Title
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Realized and Projected Impacts of U.S. Energy Efficiency Standards for Residential and Commercial Appliances

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ABSTRACT

This study estimated energy, environmental and consumer economic impacts of U.S. Federal residential energy efficiency standards that became effective in the 1988-2006 period, and of energy efficiency standards for fluorescent lamp ballasts and distribution transformers. These standards have been the subject of in-depth analyses conducted as part of DOE's standards rulemaking process. This study drew on those analyses, but updated certain data and developed a common framework and assumptions for all of the products in order to estimate realized impacts and to update projected impacts. It also performed new analysis for the first (1990) fluorescent ballast standards, which had been introduced in the NAECA legislation without a rulemaking.

We estimate that the considered standards will reduce residential/commercial primary energy consumption and carbon dioxide emissions in 2030 by 4% compared to the levels expected without any standards. The reduction for the residential sector is larger, at 8%. The estimated cumulative energy savings from the standards amount to 39 quads by 2020, and 63 quads by 2030. The standards will also reduce emissions of carbon dioxide by considerable amounts.The estimated cumulative net present value of consumer benefit amounts to $241 billion by 2030, and grows to $269 billion by 2045. The overall ratio of consumer benefits to costs (in present value terms) in the 1987-2050 period is 2.7 to 1. Although the estimates made in this study are subject to a fair degree of uncertainty, we believe they provide a reasonable approximation of the national benefits resulting from Federal appliance efficiency standards.

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1. Introduction

This report presents updated results from an ongoing analysis of the energy, environmental, and consumer economic impacts of U.S. Federal energy efficiency standards for nine residential appliances that became effective in the 1988-2006 period or will take effect by the end of 2007. In addition, it presents results from analyses done for standards on fluorescent lamp ballasts and electrical distribution transformers. Table 1 shows the appliances and standards considered in this report.

These standards have been the subject of in-depth analyses conducted by the Energy Efficiency Standards Group (EES) at Lawrence Berkeley National Laboratory (LBNL) as part of the standards rulemaking process of the U.S. 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 1.

This project differs from the in-depth analyses done for the TSDs in several ways:

- The TSD analyses estimated prospective impacts only, whereas this study estimated both realized (through 2006) and prospective impacts (through 2050).

- The TSD analyses were performed at different times in the past and thus considered appliance installations and impacts over varying periods. For all products, this study considered installations through 2030 and impacts through 2050.[a]

- 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.

- Each TSD used then-current DOE/EIA projections of future energy prices made in different years. We used residential prices from the latest DOE/EIA projections of future energy prices.

- The TSD analyses varied in their specification of a base case efficiency trend against which the impact of standards was evaluated. In some of the analyses in recent years, the base case incorporated an expectation of improvement in energy efficiency without a standard (in other words, a dynamic base case), but in earlier analyses the base cases reflected no change over time in efficiency (static base case). This study used a dynamic base case for all products, and adopted the perspective that manufacturers would have made some improvements in energy

[a] Most 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.

efficiency without standards in most cases (either market-driven or government-induced through non-regulatory voluntary programs).

Table 1.
Federal Energy Efficiency Standards for Residential and Commercial Appliances Included in This Study

Product	Year Effective for Original Standard* and Updates
RESIDENTIAL	
Refrigerators	1990, 1993, 2001
Freezers	1990, 1993, 2001
Central Air Conditioners and Heat Pumps	1992, 2006
Room Air Conditioners	1990, 2000
Water Heaters	1990, 2004
Gas Furnaces	1992, 2007
Clothes Washers	1988, 1994, 2004, 2007
Clothes Dryers	1988, 1994
Dishwashers	1988, 1994
COMMERCIAL	
Fluorescent Lamp Ballasts	1990, 2005/2010
Distribution Transformers	2010
* Efficiency levels were written into the NAECA of 1987 or Amendment of 1988.	

We did not analyze the impact of existing standards for oil furnaces and boilers, kitchen ranges and ovens, direct heating equipment (wall, floor, and room heaters), and swimming pool heaters. Based on limited available data, it appears that these standards had a relatively small impact on the market.

This study does not include some commercial equipment for which standards have taken effect. These are commercial HVAC equipment and commercial water heating equipment. The initial standards for these appliances were written into the Energy Policy Act of 1992, and updates became effective in 2003 and 2004.[b] It also does not include standards that will become effective in the near future for certain commercial-sector equipment. Such standards to be determined include those for packaged terminal air conditioners (final rule expected in 2008), commercial refrigeration equipment (final rule expected in 2009), vending machines (final rule expected in 2009), electric motors (final rules expected in 2010 and 2011), and various lamps (final rule expected in 2009).

[b] We report impacts of these standards estimated by other analysts in section 4.

2. Method and Data

Overview of Methodology: Residential Appliances

We developed a spreadsheet accounting model to calculate energy savings and consumer costs and savings for each product. The model tracks the energy use of products sold in each year, beginning in the late 1980s and ending in 2030. The model uses historic and projected data on annual shipments of each product, and subtracts units from the stock using a retirement function based on the estimated average lifetime of each product.

The key feature of the model is that it associates a specific average energy consumption and average product price for each vintage of a given product.[c] Both of these variables are a function of the energy efficiency assigned to each vintage. In most cases, we assign the actual energy efficiency for each vintage of a product based on industry sources.

The approach for estimating the impacts of standards involves deriving a base case scenario for average energy efficiency and product price that assumes no standards were or will be implemented. In principle, the base case assumes energy efficiency increases over time as a result of all factors that shape energy efficiency other than Federal standards.

For each product, the model calculates total annual site energy consumption in the base case and the standards case by summing the energy consumption for all units that are still in the stock in a given year. The total site energy savings is the difference between these two cases. We estimate the savings in primary energy consumption using factors for converting site energy to primary energy consumption.

The model uses the average product price to calculate the total consumer purchase cost of the products installed in each year. It calculates total consumer operating costs in each year by reference to the consumption of electricity and natural gas and the average residential price of electricity and natural gas in each year (both historic and forecast).[d] The model then calculates the difference in both total consumer purchase cost and total consumer operating costs between the base case and standards case. This yields the net consumer benefit or cost from standards for each year. The final step involves discounting future monetary benefits and costs to the present, and compounding past monetary benefits and costs to the present.

For residential appliances, the focus and approach of this report is similar as in the 2005 LBNL report by Meyers et al.[1] Since that report, however, we have made improvements in the method, updated input data, and revisited various assumptions.

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[c] A vintage refers to the products shipped in a given year.

[d] And water consumption and water for clothes washers and dishwashers.

The sections below further describe the data sources and assumptions used.

Residential Appliances

Shipments

We used historical data on annual domestic shipments from the Association of Home Appliance Manufacturers (AHAM)[2] and the Air-Conditioning and Refrigeration Institute (ARI)[3] for the 1980-2005 period. In the case of central air conditioners, the industry data include single- and three-phase equipment. As the latter are generally not used in residential applications, LBNL estimated the share of single-phase units for the rulemaking analysis (see Appendix 1, #7), and we used only those data. For 2006, in most cases we adopted forecasts given in *Appliance* magazine (January 2006). These forecasts were made by industry experts.

For 2007-2030, we made projections for this study using simple assumptions for most products. The projections used in LBNL's previous technical analyses for DOE were made during the rulemaking process for each product. In most cases, shipments in the 1998-2005 period were greater than had been previously estimated due to the substantial growth in disposable income and housing construction in this period. Given this trend, adjustment to the projections made for the TSDs were necessary for most products. For central air conditioners and clothes washers, we applied the annual percentage growth in each year from the most recent TSD projections. For clothes dryers, there were no recent TSD projections, so we used the projected annual growth in clothes washer shipments as a proxy for clothes dryer shipments.

In the TSDs for some products, the projection of shipments is lower with the standard than without, as the analysis predicts that the higher price associated with the standard will lead to either switching among fuel types (e.g., for water heaters) or fewer purchases. The TSD methodology has a module for adjusting energy consumption in the "no standards" case to account for products that would be kept in use if a new product were not purchased. The simpler framework used in this study does not have the same capability. Thus, we use the "no standards" (base case) projections in most cases. In the case of water heaters, we accounted for the estimated impacts of fuel switching from electric to gas units due to the 2004 standards.

Average Annual Energy Efficiency and Energy Consumption

We used average energy efficiency as an indicator for some products, and average energy consumption as the indicator for others. The choice reflected data availability or specific analytical issues.

AHAM publishes time series of average energy efficiency and/or energy consumption of products sold in a given year for refrigerators, freezers, clothes washers, dishwashers and room air conditioners. The AHAM data are based on laboratory measurement using standard test procedures.

For clothes washers, we did not use the AHAM data directly because they reflect different assumptions concerning hot water inlet temperature than DOE's TSD analysis, and they do not include energy use for clothes drying. Instead, we relied on an estimated time series from the TSD of average energy consumption associated with a washer. The energy consumption includes energy use by the clothes washer as well as the estimated energy use for clothes drying and for heating the water for the washer. The trend in the data from the TSD is similar to the AHAM estimates.

For room air conditioners, we used the AHAM data on energy efficiency, but not on energy consumption, as the AHAM data reflect a different assumption concerning annual hours of use than DOE's TSD analysis. We calculated energy consumption based on annual data from AHAM on the average cooling capacity, and a fixed value for annual hours of operation, based on analysis for the TSD.

For central air conditioners and heat pumps, ARI publishes data on average energy efficiency. We estimated average energy consumption for central air conditioners and heat pumps using data on average cooling capacity and average cooling load in the TSD. The available evidence suggests that there has been relatively little change in average capacity since the mid 1980s. Data on change in home size and thermal integrity are insufficient to reliably estimate past and future change in the average cooling load, so we used the TSD value for all years.

For gas furnaces, LBNL estimated historical time series of the average fuel utilization efficiency (AFUE) of new non-weatherized gas furnaces as part of the analysis for DOE's latest rulemaking for furnaces and boilers (see Appendix 1, #8). These estimates were based on data from GAMA on the AFUE of models sold in specific years and on the market shares of non-condensing and condensing furnaces. Our calculation of energy consumption uses constant values for the furnace input capacity and the home heating load.

For water heaters and clothes dryers, historical time series data on energy efficiency or energy consumption of products sold in a given year are not available from industry sources or from the TSDs. Thus, for these products, we relied on data from the TSDs to estimate trends in average energy consumption.

For future years, we estimated the average energy efficiency or energy consumption for products sold in the effective year of the standard using data from the DOE analysis for each standard. We keep the average energy efficiency or energy consumption values after standards take effect constant over time. This approach is not a projection of what is likely to happen, but rather reflects our approach to crediting impacts to efficiency standards (as described in the section Average Energy Savings).

For each product, we developed a base case that envisions likely trends in average efficiency or energy use without Federal energy efficiency standards. Each base case reflects a subjective estimate as to how energy efficiency and energy consumption might have evolved if no standards had been implemented. The base case scenarios reflect the historical trend, where available, along with judgment as to changes that might have occurred as a result of market forces. In estimating the latter, we considered the trends in residential energy prices in the 1990s as well as the future trends projected by EIA.

The base case implicitly includes non-regulatory factors that contribute to efficiency increases, such as utility and state demand-side programs, consumer information and labeling programs (such as Energy Guide and Energy Star), and government and private R&D. We assumed that policy-based incentives for higher efficiency in the future will be similar to those currently in effect (i.e., fairly minimal).

Although it is likely that States such as California would have continued their standards programs if the Federal government had not acted, our base case scenarios do not consider the potential national impact of State energy efficiency standards. Since the Federal standards preempted actual and potential state energy efficiency standards, we credit them with the full impact of standards in general for the products considered.

Figure 1 illustrates the trends in average annual energy consumption for refrigerators. It shows the historic actual data and the estimated base case. While it is likely that the actual average consumption will decline further after 2006, we only credit the standards with bringing the average to the level in 2002 (hence the constant dashed line in the future period).

For further details on the data and assumptions, see section 3 in Meyers et al. (2005).

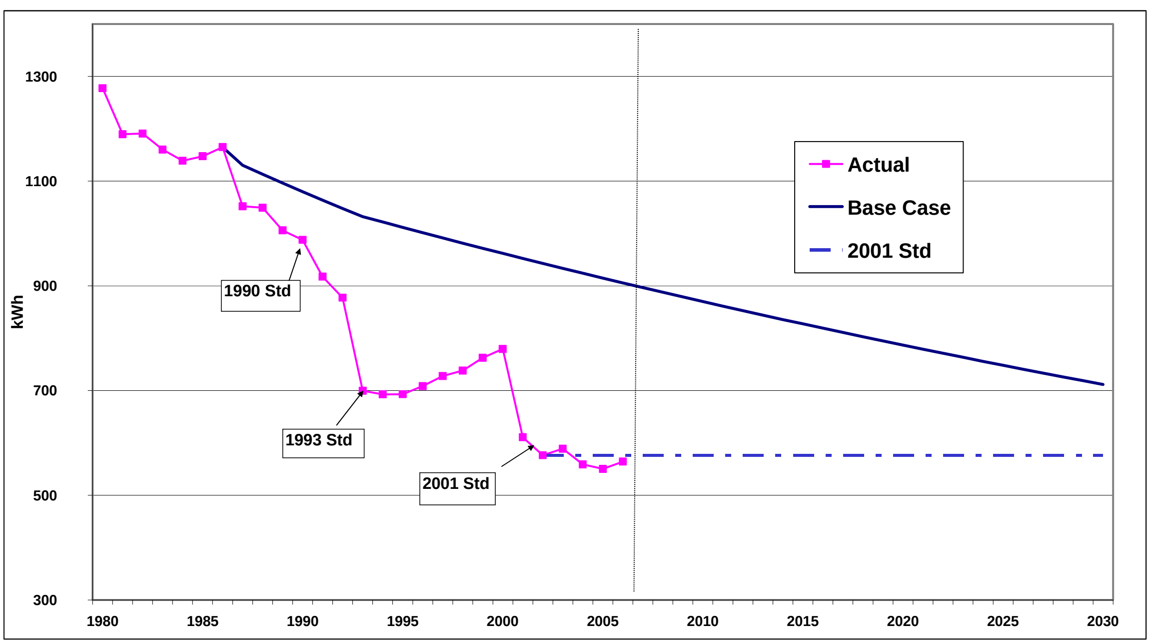


Figure 1. Average Annual Electricity Use of Refrigerators by Year of Shipment

Product Prices and the Incremental Costs of Standards

AHAM has published sporadic 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 dryers, and dishwashers. The data show considerable decline in the average price (adjusted for inflation) between 1985 and the mid 1990s for all of the above products. Looking at the trends, it is difficult to see an impact on price from efficiency standards effective in the 1990s. Since there have been changes in average size and model features in addition to design changes to meet efficiency standards, however, using these average prices to assess the effect of standards is problematic.

In DOE's analyses of appliance standards, the additional consumer cost for a higher-efficiency appliance is estimated through a detailed analysis of manufacturing costs and markups in the distribution channel. The extent to which the estimated increase in consumer cost to meet a particular standard has in fact occurred has been a matter of some debate.

To be conservative, we adopted the approach used by DOE and assumed that the standards did cause some additional cost. We utilized the AHAM data and our interpolations for missing years to represent actual average prices in the 1985-2002 period for the products listed above. However, we assumed that prices would have been 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.

DOE's incremental cost estimates refer to a standard-level efficiency and a specific baseline technology. Since we use a base case in which the average efficiency changes over time, we needed to adjust the incremental cost as well. In so doing, we maintain the relative relationship between energy efficiency and product price.

For further details on the data assumptions, see section 4 in Meyers et al. (2005).

Although the past trend of declining prices may continue to some extent, we have not attempted to estimate the shape of the future decline in average price for any of the products. Rather, we focused on the relative difference in price between the standards scenario and the base case, making sure that the price differential corresponds to the efficiency differential. If the secular decline in price continues in the future, our incremental cost estimates, which are calculated as a percentage, would be somewhat too high.

Average Energy Savings per Unit

Since the base case nominally includes the influence of all factors that shape energy efficiency other than federal standards, we calculated the past impact of Federal standards as the difference between the base case energy efficiency or energy consumption and the actual values. This difference can be seen in Figure 1, which illustrates the impact of successive updates of the standard for refrigerators.

In cases where actual data were not available, we used the difference between the average energy efficiency or energy use implied by the standard and the base case values to derive energy savings.

In most cases, we assumed that the impact of a given standard begins in the year corresponding to the legal effective date. In some cases, however, the historic data suggest that manufacturers began to anticipate the standards by marketing more efficient products one or more years in advance of the effective date. In these cases, we credit the standard for energy savings from early introduction of higher-efficiency products. This effect is seen in Figure 1 for refrigerators, as appliance manufacturers began to introduce more efficient units in preparation for the standard effective in 1990.[e]

National Energy Savings

The model uses a product retirement function to calculate the number of units in each vintage that are still in operation in a given 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 mean lifetime for each appliance is taken from the TSDs.

The model calculates the annual energy savings for each standard as the difference in national energy consumption between the base case and the standard scenario. It tracks energy savings into the future until all of the units installed in 2030 are retired.

We calculated the primary energy required for production and delivery of end-use (site) electricity and natural gas in each year using historical data and projections in EIA's *Annual Energy Outlook 2006*.[4] These data yield an average site-to-primary energy multiplier for each year through 2030. We extrapolated the trend for the years after 2030.

National Consumer Costs and Benefits

The model uses the average product price to calculate the total consumer purchase cost of the products installed in each year. It calculates total consumer operating costs in each year by reference to the consumption of electricity and natural gas and the average residential price of electricity and natural gas in each year (both historic and forecast).[f]

For products that reduce water consumption (clothes washers and dishwashers), we include consumer water and wastewater expenditures in the operating costs. For clothes

[e] This standard was negotiated in 1986, became law in 1987, and affected units manufactured in 1990.
[f] The analyses done for recent standards rulemakings derived and used marginal electricity prices to value electricity savings from each standard. Marginal energy prices are the prices consumers pay for the last unit of energy used in a given billing period. The marginal prices differ slightly from the average prices used in the present study.

washers, such savings are a significant fraction of the overall savings. All values are expressed in year 2006 dollars.

The TSD analyses include maintenance and repair costs in the operating costs. We were not able to do that in the context of this study. In most cases, however, there is little or no difference in such costs associated with efficiency standards.

The model then calculates the difference in both total consumer purchase cost and total consumer operating costs between the base case and standards scenarios. This yields the net consumer benefit or cost from standards for each year.

The final step involves discounting future monetary benefits to the present, and compounding past monetary benefits to the present. We express the benefit of appliance standards to consumers in terms of the Net Present Value (NPV) of costs and benefits over the considered period. To calculate the NPV, we discounted future costs and savings in each year to 2007 using a rate of 7% (real), which is the rate used by DOE in its analyses of appliance standards (based on guidance to all federal agencies from the Office of Management and Budget). To express the present value of net savings achieved in the 1987-2006 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 up to 2007.[g]

Commercial Products: Fluorescent Lamp Ballasts

Because there have been two sequential fluorescent ballast standards put into effect, we combined the results of their two separate analyses to produce estimates for savings from ballast standards. The first analysis was for the original ballast standards, which were in effect from 1990/1991 through mid-2005; they essentially required efficacies equivalent to those of energy-efficient magnetic ballasts, which replaced standard magnetic ballasts. For this analysis we created a new spreadsheet model, as we were not aware of previous analyses of impacts of the 1990 ballast standards, which were established by legislation.

The second analysis was for the current ballast standards, which were designed to come into effect in two phases: the first in mid-2005 for ballasts in new luminaires and the second in 2010 for replacement ballasts. These current standards essentially require ballasts that drive T12 lamps to be as efficient as electronic ballasts, which effectively replace energy-efficient magnetic ballasts. For this report, we adapted the forecasting

[g] Interest rates represent the marginal value of savings to society, determining what next year's money is worth today and what today's money will be worth next year. Economists take advantage of this definition and use interest rates to convert future savings into a present value (in which case the interest rate is called a discount rate) and to convert past savings into a present value. Interest rates vary in proportion to the level of risk. Low risk long-term government bonds have yielded roughly 3% (real) in past decades while equity stocks, which face higher risk, yielded over 7%. Consistent with this finding, economists use a low rate to convert low-risk savings into a present value and use a higher rate to convert high-risk savings into a present value. We consider past benefits of energy efficiency standards to be low risk, since there is fairly high confidence that they have occurred. Less certain about the future, we consider future benefits of standards to be higher risk.

model used for the national energy savings in the fluorescent ballast TSD (see Appendix 1, #9) to reflect actual Census shipments data reported between 1999 and 2005, and updated other inputs to match more recent EIA historical and forecasted data.

Shipments

For the original (1990) standards, we estimated shipments for 1988–1993 from an LBNL report by Koomey et al. on the impact of State standards on the fluorescent ballast market.[5] That study derived shipments from US Census Bureau data. For shipments in 1994–2005 we used annual magnetic power-factor corrected ballast shipments data from the Census Bureau's Current Industrial Reports for Fluorescent Lamp Ballasts,[6] adjusted slightly per the data trend in the Koomey et al. report. We assumed that magnetic ballast shipments in 2006–2030 would decrease from the previous year at the same rate of decrease as that of the shipments in LBNL's NES (National Energy Savings) ballast model, using the same scenario as assumed for the 2005/2010 standards analysis, as explained below.[h] That is, we projected shipments for the original standards as though the current (2005/2010) standards had not gone into effect, to avoid double-counting.

We estimated savings from two base cases: *Frozen Efficiency* and *High Efficiency*. To develop both bases cases, we used the shares that energy-efficient magnetic ballasts comprised of total magnetic ballast shipments from the Koomey et al. report for the years 1988 – 1989. In the Frozen Efficiency base case, from 1990 through 2030 the market shares of energy-efficient magnetic ballasts remained at the 1989 level; this assumed that no additional State or Federal standards were imposed and that the market was affected only by the continuation of existing State standards. The remainder of the magnetic ballasts shipments was assumed to be standard magnetic ballasts. For the High Efficiency base case, we assumed that the share comprised by energy-efficient magnetic ballast shipments from 1990 through 2030 grew linearly from the 1989 percentage to a 50% market share in 2001, and remained at 50% through 2030. This assumed that the market (with possible additional State standards) reached a level (50%) that seemed to be an upper bound from industry testimony to Congress prior to the enactment of the Federal standards (according to the Koomey et. al. report).

For this analysis, we assumed that the High Efficiency base case was the most likely and report savings from this scenario. Savings and costs were calculated beginning in 1991, since the NAECA standard prohibited the manufacture of standard magnetic ballasts after January 1, 1990 and their *sale* or incorporation into luminaires after April 1, 1991.

For the current (2005/2010) standards, we forecast the decline of (energy-efficient) magnetic ballast shipments from 1997 through 2030 with and without standards. We created a magnetic ballast shipments forecast that was adapted from the forecasts used in the Technical Support Document (TSD) for DOE's ballast standards analysis.

[h] The original versions of the NES model were used to project the national energy savings in the TSD for the current 2005/2010 ballast standards.

Following is a background explanation of these forecasts. The TSD forecasts had been based on data supplied by the National Electrical Manufacturers Association (NEMA) for annual domestic shipments from 1993 through 1997 (see TSD Table 5.1). The NES model used for the TSD analysis had two base cases in which shipments decreased at two different rates to account for uncertainty about future shipments.[i]

More recent Census data for 1998 through 2005 showed that the actual rate of decline of magnetic ballast shipments was even greater than the rate of decline expected from the 1993-97 trend. Therefore, for this analysis, we used shipments data also supplied by NEMA for 1993 through 1998 (see TSD Table 5.2) and used Census data for 1999 – 2005 shipments. Since NEMA's data estimates represented those ballasts that would be subject to the new standards, they were a subset of total magnetic power-factor corrected shipments reported to the Census Bureau. To create a similar subset for 1999 – 2005, we adjusted the Census shipments data by the ratio of NEMA shipments to Census shipments in 1998. Then we performed a linear regression through the resulting 1993 – 2005 shipments to project a new base case shipments scenario. In this scenario, the year the shipments fell to the base level was 2011.[j]

Average Annual Energy Efficiency and Energy Consumption

For the 2005/2010 standards, most inputs were from LBNL's previous technical analyses performed for DOE and documented in the ballast standards TSD. Differences from these assumptions are described in sections below.

For both ballast standards, efficiency levels in the analysis correspond to discrete ballast types (standard magnetic, energy-efficient magnetic, electronic rapid start, or electronic instant start). We used the average wattage for each ballast type and number of lamps and created aggregated wattages by weight-averaging by shipments. For future years, we assumed that ballast wattage would track ballast/lamp type according to the shipments projections.

For further details on the data and assumptions, see the ballast standards TSD.

Product Prices and the Incremental Costs of Standards

For the 1990 standards we estimated ballast prices from 1989 product catalogs and applied volume discount multipliers. The resulting incremental prices were weight-averaged by the market shares of the three ballast types (4-foot, 8-foot, and 8-foot high-output) from shipments data used in the NES analysis.

[i] The TSD NES model also had a "Constant Shipments" base case.

[j] For the decreasing shipments scenarios, we considered that there would be some persistent magnetic ballast sales. We estimated that this "base level" would be equivalent to 10% of 1997 magnetic ballast shipments levels. The year in which magnetic ballast shipments decreased to the base level was listed in the name of each scenario.

For the 2005/2010 standards we used the ballast prices, as well as the associated lamp prices, from the TSD. Lamp equipment and labor costs were necessary for the analysis because they differed between baseline and standards options if their ballast lifetimes were different.[k] (For the 1990 standards, ballast lifetime between the baseline and standards options was identical, so no lamp costs needed to be included.) Those ballast and lamp prices were derived from market analysis performed by LBNL as reported in the TSD. In the analysis ballast and lamp prices tracked the shipment types in the base case and standards scenarios. For further details on the data assumptions, see the ballast standards TSD.

Average Energy Savings per Unit

For ballasts, we assumed that the standards impacts began in the year corresponding to the legal effective date. We did not credit either of the standards for energy savings from early introduction of higher-efficiency products. (As noted above, the 1990 standards did include continuing impacts from existing State standards.) Other increases of efficient ballast shipments were due to projections of market trends.

For the 1990 standards, average fixture watts[l] are the same as those calculated for an earlier DOE draft ballast standards analysis.[7] These shares were weight-averaged for F40T12 1-, 2-, 3- and 4-lamp ballasts and F96T12 2-lamp ballasts by shares of lamps per fixture derived from building energy audit data LBNL obtained from Xenergy Inc. In 1988–1993, we assumed market shares of 60% for full-wattage lamps and 40% for reduced-wattage ("energy saver") lamps based on a report analyzing potential lamp efficiency standards for Massachusetts.[8] Beginning in 1994, when the EPAct 1992 lamp standards for 8-foot lamps took effect, we assumed that all 8-foot lamp shipments were reduced-wattage lamps. Beginning in 1995, when the EPAct 1992 lamp standards for 4-foot lamps took effect, we assumed that all 4-foot lamp shipments were reduced-wattage lamps. We assumed operating hours from LBNL's analysis of Xenergy's data for F40T12, F96T12, and F96T12HO ballast types for the commercial and industrial sectors; see the ballast standards TSD for details.

For the 2005/2010 standards, wattage data were supplied by NEMA; see the DOE draft analysis report cited above, Table 3.4. (The data were also normalized by light output and thermal factors in consultation with industry, as documented in that report). Operating hours were the same as those used in the TSD analysis, derived from Xenergy data. For further details on the data assumptions, see the ballast standards TSD.

National Energy Savings

[k] This occurred between electronic rapid start and electronic instant start ballasts.
[l] Fixture watts are lamp/ballast system watts adjusted for the installed fixture's thermal effects on wattage and light output .

For the 1990 standards, the base case projections assumed that State standards already in place for energy-efficient magnetic ballasts continued to affect shipments throughout the analysis period, but that no new State standards were enacted. .

We used the shipment scenario described in **Shipments** above. We calculated a combined commercial/industrial sector electricity price for use in the spreadsheet model. We assumed that electricity prices for the commercial sector apply to F40T12 and F96T12 ballasts. For F96T12 ballasts used in the industrial sector, we assumed that (1) 19% of combined shipments are F96T12 per the NES model's projection for 2005 and (2) projected industrial floor space as a percentage of commercial + industrial floor space is 15% in 2005, 14% in 2010 and 13% in 2015, as projected in the draft ballast standards analysis mentioned above. This resulted in an estimate that 3% of total magnetic ballasts were F96T12 ballasts used in the industrial sector. We assumed that industrial sector electricity prices applied to F96T12/HO ballasts, which were 3% of total shipments. Thus, the industrial electricity sector prices applied to 6% of total magnetic ballast shipments.

For the 2005/2010 ballast standards, the base case implicitly included non-regulatory factors that contributed to efficiency increases, such as utility demand-side programs, consumer information and incentive programs (ENERGY STAR), Federal programs (FEMP), and the ASHRAE/IESNA 90.1 building code for new construction/renovation.

To prepare the inputs to the spreadsheet model, we used the same NES model that DOE used to calculate the impacts of the fluorescent ballast standards for the TSD. We used the same assumptions for wattage and operating hours as in the TSD. For consistency with the residential sector approach, we used comparable data from AEO 2007 for future electricity prices for the commercial and industrial sectors and for site-to-source conversion factors. We converted the NES model's \$1997 to \$2006 using GDP price deflators from U.S. Department of Commerce, Bureau of Economic Analysis (BEA).

The energy savings and energy cost savings represent the savings for ballasts sold through 2030, through the remaining years of their lifetimes. The equipment costs include lamp replacement costs over the lifetimes of the ballasts sold through 2030 (although these costs are small).

National Consumer Costs and Benefits

The model uses the average product price to calculate the total consumer purchase cost of the products installed in each year. For the 2005/2010 standards, we included lamp equipment and labor costs along with ballast costs for reasons noted in Product Prices and the Incremental Costs of Standards above.

For the 1990 standards we did not need to include lamp costs, because the baseline standard magnetic ballasts and the energy-efficient design option have the same lifetime, so there is no difference in lamp replacement costs.

Distribution Transformers

For this report we used the annual energy and cost impacts through 2050 as estimated in the TSD for DOE's Final Rule on standards for distribution transformers, which was prepared for DOE by EES/LBNL (see Appendix 1, #10). For information on the methods, data, and assumptions, see that report.

Environmental Impacts

Reductions in carbon dioxide (CO_2) and nitrogen oxide (NO_x) emissions due to DOE's appliance standards are based on the estimated savings in primary energy use for electricity generation and primary natural gas consumption. We derived average emissions factors in terms of million metric tons of carbon (MtC) per quad of primary energy consumption for each year in the 1987-2050 period, using historic and projected data from EIA on total CO_2 emissions from U.S. electricity generation, along with corresponding data on primary energy consumption by the power sector. We used a similar approach and data for annual NO_x emissions factors.

Emissions of SO_2 from electricity generation will be only minimally affected by appliance standards. The Clean Air Act Amendments of 1990 set an SO_2 emissions cap on all power generation. The attainment of this target is flexible among generators through the use of emissions allowances and tradable permits. Accurate simulation of SO_2 trading tends to imply that physical emissions effects will be zero, as long as emissions are at the ceiling. However, there is an SO_2 benefit from energy conservation in the form of a lower allowance price.

Appliance standards also reduce emissions of mercury from coal-fired generation, but we are not aware of reliable emissions factors.

Sources of Uncertainty

A measure of uncertainty applies to all of the variables used in this analysis. For example, future shipments may be higher or lower than projected due to changing economic factors.

Perhaps the greatest uncertainty concerns the estimation of the baseline scenarios – what would have occurred in the absence of standards. Both technological and economic factors have contributed to energy efficiency trends in the past. The baseline trends in efficiency improvement developed in this study are inherently speculative. Considering historical efficiency trends, expected future residential energy prices, and the intensity of price competition in the appliance market, however, we believe them to be reasonable approximations.

Another source of uncertainty concerns the incremental cost to consumers of products that meet the standards. Real prices of these goods have tended to decline over time and the competitive nature of the market continues to exert downward pressure. As mentioned above, we believe that the incremental cost estimates used in this study (and in the TSDs) are more likely to be overstated than understated.

Lastly, the present value of economic impacts is sensitive to assumptions about the rate used to discount future costs and benefits and the rate used to compound past savings to the present.

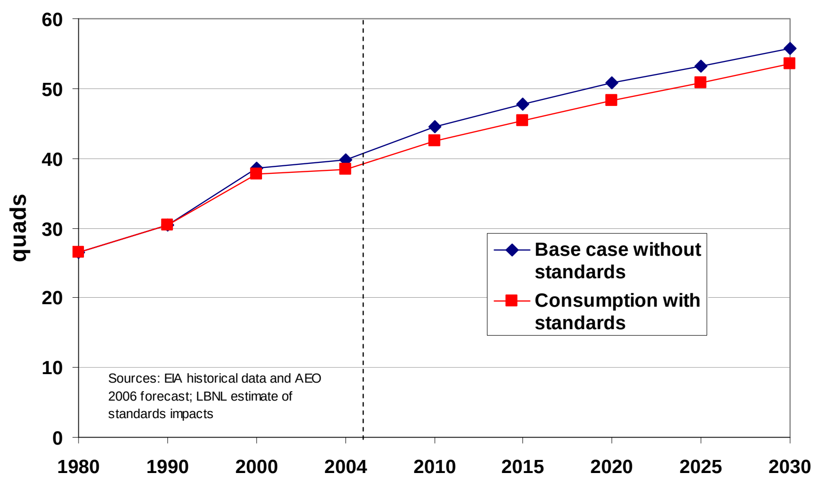
3. Results

National Energy Savings

The impacts of Federal energy conservation standards on total residential/commercial primary energy use are expanding as more products affected by standards enter the buildings stock. The standards have a much larger effect on residential energy use than on commercial sector energy use. This is due to the fact that standards affect a larger share of end-use energy consumption in the residential sector, to the earlier effective dates of many residential standards, and to factors related to product purchase decision-making in each sector.

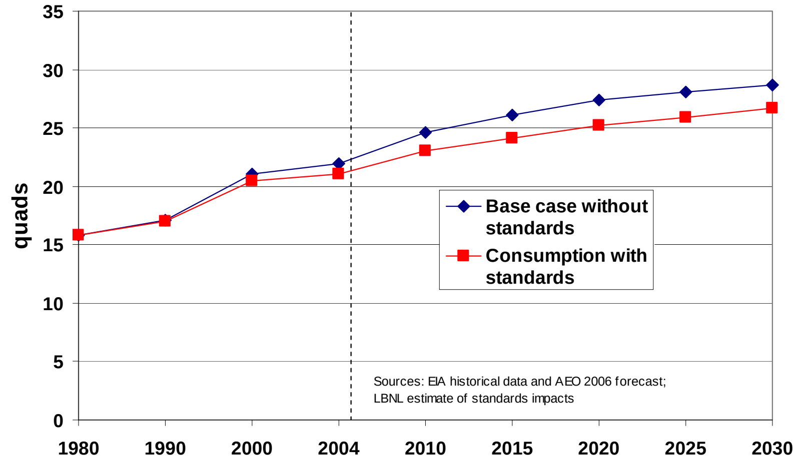
The following graphs show U.S. energy consumption with and without the energy conservation standards considered in this study.[m]

Figure 2. US Residential and Commercial Primary Energy Consumption



[m] The consumption with standards is equal to that amount forecast by EIA in its Annual Energy Outlook 2006, as EIA's forecasts nominally include the impact of standards. To derive the base case without standards, we added our estimates of annual energy savings from standards to the EIA forecast quantities.

Figure 3. U.S. Residential Primary Energy Consumption



The following three figures show the annual energy savings for both the residential and commercial sector, the residential sector by product and the commercial sector by product, respectively.

Figure 4. Annual Primary Energy Savings for Residential and Commercial Products

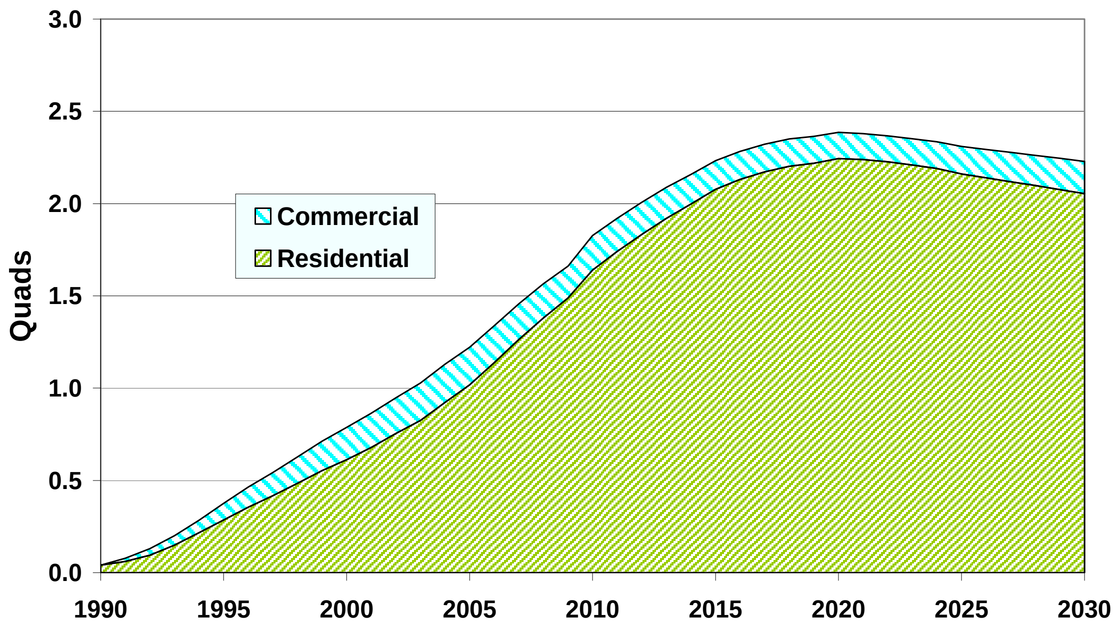


Figure 5. Annual Primary Energy Savings for Residential Appliances

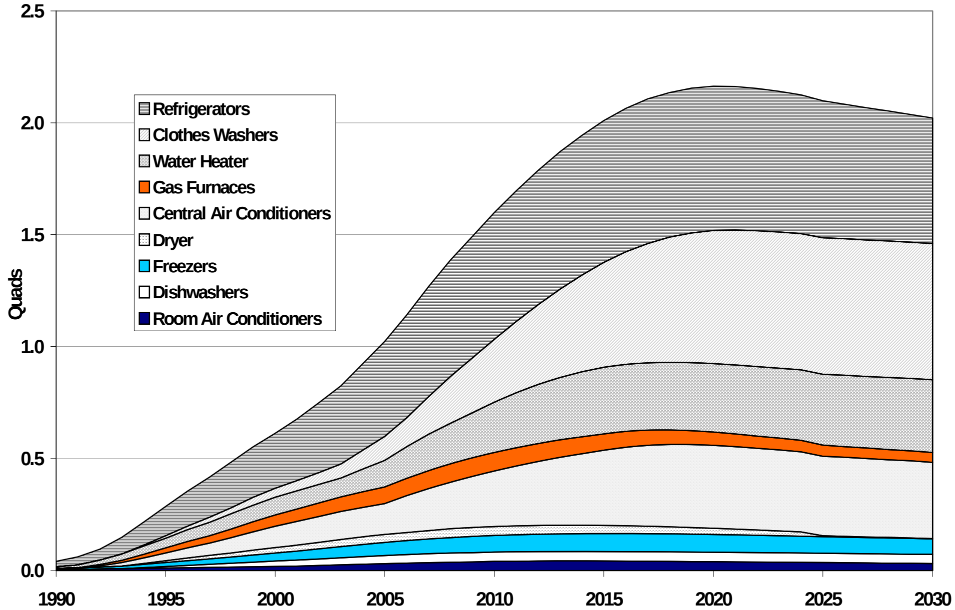
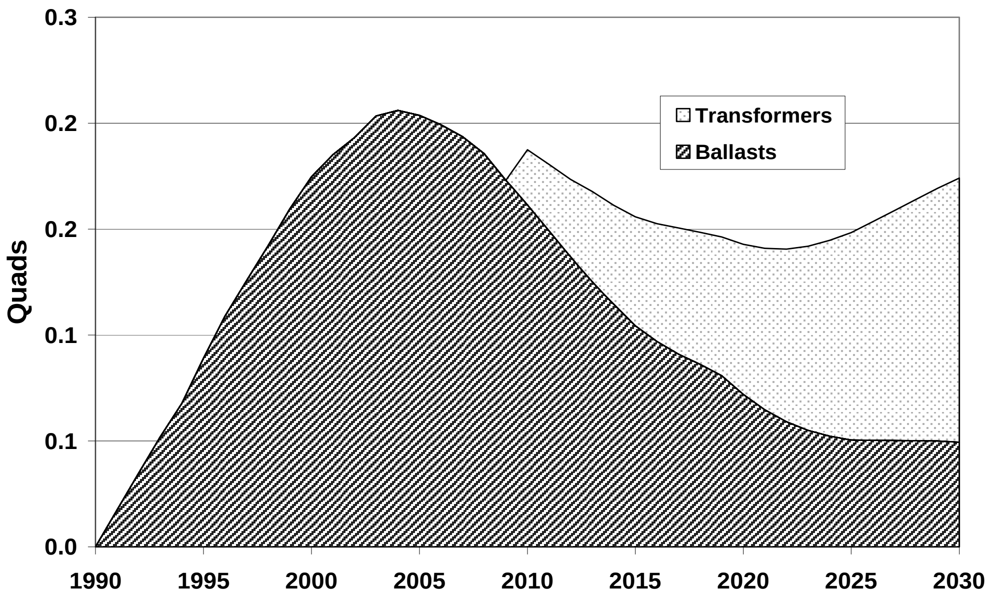


Figure 6. Annual Primary Energy Savings for Commercial Products



The following figures show the cumulative energy savings through various years. The estimated cumulative primary energy savings by 2045 total 78 Quads: 70 Quads from residential appliance standards and eight Quads from the commercial sector standards.[n] The breakdown by product for cumulative energy savings in the residential sector is shown in Figure 8.

Figure 7. Cumulative Primary Energy Savings for Residential and Commercial Products

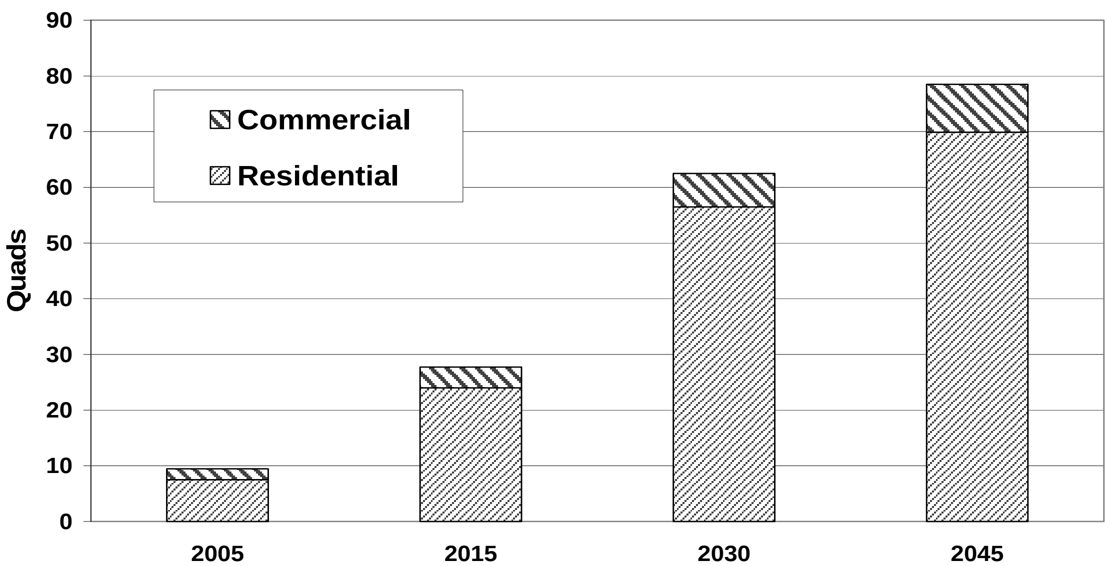
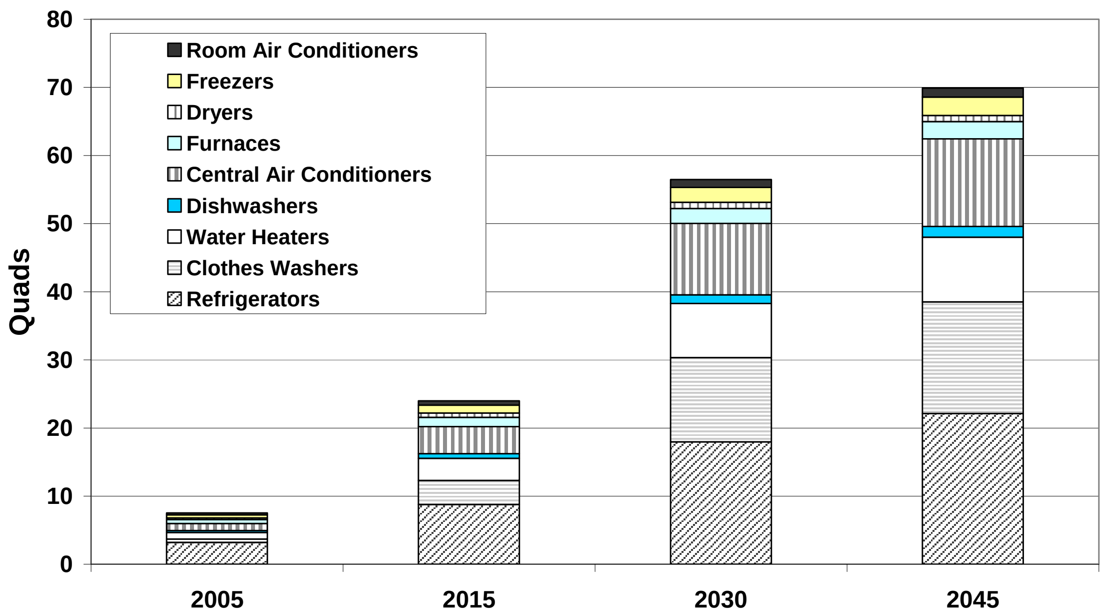


Figure 8. Cumulative Primary Energy Savings -- Residential Products



[n] An internal report prepared for DOE in 2004 by Belzer and Winiarski at Pacific Northwest National Laboratory estimated that the Federal standards for a number of commercial heating, cooling, and water heating products would have cumulative energy savings of 1.6 quads through 2045.

Consumer Economic Benefits

For consumers, standards typically involve an increased initial expenditure for more energy-efficient appliances, which is more than balanced by savings in operating costs over the appliance lifetime. The operating cost savings primarily include energy costs, but for some appliances (e.g., clothes washers and dishwashers) water cost savings are also important.

The following graph show annual undiscounted monetary benefits to consumers. The decline in net savings in 2006-2007 is due to the additional installed costs associated with the new standards for central air conditioners and heat pumps (effective 2006) and clothes washers (effective 2007). As the substantial operating cost savings for these products come to the fore, the total net savings from standards for all products climb strongly. After 2020, the annual net savings level off as the impacts of earlier standards wane.

Figure 9. Annual Consumer Net Monetary Savings for Residential and Commercial Products

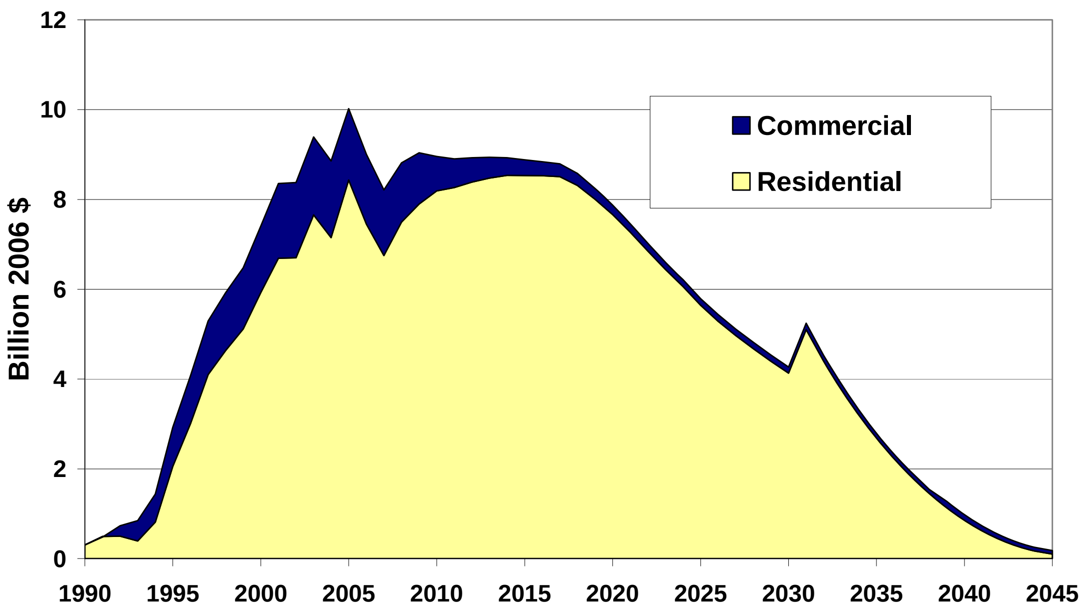


Figure 10 shows the discounted cumulative monetary savings for residential and commercial appliance standards. Since we discount future benefits to the present using a 7-percent real discount rate, savings in the distant future have a small present value. By the end of 2005, the standards had saved U.S. consumers a total of $64 billion. The present value of projected net savings over the entire 1987-2045 period is $269 billion.[o]

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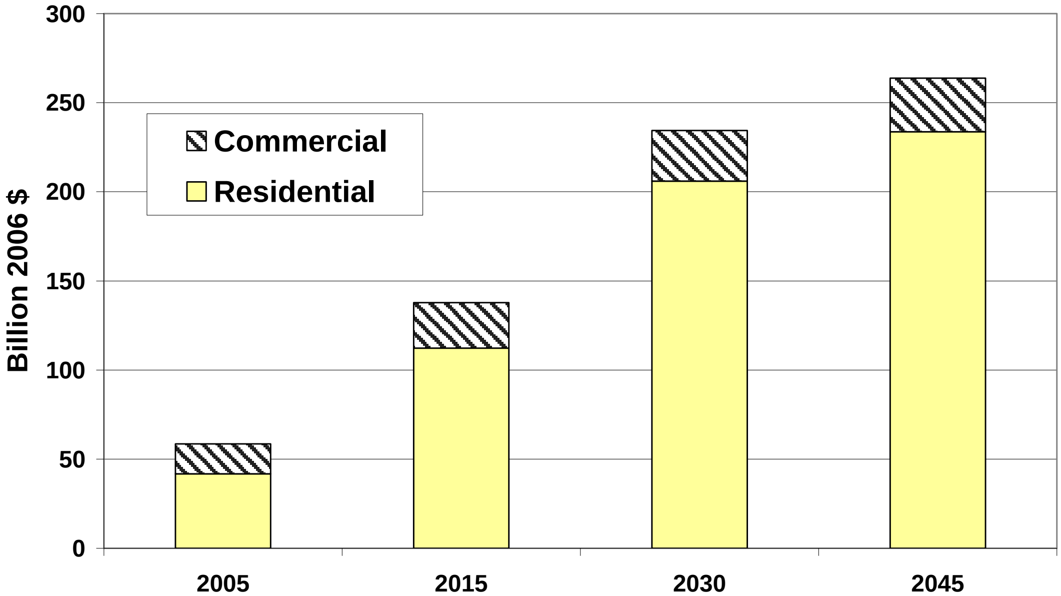
[o] The PNNL study cited earlier estimated that the commercial HVAC and water heating standards will have a cumulative net benefit of $1.6 billion by 2045.

The ratio of consumer operating cost savings (NPV of $407 billion) to additional consumer expenditures (NPV of $149 billion) is 2.7 to 1.

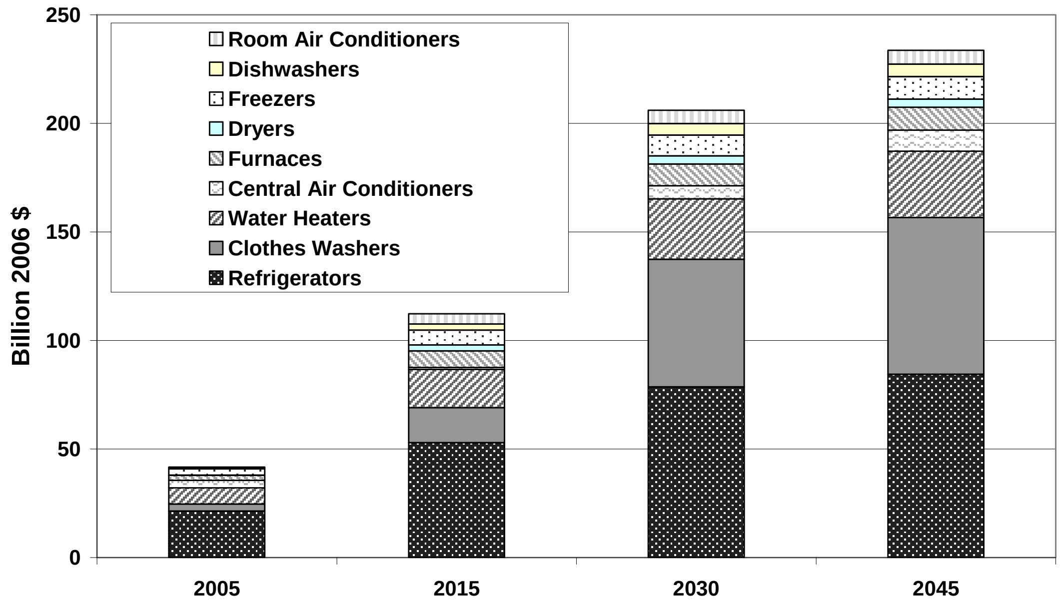
Figure 10. Cumulative Consumer Net Monetary Savings for Residential and Commercial Standards (NPV in 2007 at 7% discount rate)



For residential appliances (Figure 11), the greatest net monetary savings are associated with standards for refrigerators and clothes washers.

The amount of taxpayer funds used to support DOE's residential appliance standards program over the past 20 years is in the range of $200-250 million. Thus, the leveraging effect of the government expenditure on consumer benefit is quite large.

Figure 11. Cumulative Consumer Net Monetary Savings for Residential Products (NPV in 2007 at 7% real)



Environmental Benefits

The environmental benefits associated with energy efficiency standards mainly result from reduced emissions of carbon dioxide and air pollutants from power plants. Standards also result in lower emissions from direct fuel combustion in buildings (such as in gas furnaces).

Figures 12 and 13 show the annual and cumulative reduction in emissions of carbon dioxide resulting from Federal appliance standards. The annual reduction peaks at 38 million tons C around 2020. The cumulative reduction in 2045 amounts to 1,200 million tons C.

Figure 14 show the annual reduction in NO_x emissions resulting from Federal appliance standards. The annual reduction peaks at 430 thousand tons around 2020. The cumulative reduction in 2045 amounts to 14 million tons.[p]

[p] Two recent regulatory actions proposed by the EPA regarding regulations and guidelines for best available retrofit technology determinations and the reduction of interstate transport of fine particulate matter and ozone are tending toward further NOx reductions and likely to an eventual nationwide emissions cap. As with SO2 emissions, a cap on NOx emissions will likely result in no physical emissions effects from equipment efficiency standards. However, there would be a benefit from conservation in the form of a lower allowance price.

Figure 12. Annual CO2 Emissions Reduction from Federal Standards for Residential and Commercial Products

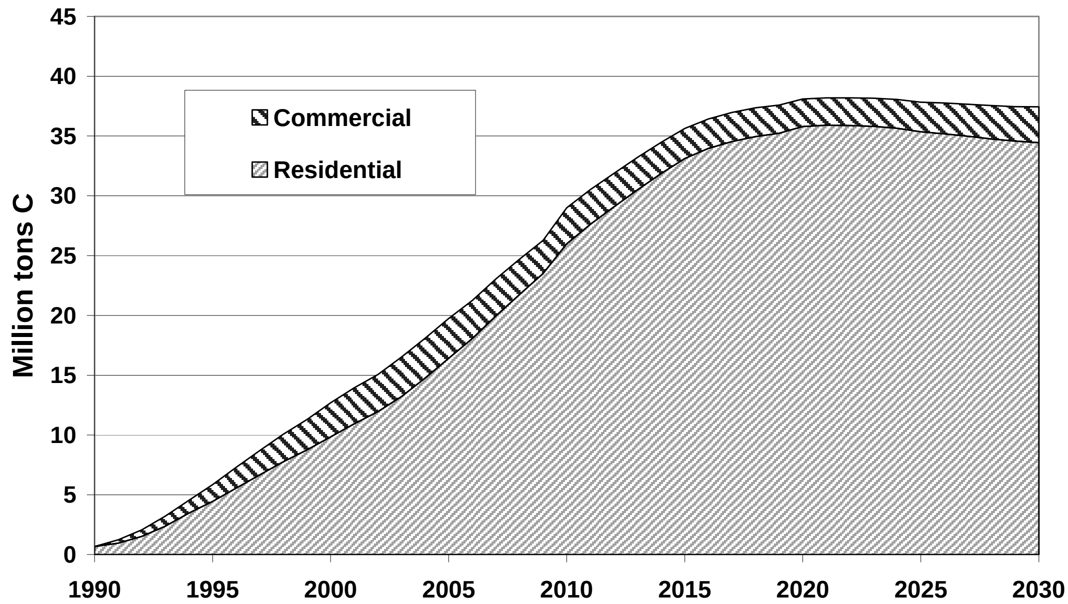


Figure 13. Cumulative CO2 Emissions Reduction from Federal Standards for Residential and Commercial Products

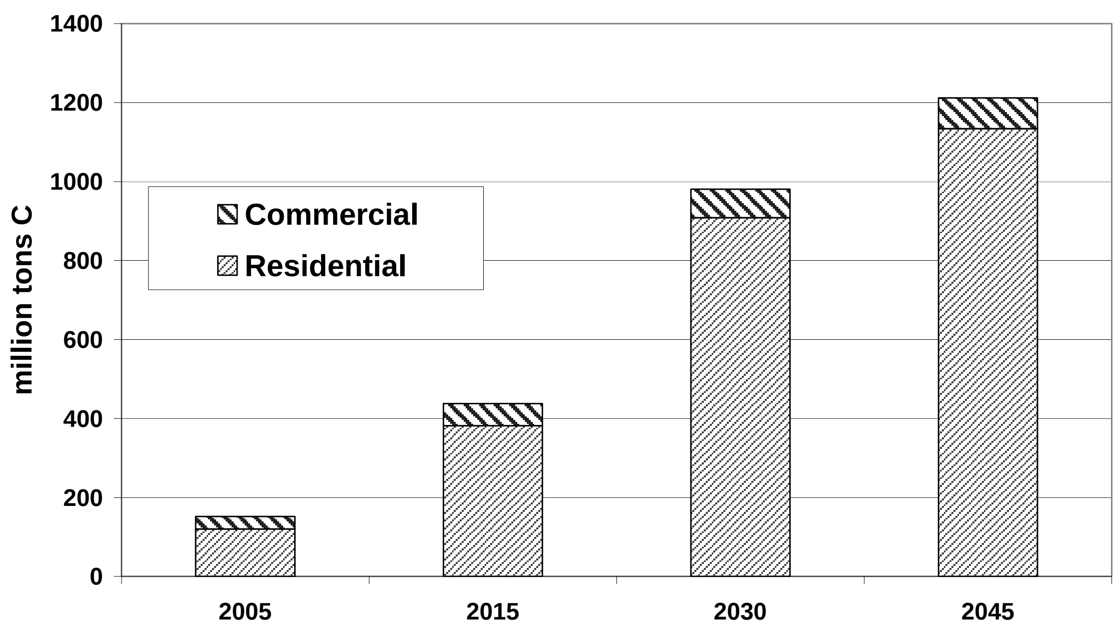
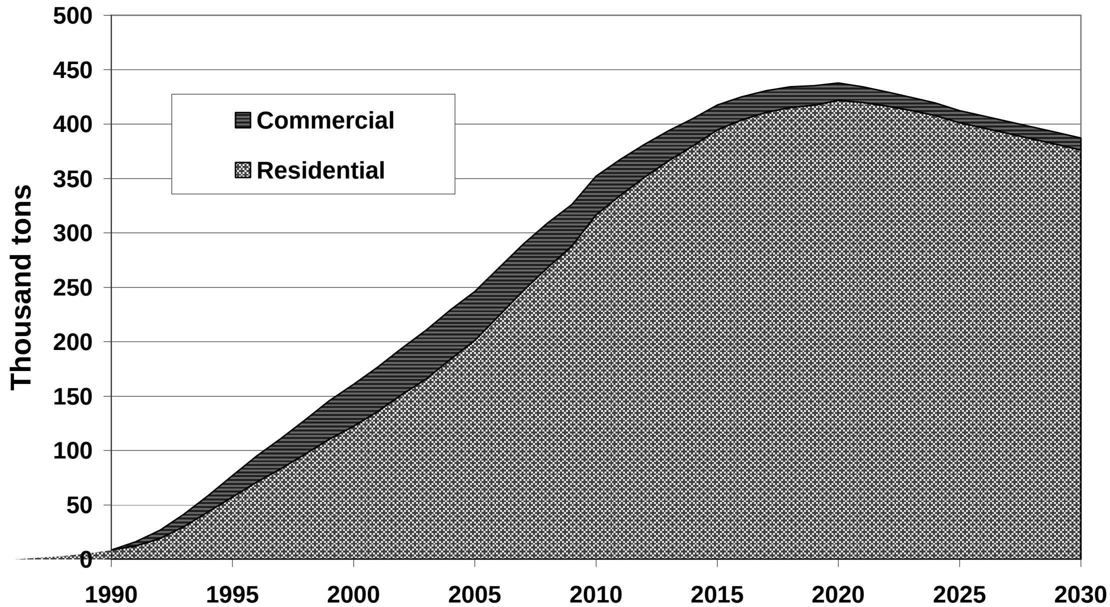


Figure 14. Annual NO_x Emissions Reduction from Federal Standards for Residential and Commercial Products



4. Conclusion

The impact of the U.S. Department of Energy's energy efficiency standards for residential and commercial appliances that became effective in the 1988-2006 period or will take effect by the end of 2010 is steadily accumulating as the stock of appliances expands. We estimate that these standards will reduce residential/commercial primary energy consumption and carbon dioxide emissions in 2030 by 4% compared to the levels expected without any standards. The reduction for the residential sector is larger, at 8%.

The estimated cumulative energy savings from the standards amount to 39 quads by 2020, and 63 quads by 2030. The standards will also reduce emissions of carbon dioxide by considerable amounts.

The standards had saved residential and commercial consumers an estimated $64 billion by the end of 2005. The estimated cumulative net present value of consumer benefit amounts to $241 billion by 2030, and grows to $269 billion by 2045. The overall ratio of consumer benefits to costs (in present value terms) in the 1987-2050 period is 2.7 to 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 $200-250 million. Thus, the leveraging effect of the government expenditure on consumer benefit is quite large.

Although the estimates made in this study are subject to a fair degree of uncertainty, we believe they provide a reasonable approximation of the national benefits resulting from Federal appliance efficiency standards.

Appendix 1 Technical Support Documents for DOE Energy Efficiency Standards

1. U.S. Department of Energy-Office of Codes and Standards, *Technical Support Document: 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 & Television Sets*, 1993. Washington, DC. Report No. DOE/EE-0009.

2. U.S. Department of Energy-Office of Codes and Standards, *Technical Support Document: Energy Efficiency Standards for Consumer Products: Refrigerators, Refrigerator-Freezers, and Freezers, including Environmental Assessment and Regulatory Impact Analysis*, July, 1995. Washington, DC. Report No. DOE/EE-0064. <http://www.osti.gov/bridge/product.biblio.jsp?osti_id=90266>

3. U.S. Department of Energy-Office of Codes and Standards, *Technical Support Document For Energy Conservation Standards for Room Air Conditioners*, September, 1997. Washington, DC. Docket Numbers EE-RM-90-201 & EE-RM-93-801-RAC.

4. U.S. Department of Energy-Office of Codes and Standards, *Technical Support Document: Energy Efficiency Standards for Consumer Products: Residential Central Air Conditioners and Heat Pumps*, 1999. Washington, DC. <http://www.eren.doe.gov/buildings/codes_standards/reports/central_air_tsd/index.htm>

5. U.S. Department of Energy-Office of Building Research and Standards, *Technical Support Document: Energy Efficiency Standards for Consumer Products: Residential Water Heaters*, 2000, U.S. Department of Energy. Washington, DC. Report No. LBNL-47419. <http://www.eren.doe.gov/buildings/codes_standards/reports/waterheater/index.html>

6. U.S. Department of Energy-Office of Building Research and Standards, *Final Rule Technical Support Document (TSD): Energy Efficiency Standards for Consumer Products: Clothes Washers*, 2000, U.S. Department of Energy. Washington, DC. Report No. LBNL-47462. <http://www.eren.doe.gov/buildings/codes_standards/reports/cwtsd/index.html>

7. U.S. Department of Energy-Office of Building Research and Standards, *Technical Support Document: Energy Efficiency Standards for Consumer Products: Residential Central Air Conditioners and Heat Pumps*, 2000, U.S. Department of Energy. Washington, DC. Report No. LBNL-47463. http://www.eren.doe.gov/buildings/codesstandards/reports/cac_hp_tsd/index.html

8. U.S. Department of Energy-Office of Building Technologies. Technical Support Document: Energy Efficiency Program for Consumer Products: Energy Conservation Standards for Residential Furnaces and Boilers - NOPR. Washington, DC: U.S. Department of Energy, 2006.

9. U.S. Department of Energy-Office of Codes and Standards, Technical Support Document: Energy Efficiency Standards For Consumer Products: Fluorescent Lamp Ballast Proposed Rule, including Environmental Assessment and Regulatory Impact Analysis, September, 2000. Washington, DC. LBNL- 47464 http://www.eere.energy.gov/buildings/appliance_standards/residential/gs_fluorescent_0100_r.html

10. U.S. Department of Energy-Building Technologies Program. Technical Support Document: Energy Efficiency Program For Commercial And Industrial Equipment: Electrical Distribution Transformers. September, 2007. Washington, DC: U.S. Department of Energy. http://www.eere.energy.gov/buildings/appliance_standards/commercial/distribution_transformers_fr_tsd.html

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[2] Association of Home Appliance Manufacturers (various years). Major Appliance Industry Fact Book. Chicago, IL.

[3] Air-Conditioning and Refrigeration Institute (various years). Statistical Profile of the Air-Conditioning, Refrigeration, and Heating Industry. Arlington, VA.

[4] Energy Information Administration (2006). *Annual Energy Outlook 2006*. U.S. Department of Energy, Washington, D.C.

[5] Koomey, J.G., A.H. Sanstad, and L.J. Shown (1995). *Magnetic Fluorescent Ballasts: Market Data, Market Imperfections, And Policy Success.* Lawrence Berkeley National Laboratory, Berkeley CA. LBL-37702.

[6] U.S. Census Bureau (1994-2005). *Current Industrial Report for Fluorescent Lamp Ballasts*. Most recently named MQ335C. (The survey was discontinued with 2005 as the last full year reported.) http://www.census.gov/industry/1/mq335c055.pdf

[7] DOE (1997). *Draft Report on Potential Impact of Possible Energy Efficiency Levels For Fluorescent Lamp Ballasts*. Lawrence Berkeley National Laboratory, Berkeley CA.

[8] Nadel, S., H. Geller, F. Davis, and D. Goldstein (1989). *Lamp Efficiency Standards for Massachusetts: Analysis and Recommendations*. American Council for an Energy-Efficient Economy, Washington DC. Report A981 (Reference 29).