the need for hot water. The commercial heat pump water heater occupies a small, niche market for buildings such as commercial laundries and fast-food restaurants where there is a need for space cooling and water heating. Estimates put the market for all heat pump water heaters in the range of 2,000 units per year, and most of this market is for the commercial heat pump water heater.

Integrated Energy Systems: The highest and most consistent energy savings from distributed energy resources occur when the thermal exhaust from the electric generation is used for other purposes at the site such as heating, cooling, dehumidification, or steam. Total efficiencies from this combined cooling, heating and power (CHP) can easily exceed 70% (DOE 2004). A significant hurdle to market development and penetration is the complexity of a CHP system, with different manufacturers for various components. An equipment packager must integrate the various components for each site, resulting in higher costs. Especially for smaller potential users where energy use may not be a major consideration, this added complexity can be sufficient to prevent its acceptance. The potential market for commercial CHP is shown in Figure 9. In addition, many industrial sectors, such as chemical, metals, equipment manufacturing, paper, and food have great CHP potential.

Table 12. Examples of potential applications for integrated energy equipment

Application	Integrated appliance	Primary function	Secondary function	Commercially available?
Residential buildings	Water-heating refrigerator	Refrigeration of fresh and frozen food	Water heating	No
	Heat pump water heater	Domestic water heating	Space cooling with some dehumidification	Yes, two product variations: one an integrated heat pump water heater with tank; the other, an add-on heat pump water heater but the dehumidification function has not been optimized in either.
	Refrigerator heat pump water heater	Refrigeration of fresh and frozen food	Water heating and space cooling with some dehumidification	No
	Water heating dehumidifier	Water heating	Two operating modes: (1) water heating priority with space cooling and dehumidification as secondary benefit, and (2) dedicated mode for space dehumidification and modest sensible heating when water heating load is satisfied	No
	Multifunction heat pump	Space heating and cooling	Domestic water heating	Systems developed in the past; none currently on market
	Combination space and water heaters (combos)	Space heating	Water heating done by gas using a furnace or boiler and a heat exchanger to provide domestic hot water	Yes by five U.S. manufacturers
Commercial buildings	Heat pump water heaters	Water heating	Space cooling	Yes by six U.S. manufacturers
	Heat recovery chillers	Space cooling	Water heating	Current technology is simply a double-bundle condenser applied to a chiller. Improved chillers would improve the energy savings potential.

Figure 9. Potential CHP commercial market by sector (Resource Dynamics 2002)



4.1.3 R&D needed

Integrated Appliances: Table 12 above indicates that other opportunities exist for development of integrated appliances, particularly for residential buildings. Additional R&D is needed in a number of areas:

Heat exchangers – Research on advanced, three-fluid heat exchangers so that heat pumping can be used to exchange energy efficiently and safely between a refrigerant, air or water;

Adaptive controls – Research on adaptive controls that optimize the performance of the integrated appliance for best performance and lowest energy consumption; and

Desiccants – Research on dehumidifying materials (e.g. desiccants) that can be regenerated at low temperatures. These R&D needs could easily be met in the near term (5-10 year time frame).

Other advances may need a whole-building approach that take longer to advance and implement.

Integrated Energy Systems: Research is ongoing on development of practical integrated energy systems at multiple sizes, increasing the potential market penetration. Currently, United Technologies and Capstone have developed a packaged system consisting of four 60 kW microturbines plus heat exchangers, chillers, and other equipment to provide space heating, cooling and hot water. NiSource Energy Technologies is developing an integrated system for the hotel industry that combines baseload electricity, heating, absorption-based air conditioning, dehumidification, and emergency isolation from the power grid. The Gas Technology Institute has teamed with Waukesha, Trane, and Ballard Engineering to create a packaged engine generator and absorption chiller for sizes between 280 kW and 810 kW for a variety of building types and markets. These are all described in more detail at DOE’s Distributed Energy Program website (DOE 2004).

The individual components within the packaged systems have numerous research challenges as well. For example, microturbines must increase in efficiency by 10% (from ~30% to 40%), which is a major materials challenge. Power electronics that interface the electrical production with the grid need improvement to increase the power quality. Fuel flexibility will increase the robustness and value to the user, and emissions reductions are necessary to allow the technology to penetrate markets in areas with poor air quality.

Furthermore, research is being conducted on developing tools to optimize the components of the integrated CHP to balance between electrical and thermal needs. Since different types of commercial (and possibly residential) facilities will have different relative requirements for each type of energy, it is important that the equipment is designed to provide the correct mix at the highest efficiency and lowest cost.

4.2 Cost

4.2.1 Cost of the new technology

Integrated Appliances: Experience is greatest with residential combined water heating and space cooling. The installed cost of the residential heat pump water heater is $1200 - $1400 as compared to the $400 cost of a conventional electric resistance water heater. Some of the additional cost is related to the additional components needed; however, much of the premium is due to market issues (small current market, lack of infrastructure, no product offering by major manufacturers). High first cost was also a major barrier for the multifunction heat pump developed by Carrier Corporation and later by Nordyne; consequently, only a small market developed for this product. Based on these experiences, it is clear that new integrated appliance designs provide additional customer benefits and better meet customer needs.

Integrated Energy Systems: The cost savings from packaging CHP systems into a single commercial package, as opposed to purchase and installation of individual components, is estimated at 30% (DeVault 2004). These cost savings are from the economic efficiencies of standardization, lowered transportation costs, and simpler fieldwork.

4.2.2 Cost-effectiveness

Integrated Appliances: Since water heating is a significant component of overall building energy consumption, the heat pump water heater is a good example of cost-effectiveness for certain applications. Data show that a conventional electric resistance water heater costs about $450 per year to operate based on typical electric rates. The residential heat pump water heater uses 50% of the energy of a conventional electric water heater. Therefore, the heat pump water heater would save $225 per year in operating cost. Based on an incremental cost of $800, the payback for switching to the heat pump water heater would be 3.6 years. However, with continued research and technology experience, the incremental cost of the HPWH could decline to less than $400, with a consequent payback of less than two years. This estimate is based on the cost of window air conditioners, which use many of the same components as a heat pump water heater and can cost less than $200 currently. It is likely that other integrated appliances would have similar economics as well, and similar opportunities for improvement with further research and with manufacturing experience.

Integrated Energy Systems: Cost effectiveness of the overall technology depends on a broad number of site-specific characteristics including electrical and thermal energy needs, electricity and gas rates, utility cooperation on installation, building owner investment hurdle rates, and value of reliability.

4.3 Energy

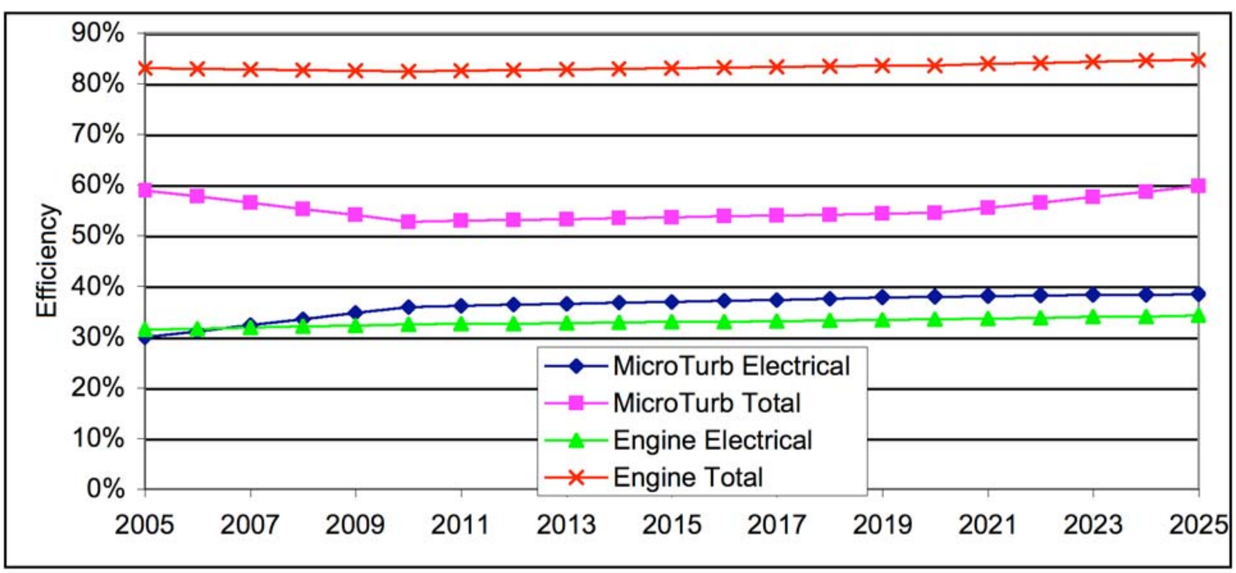
These types of equipment integration could significantly improve the overall efficiency for residences and commercial facilities. The amount of market penetration of these improvements will depend on the first and long-term costs, performance, flexibility, and reliability of the equipment and the rate of equipment replacement in applicable buildings.

4.3.1 Energy consumption

Integrated Appliances: The energy consumption of an integrated appliance depends on the type of appliance and its application. In the case of a water-heating refrigerator, the energy consumption would be the same as for a conventional refrigerator (~600 kWh/y); however, the refrigerator would also provide hot water with no additional energy consumption. In an air-conditioning climate, the water-heating refrigerator delivers additive benefits: condenser heat to space is eliminated and hot water is produced as a free benefit. Room dehumidifiers, as another example, use approximately 1,000 kWh/year (ref. E-source), and much of this energy ends up as space heating. A water-heating dehumidifier (integrated appliance) could save on an annual basis, more than half of this energy at an approximate operating cost savings of $40/year.

Integrated Energy Systems: Energy consumption by the technology would be roughly equivalent to the equipment in a non-packaged form. The difference is in the equipment cost, and consequent potential for market penetration. For microturbines, NEMS shows electrical and total (including thermal energy) efficiencies as shown in Figure 10.

Figure 10. Microturbine and Gas Engine efficiency assumptions - Electrical and Total (including thermal) from the *AEO2004* (EIA 2004)



4.3.2 Potential energy savings

Integrated Appliances: Integrated appliance types span the gamut from water-heating dehumidifiers to heat pump water heaters, and therefore, there is a wide range of energy savings depending on the technology. For example, the typical heat pump water heater saves on average 2100 kWh/year, and the integrated water-heating dehumidifier 500 kWh/year. The market for electric residential water heaters is about 4 million per year, and the market for dehumidifiers is 1 million per year. A reasonable approach is to assume averages for these technologies over two rates of penetration. At a penetration rate of 10% per year, the end-use energy savings would be 900 million kWh/year or 9.6 trillion Btu of primary energy.

Another way to look at potential savings is the expected electric water-heating load. The *AEO2004* shows residential electric hot water energy use at 0.37 Quads (EIA 2003). Integrated heat pump water heaters and space coolers can heat water at over twice the efficiency of a resistance heater, plus the savings from reduced air conditioner load. This gives a minimum potential of 0.2 Quads for this end-use and sector alone. While penetration will likely not be near 100%, other integrated technologies have additional potential savings.

Integrated Energy Systems: The energy savings from packaged systems will come principally from increased penetration of the distributed generation and CHP market. In the *AEO2004* reference case, 12.4 GW of commercial distributed generation is deployed by 2025. Packaged systems should increase that amount if it succeeds in improving the acceptability of CHP into new market niches. Besides the energy savings from the increase in the overall market for CHP, packaged systems can be 10% to 15% more efficient than the equivalent energy end-use production from separate equipment. Integration of the design and function allows better utilization of the energy inputs.

In the *AEO2004*, industrial and commercial CHP provides 157 GWh of electricity in 2002, which translates into 1.7 Quads of primary energy. (Another 2.1 Quads are provided by the electric utility sector for CHP.) The commercial and industrial production is expected to grow to 3.1 Quad by 2025. Most of this production is from large producers for which packaged systems' advantages are not as crucial for acceptance. However, if packaged systems influence the use of just 10% of this amount, and total energy efficiencies for CHP are double that of central station generation, then packaged systems could result in roughly 0.3 Quads of energy savings. This calculation is very rough; a more complete evaluation would require evaluation of the penetration of packaged systems versus regular CHP systems.

4.4 NEMS approach

Integrated Appliances: NEMS models a large variety of residential and commercial building technologies, but currently the only explicit multi-function technology is heat pump for combined space heating and cooling. Heat pump water heaters are modeled as well but the space cooling they provide is not. EIA has plans to add a method that allows flexible multiple-function equipment to be modeled. The initial methodology has been developed by contractors but has not been implemented yet. A bounding analysis of the potential for integrated space/water heat pumps could be done by using the incremental cost of the water heaters but try to limit the acceptance to those who also have heat pumps for space heating. More extensive code changes would be required to explicitly connect the technologies.

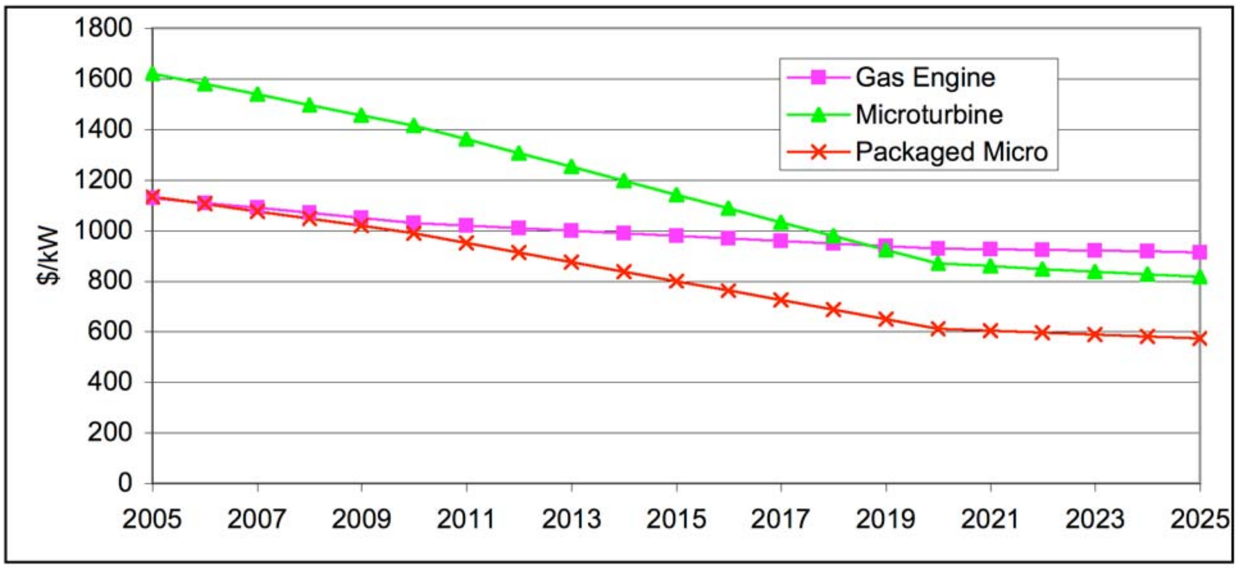
Integrated Energy Systems: NEMS models up to ten distributed generation technologies within the commercial sector. The technology description data includes for each year the information in Table 13. Other parameters such as those concerning program-related penetration, net metering, learning, and operating hours are included in the input file kgentk.txt.

Table 13. Distributed generation technology data used in NEMS

Equipment Type	Fuel Type	First Year	Last Year	Avg kW	Elec Effic	Loss Factor	Degr'd Factor	Eq Life	Tax Life	Depr Meth	Rec'v Eff	Inst. Cost	Equip Cost	Maint Cost	Avail	Tax Credit %	Max $

If packaged systems reduce the equipment cost by 30%, then the values in the table for microturbines (if that is the packaged equipment) can be lowered by 30%, giving an equipment profile as shown in Figure 11. Other values would remain the same as for microturbines.

Figure 11. Equipment costs for gas engines and microturbines (from *AEO2004* inputs) and packaged microturbines, assuming a 30% reduction.



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5. Efficient Operations Technology

5.1 Technology

Research has indicated many reasons why energy efficiency varies so much in commercial buildings. The causes of variation in efficiency can be categorized as variations in: efficiency of operation, efficiency of systems, and efficiency of equipment. Of these three, about half of the potential improvement in energy efficiency for commercial buildings would result from operational improvements, with the remainder from equipment and system upgrades.

Many studies have shown the importance of operational improvements, with typical savings of 10–20% possible in a wide range of buildings (see Haasl and Sharp 1999 for data and additional references). Effective operations provide one of the most cost-effective methods for achieving energy efficiency. Since the Oil Embargo of 1973, the improvement of building operations has been a key means of achieving energy savings. The experience of the Energy Systems Lab at Texas A&M in the 1980's and 1990's demonstrated that operational efficiency improvement opportunities were still abundant, and experience in the Federal Energy Management Program indicates abundant opportunities remain (MacDonald 2003). The Texas A&M experience indicated that lowering energy use by 10% to 40% merely by improving the operational strategies of buildings was common (Claridge and Haberl 1994).

Despite the demonstrated opportunities, the "technology" for achieving higher-efficiency building operations currently is not based in hardware so much as in software and expert knowledge. Because of this current "soft"-ware dominance, transfer and wide distribution of knowledge is challenging.

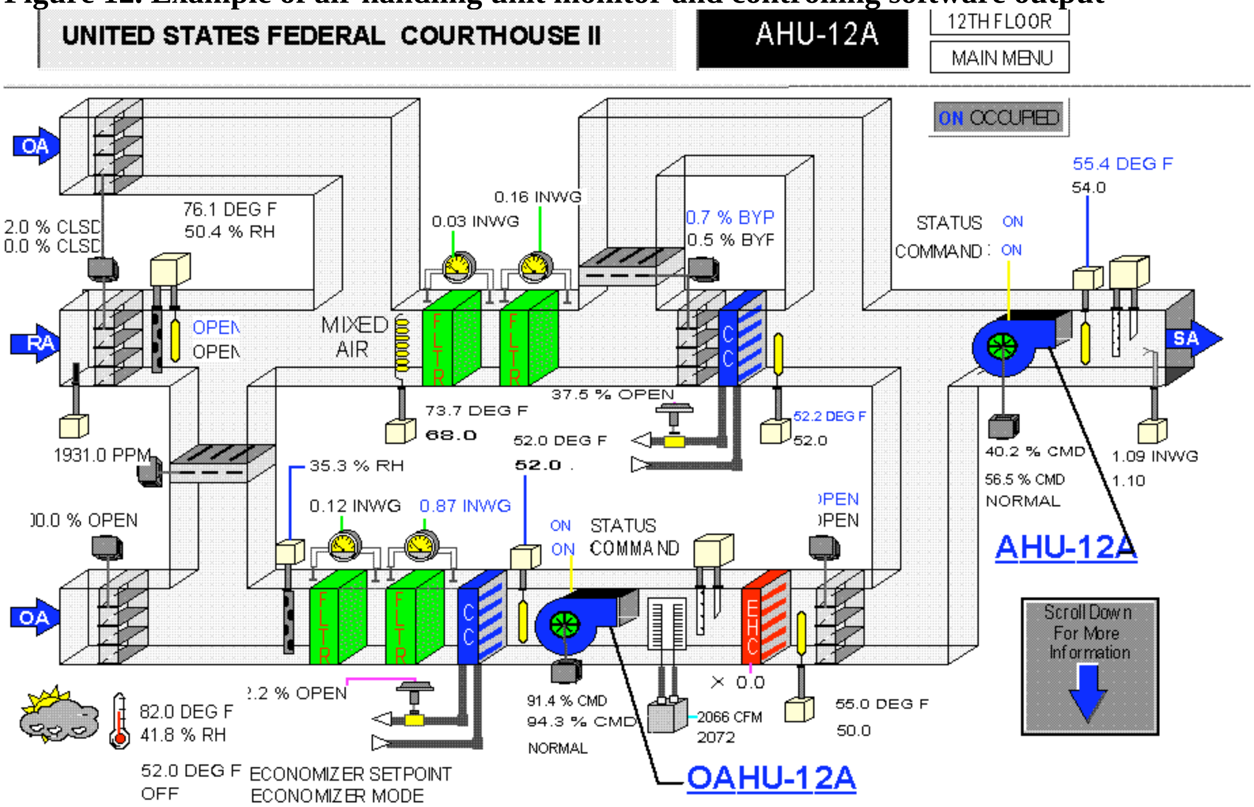
Documented research on advanced hardware and software for diagnostics and performance information monitoring has had limited publication (e.g., Piette 2000). Undocumented R&D is more extensive but remains mostly proprietary (for example, Facility Dynamics Corporation in Maryland has conducted extensive R&D on both software and hardware configurations, but the technology remains primarily proprietary).

Advances in information technologies such as diagnostic and monitoring software and hardware are still important for achieving improvements in building energy operations. Continued changes toward miniaturization of hardware and toward enhanced measurement and diagnostic capabilities emerge regularly and impact how building operations can be diagnosed and improved.

In recent years, a new class of tools has emerged to make the decision to knowingly seek improved efficiency of building energy operations easier. These tools can be generically called building energy performance rating systems, and the best-known tools of this type in the United States are the Energy Star building certification systems. An extended discussion on the commercial sector, energy use, efficiency issues, and energy certification systems can be found in the forthcoming Encyclopedia of Energy (MacDonald 2004). Figure 12 shows an example readout from the air handling control software for a single floor of a federal courthouse. Use of such software can contribute to the energy savings available through improved operations.

The challenge is to move all phases of technology development, both hardware and software, toward specifically helping and improving building energy operations, especially in order to be able to conduct diagnostics and remediation on increasingly larger scales with fewer expert personnel required.

Figure 12. Example of air handling unit monitor and controlling software output



5.1.1 Brief description of the emerging technology and application

Energy-efficient operations technology currently involves an event in the life of a building where a systematic investigation and application process for improving and optimizing a building's operation is applied. The focus is usually on energy-using equipment such as mechanical equipment, lighting, and related controls. Improvements in operations strategy and controls are often the major source of benefits. The potential improvements exist because building systems are often very complicated, and many owners and operators are not capable, in many cases, of understanding energy-efficient use of the systems. Increased automation of the improvement process is a potential key area for research and development.

The technology application works best when an initial energy performance rating is determined, an energy assessment is completed (simple may be better here), beneficial hardware and software improvements are identified and prioritized according to objectives for improvement, an energy performance improvement target is set, and improvements are implemented according to priority.

The energy performance rating of some type is important because then energy performance is measured and the energy improvement potential can be more clearly quantified.

Following the energy performance rating and decision to pursue operational energy-efficiency improvements, expert assessment of the means to achieve improvements in controls and other hardware is still needed.

Enhanced diagnostics and performance information monitoring could potentially allow this step to be performed automatically. A systematic process that optimizes how equipment and systems operate and how the systems function together is needed, and advanced diagnostics and performance assessment algorithms could allow much of this process to be performed by computers.

The key issue of persistence of benefits should also be addressed. In order to ensure that building systems remain optimized over time, a commitment to continuously check the energy performance rating of a building must be made, at a minimum. If performance begins to degrade, benefits also degrade over time. Advanced hardware and software could also allow continuous checking of energy systems performance to help diagnose any causes of reduced performance indicated by the performance ratings.

5.1.2 End-uses

The focus of the technology is the major energy end-uses of cooling, heating, HVAC fans, and lighting, although all end uses can be affected.

5.1.3 R&D needed

The technology includes components across the development spectrum. Expert knowledge on the systematic process of energy system evaluation of potential improvements is fairly well developed, although there are still major difficulties in managing the transaction between expert providers and non-expert procurers of such services. Development in sensors and controls is needed to improve their performance and lower their cost.

Energy Performance Rating Systems – The development of energy performance rating systems is, in certain ways, still in its infancy, as so little time has passed since these systems were first successfully developed (in 1999). In addition, the range of building types for which these tools are available is limited, and application in mixed-use buildings is often difficult. Oak Ridge National Laboratory has the only tool available for application in mixed-use buildings, and this tool has not been extensively tested. Significant R&D on these systems and their application is still important, although a major portion of commercial buildings is currently covered by the Energy Star tools.

Monitoring and diagnostic systems – The major gap in the technology results from the limited development to date of advanced monitoring and diagnostics systems. Advances in reliability and reductions in cost of hardware are needed. Expert knowledge must be codified and transferred to diagnostic and remediation recommendation algorithms.

With the high number of components in a commercial building, it is difficult for operation staff just to keep fully aware of equipment and system conditions. Without automated monitoring and fault detection, and the sensors and controls on which they rely, performance can degrade. The number and range of types of sensors installed in commercial buildings today is inadequate to provide sufficient automated (or even visual) monitoring. The primary impediment often cited to more and better sensing is the cost of additional sensors. Installed costs of sensors need to be reduced and decision makers need to become informed regarding the benefits they can derive from better sensing and control.

Automatic control needs to be developed that controls indoor conditions adequately that building staff build confidence in control systems. Control based on more plentiful sensors is required to control at the level desired by occupants and optimize energy use. Optimal control techniques at the system and whole-building level are needed to reach the level of performance where high-quality indoor conditions are provided at minimum net energy use. Control must be extended from individual independent loops to system level controls to achieve least-cost, highly efficient, building operation.

Sensors and controls – Sensor and control needs for commercial buildings span a broad range of technical activities. Sensors at a sufficiently low cost are needed for a broad range of measurements that includes lighting quality, volumetric fluid flow rates, rotational position, wear, vibration, and power consumption, as well as the usual measurements of temperature and humidity that are currently performed in commercial buildings. Sensor technology will require built in intelligence to ensure accuracy, self-diagnostics, and be easily integrated into existing systems. These emerging technologies should facilitate broader applications of sensors in buildings including automated diagnostics of HVAC and other energy systems, lighting, fire and safety systems, demand responsiveness and optimal control, indoor air quality, and counter measures against bio/chem attacks (building security).

In addition to possessing lower installed cost than today's sensors, R&D must lead to sensors with enhanced performance: longer lives, greater reliability, higher accuracy, persistent calibration. These enhancements will lead to higher, persistent, performance of building systems.

Streamlined installation – In addition to improving the quality of sensors themselves, streamlined installation is required. One of the largest cost components for sensors is the cost of installation. Installation, particularly in retrofits, requires running cabling in spaces such as walls and ceilings that are frequently difficult to access, running up expenses for labor. Wireless network technology or communications over existing power wiring can significantly reduce installation costs in new or retrofit applications.

5.2 Cost

5.2.1 Cost characterization

Cost of applying this technology in its current state varies significantly, depending on several factors. Cost for applying advanced, automated technology is expected to be approximately comparable once lower-cost components are developed and application algorithms are developed. The cost information supplied here is for current technology.

Costs for the energy performance rating vary, depending on whether the energy and characteristics data are already readily available or not, on potential complexities of building use, and on potential difficulty with adjusting for major ancillary spaces in a building, e.g., a major computer center in an office building. If data are readily available and no adjustments are needed, an expert can obtain a quick rating in less than an hour, so costs are low, in the range of $100.

If data have to be collected for the rating, costs for a rating could be $1,000 – $3,000, depending on complexity of the data. If major adjustments beyond those typically available are needed for ancillary spaces, costs could increase an additional $1,000 – $10,000 or more, depending on complexity, e.g., especially if an expert rating assessment is needed or energy use submetering must be installed.

Costs for the expert assessment of improvements needed depend on travel costs, the rigor demanded, the level of reporting required, and the expertise of the assessor. A minimum cost is about $5,000 (to at least handle startup). Cost per gross square foot (GSF) of building to be assessed can typically range from $0.03 – $0.08, depending on these factors, but can be more. For buildings under 100,000 GSF in size, costs will often be higher and possibly driven by a minimum startup cost for the work. As an example, for a 10,000 GSF office building, costs might be $5,000 plus $0.10 per GSF for a very simple report.

Costs for implementation of actual system improvements might be as low as $0.05 per GSF for very large buildings (greater than 500,000 GSF) and could be as high as $5.00 per GSF or more for small buildings.

Costs for verifying persistence of benefits should be low, less than $500/yr per building.

5.2.2 Cost-effectiveness

The base technology is to leave operations alone, or to do nothing. Cost effectiveness varies by building energy efficiency rating and building size. As building size increases, cost effectiveness usually increases, due to relatively fixed technology initialization costs. As building efficiency rating decreases, cost effectiveness often increases, although not always, as systems configuration issues and energy costs also have an important influence.

For buildings 100,000 GSF or more, simple payback for implementing operations technology improvements will typically be 0.5–2 years. For buildings 20,000–100,000 GSF, simple paybacks will typically be 2–7 years. Under 20,000 GSF, implementation becomes difficult on a building-by-building basis, although a portfolio of many small buildings might be able to achieve simple paybacks of 5–9 years for the portfolio.

5.3 Energy

5.3.1 Consumption

This technology uses NO energy per se, but reduces the energy use of existing energy systems in a building. Energy savings of 10–20% of existing energy use is typical(Haasl 1999, Claridge 1994).

5.3.2 Potential energy savings

For the U.S. commercial sector as a whole, consumption of fossil fuels in buildings directly is a little over 2.6 Quads/yr. Consumption of electricity in these buildings directly is about 1 Million GWh/yr or 9.3 Quads of primary energy. Buildings over 100,000 GSF consume about 38% of the electricity and about 35% of the fossil fuel of the sector, for total primary energy use of 4.4 Quads/yr. Using the simplifying assumption that buildings over 100,000 GSF represent the sector's savings potential, together with an average savings of 15%:

- Electricity savings potential is estimated as 15% x 38% x 1e6 = 60,000 GWh/yr
- Primary energy savings from electricity = 60,000 x 9287 Btu/kWh / 1e9 = 0.56 Quads/yr
- Fossil fuel savings potential is estimated as 15% x 35% x 2.6 = 0.15 Quads/yr
- Total technical potential primary savings = 0.56 + 0.15 = 0.71 Quads/yr

These estimates are below what would be estimated using State Energy Data System (SEDS) data for the commercial sector. Achieving these savings requires wide-scale adoption of building energy performance systems, which means further advances in making these simpler and more accessible to ordinary businesses and building operators. Of this total potential, only a fraction of buildings will accept the technology by 2025. If 10% of these buildings incorporate these technologies into their operation, then savings would 0.07 Quads/yr.

5.4 NEMS approach

Because operations efficiency is an application of technology (software and expertise) that cuts across multiple end-uses, it is more difficult to model in NEMS as an endogenous option. If performance assessments are assumed to occur at major HVAC technology changes, then alternative equipment with higher capital costs (to cover the evaluation) and greater efficiency could be included in the technology options. However, this does not capture the savings from improved operation of other existing energy-using equipment or possible replacement of that equipment at the same time.

Further, NEMS models different commercial sectors, but not the variety of building sizes within each sector. Instead, it applies a total square footage for each sector for each region, expanding this amount as the economy grows, and reducing it as buildings are assumed to wear out (EIA 2004). The increase is modeled as new building area. Equipment in existing space is also replaced based on its life and age, and retrofits can be calculated where the full cost of new technologies is lower than ongoing costs of existing technologies. Limits are placed on the types of technologies that can be considered, and hurdle rates discount future savings compared to capital costs.

Other mechanisms that influence the energy use of buildings are the shell efficiency and weather impacts. In the *AEO2004*, new buildings are projected to increase their shell efficiency by 7% by 2025 and existing buildings by 5% over the 1999 stock average (EIA 2004). Possibly changing these parameters could simulate the gradual influence of operations efficiency. The standard NEMS model assumes a constant climate from 2003 to 2025. Modifications can be made to allow the heating and cooling degree-days to vary over these years. Reductions in these values as compared to 1997 base values should change heating and cooling requirements proportionately. However, use of either of these two mechanisms (shell efficiency or weather) would require exogenous estimates of the penetration and effect of operations efficiency improvements on commercial building energy use. Also, they would only affect heating and cooling demands, not other loads such as lighting, which are major contributors to commercial building energy use.

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6. Smart Roofs

6.1 Technology

Today there is a great deal of discussion in the roofing industry about cool roofs, green roofs, garden roofs, vegetated roofs and other roof systems that are expected to be more energy efficient and ecologically friendlier than "conventional roofs". Cool roofs have received positive trade press, and some state and federal support for installation where cooling is the dominant building energy load. In mixed climates with both significant heating and cooling loads, the high reflectance that helps in the summer hurts in the winter by turning away solar energy that would otherwise heat the building.[1] What the roof industry needs is a smart surface that changes reflectance with temperature.

Residential roofing (shingles and clay tile) has a fixed reflectivity with respect to infrared (IR) solar radiation, which is maximally 20%. Over time, this reflectivity degrades through roof wear and subsequently adds to the cooling load during the hotter parts of the year. The technology area presented here is the development of an artificial roof surface that will overlay conventional low slope roofing materials, and which will provide high reflectivity to IR solar radiation in the hotter portions of the year and low reflectivity during the cooler seasons. The technology is based on combining recent developments in optical nanotechnology and polymer science.

An improvement in the roof's ability to modify heat flux based on air temperature therefore has substantial potential for energy savings. Simulations have shown that a roof with a reflectivity of 85% above 65°F and 5% below 65° provides estimated energy savings of 5-10¢/sq ft-yr over the best available commercial roofing material and from 10-20¢/sq ft-yr over standard shingles in a wide variety of climates.

6.1.1 Brief description of the emerging technology

Controlling the optical properties of a surface with nano- and micro-scale physical surface features is a phenomenon that can be found in nature. In the 1960's, it was discovered that the surface of a moth's eye contains small cone-shaped periodic structures that provide a very efficient anti-reflection "coating".[2] Moths have particularly large eyes and their anti-reflection property has a survival benefit by making it difficult for predators to detect moths in flight from light reflecting from the surface of the eye.

The scientific community has successfully mimicked the cone-like structures found on the moth eye to produce artificial surfaces with anti-reflection properties and is currently investigating the interaction of light waves with a wide variety of surface features and shapes to control optical properties.[3] The focus of this technology area is to provide large artificial surfaces for roof structures containing nano- and micro-scale features that can effectively control the solar

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[1] The cost of energy savings based on peak demand charges in northern cities may still make cool roofs a viable option despite the winter energy penalty exceeding the summer savings.

[2] Clapham PB and Hutley MC, "Reduction of lens reflection by moth eye principle," Nature 244(5414): 281-282, 1973.

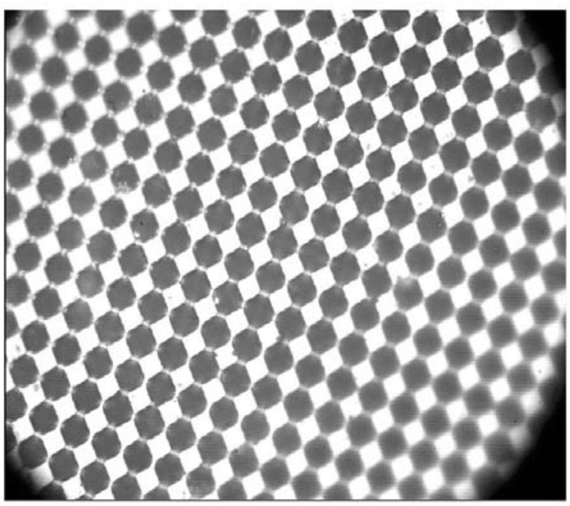
[3] Hadabos K, et. al., "Reflection properties of nanostructure-arrayed silicon surfaces," Nanotechnology 11(3), 161, Sept. 2000.

reflectivity and thermal emissivity of the surface as a function of the ambient air temperature. For a non-optically transmitting surface, from Kirchoff's law, optical reflectivity and emissivity are inversely related. By customizing the spectral reflectance of the roof, one can control the surface thermal properties. From an energy balance of the roof surface, the key parameters affecting the building's heating and cooling load are the solar reflectance and the IR emissivity.

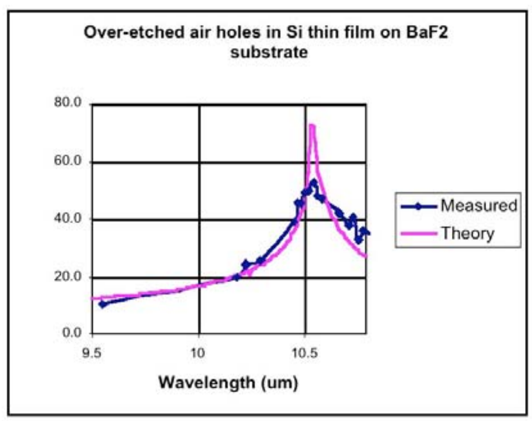
The key to this technology is then the combination of sub-wavelength structures, to control the reflectivity, with materials that change their optical properties with temperature. The resulting artificial roof surface would provide high reflectivity to IR solar radiation in the hotter portions of the year and low reflectivity during the cooler seasons.

As part of a special technologies program funded by DOE's Defense Programs, ORNL has been investigating artificial surfaces based on sub-wavelength optical structures that provide very high reflectivity for tagging, tracking, and locating in the long wave IR region of the spectrum.[4] In this region of the spectrum, the current selection of optical materials is sparse and the research at ORNL aims to provide artificial materials that are customizable with respect to a wide variety of optical parameters. The optical properties of the artificial surface depend on the periodicity and refractive index of arrays of physical structures etched or imprinted on the surface. Unlike diffraction gratings, these structures are much smaller in size than the wavelength of the incident light (typically from one third to one half of the wavelength) and are also similar to the types of structures and configurations being investigated in photonic crystal R&D.[5,6] Figure 13 shows a periodic array of holes etched in a thin film of silicon on a barium fluoride substrate and also the measured and predicted reflectance in the long wave IR.

Figure 13. Subwavelength optical structure designed for high reflectivity in the IR



Subwavelength structures in Si on BaF_2



Sample measured reflectance compared with simulated theoretical reflectance

[4] Simpson ML, et. al., "Resonant Dust: IR Targets for Tagging and Identification," JASON Summer Study, La Jolla, CA, June 21, 2001.
[5] Joannopoulos JD, et. al., "Photonic crystals: putting a new twist on light," Nature **386**, 143-149; 1997.
[6] Joannopoulos JD, Meade RD, and Winn, JN, Photonic Crystals, Princeton University Press, 1995.

What would the smart roof concept look like? The product would consist of four layers. The first layer is the roof substrate whether metal, concrete, thermoplastic membrane or wood. The second layer is a customized polymer layer with a top surface that has a specially designed indentation pattern. The third layer is an opaque material used to fill the nanoscale indentations on the polymer surface. The fourth layer is a clear coating providing both physical and UV protection. The composite can be manufactured as a laminate that overlays the existing roof or that becomes part of the manufacturing process for the respective roof product. As a result, it is not expected to add any weight penalty versus existing roof materials.

6.1.2 End-uses

Cool roofs are about saving energy during sunny weather and about mitigating urban heat island effects. These reflective materials are capturing more and more of the market because of the implementation of roof certification protocols initiated by the Environmental Protection Agency (EPA) and the Cool Roof Rating Council (CRRC) and because of state building codes mandating higher and higher reflectance and emittance levels for residential and commercial roofs.

The total sales for new and replacement roof construction is booming and nearly doubled between 1997 and 2000, from $20 billion to $36 billion (Good 2001). Of the sales volume in 2000, low-slope roofing accounted for 64% ($21.7 billion), while steep-slope "residential" roofing comprised about 35.6% ($14 billion) (Good 2001). Almost 70% of the new low-slope roofs installed in 2001 for the western U.S. were finished in dark absorptive built-up roof (BUR), ethylene-propylene-diene-terpolymer (EPDM) and bitumen-based single-ply membranes (Dodson 2001). However, reflective thermoplastic membranes are capturing more and more of the low-slope roof market, and are the most rapidly growing segment of the United States sheet membrane industry. The 2000 and 2001 market surveys show that the footprint for installed BUR and EPDM dropped 18%, (Good 2001). While the sales for thermoplastic membranes were up almost 20% (SPRI, 2003). The time is right for applying the smart roof concept to BUR systems and thermoplastic membranes. The envisioned product can be manufactured as a clear laminate lain on existing low-slope BUR systems. It can also be easily integrated into the manufacture of thermoplastic membranes that are typically rolled over the roof’s insulation, overlapped a few inches and welded together using a hot air gun. Hence the smart roof can work for both new and replacement low-slope roof construction.

The metal building industry shipped and installed about 29,000,000 square feet of metal roofs to California in 2002, and about 95% of the total square footage was finished in low-slope roofing (less than 2-in rise over 12-in of run). Further, about 90% of the metal roof systems supplied in 2002 for building projects within the state of California used unpainted Galvalume® steel, coated with an aluminum-zinc alloy (Shoemaker 2003). At issue here is the cool roof provisions proposed by the California Energy Code Title 24. The provisions will reduce energy consumption and conserve energy resources; however, the new legislation will also significantly affect the substantial metal roofing market, because the reflectance and emittance of Galvalume® does not meet Title 24 certifications. Further California has a diversity of climates from the alpine climate in the north to the hot desert climate in the southern areas of the state. The circumstances and needs are ideal for implementing the smart roof concept. Metal roofing for commercial low-slope roofs is typically made as structural standing seam metal. Again, a laminate can easily be laid on the metal as an artificial roof surface having combinations of sub-wavelength optical structures and temperature-sensitive polymers to provide high reflectance to

IR solar radiation in the hotter portions of the year and low reflectance during the cooler seasons. The laminate with optical structures would also boost the emittance of the roof, because metals typically have low emittance.

A residential homeowner wants a roof to protect the underlying structure for a long period of time at an affordable cost. He is concerned with the issues of appearance and durability; energy efficiency is often ignored. To the homeowner, dark roofs simply look better than their counterpart, a highly reflective "white" roof. What the homeowner does not know, however, is that he can have the best of both worlds. The smart roof can be applied as a clear sheet to the existing steep-slope roof product. The smart roof is adaptable to concrete and clay tile, cedar shake and painted metal residential roofing. However, the composition shingle holds the major market share in residential roofing and application of the laminate poses the greatest technical challenge because of the trade-off between the energy efficiency and the first cost for applying the laminate to an already inexpensive product.

6.1.3 R&D needed

Controlling optical properties using micro and nano-scale structures has been demonstrated on chip-sized surfaces. In addition, available software packages based on finite difference time domain analysis provide accurate simulations of the interaction of light with these structures and are excellent tools for design.

To develop these technologies for "smart roofs", much additional research is needed to provide robust, cost effective, large area surfaces that contain nano-scale structures:

Polymer and material science – Materials with the optical properties needed must be researched. Not only must the materials have high reflectivity, it must be adjustable to react to the changes in temperature, while robust enough to withstand long-term exposure to the elements.

Fabrication technology – Even if a suitable material is found, fabrication processes to make the material acceptable in quality yet affordable must also be determined. Otherwise, the material will not find acceptance in a market dominated by low-cost materials currently.

These are also primary research areas within the current DOE Office of Science nanotechnology thrust.[7] It is expected that there will be substantial leveraging of on-going research at the National Laboratories, however, it is anticipated that commercialization of the technology is in the 5+ year timeframe.

[7] Nanotechnology Research Directions: IWGN Workshop Report, National Science and Technology Council, September 1999. http://www.science.doe.gov/bes/IWGN.Research.Directions/welcome.htm

6.2 Cost

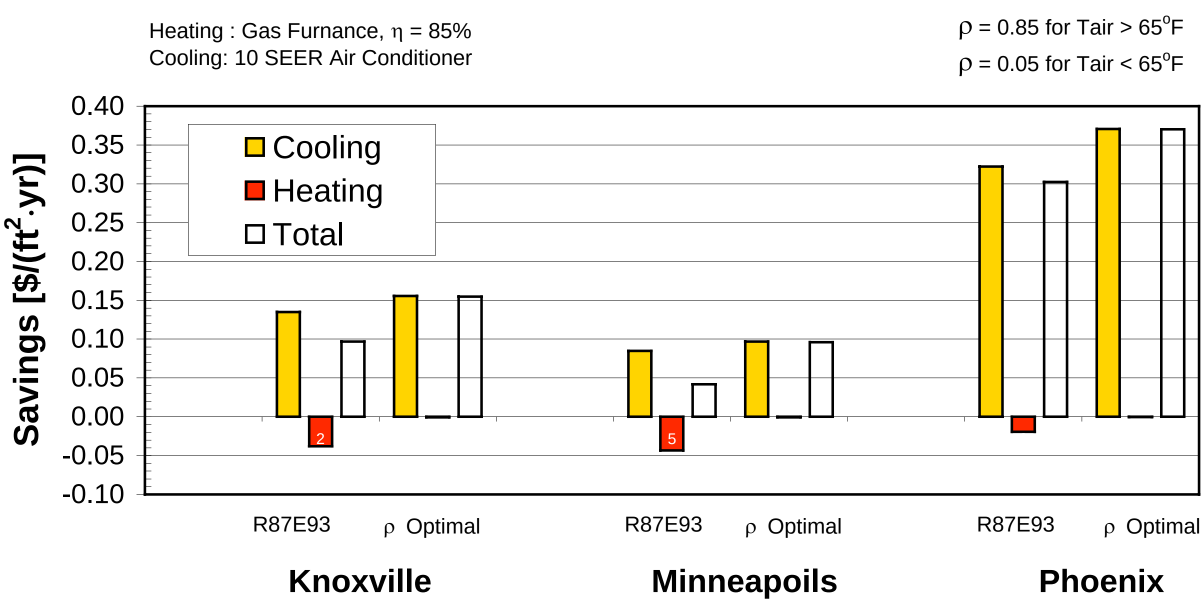
6.2.1 Cost of the new technology

It is too early to provide accurate data on the cost of the new technology. Typical costs for roofing material currently average $0.80/sq. ft.

6.2.2 Cost-effectiveness measures

Simulations described in section 6.3.1 show that a roof with a reflectivity of 0.85 above 65ºF and 0.05 below 65ºF has the potential for substantial energy cost reduction in a variety of climates as compared to conventional roofing. Figure 14 shows a comparison of the cost of heating and cooling savings for the best available current practice roof surface (R87E93) and the smart roof (ρ optimal) compared to a smooth BUR for the three cities cited in section 3.1 having substantially different climates. Cost estimates for the increase in building load were calculated by subtracting the roof energy for a BUR from a thermoplastic membrane that soils with time (R87E93) and comparing those savings with similar savings computed for the smart roof versus the BUR. Service charges for electricity and natural gas were gleaned from the Energy Information Administration (EIA 2001). The field SEER, which describes the performance of the air conditioner, was set at 10 and the efficiency of the gas furnace was assumed moderate at 0.85.

Figure 14. Cost savings for the smart roof (ρ Optical) and current practice (R87E93) as compared to the BUR having 0.05-reflectance and 0.90-emittance.



Cost savings are realized in all climates investigated with annual savings increasing about 7¢ per square foot of roof per year (see difference in total savings bars for the ρ optimal versus R87E93). Using the manufacturer's data form Shoemaker, the 29 million square footage of low slope metal roofs save about $2.03 million dollars annually just in California, which comprises roughly 18% of the U.S. population. Extrapolating to the US population increases the savings to about $11 million annually just for metal roofing. The potential savings and market are there, and the opportunity therefore exists to bring forth a new generation of roof products that supports the building owner, the roofing industry and the national economy.

6.3 Energy

A building's required comfort cooling and heating energy, termed load, is directly related to several factors: the solar irradiance absorbed by the building; the level of roof, wall, and foundation insulation; the amount of fenestration; and the building's tightness against unwanted air and moisture infiltration. The solar reflectance and long-wave IR emittance and the airside convective currents strongly affect the envelope's exterior roof temperature, which in turn drives the building's cooling and heating load.

Implementing smart roofs would benefit the roof industry by helping them penetrate markets in predominantly heating load climates that previously had no economic justification for reflective roofing. Benefits to the economy are the savings in roof energy because the new products are less susceptible to the wintertime heating energy penalty while still affording energy and peak demand savings in the hot summer months while also improving urban air quality.

6.3.1 Energy consumption of the new technology

ORNL's Simplified Transient Analysis of Roofs or STAR computer code predicts the roof surface temperature within about ±5% of field measurements and predicts the daily roof heat flux within about ±10% [Petrie et al. (2001a) and Miller et. al (2002)]. STAR generated the annual heating and cooling roof loads for different geographic regions within the United States using typical meteorological year (TMY2) data (NREL 1995). The code calculated the amount of energy cost savings for a smart roof and current practice roof as compared to a smooth, dark BUR with the same amount of insulation but with a solar reflectance of only 0.05 and an infrared emittance of 0.90. The current practice thermoplastic membrane has a reflectance of 0.87 and emittance of 0.93, identified in Table 14 as R87E93. The STAR simulations accounted for soiling of the thermoplastic membrane (Miller et al. 2002); it lost 50% of its reflectance due to climatic soiling over three years. For the smart roof, the computations switched the reflectance of the smart roof from 0.05 if air temperature dropped below 65ºF, and up to 0.85 if the air temperature exceeded 65ºF. Table 14 shows the energy savings for the smart roof applied to commercial building having a low-slope roof. Peak demand charges are not included in the analysis.

Table 14. Annual energy savings (Btu/ft^2) for the smart roof (ρ Optical) and current practice (R87E93) as compared to the BUR having 0.05-reflectance and 0.90-emittance.

	Knoxville		Minneapolis		Phoenix	
Energy Savings	R87E93 vs BUR	ρ Optical vs BUR	R87E93 vs BUR	ρ Optical vs BUR	R87E93 vs BUR	ρ Optical vs BUR
Cooling	17275	19897	10534	12020	32021	36854
Heating	-8924	-175	-10161	-156	-4591	-86
Annual	8351	19721	373	11864	27430	36768

These simulations include the effects of climatic soiling for the thermoplastic membrane R87E93.

Cooling energy savings for the smart roof versus the BUR are about 15% higher than savings for R87E93 membrane versus the BUR for the climates of Phoenix, Knoxville and Minneapolis (Table 2). More importantly, the smart roof almost fully eliminates the heating penalty observed for a reflective roof system versus a BUR (Table 14). As result, annual savings in the hot climate of Phoenix and the moderate climate of Knoxville are 36% greater than best practice. In heating climate of Minneapolis, the reduction in the heating penalty is very promising and reveals the market potential of the proposed smart roof concept.

6.3.2 Potential energy savings

The DOE 2003 Buildings Energy Databook website (DOE 2003) lists the primary energy consumption for space heating and cooling of commercial buildings and residences (Table 15). Low-slope commercial buildings consume about 4.2 Quads of primary energy for space conditioning, and about 15% is due to the heat transfer through the roof (Huang and Franconi, 1999). Residential energy consumption for heating and cooling is 8.1 Quads, and about 25% is attributable to the heat leakage through the ceiling and attic of the house (Parker, Sonne and Sherwin 2002).

Table 15. Maximum potential energy savings from smart roofs, Quads

	Heating Primary Energy (Quads)		Cooling Primary Energy (Quads)		% Energy Loss thru Roof	Savings from Smart Roofs	Maximum Potential from Existing Roofs	
Building Type	Electric	Total	Electric	Total			Electric	Total
Commercial	0.63	2.32	1.84	1.85	15%	25%	0.09	0.16
Residential	1.51	6.14	1.97	1.97	25%	50%	0.44	1.01
Total Building	2.14	8.46	3.80	3.81			0.53	1.17

Assuming that 25% of commercial energy and 50% of residential energy could be saved by using smart roofs on buildings, conversion of existing buildings could save 1.17 Quad of primary energy. As the building stock increases, this value would also increase. Of course, conversion of all or even a significant fraction of roofs will take many years. With the long life of roofs, the conservative purchasing behavior of homeowners and contractors, and the amount of research required to develop affordable smart roof materials, decades may pass before a large share of roofs will use this material. The technology is still too new for a market analysis to be done to determine the speed of its acceptance in the market. By 2025, perhaps only 10% of roofs at most could be expected to use smart roof technologies, giving potential market savings of 0.117 Quads.

6.4 NEMS approach

Smart roofs would impact the building shell efficiency of future and existing buildings. In the *AEO2004*, new buildings are projected to increase their shell efficiency by 7% by 2025 and existing buildings by 5% over the 1999 stock average (EIA 2004). Possibly changing these parameters could simulate the gradual introduction of smart roofs. Another method could be through modifications of heating and cooling loads. The standard NEMS model assumes a constant climate from 2003 to 2025. Modifications can be made to allow the heating and cooling degree-days to vary over these years. Reductions in these values as compared to 1997 base values should change heating and cooling requirements proportionately. However, use of either of these two mechanisms (shell efficiency or weather) would require exogenous estimates of the penetration and effect of smart roofs on commercial and residential building energy use.

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7. Conclusions

Increasingly, residential and commercial building owners are confronted with the challenge of moving toward a cleaner, more sustainable energy path while maintaining the energy services they desire. Technology will be essential for meeting these challenges. At any given point, business and residential owners are faced with the question of investing in new equipment. At this decision point, new and emerging technologies compete for capital investment alongside more established or mature technologies. Understanding the dynamics of the decision-making process is important to perceive what drives technology change and the overall effect on building energy use. From a policy-making perspective, the better we understand technology developments the more effective we will be in utilizing our future research dollars and in undertaking sound strategy development.

This report focuses on the long-term potential for energy-efficiency improvement in buildings. In 2002, residential and commercial buildings consumed 39% of the country's primary energy and were responsible for 38% of the greenhouse gas (GHG) emissions in the U.S. Due to the extremely diverse character of buildings, it is not possible to provide an all-encompassing discussion of technology trends and potentials. Instead, we focus on a number of key technology areas: solid-state lighting, advanced geothermal, integrated energy equipment, efficient operations technologies, and smart roofs. Each section provides a detailed assessment on future contributions to energy efficiency improvement, economics and performance, as well as the potential development path, including potential areas for research, demonstration or other support. Each section also describes ways to model the technology in NEMS (National Energy Modeling System) to aid in further model evaluation of the selected technologies.

Solid-state lighting has the potential to revolutionize the lighting market through the introduction of highly energy efficient, longer-lasting and more versatile light sources. Using a detailed, multi-market analysis of the lighting market, Navigant has estimated that SSL could save between 1.2 and 3.5 Quads of primary energy by 2025. This represents up to 33% of the expected energy use for lighting (Table 16).

Advanced geothermal heat pumps improve on the efficiency of traditional air-to-air heat pumps while lowering the capital costs and land required for their operation compared to earlier generation geothermal heat pumps. Selective water sorbent systems can use the latent heat of vaporization in groundwater to drastically shrink the footprint of geothermal systems. If the research succeeds, these systems will lower energy requirements by 35% over air-to-air heat pumps. An estimate of the savings by 2025 could be as much as 0.21 Quads (Table 16).

Integrated energy equipment include both multi-function technologies (cooling, heating, hot water, dehumidification) and packaged combined heat and power technologies that integrate multiple energy services into single pieces of equipment to lower cost and increase efficiency. For such a wide variety of technologies, it is difficult to estimate the potential energy savings but by comparing the market growth and efficiency of heat pump water heaters to conventional water heaters, we find a technical potential residential market savings of 0.18 Quads with an achievable market savings of 0.01 Quads. Commercial and industrial CHP is expected to provide 3.1 Quads by 2025. At twice the end-use efficiency of central station generation, the savings would also be 3.1 Quads. Packaged systems may only influence a small part of that overall market, so a rough estimate of savings may be 10%, or 0.31 Quads (Table 16).

Table 16. Summary of primary energy savings from five selected buildings sector technologies. The rationale behind each set is described in their respective sections.

Technology	2025 Primary Energy Use for end-use (Quad)	2025 Technical Potential Primary Energy Savings from Technology (Quad)	2025 Assumed Penetration (%)	2025 Achievable Primary Energy Savings from Technology (Quad)	Notes
Solid State Lighting	10.47	4	30%-88%	1.23-3.51	Energy savings based on Navigant detailed analysis using moderate and accelerated R&D strategies for multiple markets
Advanced Geothermal	13.75	0.433	50%	0.214	Residential and commercial electricity use for heating times 2/3 to represent heat pump energy use. SWS savings of 35%
Integrated Energy Equipment	0.37 3.1	0.185 3.1	5% 10%	0.01 0.31	First values are estimates for residential water heating. Second set for packaged CHP
Efficient Operations	4.4	0.71	10%	0.071	HVAC energy use in buildings >100,000 sq ft.
Smart Roofs	12.27	1.17	10%	0.117	Main savings from residential roofs
Total Savings		9.6		1.95-4.23	

Many studies have shown the value of improving operations of energy-using technologies within buildings, with typical savings of 10–20% possible in a wide range of buildings. Advances in information technologies such as diagnostic and monitoring software and hardware are important for achieving improvements in building energy operations. In recent years, a new class of tools, called building energy performance rating systems, has emerged to make the decision to knowingly seek improved efficiency of building energy operations easier. Based on the energy usage in large buildings for heating and cooling of 4.4 Quads, a 15% savings could mean 0.7 Quads of energy saved. The projected penetration of this sector by these operational improvements has not been analyzed; assuming that 10% of buildings implement these technologies, there would be a savings by 2025 of over 0.07 Quads (Table 16).

"Smart roofs" represent the development of an artificial roof surface that will overlay conventional low slope roofing materials, and which will provide high reflectivity to IR solar radiation in the hotter portions of the year and low reflectivity during the cooler seasons. The technology is based on combining recent developments in optical nanotechnology and polymer science. Assuming that 25% of commercial energy and 50% of residential energy lost through roofs could be saved by using smart roofs on buildings, conversion of existing buildings could save 1.17 Quad of primary energy. By 2025, perhaps only 10% of roofs at most could be expected to use smart roof technologies, giving potential market savings of 0.117 Quads (Table 16).

This report demonstrates that the United States is not running out of technologies to improve energy efficiency and economic and environmental performance, and will not run out in the future. The five technology areas alone can potentially result in total primary energy savings of between 2 and 4.2 Quads by 2025, or 3.8% to 8.1% of the total commercial and residential energy use by 2025 (52 Quads). Many other technologies will contribute to additional potential for energy-efficiency improvement, while the technical potential of these five technologies on the long term is even larger.