Energy and Economic Impacts of U.S. Federal Energy and Water Conservation Standards Adopted From 1987 Through 2012

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Abstract

This paper presents estimates of the key impacts of Federal energy and water conservation standards adopted from 1987 through 2012. The standards for consumer products and commercial and industrial equipment include those set by legislation as well as standards adopted by DOE through rulemaking.

In 2012, the standards saved an estimated 3.6 quads of primary energy, which is equivalent to 3% of total U.S. energy consumption. The savings in operating costs for households and businesses totaled $51.4 billion. The average household saved $347 in operating costs as a result of residential and plumbing product standards. The estimated reduction in CO_2 emissions associated with the standards in 2012 was 198 million metric tons, which is equivalent to 3% of total U.S. CO_2 emissions.

The estimated cumulative energy savings over the period 1990-2070 amount to 179 quads. Accounting for the increased upfront costs of more-efficient products and the operating cost (energy and water) savings over the products' lifetime, the standards have a past and projected cumulative net present value (NPV) of consumer benefit of between $1,104 billion and $1,390 billion, using 7 percent and 3 percent discount rates, respectively.

The water conservation standards, together with energy conservation standards that also save water, reduced water use by 1.8 trillion gallons in 2012, and will achieve cumulative water savings by 2040 of 54 trillion gallons. The estimated consumer savings in 2012 from reduced water use amounted to $13 billon.

Introduction

The energy conservation program for consumer products and certain commercial and industrial products was established by the Energy Policy and Conservation Act of 1975 (EPCA). EPCA established a program consisting of test procedures, labeling, and energy conservation targets for 19 types of consumer products. The National Energy Conservation Policy Act of 1978 amended EPCA by replacing the energy conservation targets program and directing that energy conservation standards be set for the covered consumer products. With the passage of the National Appliance Energy Conservation Act (NAECA) in 1987, EPCA was further amended to establish the first national energy conservation standards for consumer products. Subsequent amendments in 1988, 1992, 2005, and 2007 further expanded the scope of coverage to include additional consumer products, certain commercial and industrial equipment, as well as water conservation standards for residential and commercial products. EPCA, as amended, requires the Department of Energy (DOE) to update or establish standards at levels that "achieve the maximum improvement in energy [or water] efficiency … which the Secretary determines is technologically feasible and economically justified." EPCA defines "economically justified" standards as those for which benefits exceed the costs, given a number of factors, including impacts on consumers and manufacturers and the nation's need to save energy or water.

This paper presents estimates of the key impacts of the energy and water conservation standards that have been adopted from 1987 through 2012. It updates the results presented in Meyers et al. (2012),[1] which covered standards adopted through 2011. The standards covered include those set by legislation as well as standards adopted by DOE through rulemaking. The estimates cover both historic and projected impacts of these standards. The impacts cover primary energy savings and water savings, net present value of consumer[a] benefits, and estimated reductions in CO_2 emissions.

Table 1 lists products covered by standards, the year(s) compliance was or will be required, and the legislation that initially authorized each standard. The standards that were adopted in 2012 cover the following products (compliance year in parentheses):

- Residential clothes washers (2015/2018)
- Residential dishwashers (2013)
- ASHRAE products (2012/2013/2014)[b]

[a] The term "consumer" as used in this report refers to all buyers and users of appliances and equipment covered by standards.
[b] Water and evaporatively cooled air conditioners, VRF water source heat pumps, computer room air conditioners.

Table 1. Federal Energy and Water Conservation Standards for Appliances and Equipment Adopted From 1987 Through 2012

Product	Compliance Date for Original Standard and Updates	Authorizing Legislation*
RESIDENTIAL		
Clothes Washers+	1988, 1994, 2004/2007, 2015/2018	NAECA 1987
Clothes Dryers	1988, 1994, 2014	NAECA 1987
Dishwashers +	1988, 1994, 2010, 2013	NAECA 1987
Refrigerators and Refrigerator-Freezers	1990, 1993, 2001, 2014	NAECA 1987
Freezers	1990, 1993, 2001, 2014	NAECA 1987
Room Air Conditioners	1990, 2000, 2014	NAECA 1987
Central Air Conditioners and Heat Pumps	1992/1993, 2006, 2015	NAECA 1987
Water Heaters	1990, 2004, 2015	NAECA 1987
Furnaces	1992, 2013	NAECA 1987
Boilers	1992, 2012	NAECA 1987
Direct Heating Equipment	1990, 2013	NAECA 1987
Cooking Products	1990, 2012	NAECA 1987
Pool Heaters	1990, 2013	NAECA 1987
Ceiling Fans and Ceiling Fan Light Kits	2007	EPACT 2005
Torchieres	2006	EPACT 2005
Dehumidifiers	2007, 2012	EPACT 2005
External Power Supplies	2008	EISA 2007
COMMERCIAL & INDUSTRIAL		
Electric Motors	1997, 2010	EPACT 1992
Warm Air Furnaces	1994	EPACT 1992
Packaged Boilers	1994	EPACT 1992
Air Conditioners and Heat Pumps	1994/1995, 2003/2004, 2010, 2012, 2012-14	EPACT 1992
Water Heaters, Hot Water Supply Boilers and Unfired Hot Water Storage Tanks	1994, 2004	EPACT 1992
Distribution Transformers	2007, 2010	EPACT 1992, EPACT 2005
Refrigerators, Refrigerator-Freezers and Freezers	2010, 2012	EPACT 2005
Automatic Ice Makers	2010	EPACT 2005
Clothes Washers+	2007	EPACT 2005
Unit Heaters	2008	EPACT 2005
Refrigerated Beverage Vending Machines	2012	EPACT 2005
Walk-in Coolers and Walk-in Freezers	2009	EISA 2007
LIGHTING PRODUCTS		
Fluorescent Lamp Ballasts	1990, 2005/2010, 2014	NAECA 1988
General Service Fluorescent Lamps and Incandescent Reflector Lamps	1995, 2008, 2012	EPACT 1992, EISA 2007
Medium Base Compact Fluorescent Lamps	2006	EPACT 2005

Illuminated Exit Signs	2006	EPACT 2005
Traffic Signal Modules and Pedestrian Modules	2006	EPACT 2005
Mercury Vapor Lamp Ballasts	2008	EPACT 2005
Metal Halide Lamp Ballasts and Fixtures	2009	EISA 2007
General Service Incandescent Lamps, Intermediate Base Incandescent Lamps and Candelabra Base Incandescent Lamps	2012/2014 & 2020	EISA 2007
PLUMBING PRODUCTS		
Faucets[++]	1994	EPACT 1992
Showerheads[++]	1994	EPACT 1992
Water Closets[++]	1994/1997	EPACT 1992
Urinals[++]	1994/1997	EPACT 1992
Pre-rinse Spray Valves[++]	2007	EPACT 2005

* The Energy Policy and Conservation Act of 1975 was amended to set energy or water conservation standards by the National Appliance Energy Conservation Act (NAECA 1987), the National Appliance Energy Conservation Amendments of 1988 (NAECA 1988), the Energy Policy Act of 1992 (EPACT 1992), the Energy Policy Act of 2005 (EPACT 2005), and the Energy Independence and Security Act of 2007 (EISA 2007).

[+] Water and energy conservation standard
[++] Water conservation standard

Analysis Method Overview

Different analytical methods were used for five sets of standards. For NAECA 1987 and NAECA 1988 standards and DOE updates of those standards issued before 2007, we utilized the analyses conducted by Lawrence Berkeley National Laboratory (LBNL) in 2007-2008.[2] For EPACT 1992 standards, we developed new estimates for this study. For EPACT 2005 standards, we reviewed and utilized an analysis conducted by Nadel *et al.*[3] and added information from DOE analyses where available. For most of the EISA 2007 standards, we drew upon an analysis conducted by DOE.[4] For the other EISA 2007 standards,[c] we used unpublished national impact analyses that were prepared by LBNL for DOE. For standards adopted by DOE in 2007-2012, we drew on the national impact analyses performed for the rulemakings for each of the standards and adapted the results for the framework of this study. Appendix A further describes the use of the above sources in this study.

It is important to note that the analyses performed for the rulemakings for each of the standards adopted by DOE in 2007-2012 were highly detailed and were carefully reviewed by stakeholders. All of the other sources used for this study were much less detailed in their approach and less extensively reviewed.

The most challenging aspect of estimating the impacts of standards is characterizing what would have happened without new or amended standards. We call this counterfactual against which

[c] Dishwashers, residential boilers and dehumidifiers.

impacts of standards is measured the "base case." The sources used for this study vary in how they characterized the base case. The LBNL analysis of the NAECA standards and DOE updates of those standards before 2007 estimated a dynamic base case in which the energy efficiency of the products improves somewhat even without standards. The analyses performed for DOE's rulemakings also consider how the market might change in the absence of new or amended standards. In contrast, the analyses used for EPACT 1992, EPACT 2005, and EISA 2007 standards used simple assumptions (in many cases, no change in efficiency) regarding the base case.

We focused on three key impacts associated with standards: (1) primary energy savings; (2) additional installed costs; and (3) operating cost savings. Operating cost savings primarily consist of energy cost savings. Energy cost savings were estimated using historical average annual energy prices through 2011, and recent projections of average annual energy prices after 2011. For standards that save water, we also included water cost savings where possible. In some cases (primarily the DOE rulemakings in 2007-2012), the operating cost savings also include changes in maintenance and repair costs associated with the standards.

From (2) and (3) we derived net cost or savings for each year. We also estimated annual reductions in CO_2 emissions associated with the standards using the annual energy savings and annual average CO_2 emissions factors for the electricity generation sector and for natural gas.

For each standard we developed a time series of annual impacts, with economic impacts expressed in constant dollars. For the NAECA standards and DOE updates of those standards before 2007, and for standards adopted by DOE in 2007-2012, we estimated annual impacts for each standard for 30 years worth of shipments. For most of the other standards, for which the base case often assumed no change in efficiency, we used a shorter period of shipments as a way of compensating for the lack of a dynamic base case, which might tend to overstate the savings from standards. For all standards, we estimated annual energy savings and operating cost savings until products installed in the final year considered are retired from the stock. Retirement is based on the average lifetime for each product.

Using the annual economic impacts, we derived a net present value (NPV) by discounting future impacts to the present (defined as 2012 for this report). For economic impacts occurring after 2012, we used discount rates of 3% and 7%, which are the rates used by DOE in its analyses of national impacts, in accordance with guidance from the Office of Management and Budget to Federal agencies on the development of regulatory analysis.[5] For economic impacts occurring before 2012, we derived estimates of their present value using interest rates of 3% and 7%. This approach reflects the view that the present value of the past stream of benefits should reflect the returns to those "profits" had they been invested elsewhere in the economy.

We estimated a monetary value of the reductions in CO_2 emissions using the mid-range series for the global Social Cost of Carbon (SCC) developed by a Federal interagency process.[d] The series used has a value of $22.3 per metric ton in 2010 and increases at 3 percent per year.

Product-Level Impact of Standards: The Case of Refrigerator-Freezers

Figure 1 illustrates how standards have had an important effect on the energy efficiency of new products, in this case refrigerator-freezers. The average new refrigerator-freezer in 2010 used only 44% of the energy per year as an average new unit in 1985. Total energy use for these products has declined even as shipments increased and the average size of new units grew. Nationally, in 2010 refrigerator-freezers used one-third less total energy than in 1985 even though there were 70 million more units in use.[e]

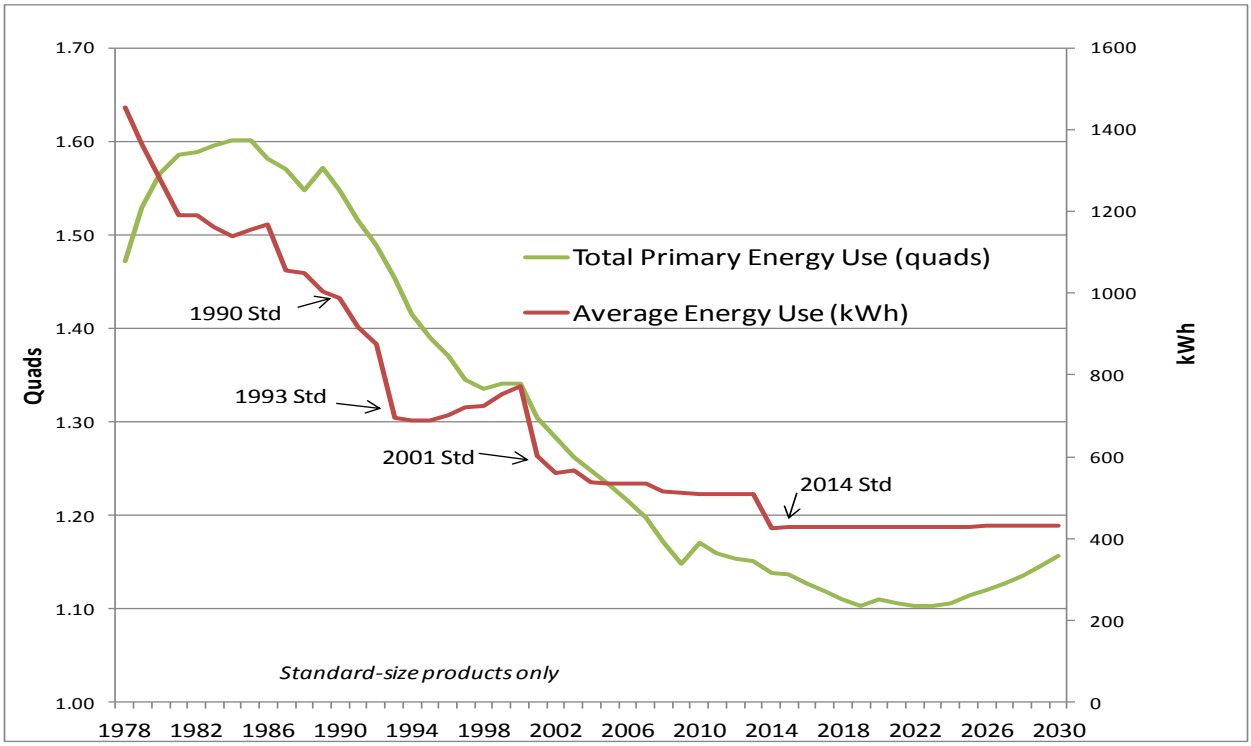

Figure 1. Refrigerator-Freezer Energy Use Trends: Average Energy Use for New Products and Total Energy Use for Refrigerator-Freezers

Source: AHAM Fact Books and 2011 DOE standards rulemaking for residential refrigeration products.[f]

[d] For details on the SCC values, see appendix 16-A of the Technical Support Document for the final rule for residential refrigeration products. http://www1.eere.energy.gov/buildings/appliance_standards/pdfs/refrig_finalrule_tsd.pdf

[e] The increase in total energy use depicted after 2025 is due to growth in purchases of refrigerator-freezers. If the standard is updated as required by EPCA, the declining trend would continue.

[f] http://www1.eere.energy.gov/buildings/appliance_standards/pdfs/refrig_finalrule_tsd.pdf

National Impacts[g]

In 2012, the energy and water conservation standards saved an estimated 3.64 quads of primary energy, which is equivalent to 3% of total U.S. energy consumption. The savings in operating costs totaled $51.4 billion.

As shown in Table 2, the cumulative primary energy savings through 2012 amount to 32.7 quads. The cumulative consumer NPV through 2012, which equals the operating cost savings minus the additional product costs associated with standards, is between $372 billion and $484 billion. Standards on plumbing products account for a large share of the total NPV because they were highly cost-effective.

Over the entire time period considered (1990-2070), the cumulative primary energy savings amount to 178.7 quads and the cumulative consumer NPV is between $1,104 billion and $1,390 billion (Table 3). Residential products account for more than half of the total cumulative primary energy savings. In addition to energy cost savings from energy conservation standards, the consumer NPV includes water cost savings from those standards that affect both energy and water use (such as standards on clothes washers), as well as energy cost savings from water conservation standards that save hot water (i.e., standards on faucets and showerheads).

The cumulative energy savings achieved through 2012 are only 18 percent of the total cumulative energy savings. Thus, most of the savings from standards already adopted will occur in the future. Furthermore, future savings will grow as new standards are adopted.

Table 2. Cumulative Primary Energy Savings and Cumulative Consumer NPV Through 2012 for all Standards

Product type	Primary energy savings (quads)	Share of primary energy savings	Cumulative NPV (billion 2012$)*	Share of NPV
Residential	19.3	59%	$145 - $186	39-38%
Commercial & Industrial	3.9	12%	$20 - $25	5%
Lighting Products	6.0	18%	$52 - $75	14-16%
Plumbing Products	3.5	11%	$154 - $198	41%
Total	32.7	100%	$372 - $484	100%

* The first value refers to the NPV using 3% interest rate, while the second value refers to the NPV using 7% rate.

[g] Additional results, including impacts by each standard, are presented in the Excel spreadsheet used to calculate the impacts, which may be found at the page for this report at: http://efficiency.lbl.gov/bibliography/

Table 3. Cumulative Primary Energy Savings and Consumer NPV for All Standards (1990-2070)

Product type	Cumulative primary energy savings (quads)	Share of total cumulative primary energy savings	Cumulative NPV (billion 2012$)*	Share of total cumulative NPV
Residential	99.1	55%	$518 - $716	47-52%
Commercial & Industrial	28.1	16%	$83 - $126	7-9%
Lighting Products	43.2	24%	$195 - $252	18%
Plumbing Products	8.3	5%	$308 - $296	21-28%
Total	178.7	100%	$1,104 - $1,390	100%

* The first value refers to the NPV using 7% discount or interest rate, while the second value refers to the NPV using 3% rate.

Standards set by legislation account for 69 percent of cumulative energy savings through 2012, and DOE rulemakings account for 31 percent (Table 4). Standards set by legislation account for 47 percent of total cumulative primary energy savings and 57-68% of the total consumer NPV (depending on which discount rate is used). Standards set by DOE rulemakings account for 53 percent of total cumulative primary energy savings and 32-43% of the total consumer NPV (see Table 5).

Table 4. Cumulative Primary Energy Savings and Consumer NPV Through 2012 for All Standards by Source of the Standards

Source of Standards	Cumulative Primary Energy Savings (quads)	Consumer NPV at 3% discount rate (billion 2012$)	Consumer NPV at 7% discount rate (billion 2012$)
Legislation			
NAECA 1987/1988	11.7	121	167
EPACT 1992	8.7	194	251
EPACT 2005*	1.1	10.6	11.4
EISA 2007*	1.2	-2.3	-2.7
Subtotal	22.7	323	426
DOE Rulemakings			
Subtotal	10	48.7	57.2
Total	**32.7**	**372**	**484**

***** Savings through 2012 are very small since the standards are just taking effect.

Table 5. Cumulative Primary Energy Savings and NPV for all Standards by Source of the Standards (1990-2070)

Source of Standards	Primary Energy Savings (quads)	Consumer NPV at 3% discount rate (billion 2012$)	Consumer NPV at 7% discount rate (billion 2012$)
Legislation			
NAECA 1987/1988	21.3	197	223
EPACT 1992	15.3	346	370
EPACT 2005	15.5	117	77.6
EISA 2007	31.0	136	77.2
Subtotal	83.1	795	747
DOE Rulemakings			
Subtotal	95.5	595	357
Total	**178.7**	**1,390**	**1,104**

Table 6 presents the annual and cumulative water savings from standards. The results include water savings from water conservation standards as well as from energy conservation standards that also save water (such as standards on clothes washers and dishwashers).[h] The annual savings of 1.5 trillion gallons in 2010 are equal to 9 percent of the total water withdrawals for public supply in 2005.[i] The estimated dollar savings from reduced water use in 2010 amounted to $10.8 billon. Lower water use in 2010 due to standards also reduced energy use in municipal sewage and water systems by an estimated 0.05 quad.[j]

Table 6. Annual and Cumulative Water Savings for All Water-Conserving Standards

	Water Savings (trillion gallons)	
	Annual	Cumulative through
2010	1.5	11.7
2025	1.5	38.6
2040	0.3	51.4

[h] Note that water savings estimates are not available for standards on commercial plumbing products (water closets, urinals, and faucets). Thus, the results in Table 6 understate the true savings from standards.

[i] USGS estimates that water withdrawals for public supply were 44.2 billion gallons/day in 2005. http://pubs.usgs.gov/circ/1344/

[j] The calculation uses an energy use value of 3,000 kWh per million gallons, which is an estimated average for the U.S. based on several sources.

As shown in Table 7, the estimated reduction in CO_2 emissions associated with the standards in 2012 was 198 million metric tons of CO_2, which amounts to 3.0% of total U.S. CO_2 emissions in 2012. The estimated economic (present) value of reductions in CO_2 emissions associated with the standards through 2055 is $207 billion.

Table 7. Annual and Cumulative Reduction in Carbon Dioxide Emissions for All Energy Conservation Standards

	CO_2 Emissions Reduction (million tons CO_2)		**Present Value (billion 2012$)***	
	Annual	Cumulative through	Annual	Cumulative through
2012	198	1,917	4.82	49
2025	271	5,203	5.93	124
2040	132	8,504	2.46	192
2055	20.9	9,402	0.31	207

***** The present value was calculated using a discount rate of 3%, in keeping with the method used by DOE in recent rulemakings. See discussion in appendix A.

Figure 2 shows the annual primary energy savings for each grouping of standards, and Figure 3 shows the annual undiscounted net consumer impact. The impacts peak in the 2020-2025 period as purchases of products subject to standards increase. The annual savings peak at over $55 billion around 2025. The decline in impacts reflects the analytical convention of counting impacts for 25-30 years of shipments for each standard. As current standards are revised and new standards are adopted, the impacts from all standards will likely not decline.

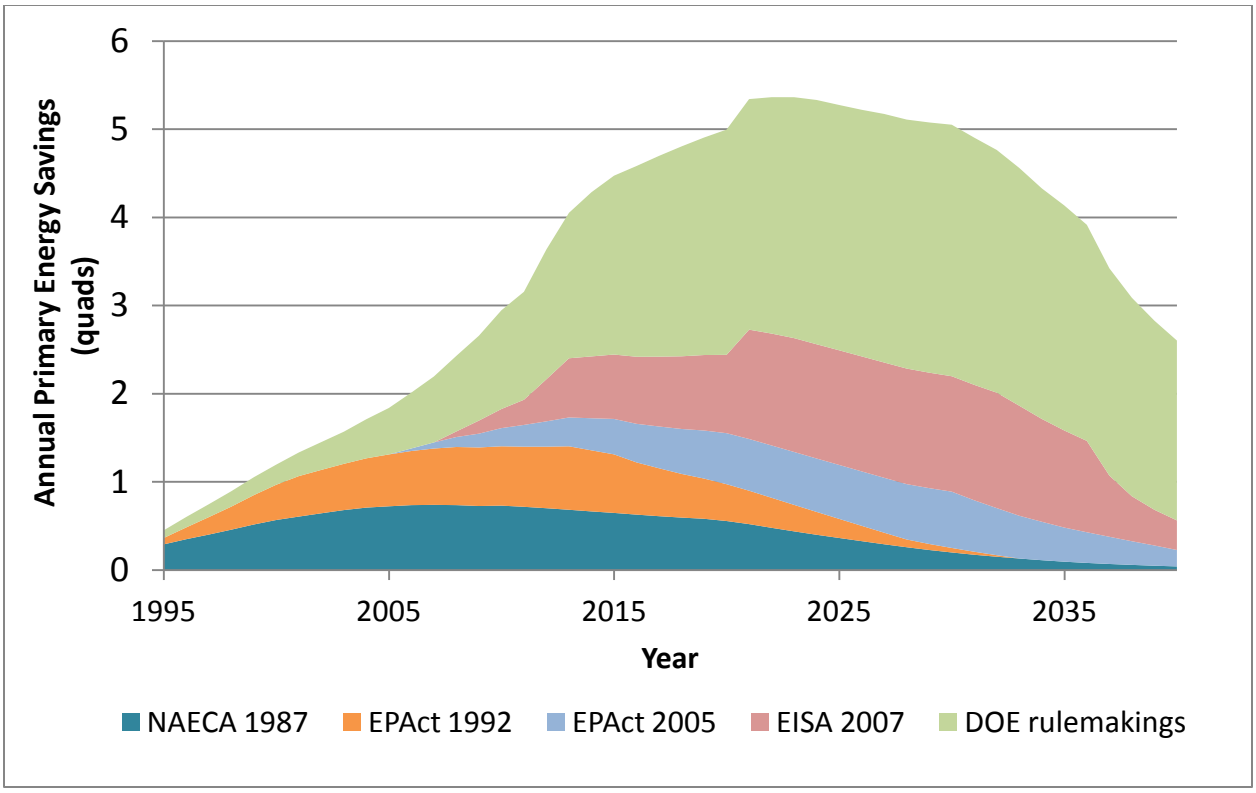

Figure 2. Annual Primary Energy Savings for all Standards by Source of the Standards

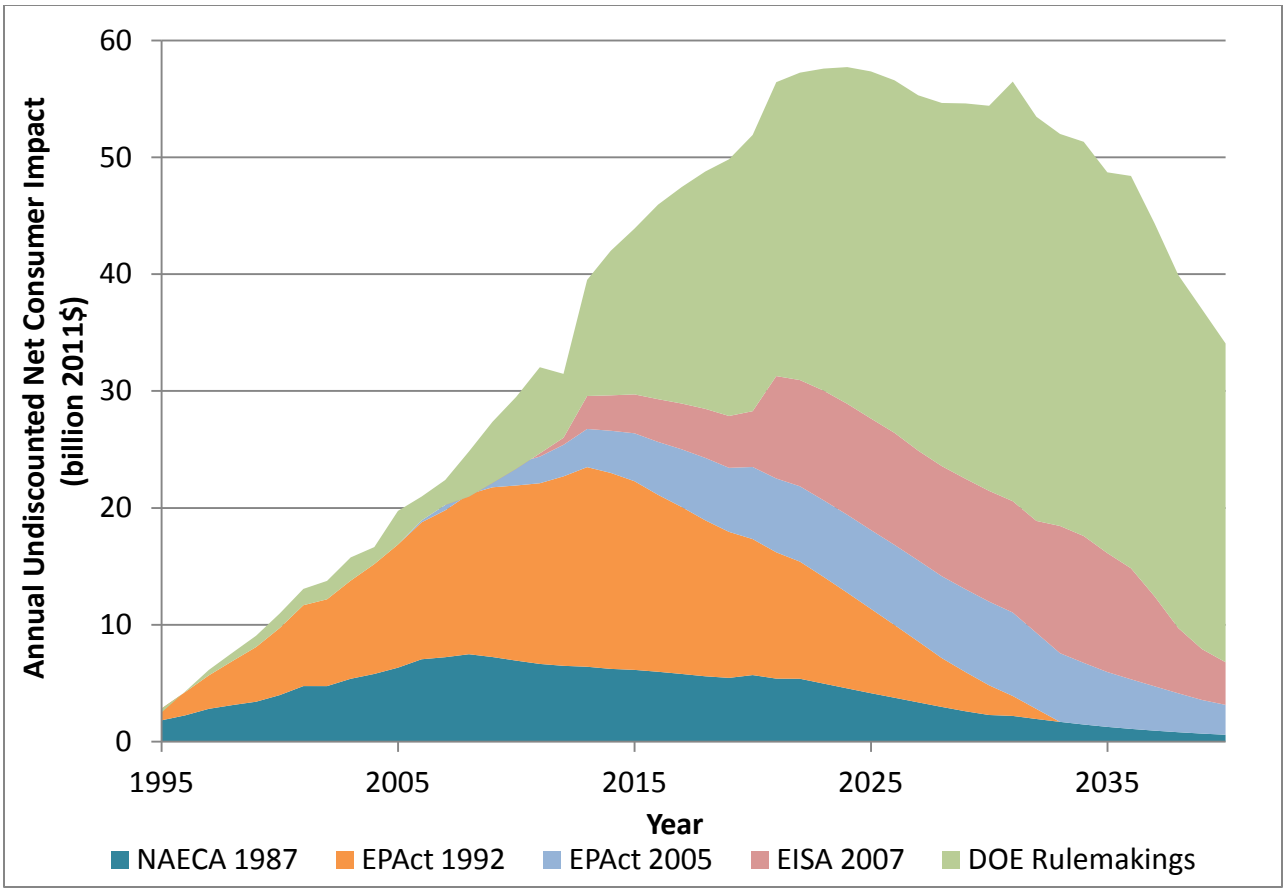

Figure 3. Annual Undiscounted Net Consumer Benefit for all Standards

Consumer (Residential) Impacts

In 2012, we estimate that the typical household saved $347 in energy and water expenses as a result of residential and plumbing product standards. By now, most U.S. households use one or more appliances that were subject to Federal energy or water conservation standards. On average, the primary energy savings from residential and plumbing standards in 2012 amounted to 22 million Btu per household, which is equivalent to 12 percent of the total energy use of 186 million Btu per household.[k]

Sources of Uncertainty

The estimates made by this study are subject to considerable uncertainty. A major source of uncertainty is the assumed base case against which the impacts of standards are measured. In principle, a base case should reflect how the market for a given product will evolve without the standards under consideration. Estimating the consumer demand for higher efficiency products

[k] Consumers also saved energy from lighting products standards, but we were not able to disaggregate the estimated savings by these standards by end-use sector.

and the marketing decisions of product manufacturers is difficult. Even more difficult is estimating what other policies, either Federal or State, might be implemented if there were no Federal efficiency standards for a given product. For the standards adopted by DOE in the past five years, a good amount of consideration and stakeholder input went into the construction of the base case. For many of the other standards included in this report, the base case reflects simple assumptions.

The estimates of per-unit energy savings and additional cost in the sources used for this study are also subject to uncertainty. Most of the sources assume that the incremental costs of higher efficiency remain constant over time.[l] This assumption likely overstates the true costs for two reasons. First, manufacturers of appliances and equipment often find ways to reduce the cost of producing higher efficiency products when forced to adapt to standards. Second, inflation-adjusted prices of many types of appliances and equipment have trended downward in recent decades. To the extent that this trend continues, it means that the incremental cost of higher efficiency products may decline over time.

The estimates of primary energy savings in the sources we used are based on estimates of "site" energy savings (i.e., savings where the product is in operation). Most of the sources we used convert site savings to primary savings using an average multiplier. In contrast, the National Impact Analysis spreadsheets from the DOE rulemakings incorporate marginal site-to-primary energy conversion factors. These factors represent the response of the electricity system to an incremental decrease in consumption associated with appliance standards. DOE uses annual site-to-source conversion factors based on a version of the Energy Information Administration's National Energy Modeling System (NEMS). The marginal factors are lower than average site-to-source conversion factors and are likely more accurate. If we had been able to apply marginal site-to-source conversion factors to all of the standards included, the estimated primary energy savings (and also the reductions in CO_2 emissions) would be lower.

For consumer cost savings that occurred in the past, there is some question as to whether the compounding of past savings used in this study is appropriate. We have not found clear guidance in the literature, but there is some precedent for the practice of compounding past savings to estimate their present value.[m] There is uncertainty regarding the extent to which the savings from appliance standards were invested elsewhere in the economy, and what the appropriate interest rate should be. Without compounding, the cumulative consumer NPV for all standards through 2010 would be around 15 percent less than reported here.

There is some evidence that consumers use higher efficiency appliances more intensively due to the reduction in operating cost. The extent of this so-called direct rebound effect varies among products.[6] In recent years DOE has accounted for a rebound effect in many of its rulemakings. Thus, the energy savings estimates for many standards adopted by DOE since 2008 include an

[l] In 2011 DOE began to account for change in product prices in its forecasts.
[m] See for example: http://www.dalemarsden.ca/docs/publications/Marsden_etal_2006.pdf

adjustment (subtraction) for a rebound effect.[n] The other sources used for this study do not include such an adjustment. The lack of this adjustment means that the savings may be overestimated by 5%-10%.

Conclusion

We estimate that energy efficiency standards for appliances and equipment adopted from 1987 through 2012 have saved a total of 33 quads through 2012, an amount equal to one-third of total annual U.S. energy use. In 2012, the standards saved an estimated 3.6 quads of primary energy, which is equivalent to 3% of total U.S. energy consumption. The savings in operating costs for households and businesses totaled $51 billion. The average household saved $347 in operating costs as a result of residential and plumbing product standards. The estimated reduction in CO_2 emissions associated with the standards in 2012 was 198 million metric tons of CO_2, which is equivalent to 3 percent of total U.S. CO_2 emissions.

The majority of the savings attributable to the standards adopted thus far are still to come, as products subject to the standards enter the stock. The standards are projected to achieve cumulative energy savings of 179 quads. Accounting for the increased upfront costs of more-efficient products and the operating cost (energy and water) savings over the products' lifetime, the standards have a past and projected cumulative net present value (NPV) of consumer benefit of between $1,104 billion and $1,390 billion, using 7 percent and 3 percent discount rates, respectively.

The water conservation standards, together with energy conservation standards that also save water, reduced water use by 1.8 trillion gallons in 2012, and will achieve cumulative water savings by 2040 of 54 trillion gallons. The estimated consumer savings in 2012 from reduced water use amounted to $13.0 billon.

Standards set by legislation account for 47 percent of total cumulative primary energy savings and 55 to 66 percent of the total cumulative NPV (depending on which discount rate is used). Standards set by DOE rulemakings account for 53 percent of total cumulative primary energy savings and 34 to 45 percent of the total cumulative NPV.

[n] DOE does not adjust the energy cost savings for the rebound effect because it believes that, if it were able to monetize the increased value to consumers associated with the rebound effect, this value would be similar to the foregone energy savings.

Appendix A: Methods for Estimating National Impacts from Standards[o]

General Methods

Energy cost savings were estimated using historical average annual energy prices through 2011, and projected average annual energy prices after 2011. The historical prices were taken from various DOE Energy Information Administration (EIA) sources. The projected prices are based on EIA's *Annual Energy Outlook 2012.*

We converted dollars from the year given in the various sources to 2012$ using the Consumer Price Index for residential appliances and the GDP implicit price deflator for commercial and industrial equipment.

The annual average CO_2 emissions factors for the electricity generation sector are derived for each year through 2008 from EIA statistics on total CO_2 emissions from the electric power sector and total primary energy consumption by the electric power sector. For each year in 2009-2035, they are derived from similar forecasted outputs in EIA's *Annual Energy Outlook 2012.* The values after 2035 are the same as the 2035 factor.

The social cost of carbon (SCC) values from 2010 onward are from the mid-range series developed by a Federal interagency process. This series is based on the average SCC derived from the three integrated assessment models that were examined, using a 3-percent discount rate.[p] Because the SCC values are based on a 3-percent discount rate, we used the same discount rate to discount the future annual estimates of the value of reduced CO_2 emissions. SCC values prior to 2010 were estimated based on the post-2010 trend.

NAECA 1987 and 1988 Standards and DOE Updates before 2007

For all of the standards except one, we used the data developed by Meyers *et al*.[1] That study 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. 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. (A vintage refers to the products

[o] Further details are given in cell comments in the Excel spreadsheet used to calculate the impacts, which may be found at the page for this report at: http://efficiency.lbl.gov/bibliography/

[p] For more information on these SCC values, see chapter 16 and appendix 16-A of the Residential Clothes Dryers and Room Air Conditioners Direct Final Rule Technical Support Document. http://www1.eere.energy.gov/buildings/appliance_standards/residential/residential_clothes_dryers_room_ac_direct_final_rule_tsd.html

shipped in a given year.) Both of these variables are a function of the energy efficiency assigned to each vintage. In most cases, the actual energy efficiency for each vintage of a product is assigned 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 further discussion, see section 2 of Meyers *et al*.

For the commercial heating, air conditioning, and water heating standards with compliance dates of 2003 and 2004, we started from the following data reported by Belzer and Winiarski:[7] (1) primary energy savings cumulative through 2030 and (2) net economic impacts at a 7-percent discount rate cumulative from units shipped through 2030. We used an average lifetime for these products of 15 years.

We assume that units retire uniformly over the lifetime and that the annual energy savings will go up after the effective date until it stabilizes when all the pre-standard units have been replaced by units meeting the standards. This period that it takes for the annual energy savings to reach its maximum is equal to the lifetime of the product. Using these assumptions, we calculate the annual site and primary energy savings that will match the given cumulative energy savings from 2003 to 2030. Then we used the Excel Solver to solve for the unit energy saving and incremental equipment cost per unit that will give a net present value (NPV) that closely matches the given NPV at a 7-percent discount rate. We then extended the time series to include shipments through 2032 to yield a 30-year analysis period.

EPACT 1992 Standards

We developed new estimates for this study, as described below. We assumed no change in base case efficiency over time. To compensate for potential overstatement of savings, we counted impacts for only 20 years worth of product shipments. Further details may be found in spreadsheets that are available from the authors.

Commercial furnaces and boilers, air conditioners and heat pumps, and water heaters

We modified the analytical structure and some of the data developed by Rosenquist et al. for the 2004 study for the National Commission on Energy Policy (NCEP).[8]

We estimated base case efficiencies and unit incremental costs for these products using PNNL (2000). This report presents average efficiencies in 1999 and costs for both an EPACT 1992 baseline product and an average product in 1999. We applied these differentials to derive an approximate pre-EPACT 1992 baseline efficiency and contractor cost for each product.

Electric motors

We developed a simplified NIA model to estimate the impacts of the EPACT 1992 standards for electric motors, using one "average motor" as the basis for the calculations.

The "average motor" energy use was calculated in the base case and in the standards case, using market-weighted averages across the covered horsepower (hp) ranges, pole configurations, and enclosure type to determine the following parameters: operating hours, load, lifetime, horsepower, and efficiency. All inputs were derived from the draft preliminary analysis from DOE's 2011 rulemaking for electric motors.

The base-case efficiency is estimated assuming 30% of shipped motors are at pre-EPACT standard efficiency levels, 30% are already at the EPACT 1992 efficiency levels, and 40% are at National Electrical Manufacturers Association (NEMA) premium efficiency levels. The standards-case efficiency is estimated using a "roll-up" scenario, which leads to assuming 60% of motors are at the EPACT 1992 efficiency levels and 40% are at the NEMA premium efficiency levels.

Motor equipment costs (includes the repair costs) for the "average motor" in the base case and standards case were estimated by extrapolating price and weight data from the preliminary analysis. Repairs are assumed to occur after 5 years of usage and once in a motor's lifetime.

Shipment data were obtained from the preliminary analysis and are assumed to be the same in the base-case and in the standards-case. The market-weighted average lifetime (12 years) was used to calculate the affected stock.

National site energy savings were obtained from multiplying the affected stock by the difference in energy use between the base case and standards case for the "average motor". National equipment incremental costs were calculated using the affected stock multiplied by the difference in equipment costs between the base case and standards case for the "average motor".

Fluorescent lamps and incandescent reflector lamps

Fluorescent lamps

We calculated savings for full-wattage T12 lamps covered by the standards sold after the effective dates of the standards: April 30, 1994 for 8-foot T12 and 8-foot T12/HO lamps and October 31, 1995 for 4-foot lamps. To calculate fluorescent lamp shipments, we adapted the spreadsheet used to analyze the impacts of the NAECA fluorescent ballast standards by Meyers *et al*. The base-case forecast assumed that 60 percent of lamp shipments in 1994 were full-wattage lamps, while 40 percent were reduced-wattage lamps already complying with the EPAct 1992 standards, according to a 1989 report on Massachusetts' lamp standards by Nadel et al.[9]

Since the lamps covered by the EPAct 1992 lamp standards ("covered lamps") were used with magnetic ballasts, and very few T12 lamps used electronic ballasts, we assumed that lamp

shipments tracked the pattern of magnetic ballast shipments. When the fluorescent ballast standards came into effect in 2005 for ballasts in new luminaires, there was a corresponding substantial decrease in T12 lamp shipments. By 2010, when the ballast standards took effect for the renovation market as well, very few T12 lamps were sold.

The shipments of covered fluorescent lamps for 1994 were based on estimates by Geller and Nadel.[10] For 1995 - 2010 we scaled this 1994 shipment value to decline according to the annual decrease in magnetic ballast shipments projected in the NAECA ballast standards analysis. Beginning in 2011 we made the simplifying assumption that T12 lamp shipments ceased.

Assumptions for unit wattage savings, product service lifetime, operating hours, and market shares by lamp type and by new vs. renovation market are from DOE's 2000 fluorescent lamp ballast standards analysis. Lamp prices are from the 1992 Lighting Policy Analysis by Atkinson *et al.*[11]

Incandescent reflector lamps

We estimated the impacts of the incandescent reflector lamp standards from 1996 – 2015. (The standards took effect on November 1, 1995, so we assumed that savings began in 1996.) We used shipments data from past and recent analyses to estimate the annual shipments of lamps complying with the standards. For the commercial sector, complying shipments were derived for 1996 - 2000 from the 1992 Lighting Policy Analysis (Atkinson *et al.*), for 2006 - 2015 from DOE's 2009 incandescent reflector lamp standards NIA spreadsheet (DOE 2009),[q] and for 2001 – 2005 by linear interpolation. For the residential sector, we estimated complying shipments for 1995 as 10 percent of total shipments, for 2001 – 2015 from DOE 2009, and for 1996 to 2000 by linear interpolation.

Assumptions for unit wattage savings are from Atkinson *et al.* Product service lifetime and operating hours are from DOE 2009. Lamp prices are from Atkinson *et al.*

Plumbing products

For showerheads and faucets, we started with product lifetime, 2010 site energy savings (from reduced hot water use), and 2010 water savings from Koomey *et al.*[12] For toilets, we used product lifetime and 2010 water savings.

From the energy savings for 2010, we estimated both the site and source energy savings over a 20-year period starting from the compliance date, assuming that shipments retire uniformly over the lifetime and are replaced (constant annual sales). Based on this uniform retirement function, the energy savings from units surviving beyond the 20-year period are also calculated. We performed this same estimation for the annual time series of water savings.

[q] See: http://www1.eere.energy.gov/buildings/appliance_standards/residential/incandescent_lamps_standards_final_rule_tools.html

We derived operating cost savings by applying annual time series of average fuel prices and water prices to the site energy and water savings.

We estimated that there is zero unit incremental cost for these products because when manufacturers first started to comply with EPACT 1992, they generally did not make significant changes to the products.

The estimates only cover residential use because no data were available to estimate commercial sector impacts.

EPACT 2005 Standards

For all of the standards except commercial air conditioners (AC) and heat pumps, we started from the following data reported by Nadel *et al.*[3] for each standard: (1) site energy savings in 2020 and 2030, (2) cumulative energy savings through 2030, (3) NPV for products sold through 2030, (4) lifetime, (5) unit annual energy saving, and (6) unit incremental equipment cost. Nadel *et al.* used a constant efficiency base case, but they also did not model any increase in shipments; these two factors would counteract to some extent.

From the energy savings for 2020 and 2030, we estimated both the site and source energy savings for 25 years of shipments starting from the compliance year. Using the energy savings per unit and the annual energy savings, we calculated the shipments in each year. Once we derived the shipments, we could calculate the total incremental equipment cost.

We accounted for impacts to shipments through 2030. The number of years of shipments ranges from 21 to 25, depending on the particular standard.

For commercial AC and heat pumps, DOE National Impact Analysis spreadsheets were available. For these products, we followed the methods described in the DOE Standards 2007-2010 section.

EISA 2007 Standards

For most EISA 2007 standards, we started from the following data for each product reported by DOE in its technical report:[4] (1) cumulative energy savings (through 2038), (2) NPV at 3-percent and 7-percent discount rates. From other relevant DOE sources, we obtained the lifetimes of the products. The DOE report used a constant efficiency base case, which may tend to somewhat overestimate the savings from the standards. To compensate, we used 25 years of shipments instead of 30 years.

We assumed that units retire uniformly over the lifetime and that the annual energy savings will go up after the compliance date until it stabilizes when all the pre-standard units have been replaced by units meeting the standards. The period that it takes for the annual energy savings to reach its maximum is equal to the lifetime of the product. Using these assumptions, we calculated the annual site and source energy savings that will match the given cumulative energy

savings. Then we used the Excel Solver to solve for the unit energy savings and incremental equipment cost per unit that will give an NPV that closely matches the given NPV at a 7-percent discount rate. We then adjusted the calculations to account for 25 years of shipments.

For a few EISA 2007 standards (residential boilers, dishwashers, and dehumidifiers), DOE National Impact Analysis spreadsheets were available. For these products, we followed the methods described in the following DOE Standards 2007-2010 section.

DOE Standards 2007-2012

We used the Final Rule NIA spreadsheets from the DOE rulemakings for each of these standards. We set up the spreadsheets for the compliance year and standard levels that were selected in the Final Rules. This gave the annual time series for primary energy savings, additional installed cost, and operating cost savings. In some cases, the time series presented in the spreadsheets were by individual product classes, so we summed them to arrive at totals for the product category or categories in question. In some cases we also made modifications to the spreadsheets to arrive at consistent results across products—for instance, always using 30 years of shipments and extending energy cost savings and energy savings to the end of the lifetime of the units shipped in the 30th year.

Appendix B: Quad and Carbon Equivalents

From the U.S. Department of Energy's 2010 Buildings Energy Data Book.

1.5.1 Key Definitions

Quad: Quadrillion Btu (10^15 or 1,000,000,000,000,000 Btu)

Generic Quad for the Buildings Sector: One quad of primary energy consumed in the buildings sector (includes the residential and commercial sectors), apportioned between the various primary fuels used in the sector according to their relative consumption in a given year. To obtain this value, electricity is converted into its primary energy forms according to relative fuel contributions (or shares) used to produce electricity in the given year.

Electric Quad (Generic Quad for the Electric Utility Sector): One quad of primary energy consumed at electric utility power plants to supply electricity to end-users, shared among various fuels according to their relative contribution in a given year. (Note: The consumption of an electric quad results in the delivery of just under 1/3 the electric quad due to generation and transmission losses.)

Primary Energy: The total energy consumed by an end-user, including the energy used in the generation and transmission of electricity. Also referred to as "source" energy.

Delivered Energy: The energy consumed by an end-user on site, not including electricity generation and transmission losses.

1.5.2 Consumption Comparisons in 2008

One quad equals:

- 49.5 million short tons of coal
  - = enough coal to fill a train of railroad cars 4,066 miles long (about one and a half times across the U.S.)
- 972.8 billion cubic feet natural gas
- 8.2 billion gallons of gasoline = 21.3 days of U.S. gasoline use
  - = 22. million passenger cars each driven 12,400 miles
  - = 19.2 million light-duty vehicles each driven 12,200 miles
  - = all new passenger cars and light-duty trucks sold, each driven 40,000 miles
  - = 14. million stock passenger cars, each driven 11,500 miles = 10% of all passenger cars, each driven 11,500 miles
  - = all new passenger cars each making 9 round-trips from New York to Los Angeles
- 172.4 million barrels of crude oil = 14.26 days of U.S. imports = 167 days of oil flow in the Alaska pipeline at full capacity
  - = the amount of crude oil transported by 483 supertankers
- 17.8 hours of world energy use
- the electricity delivered from 238 coal-fired power plants (200-MW each) in one year
- the electricity delivered from 37 nuclear power plants (1000-MW each) in one year
- average annual per capita consumption of 3.06 million people in the U.S.
- the approximate annual primary consumption of any one of the following states: Arkansas, Iowa, Kansas, Maryland Massachusetts, Mississippi, South Carolina, Utah, Washington, or Wyoming (1)

Note(s): 1) All states listed have annual energy consumption that is within 20% off one quad.

Source(s): EIA, Annual Energy Outlook 2011 Early Release, Dec. 2010, Summary Reference Case Tables, Table A1, p. 1-2, Table A2, p. 3-5, Table A7, p. 34-35, Table A8, p. 18-19, Table A9, p. 20-21, and Table A11, p. 23-24 for consumption; EIA, Annual Energy Outlook 2010, May 2010, Table G1, p. 215 for heat rates; EIA, State Energy Data 2008: Consumption, June 2010, Table S3, p. 5, Table R1, p. 15, and Table R2, p. 16; EIA, Electric Power Annual 2009, January 2011, Table 1.1, p. 14; DOC, Statistical Abstract of the United States 2008, May 2008, No. 1080 p. 690; DOC, Statistical Abstract of the United States 2011, 2010, No. 1031, p. 658, and No. 1074, p. 686; and Newport News Shipbuilding Web site.

1.5.3 Carbon Emission Comparisons

One million metric tons of carbon dioxide-equivalent emissions equals:

- the combustion of 525 thousand short tons of coal
- the coal input to 1 coal plant (200-MW) in ten and a half months
- the combustion of 18 billion cubic feet of natural gas
- the combustion of 118 million gallons of gasoline = the combustion of gasoline for 7 hours in the U.S.
  - = 310 thousand new cars, each driven 12,400 miles
  - = 272 thousand new light-duty vehicles, each driven 12,200 miles
  - = 260 thousand new light trucks, each driven 11,000 miles
  - = 0.14 million new passenger cars, each making 5 round trips from New York to Los Angeles
- the combustion of 190 million gallons of LPG
- the combustion of 107 million gallons of kerosene
- the combustion of 102 million gallons of distillate fuel
- the combustion of 87 million gallons of residual fuel
- 17 minutes of world energy emissions
- 90 minutes of U.S energy emissions
- 3.9 hours of U.S. buildings energy emissions
- 7 hours of U.S. residential energy emissions
- 8 hours of U.S. commercial energy emissions
- 1 day of U.S. buildings lighting energy emissions
- average annual per capita emissions of 52,000 people in the U.S.

Source(s): EIA, Annual Energy Outlook 2011 Early Release, Dec. 2010, Summary Reference Case Tables, Table A2, p. 3-5, Table A7, p. 16-17 for consumption and Table A18, p. 36 for emissions; EIA, Annual Energy Outlook 2010, May 2010, Table G1, p. 221 for heat rates; EIA, Electric Power Annual 2009, January 2011, Table 1.2, page 17; EIA, Country Energy Profiles for global emissions, available at http://www.eia.gov/country/index.cfm, accessed 2/3/2011; EIA, Assumptions to the Annual Energy Outlook 2010, May 2010, Table 1.2, p. 12 for carbon coefficients; and DOC, Statistical Abstract of the United States 2008, Jan. 2008, No. 2, p. 8 and No. 1084, p. 715.

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