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Impacts of US federal energy efficiency standards for residential appliances

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Abstract

This study estimated energy, environmental, and consumer impacts of US federal residential energy efficiency standards taking effect in the 1988–2007 period. These standards have been the subject of in-depth analyses conducted as part of the US Department of Energy's (DOE's) standards rulemaking process. This study drew on those analyses, but updated key data and developed a common framework and assumptions for all of the products. We estimate that the considered standards will reduce residential primary energy consumption and carbon dioxide (CO_2) emissions by 8–9% in 2020 compared to the levels expected without any standards. The standards will save a cumulative total of 26–32 EJ (25–30 quads) by the year 2015, and 63 EJ (60 quads) by 2030. The estimated cumulative net present value of consumer benefit amounts to nearly US$80 billion by 2015, and grows to US$130 billion by 2030. The overall benefit/cost ratio of cumulative consumer impacts in the 1987–2050 period is 2.75:1. The cumulative cost of the DOE's program to establish and implement the standards is in the range of US$200–US$250 million.
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1. Introduction

The purpose of this study was to provide consistent and updated estimates of the energy, environmental, and consumer impacts of US federal energy efficiency standards for residential appliances. We consider initial standards and updates for nine different products (Table 1).[1] (Mandatory compliance dates range from 1988 to 2007.) These standards have been the subject

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[1] This study did not analyze standards for fluorescent lamp ballasts or commercial heating, ventilating, and air-conditioning equipment.

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Table 1
Residential appliances and equipment affected by DOE energy efficiency standards

Product	Date effective																			
	88	89	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07
Refrigerators			X			X								X						
Freezers			X			X								X						
Room air conditioners			X										X							
Central ACs and heat pumps					X														X	
Clothes washers	X						X										X			X
Clothes dryers	X						X													
Dishwashers	X						X													
Water heaters			X														X			
Gas furnaces					X															
Oil furnaces					O															
Ranges and ovens			O																	
Pool heaters			O																	
Direct heating equipment			O																	

X, included in this study's estimates. O, not included in this study's estimates.

of in-depth analyses conducted by Lawrence Berkeley National Laboratory for the US Department of Energy (DOE). The results of these individual analyses have been published in a number of technical support documents (TSDs) as listed in Appendix A.

The general methodology used in the in-depth analysis of US appliance standards is described in Turiel et al. [1], who also discuss methods used outside the US. For an overview of experiences with appliance efficiency standards around the world, see the recent book by the International Energy Agency [2].

This study used the analyses done for the TSDs as a fundamental source, but it differed from them in several ways:

- The TSD analyses estimated prospective impacts only, whereas this study estimated both realized (through 2000) and prospective impacts (through 2050).
- The TSD analyses were performed at different times over the past 13 years and thus considered product installations and impacts over varying periods. For all products, this study considers installations through 2030 and impacts through 2050.[2]

[2] Appliances have useful lifetimes of 10–20 years. In order to capture the lifetime energy savings of products purchased in the 2020–2030 period, we consider impacts through 2050.

- Each TSD analysis used forecasts of product shipments and energy prices that were current at the time. This study used recent data on actual product shipments and energy prices to calculate realized savings. To estimate prospective impacts, we developed new projections of product shipments based on recent trends and appliance industry near-term forecasts. We also used the most recent DOE projections of future energy prices [3].
- The TSD analyses have varied in their specification of a base case efficiency trend against which the impact of standards was estimated. In some of the analyses in recent years, the base case incorporates an expectation of improvement in energy efficiency without a standard, but in earlier years the base case reflected no change over time in efficiency. This study used a dynamic base case for all products, and adopted the perspective that manufacturers would have made improvements in energy efficiency without standards in most cases. We estimate the incremental improvement due to standards, beyond the dynamic baseline.

This study was not as detailed as the retrospective analysis of US federal energy efficiency standards for refrigerators by Greening et al. [4], but it covers a much broader array of standards.

1.1. Overview of methodology for this study

We developed a spreadsheet accounting model to calculate national energy savings and consumer costs and benefits for each product. The initial data input is the number of shipments of a given product in each year, beginning in the late 1980s and ending in 2030. The key energy-use variable is the average annual energy use or energy efficiency of a given product sold in each year. A key consumer impact variable is the average product price in each year.

Other input data are the US average residential price of electricity and natural gas in each year (used to calculate the dollar value of energy savings), and factors for converting site energy to primary energy consumption.

For each of the aforementioned, we used actual data where available and made (or adopted from the TSDs) projections of future trends through 2030. For average energy use/efficiency and product price, we made projections of trends under alternative scenarios in order to estimate the impact of specific standards and updates.

The approach for estimating impacts of standards involves creating a base case scenario that assumes no standards were or will be implemented, and then comparing various scenarios with standards to the base case. Further each section describes the data sources and assumptions used.

2. Annual product shipments

We used data on annual domestic shipments from industry sources [5,6] for all of the considered products for the 1980–2000 period. In the case of central air conditioners and heat pumps, the industry data include single- and three-phase equipment. As the latter are generally not used in residential applications, DOE estimated the share of single-phase units for the rulemaking analysis, and we used those data here (see Appendix A, no. 7).

For the 2001–2030 period, we prepared new projections that take into account the actual data through the year 2000. In most cases, shipments in the late 1990s were greater than had been

previously estimated due to the substantial growth in disposable income in this period. Revisions of projections were not necessary for water heaters and gas furnaces.

In making projections, we modified industry forecasts for 2001–2002. For 2003–2030, we applied the annual percentage growth in each year from the most recent TSD projections. In all cases where we made revised projections, the forecast shipments are considerably higher than in the TSDs. Fig. 1 shows the actual and projected shipments of new refrigerators.

2.1. Average annual energy use or energy efficiency of new products

Industry sources, the Association of Home Appliance Manufacturers (AHAM) and the Air-Conditioning and Refrigeration Institute (ARI), have published estimates of average annual energy use (AAEU) or energy efficiency of products sold in a given year in a consistent manner over time for refrigerators, freezers, room air conditioners, clothes washers, dishwashers, central air conditioners, and heat pumps [5,6].

For gas furnaces, historical estimates of the average fuel utilization efficiency (AFUE) of products sold in a given year were made for a number of years in the period 1980–1995, based on industry data [7]. For water heaters and clothes dryers, historical estimates of AAEU of products sold in a given year are not available from industry sources. In these cases, we utilized the estimates made in the respective TSDs.

For each product, we developed a base case that envisions likely trends without DOE energy efficiency standards. The initial years are based on actual values, where available. We then made a subjective estimate as to how AAEU (or energy efficiency) might have evolved if no standard had been implemented. We based the estimate on the historical trend, where available, along with

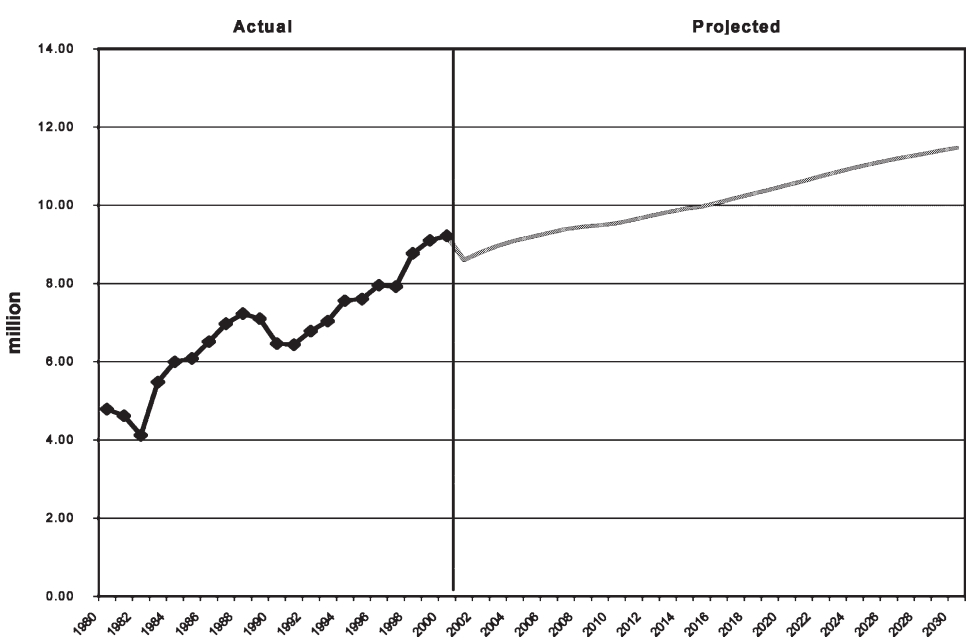

Fig. 1. New refrigerators annual shipments, 1980–2030.

judgement as to technical changes that might have been introduced by manufacturers that would improve energy efficiency. Non-regulatory factors that contribute to efficiency increases in the base case include government and private research and development, utility and state demand-side programs, and consumer information programs (such as energy labels).

For each product, we developed separate scenarios for the initial standard and for each update (Fig. 2). The scenario for the initial standard assumes that no updates were implemented afterward. These scenarios also make use of historic data to estimate a trend for future years.

For the updates taking effect in 2000 and later, we first derived the AAEU or energy efficiency from the TSD engineering estimates for products that just meet the standard. We then estimated the average value in the market, assuming that some share of the shipments has higher efficiency than the minimum required. We assume this value remains constant over time (see bottom line in Fig. 2).

In most cases, we assumed that the impact of a given standard begins in the year corresponding to the legal implementation date. In some cases, however, the historic data suggest that manufacturers introduced products meeting a standard one or more years in advance of the implementation date. In these cases, we credited the standard with having some impact before the implementation date.

The value for any given year refers to the AAEU or energy efficiency of products sold in that year. The calculations assume that the original value for a given annual cohort remains constant for all years in which those units continue to operate. Further details are given in Meyers et al. [8].

2.2. Product prices and incremental costs of standards

AHAM has published data based on market research on the average retail price of products sold in a given year for refrigerators, freezers, room air conditioners, clothes washers, clothes

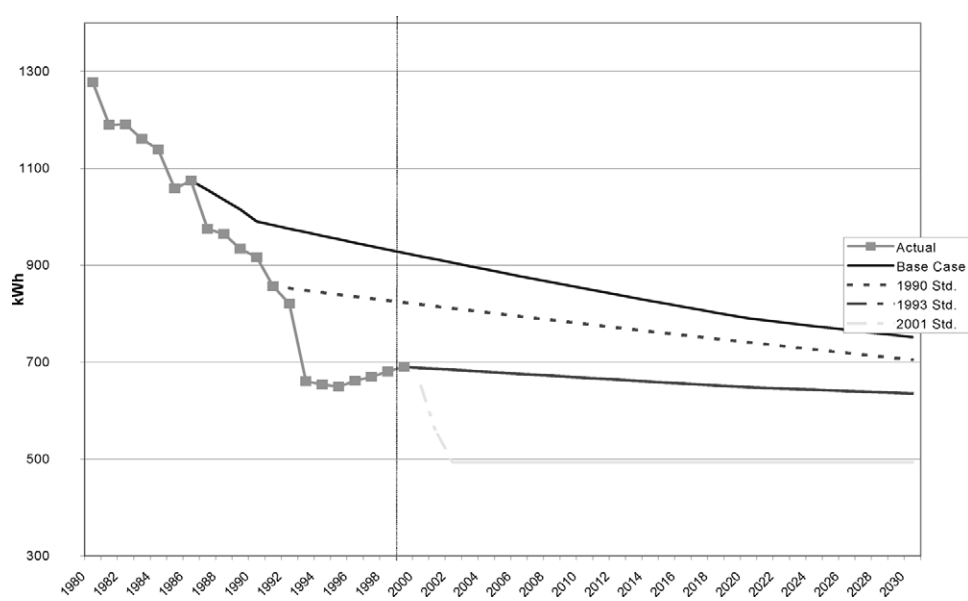

Fig. 2. New refrigerators average annual electricity use, 1980–2030.

dryers, and dishwashers. We utilized these data to represent actual average prices in the 1985–1999 period.

The industry data show considerable decline in the average price (adjusted for inflation) between 1985 and the late 1990s for all of the above products. Looking at the trends, it is difficult to see an impact on price from DOE standards in most cases. However, we have adopted the approach used in the TSDs and assumed that the standards did cause some additional cost. Effectively, we assume that prices would have been even lower in the absence of standards.

Wherever incremental cost estimates were available from the TSDs, we applied the percentage incremental cost as estimated in the TSDs to the appropriate actual prices. Where such estimates were not available, we made estimates for this study. In doing so, we made use of data on the prices of models of different efficiencies in a given year. For central air conditioners and heat pumps, for example, we relied on cost estimates for different efficiency levels for 1998 new units made for the 2001 TSD. We applied these data to specific years in each scenario based on the estimated average seasonal energy efficiency ratio (SEER) for each year, interpolating as needed. This method does not capture any cost trends independent of efficiency change that have occurred in the past. Thus, the estimated past values may not be accurate in absolute terms, but they should reasonably reflect the percentage change from one efficiency level to the next. See Meyers et al. [8] for further details on derivation of product prices.

Although it is likely that the past trend of declining prices will continue to some extent, we have not attempted to estimate the shape of the future decline in average price in any of the scenarios. Rather, we focused on the relative difference in price between the base case and the standards cases, making sure that the price differential corresponds to the efficiency differential.

2.3. Energy savings due to appliance standards

In estimating energy savings due to standards, we considered each update as building on top of the previous standard level. Thus, the original standard continues to have some impact for new shipments throughout the considered period, since the difference between the “no standards at all” baseline and the original standard scenario is always attributed to the original standard, even when its minimum efficiency levels have been superceded by a new update. In turn, the savings attributed to the update are relative to the original standard scenario. In all scenarios, the savings end when the last of the products purchased in 2030 leaves the stock.

2.3.1. End-use energy savings per new unit

For products sold in 1987–1999, we used the actual data [5,6] described in Section 2.1 to estimate the energy savings due to standards. For each standards scenario, we calculated end-use energy savings per unit for each year as the difference between the actual AAEU or energy efficiency and the value in the particular scenario.

In all cases, the actual energy efficiency exceeded the minimum required by the standard, sometimes by a significant amount. Such an outcome is to be expected. Since some models already were above the minimum required, when the standard removed the less efficient models, the resulting average was greater than the standard level. For gas furnaces, for example, the 1992 standard set a minimum AFUE of 78%, but the average AFUE of furnaces sold in 1992 was 83%. The reason is that roughly 20% of sales were of highly efficient (90–92%) condensing

furnaces, while the remainder were at or better than the 78% minimum. The increasing share of condensing furnaces was occurring without the standard, but the standard increased the average efficiency of the other furnaces in the market.

Where actual data are lacking (water heaters and clothes dryers), we used the difference between the standard scenario and the base case to derive energy savings.

For products sold in 2000–2030, we calculated the end-use energy savings per unit for each year as the difference between the AAEU (or energy efficiency) in each standard scenario relative to the previous scenario. For refrigerators, for example, the savings from the 2001 update are in addition to those estimated for the 1990 standard and the 1993 update. The total savings are the sum of the savings of each standard and update.

2.3.2. National end-use energy savings

The calculations use a product retirement function to calculate the number of units in a given vintage that are still in operation in each year. The retirement function assumes that individual appliance lifetime is normally distributed around a mean lifetime. The width of the distribution is such that almost all units retire within a few years of the average lifetime. The model calculates the energy savings for each standard or update as the difference in national energy consumption between the appropriate scenarios. It tracks energy savings into the future until all of the units installed in 2030 are retired.

2.3.3. National primary energy savings

We calculated the primary energy required for production and delivery of end-use electricity and natural gas in each year using data for the residential sector in DOE's *Annual Energy Outlook 2002* [3]. These data yield an average primary-to-end use multiplier for each year.

Fig. 3 shows the annual primary energy savings for all products together. The projected savings

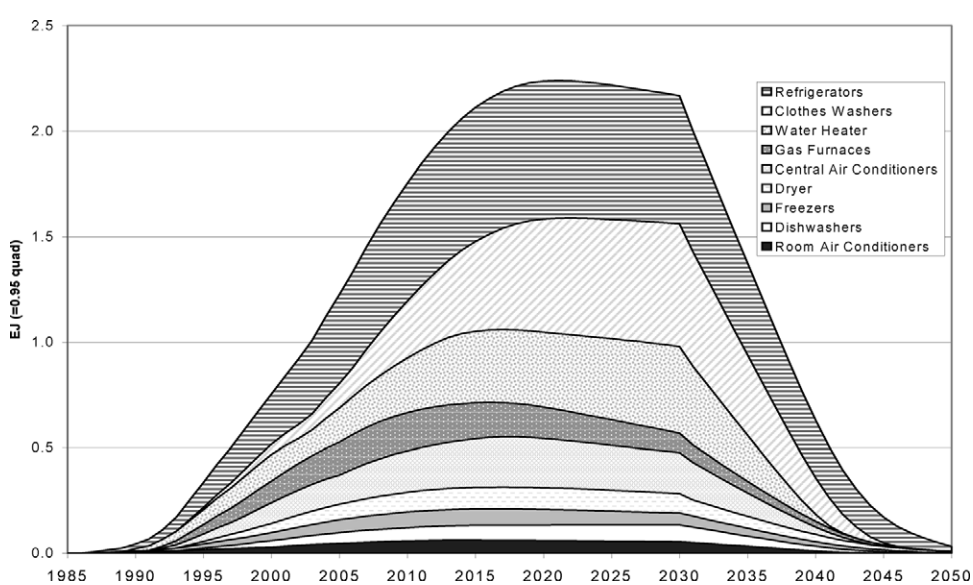

Fig. 3. Annual primary energy savings from DOE appliance standards by product.

increase at a rapid rate over the next 20 years as more new appliances enter the stock. The dropoff in savings after 2030 occurs because that is the last year for which we count product shipments. After 2030, as the products purchased in earlier years age, energy savings continue until the products retire.

The total primary energy savings from the considered standards in 2020 are 2.4 EJ (2.3 quads). DOE's Annual Energy Outlook 2002 has a projection for total residential primary energy consumption of 25 EJ (24 quads) in the reference case [3]. As this projection includes the effect of appliance standards, the consumption without the standards would be approximately 27 EJ (26 quads). Thus, we estimate that the standards will reduce residential energy consumption in 2020 by 8%.

The estimated absolute growth in residential primary energy consumption between 1990 and 2020 without standards is 10.5 EJ (10 quads). The standards reduce this growth to 8.4 EJ (8 quads).

Fig. 4 presents the cumulative primary energy savings from 1987 through 2050 for each product. Refrigerators, clothes washers, and water heaters account for the greatest savings. Fig. 5 presents the cumulative primary energy savings for all products together in selected years. The cumulative savings are just over 63 EJ (60 quads) by 2030, and approach 84 EJ (80 quads) by 2050.

3. National consumer costs and benefits due to appliance standards

Fig. 6 shows the annual operating cost savings, additional product cost, and net benefit for all of the standards together. The operating cost savings are electricity and natural gas savings valued

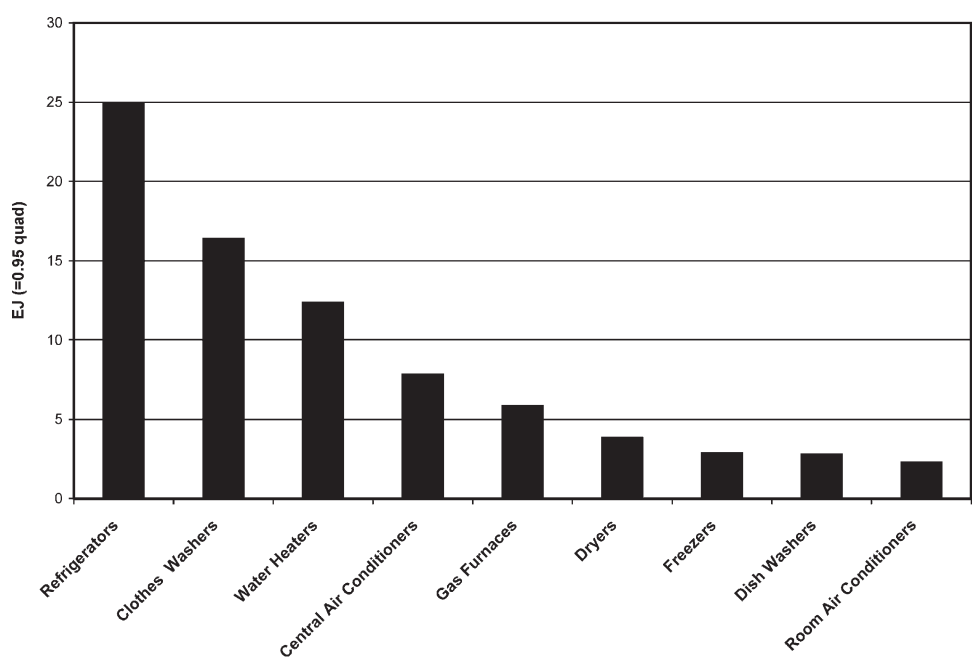

Fig. 4. Cumulative primary energy savings from DOE standards by product, 1987–2050.

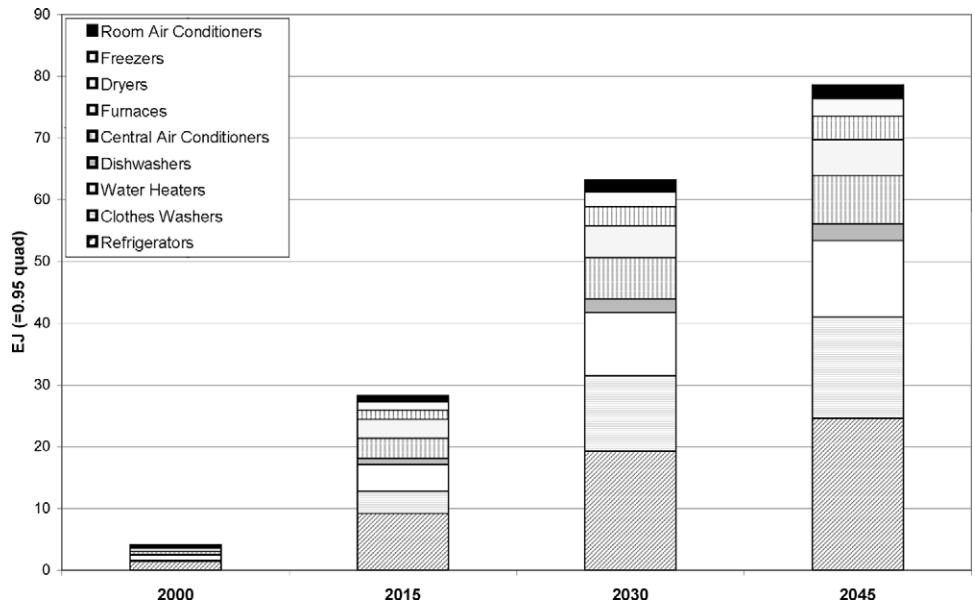

Fig. 5. Cumulative primary energy savings between 1987 and specific years from DOE appliance standards.

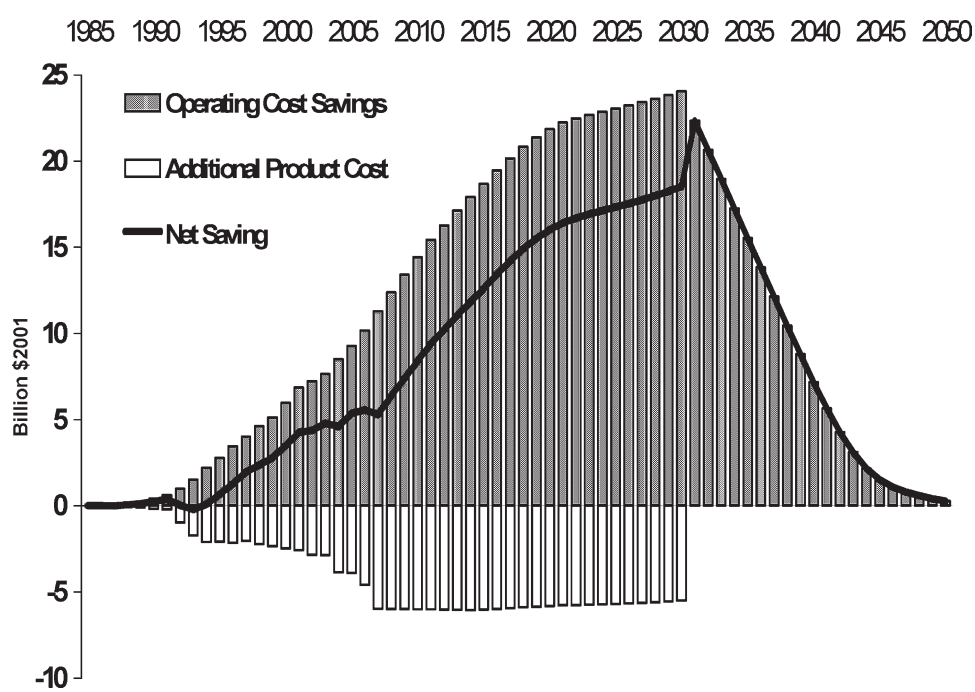

Fig. 6. Annual Consumer Impacts of DOE Appliance Standards B All Products (Not Discounted).

at the national average residential retail price for each year. The additional product cost is the estimated incremental purchase price. For products that reduce water consumption (clothes washers and dishwashers), we include savings on water expenditures in the operating cost benefits. For clothes washers, such savings are a significant fraction of the overall savings. All values are expressed in dollars in the year 2001.

We express the benefit of appliance standards to consumers in terms of the net present value (NPV) of additional product costs and operating cost savings over the expected lifetime of products. To express NPV, we discount future costs and savings in each year to 2001 using a rate of 7% (real), which is the rate used by DOE in its analyses of appliance standards. To express the present value of net savings in the 1987–2000 period, we apply an annual interest rate of 3% (the approximate average return on long-term government bonds) to the net savings in each year, allowing interest to accumulate through 2001. The resulting NPV of cumulative benefits from the standards for each product is shown in Fig. 7. The bulk of the net savings are associated with standards for three products: refrigerators, clothes washers, and water heaters.

Fig. 8 gives the cumulative benefits for all products together for various periods. As of end-2000, the standards had saved US consumers an estimated US$17 billion. The present value of estimated net savings over the entire 1987–2050 period is approximately US$150 billion, and the ratio of consumer benefits to additional consumer expenditures is 2.75:1. The amount of taxpayer funds used to support DOE's residential appliance standards program over the past 20 years is in the range of US$200–US$250 million. Thus, the leveraging effect of the government expenditure on consumer benefit is quite large.

We believe that the actual consumer benefits achieved to date, as well as the prospective benefits, may be understated in this study. We have relied on engineering estimates to calculate the incremental cost of products that meet efficiency standards. However, both statistical analysis and anecdotal evidence indicate that the actual extra cost faced by consumers has been less than that

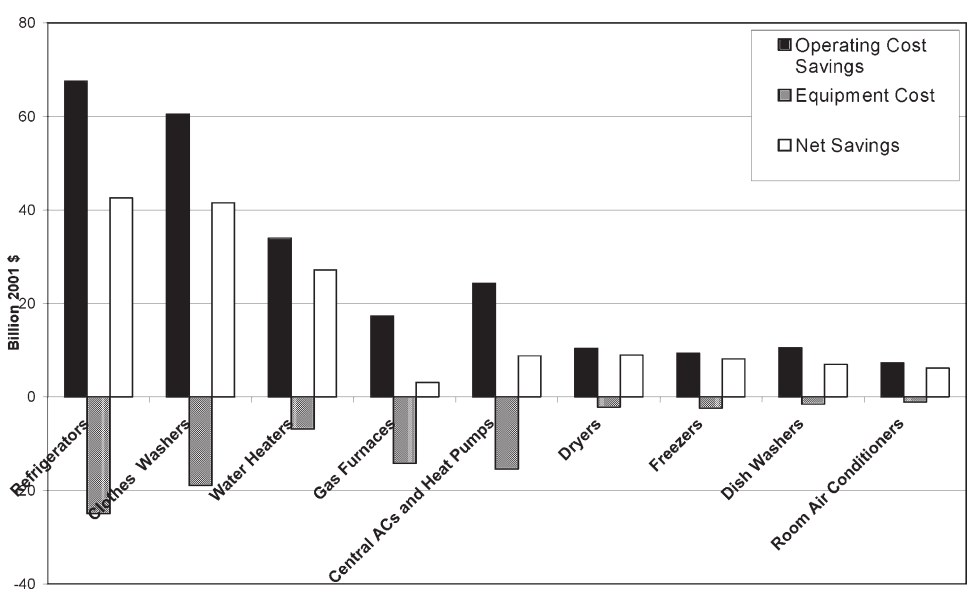

Fig. 7. Present value in 2001 of cumulative consumer benefits of DOE appliance standards in 1987–2050.

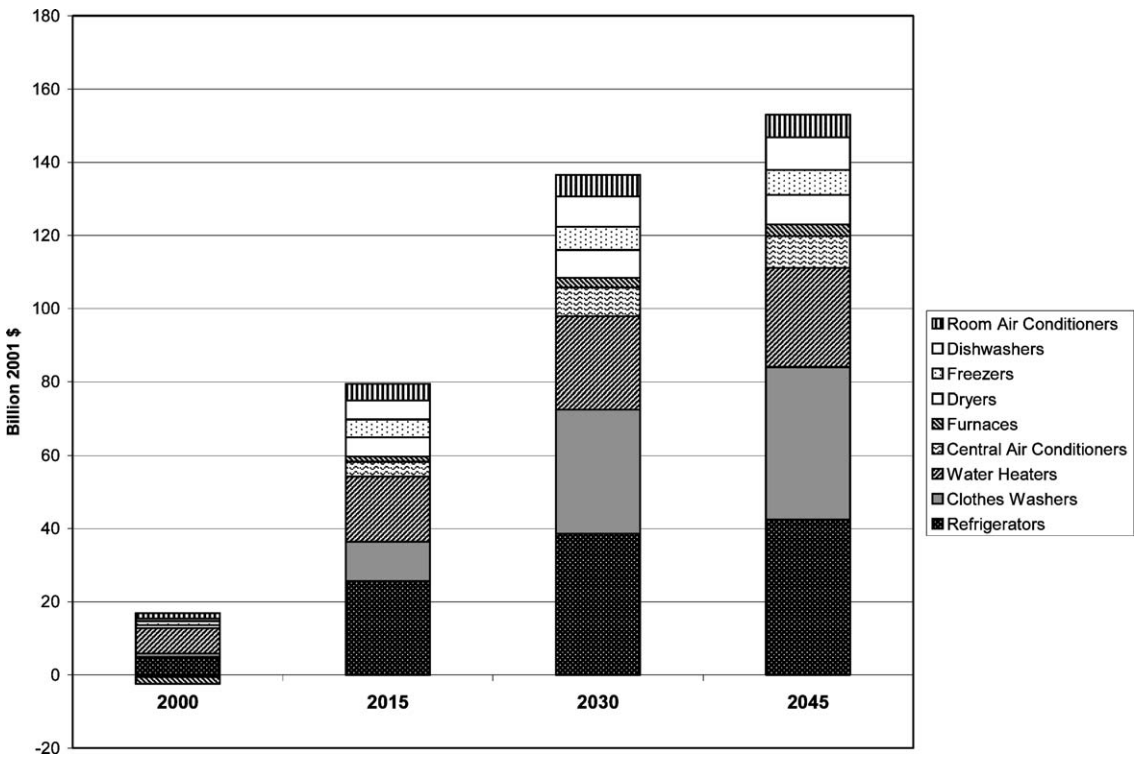

Fig. 8. Net present value in 2001 of cumulative consumer benefits from DOE appliance standards from 1987 through specific years.

estimated by DOE [4]. One possibility is that the estimated manufacturing costs were reasonably accurate, but that competitive pressure prevented the manufacturers from passing all of the extra cost onto consumers. Another possibility is that manufacturers responded to the reality of standards by developing less expensive ways of meeting the standards relative to the engineering estimates made years in advance.

4. National carbon dioxide emissions reduction due to appliance standards

We calculated reductions in carbon dioxide (CO_2) emissions due to DOE's appliance standards based on the estimated savings in primary energy for electricity generation and primary natural gas consumption. Using historic and projected data [9,3] on total CO_2 emissions from US electricity generation, along with data on primary energy consumption by the power sector, we derived emissions factors in terms of million metric tons of carbon (MtC) per quad of primary energy for each year in the 1987–2050 period.

The trend in annual reductions in CO_2 emissions due to DOE's appliance standards is very similar to the trend in primary energy savings (Fig. 4). Without the standards, total projected CO_2 emissions from the residential sector (including emissions associated with electricity use) in 2020

are 418 MtC. With the standards, the estimated value is 381 MtC 9% less.[3] The reduction of 37 MtC is equivalent to the CO_2 released by typical annual operation of 28 million of today's average cars. The cumulative emissions reduction for all product standards combined amounts to 964 MtC by end of 2030 and 1216 MtC by end of 2050.

4.1. Sources of uncertainty

A degree of uncertainty applies to all of the variables used in this analysis. Perhaps the greatest uncertainty concerns the estimation of the baseline scenarios: what would have occurred in the absence of standards. We assumed that the average energy efficiency of new products would improve in future years in the absence of federal regulations. If the rate of future efficiency improvement would have been higher or lower than we assumed, the savings from standards described here would be too high or low. Given the expectation of little long-run change in residential energy prices, the intensity of price competition in the appliance market, and the relatively modest emphasis given to energy efficiency as a selling point by manufacturers and retailers, we believe that it is relatively unlikely that future efficiency improvement in the absence of standards would have been very much greater than we assumed.

The other large source of uncertainty concerns the incremental cost to consumers of higher efficiency products. As mentioned above, we believe that the estimates used in this study (and in the TSDs) are more likely to be overstated than understated. This means that even if the absolute level of consumer benefits is too high (as would be the case if the energy savings estimates are too high), the benefit/cost ratio would be the same or better.

5. Conclusion

We estimate that US federal energy efficiency standards for residential appliances taking effect in the 1988–2007 period will reduce residential primary energy consumption and CO_2 emissions in 2020 by 8–9% compared to the levels expected without any standards. The standards will save a cumulative total of 26–32 EJ (25–30 quads) by the year 2015, and 63 EJ (60 quads) by 2030. The cumulative net present value of consumer benefit amounts to nearly US$80 billion by 2015, and grows to US$130 billion by 2030. The overall benefit/cost ratio of impacts in the 1987–2050 period is 2.75:1. The cumulative cost of DOE' s program to establish and implement the standards is in the range of US$200–US$250 million.

Acknowledgements

This study built upon past work at LBNL by Sachu Constantine and Johanna Kollar. Peter Biermayer, Jim Lutz, and Greg Rosenquist provided assistance with specific products, and Peter

[3] The "with standards" value is the total residential sector emissions in 2020 given in DOE's Annual Energy Outlook 2002 [3]. We derived the "without standards" value by adding our estimate of carbon reduction due to standards to the DOE projection, which nominally includes the impact of standards.

Chan assisted as well. Helpful comments were provided by Jim Lutz and Steve Wiel. Diana Morris and Karen Olson assisted with production.

Appendix A. TSDs for DOE residential energy efficiency standards

All of the following were written and published by US Department of Energy, Washington, DC.

1. TSD: Energy efficiency standards for consumer products—room air conditioners, water heaters, direct heating equipment, mobile home furnaces, kitchen ranges and ovens, pool heaters, fluorescent lamp ballasts and television sets, report no. DOE/EE-0009, 1993.
2. TSD: Energy efficiency standards for consumer products—refrigerators, refrigerator-freezers, and freezers, including environmental assessment and regulatory impact analysis, report no. DOE/EE-0064, 1995.
3. TSD: Energy conservation standards for room air conditioners, 1997.
4. TSD: Energy efficiency standards for consumer products—residential central air conditioners and heat pumps, 1999.
5. TSD: Energy efficiency standards for consumer products—residential water heaters, report no. LBNL-47419, 2000.
6. Final rule TSD: Energy efficiency standards for consumer products—clothes washers, report no. LBNL-47462, 2000.
7. TSD: Energy efficiency standards for consumer products—residential central air conditioners and heat pumps, report no. LBNL-47463, 2000.

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