Next Generation Standards: How the National Energy Efficiency Standards Program Can Continue to Drive Energy, Economic, and Environmental Benefits

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Executive Summary

Appliance, equipment, and lighting efficiency standards have ranked among the top policies for saving energy and water since first adopted by California in the 1970s. Congress spread standards nationwide with enactment of the National Appliance Energy Conservation Act of 1987 (NAECA) and major expansions under laws passed in 1992, 2005, and 2007. NAECA and each subsequent legislative expansion and revision were enacted with broad bipartisan support. In general, the laws established initial standards for specific products and created a schedule, process, and criteria for the US Department of Energy (DOE) to review and, if warranted, update standards.

DOE's updates to standards completed through the public rulemaking process have added substantially to the savings achieved by congressionally set standards. Under the Obama administration, the pace of regulatory activity, which had lagged behind legal deadlines under prior administrations, picked up. The agency caught up on all previously missed deadlines and managed not only to largely stay abreast of its legal requirements to review and update standards but also to exercise its authority to develop standards for new, previously unregulated product categories.

DOE estimates that existing efficiency standards completed through February 2016 will, on a cumulative basis between NAECA's 1987 enactment and 2030, save 132 quadrillion Btus (quads) of energy, save consumers nearly $2 trillion on their utility bills, and reduce CO_2 emissions by more than 7 billion metric tons. For comparison, the entire US economy uses about 100 quads per year.

Given this successful history, this paper addresses two research questions:

- With so much progress to date, especially over the past eight years, what is the potential for future savings with updates to existing standards?
- What strategies could be employed to further increase savings available from standards?

To address the first question, we developed product-by-product estimates of the potential future savings resulting from the next update due after January 2017 (i.e., after the inauguration of the next president). We assessed savings potential based on currently available technology, using existing metrics, test procedures, and product scopes. The national appliance standards law requires DOE to review each standard at least once every six years to determine if an update is warranted and, if so, to complete that update within an additional two years. The analysis assumed future standards will be completed and take effect on the latest date allowable under the law. We were able to develop estimates for 45 of the roughly 55 products currently included in the national standards program.

We found that the potential savings from updated standards are enormous. As shown in figure ES1, potential primary energy savings grow to an annual rate of 2.6 quads of energy in 2035 and increase to 4.0 quads per annum in 2050. Annual savings rates grow over time as more updated standards come into force and those already in place affect a greater portion of products in use. Potential annual energy savings in 2035 equal the current annual energy consumption of all the homes in Texas and Ohio combined. Potential savings in 2050

grow to cover current consumption of homes in those states plus New York and South Carolina.

As figure ES1 shows, electricity accounts for most of the energy savings. These increase to an annual rate of 215 billion kilowatt hours (kWh) by 2035 and 335 billion kWh by 2050 (table ES1). For comparison, 60,000 new wind turbines generate about 335 billion kWh per year. The potential annual rate of CO_2 reductions from all fuels rises to more than 130 million metric tons in 2035, further increasing to an annual rate of more than 200 million metric tons in 2050, an amount about equal to the emissions of 60 coal-fired power plants.

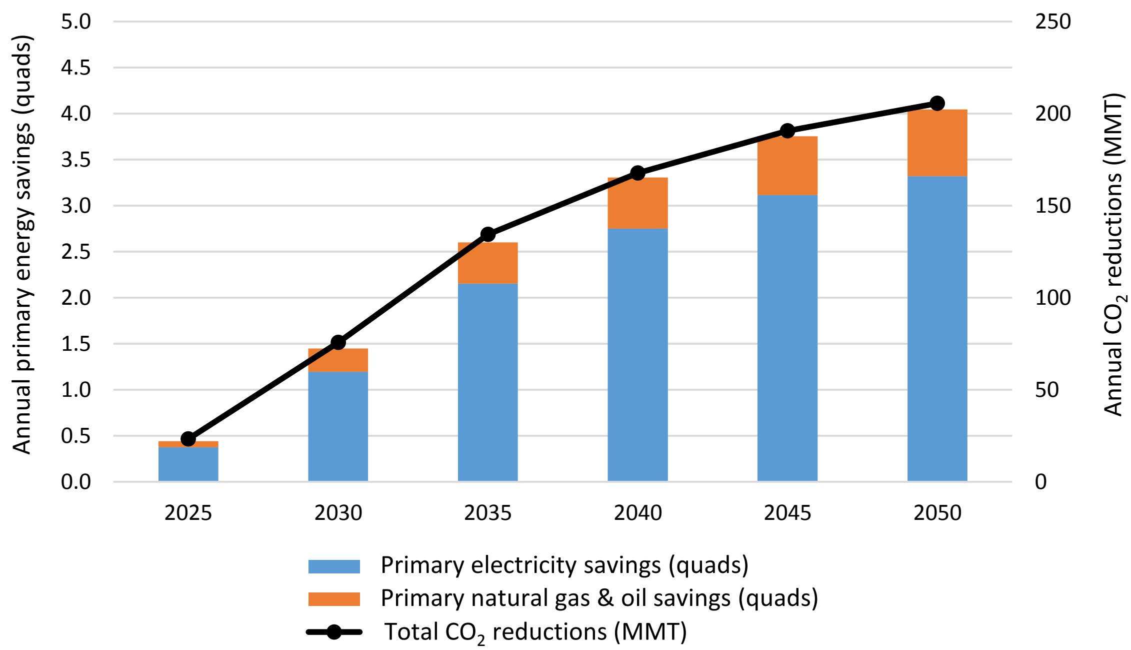


Figure ES1. Potential annual primary energy savings and CO_2 reductions from post-2016 standards for 2025–2050

Several standards address water-using products such as showerheads and faucets. Updates to these standards have the potential to save 770 billion gallons of water annually by 2035, increasing to an annual rate of 850 billion gallons by 2050, an amount greater than that used each year by all the nine million-plus households in Texas.

These energy and water savings translate into very large utility bill reductions for consumers and businesses. The potential annual bill savings for electricity, gas, oil, and water reach nearly $43 billion by 2035, growing to $65 billion in 2050, with electricity accounting for the majority of the bill savings. Table ES1 shows the potential annual electricity, natural gas, water, CO_2, and utility bill savings in 2035 and 2050 for the residential and commercial/industrial products analyzed.

Table ES1. Potential annual energy and water savings, CO_2 reductions, and utility bill savings from post-2016 standards

	Annual savings in 2035					Annual savings in 2050				
Sector	Electricity (TWh)	Natural gas (TBtu)	Water (billion gallons)	CO_2 (MMT)	Utility bills (million 2013$)	Electricity (TWh)	Natural gas (TBtu)	Water (billion gallons)	CO_2 (MMT)	Utility bills (million 2013$)
Residential	138	388	737	92	33,732	182	554	816	121	45,888
Commercial & industrial	77	56	30	43	9,178	153	161	32	85	19,604
Total	215	444	768	134	42,910	335	715	848	206	65,493

Cumulatively, updates for the evaluated products have the potential to reduce US primary energy use by 70 quads by 2050 while cutting consumer and business utility bills by $1.1 trillion (table ES2). Potential cumulative CO_2 emissions reductions are 3.5 billion metric tons. For comparison, total US CO_2 emissions in 2014 were about 5.6 billion metric tons.

Table ES2. Potential cumulative primary energy and water savings, CO_2 reductions, and utility bill savings from post-2016 standards

	Cumulative savings through 2050			
Product sector	Primary energy (quads)	Water (billion gallons)	CO_2 (MMT)	Utility bills (billion 2013$)
Residential products	45	17,006	2,319	865
Commercial & industrial products	24	659	1,237	279
Total	70	17,665	3,556	1,144

A disproportionate share of the potential savings derives from the top 10 standards, which account for more than 70% of cumulative energy and utility bill savings potential. Figure ES2 shows the potential cumulative primary energy savings and utility bill savings through 2050 from these top 10 standards. For products that save both electricity and natural gas or oil, the share of energy savings for each energy source is shown.

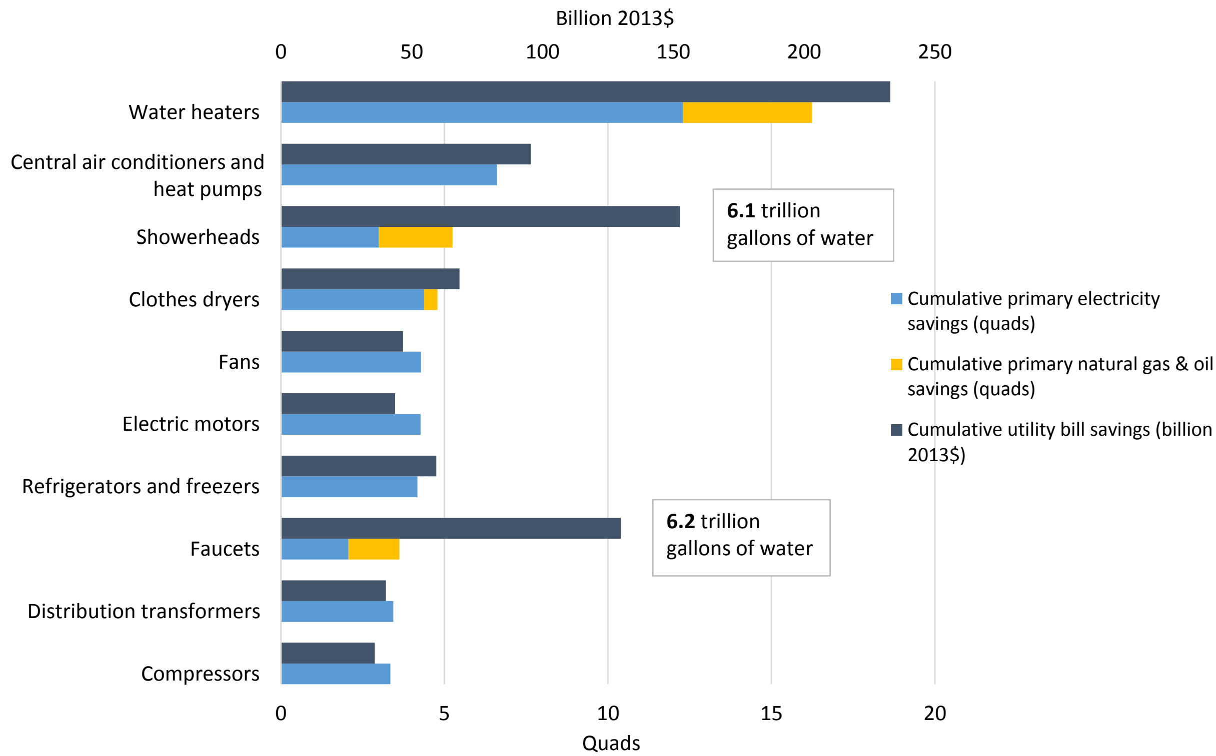


Figure ES2. Potential cumulative primary energy savings and utility bill savings through 2050 for top 10 standards updates

Six of the 10 products with the greatest savings potential have already had their standards updated, in some cases several times, demonstrating that innovation continues to open up new savings opportunities even for products that have already improved substantially. For the other top savings potential products—showerheads, commercial and industrial fans, faucets, and compressors—the next new national standard completed after January 2017 will be only the second.

To address the second research question, we convened two expert panels, conducted individual expert interviews, and drew on our own knowledge to consider a wide range of ideas for increasing savings from national standards. We applied two criteria: Actions had to be indisputably within DOE's control (i.e., they could not require new legislation), and they had to offer potentially very large savings benefits. We distilled these ideas into five actionable recommendations.

- **Invest in improved test methods, including expedited updates for top priorities.**

DOE has been reviewing all test methods, as required by law, with some updates enabling larger savings than would have been possible with old test methods. By continuing to invest in better test methods and prioritizing test method updates for key products—including clothes dryers, commercial air conditioners, walk-in coolers, water heaters, televisions, computers, central air conditioners and heat pumps, and commercial boilers—DOE could enable significantly increased savings. As DOE undertakes test method reviews, the agency should take into account a number of crosscutting developments that may affect many products' test methods, including new modes of operation such as network standby, expanded user-selectable options or modes, controls that might help save energy, and the effect of software or firmware updates post-installation.

- **Systematically assess opportunities to expand scope and conduct rulemakings for the biggest new opportunities.**

In certain cases, DOE can either develop standards for categories of products not previously subject to national standards or expand the types of products within a given category that are subject to standards. Potential opportunities for expanded scope include televisions and additional categories of motors, pumps, and lighting products. The growing but ill-defined category "other uses" may also reveal new opportunities for standards. Some existing lighting standards, such as the incandescent reflector lamp standard, should be superseded by technology-neutral standards, which would dramatically increase savings potential.

- **Continue to improve analysis methods and data sources.**

DOE's analysis methods have improved significantly over the more than 30 years that the agency has conducted rulemakings. Nevertheless, its analyses can be made even better. DOE should undertake a major data gathering effort aimed at better characterizing the energy usage of products subject to standards. Further work building on DOE's recent efforts to improve product price estimates would strengthen the agency's analyses. And periodic retrospective analyses would help DOE continuously improve analysis approaches.

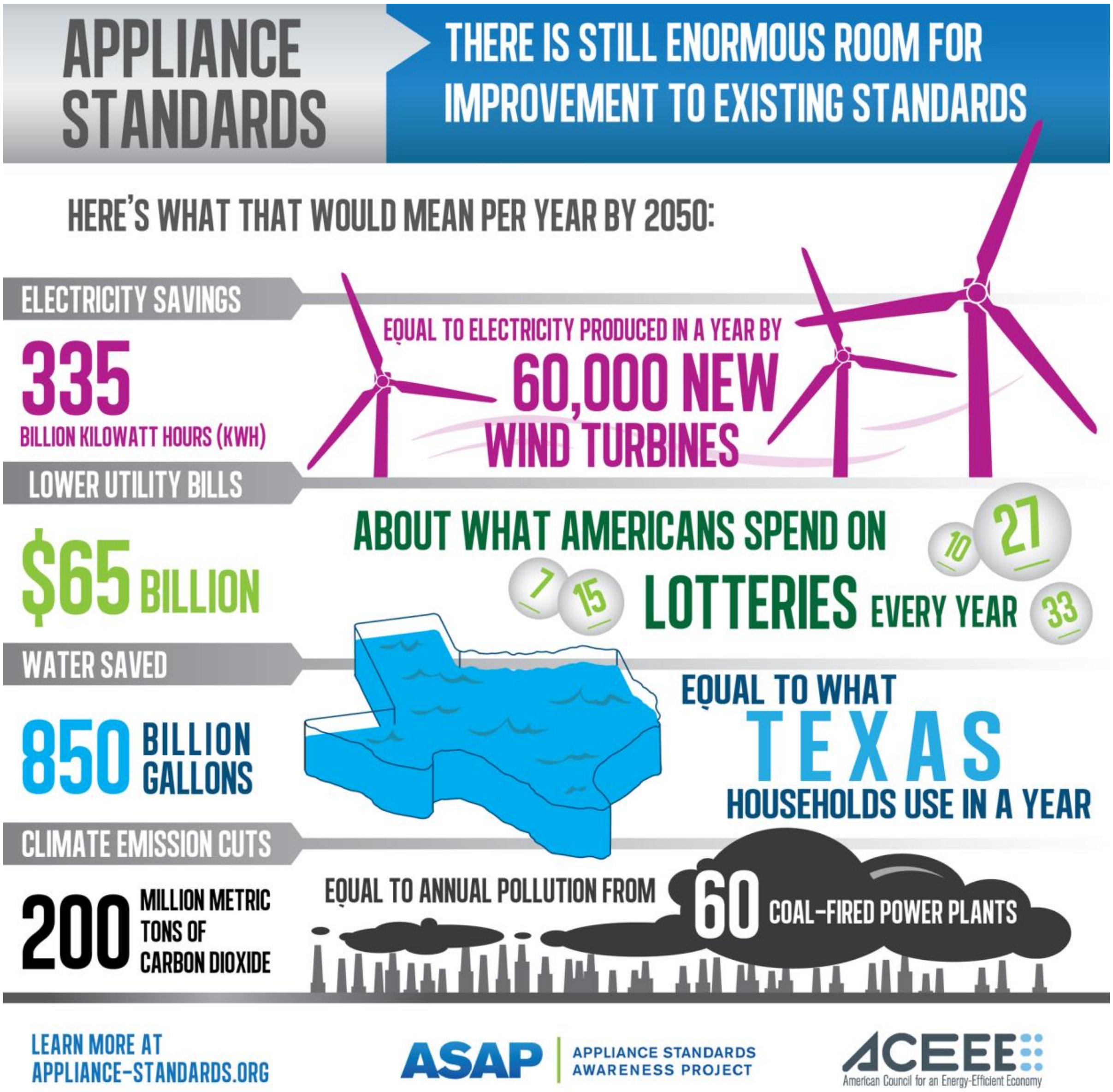
- **Consider how DOE test methods, ratings, and standards can realize or facilitate systems savings opportunities.**

Although most systems savings opportunities are outside the purview of standards, which apply to product manufacturers, some creative approaches have been used to capture systems benefits. Including the energy use of related products (e.g., dryer energy use reflected in washer ratings), developing ratings that reflect the better performance of efficient packaged systems (e.g., new pump standards), and using default values in test methods to encourage higher-efficiency systems (e.g., walk-in cooler standards) are systems strategies that should be considered in future rulemakings when relevant.

- **Develop a strategic approach to address connected products.**

As more and more products are connected to the Internet, these connected products will both draw power to maintain this connectivity and offer the potential for remote control, which may affect energy usage. DOE should develop a strategic approach to address the increased connectivity of products. This strategic approach should address the power used to maintain connectivity, the potential for connected appliances to reduce energy use, the potential for connected devices to circumvent standards, and the ability of these devices to provide usage data that can inform future standard-setting work.

In short, our analysis shows that efficiency standards updated within the next eight years have the potential to reap very large energy and consumer bill savings. The next administration could achieve cumulative nationwide savings of 70 quads of energy and 3.5 billion metric tons of CO_2 by 2050 while cutting consumer and business utility bills by $1.1 trillion. Even greater savings may be achieved by investing in improved test procedures, systematically assessing opportunities for expanding the scope of national standards, improving analysis techniques and data sources, assessing opportunities for standards to contribute to systems-level savings, and taking connectedness into account. With focused attention from the next administration, the national standards program will deliver significantly increased energy, economic, and environmental benefits for the nation.


APPLIANCE STANDARDS
THERE IS STILL ENORMOUS ROOM FOR IMPROVEMENT TO EXISTING STANDARDS
HERE'S WHAT THAT WOULD MEAN PER YEAR BY 2050:
ELECTRICITY SAVINGS
335
BILLION KILOWATT HOURS (KWH)
EQUAL TO ELECTRICITY PRODUCED IN A YEAR BY
60,000 NEW WIND TURBINES
LOWER UTILITY BILLS
$65 BILLION
ABOUT WHAT AMERICANS SPEND ON
LOTTERIES EVERY YEAR
10
27
7
15
33
WATER SAVED
850 BILLION GALLONS
EQUAL TO WHAT
TEXAS
HOUSEHOLDS USE IN A YEAR
CLIMATE EMISSION CUTS
200 MILLION METRIC TONS OF CARBON DIOXIDE
EQUAL TO ANNUAL POLLUTION FROM
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Introduction

Appliance, equipment, and lighting standards have been among the most successful policies for reducing energy use in the United States and, in turn, saving money for consumers and businesses.[1] National standards now apply to more than 55 categories of residential, commercial, and industrial products. The US Department of Energy (DOE) estimates that existing efficiency standards completed through February 2016 will, on a cumulative basis through 2030, save 132 quadrillion Btus (quads) of energy, save consumers nearly $2 trillion on their utility bills, and reduce CO_2 emissions by more than 7 billion metric tons (DOE 2016e). For comparison, the US economy as a whole uses about 100 quads per year.

A combination of congressional and administrative action over three decades has built this impressive record of savings. For most products covered by national standards, Congress enacted initial standards, often based on state standards, and charged DOE with updating those standards to increase energy and economic savings as technology improves. Laws enacted with broad bipartisan support and signed by Presidents Reagan (the National Appliance Energy Conservation Act of 1987, or NAECA), George H.W. Bush (the Energy Policy Act of 1992), and George W. Bush (the Energy Policy Act of 2005 and the Energy Independence and Security Act of 2007) each added new national standards and schedules for their review and, if warranted, updating.

DOE updated some standards during the George H.W. Bush, Clinton, and George W. Bush administrations. But by 2006, DOE had missed legal deadlines for reviewing 22 standards, some by more than a decade. In that year, DOE signed a consent decree settling litigation brought by New York, California, and 13 other states along with the Natural Resources Defense Council and consumer advocates (New York v. Bodman 2006).[2] The settlement established a five-year schedule for catching up on all missed deadlines. In addition, the 2005 and 2007 laws created new deadlines for additional DOE standards and updates. The Bush administration ramped up standards work starting in 2006, but virtually all of the new deadlines fell to the next administration. Upon taking office in 2009, the Obama administration faced the legally required task of updating many existing standards as well as establishing new ones.

Within days of his inauguration, the president issued a presidential memorandum directing DOE to meet or beat all of the deadlines for new standards (EOP 2009). President Obama's energy secretaries, Steven Chu and subsequently Ernest Moniz, embraced standards as a priority, providing staffing, budgets, and the executive attention necessary to keep up with the increased workload. Perhaps most important, the administration integrated standards

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[1] Appliance, equipment, and lighting standards are also referred to as minimum energy performance standards (MEPS), especially internationally.

[2] The full list of plaintiffs: states of California, Connecticut, Illinois, Iowa, Maine, Massachusetts, New Hampshire, New Jersey, New Mexico, New York, North Carolina, Rhode Island, Vermont, and Wisconsin; Pennsylvania Department of Environmental Protection; California Energy Commission; City of New York; NRDC; Massachusetts Union of Public Housing Tenants; and Texas Ratepayers Organizations to Save Energy.

into its overall energy and climate policy strategies, placing a newfound emphasis on standards' importance.

The president's Climate Action Plan, announced in June 2013, exemplifies the role of standards as a major plank of current energy and climate strategy. Calling for a range of actions to meet the administration's goal of reducing emissions to 17% below 2005 levels by 2020, the plan set an aggressive goal of reducing CO_2 emissions by 3 billion metric tons by 2030 through efficiency standards set in President Obama's two terms (EOP 2013). In 2015, the administration increased its overall emissions reduction goals to 26–28% below 2005 levels by 2025 in its pledge made as part of the Paris Climate Treaty process (White House 2015). Based on government estimates of 2005 emissions, this commitment requires annual reductions of about 1,600 to 1,735 million metric tons of CO_2 equivalent from 2005 levels (Department of State 2014).

We estimate that existing efficiency standards will reduce CO_2 emissions by about 325 million metric tons in 2025 relative to the 2005 baseline, achieving about 20% of the US emissions reduction commitment. The savings from the subset of standards completed during the Obama administration account for about 180 million out of the 325 million metric ton total, or about 11% of the commitment.[3]

A comparison of standards' impact with the impact of other policies can also be used to evaluate their importance. For example, we estimate that annual CO_2 emissions reductions from standards completed during the Obama administration as of June 2016 will grow to about 210 million metric tons in 2030, or about one-fourth of the emissions reductions expected in that year from the Clean Power Plan, the administration's highest-profile action to reduce climate emissions (EPA 2015a). Similarly, energy savings from standards are of a magnitude comparable to savings from other prominent policies such as vehicle fuel economy standards (Ungar et al. 2015). These comparisons demonstrate that efficiency standards are already among the top energy and climate policies.

In summary, a combination of executive attention, adequate resources, integration with overall climate and energy policy, and goal setting have served to propel enormous energy efficiency improvements through standards completed during the Obama administration. Taking into account standards enacted by law and those set by DOE, the Obama administration has completed 18 more standards than any prior administration.[4] Accounting only for standards set by DOE rulemaking, the Obama administration has completed seven times more standards than any previous administration. (Table 1 shows the number of standards signed into law or completed through the DOE administrative process since President Reagan signed the 1987 standards law.) DOE intends to issue a dozen more by January 2017 (Cama 2016).

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[3] We are including savings from standards enacted as part of the Energy Independence and Security Act of 2007 (EISA) in the Obama presidency totals. These standards were signed into law by President Bush, but placed into the US Code under President Obama.

[4] As of June 20, 2016.

Table 1. Number of standards adopted by administration

President	Number of standards adopted		
	Through legislation	Through rulemaking	Total
Ronald Reagan	13	0	13
George H.W. Bush	13	4	17
Bill Clinton	0	6	6
George W. Bush	23	4	27
Barack Obama	0	45	45*

* As of June 20, 2016

More important than the number of standards are the energy savings and economic and environmental benefits. DOE estimates that standards already completed during the Obama administration will cumulatively save 44 quads of energy and save consumers and businesses $540 billion on their utility bills through 2030 (DOE 2016a). These savings far exceed the savings from standards adopted administratively under any prior president. Standards expected to be completed between June 2016 and January 2017 will add to these totals.

Given the enormous progress achieved by DOE during the Obama presidency, ASAP and ACEEE launched this project to explore the future potential for national efficiency standards. With a new administration taking office in January 2017, we sought to answer two key research questions:

- With so much progress to date, especially over the past eight years, what is the potential for future savings with updates to existing standards?
- What strategies could be employed to further increase savings available from standards?

In order to answer the first question, we developed product-by-product estimates of the potential future savings from the next update due after January 2017 (i.e., after the inauguration of the next president). This analysis followed a "bottom up" approach similar to the one used in prior ASAP/ACEEE assessments of savings potential from future standards (Neubauer et al. 2009; Lowenberger et al. 2012). We were able to develop estimates for most but not all of the products covered by existing or pending national standards. The analysis assessed energy and water savings potential based on currently available technology, using existing metrics, test procedures, and product scopes. Through this analysis, we found very large savings potential from updating standards. Part I of this report shows our findings.

Part II of this report provides five recommendations for DOE actions that could increase the savings potential from future DOE standards. These recommendations take into account recent trends and approaches that have worked in the past to increase savings. Drawing on two expert panels, individual expert interviews, and our own knowledge, we considered a wide range of ideas. We applied two criteria: Actions had to be indisputably within DOE's control (i.e., they could not require new legislation), and they had to offer potentially very large savings benefits. We distilled these ideas into five actionable recommendations. Many of these strategies have been utilized by DOE in the past but could be more formally or systematically implemented going forward. Part II of the paper presents and develops these five recommendations:

- Invest in improved test methods, including expedited updates for top priorities.
- Systematically assess opportunities to expand scope and conduct rulemakings for the biggest new opportunities.
- Continue to improve analysis methods and data sources.
- Consider how DOE test methods, ratings, and standards can realize or facilitate systems savings opportunities.
- Develop a strategic approach to address connected products.

Part I. Savings from Updating Standards

BACKGROUND

National standards span the range of household appliances, lighting, and plumbing products as well as many types of commercial and industrial devices.[5] Some products have been covered by national standards since enactment of the 1987, 1988, and 1992 standards laws. Standards for many of these products, such as residential refrigerators and clothes washers, have been strengthened multiple times, yielding enormous benefits for consumers and energy savings for the nation. In many cases, state standards predated the national standards.

The Refrigerator Story

Figure 1 shows the progression of efficiency improvements for refrigerators, one of the best-known energy efficiency success stories. The first state standards for refrigerators took effect in 1978 in California. These were followed by two more California standards before the first national standards took effect in 1990. The current standard, which took effect in 2014, is the fourth national standard for refrigerators. Since 1972, average energy use for new refrigerators has decreased by 75%, while the average new unit's size has increased by 18% and real prices have declined by 50% (ASAP 2015). Other products covered by the original laws have seen their performance maintained or improved as more features are offered, and prices have remained constant or even declined in the wake of improved efficiency standards (Mauer et al. 2013).

[5] The entire list of covered products is available on the DOE website: energy.gov/eere/buildings/appliance-and-equipment-standards-program.

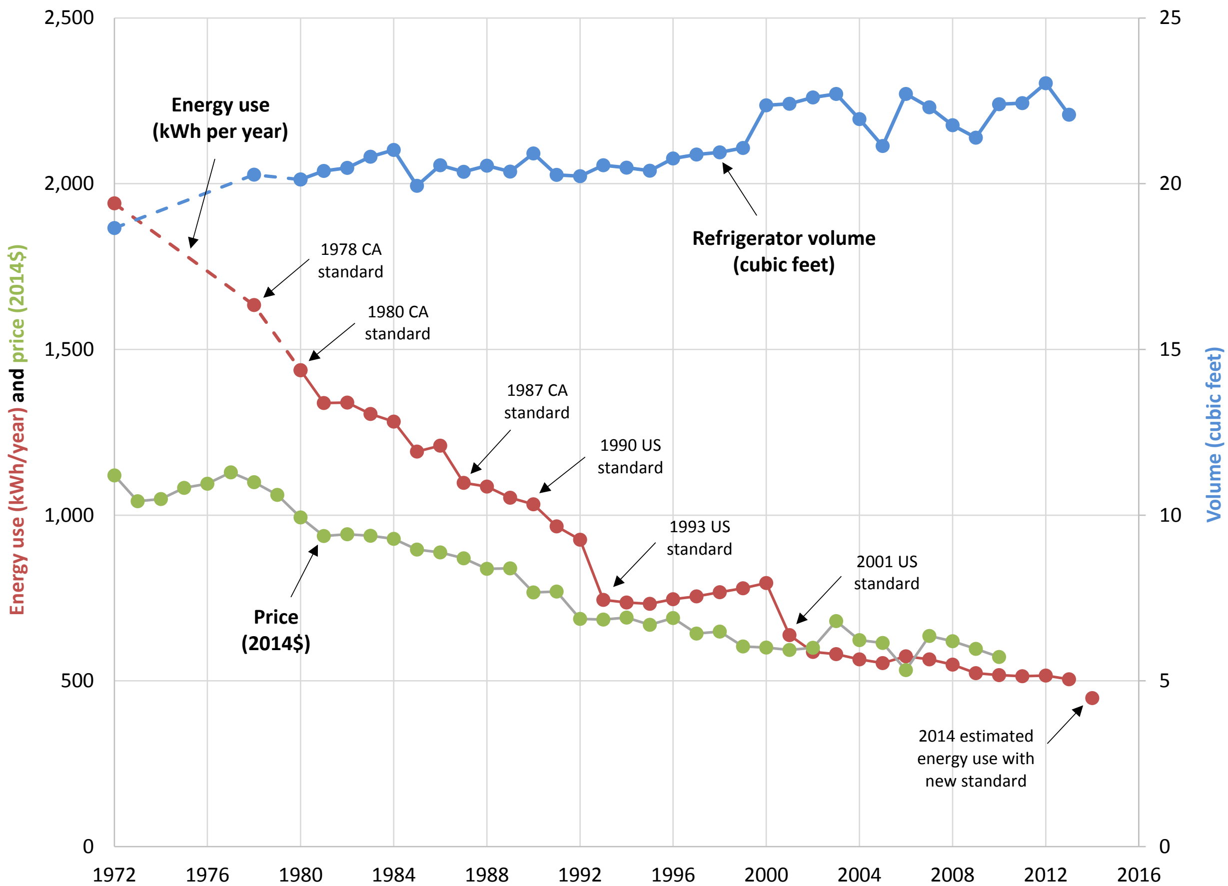

Figure 1. Average household refrigerator energy use, volume, and price over time. Data include standard-size and compact refrigerators. Energy consumption and volume data reflect the DOE test procedure published in 2010. Volume is adjusted volume, which is equal to fresh food volume + 1.76 times freezer volume. Prices represent the manufacturer selling price (i.e., excluding retailer markups) and reflect products manufactured in the US. *Sources:* Association of Home Appliance Manufacturers (AHAM); US Census Bureau.

The 2005 and 2007 energy laws added more products, and in general, standards for these products have been updated only once, if at all. In addition, under the current administration, DOE has for the first time exercised its authority to establish standards not specifically required by Congress. New standards for pumps and pending standards for commercial and industrial fans, compressors, wine chillers, and portable air conditioners are among the products being addressed by national standards for the first time.

The national standards law requires that DOE review each standard at least once every six years to determine if an update is warranted, and if so, to complete that update within an additional two years.[6] Therefore, within the span of the next two presidential terms, each existing standard will undergo at least one review for potential updating. For this report, we

[6] Based on criteria spelled out in the law, DOE must issue either a proposed revised standard *or* a determination that no change is warranted no later than six years after the last final rule amending a standard. If DOE issues a proposed rule, then a final rule—which may result in a new standard or no change—is due no later than two years from that time. If a determination of no change is made, DOE must revisit that determination within three years.

initially considered all products currently covered by standards or expected to be covered by the end of the Obama administration, more than 55 in total. We then excluded some products (e.g., unit heaters) from the analysis due to lack of sufficient information on which to base estimates of potential savings. The report develops potential savings estimates for 45 products.

We estimate final rule dates and compliance dates for post-2016 standards based on statutory requirements regarding the timing of DOE reviews, and statutory lead times between publication of final rules and compliance dates, which are typically 3 to 5 years.[7] The estimated compliance dates for post-2016 standards range from 2022 to 2029.

For the baseline efficiency (i.e., absent standards updates) of most products, we use either the current standards or standard levels that have been finalized or proposed in recent rulemakings. In a few cases, we assume a baseline efficiency equivalent to levels recommended as part of recent negotiated rulemakings (e.g., for central air conditioners). For almost all of the products, we analyze efficiency levels for post-2016 standards equivalent to the maximum technologically feasible ("max-tech") level in DOE's most recent standards analysis. For plumbing products (faucets, showerheads, toilets, and urinals), we analyze efficiency levels equivalent to recent standards adopted in California.

Max-tech, as specified in the most recent rulemaking analysis for a particular product, is a reasonable basis for estimating the potential efficiency level for the next standard. DOE usually constrains its estimate of max-tech levels to levels found in commercially available products, ignoring available technologies that have not yet been deployed in marketed products or prototypes. Implementation of a new standard will often unleash a new round of innovation and deployment of efficiency improvements, as manufacturers invest not only to comply with the new standard but also to develop products that are differentiated by their even better efficiency performance. Therefore, max-tech levels of a few years ago or even today are serious candidates for minimum standards implemented in the 2022–2029 time frame.

For example, in 2016 the best-available electric water heaters certified to DOE exceed the max-tech level from the 2010 final rule analysis by 38%. Similarly, the best-available clothes washers in 2016 exceed the max-tech levels identified in the 2012 final rule analysis by 35% for front loaders and 19% for top loaders. Earlier rounds of rulemaking showed similar patterns. Refrigerators just meeting the 2001 standard were more efficient than what was considered to be max-tech in 1989. And refrigerators just meeting today's minimum standard are more efficient than the levels considered to be max-tech in 1995. Technological progress ensures that max-tech is not a fixed level over time (McMahon 2012). Research in Europe has similarly found that levels assessed as "best available technology" during a standards development process are eclipsed by substantially more efficient products by the time the standard takes effect (Toulouse 2013).

[7] For products having a statutory deadline that has passed or that lack a clear statutory deadline, we use ASAP estimates for final rule dates and compliance dates.

Each new DOE standard must meet statutory criteria: It must achieve the maximum improvement in energy efficiency that is technologically feasible and economically justified (42 US Code 6295(o)). Economic justification takes into account consumer and manufacturer impacts. We are not necessarily endorsing the precise levels evaluated in this report for the next revision to each of these standards. In some cases higher standards will make sense, and in others, lower. In still other cases, strategies (including some discussed in Part II of this report) other than strengthening the current standard using the existing metric and test method could yield better results. Nevertheless, given the historical record of technological progress for most products covered by standards—progress spurred in part by the standards themselves—the last-round max-tech levels provide a reasonable (and perhaps conservative) basis for estimating the savings potential of updates to existing standards.

For a few products, DOE adopted the max-tech levels (or very close to max-tech levels) in the most recent rulemaking (e.g., fluorescent lamp ballasts and general service fluorescent lamps). While new technologies could allow efficiency levels beyond what DOE's recent analysis shows to be max-tech, we have not attempted to estimate potential energy savings for levels beyond DOE's most recent determination of max-tech levels. Therefore, these products are among those excluded from this analysis.

Our general methodology for estimating savings is based on sales of the affected products. We estimate savings through 2050. We use estimates of annual shipments, per-unit energy and/or water savings, and average product lifetime based on the best available data. In most cases, we use information from recent DOE rulemakings. For annual shipments, we use estimates of shipments in the year the standard is assumed to take effect. We take into account that some portion of sales are likely to meet the assumed new standard level even in the absence of a new standard. In general, for products that do not have an ENERGY STAR® specification, we assume that 10% of the shipments will meet the assumed standard level in the base case. For products that do have an ENERGY STAR specification, we assume that 25% of shipments will meet the next standard level in the base case since the ENERGY STAR labels have proved very effective in increasing the market penetration of efficient products. In a few cases where available data indicate that the portion of sales meeting the assumed standard level in the base case will be higher than 25% (e.g., faucets, showerheads, and general service lamps), we account for this higher base case. To simplify the analysis, we assume that both annual shipments and the percentage of shipments already meeting the standard level remain constant over the analysis period.[8]

Our estimates for products that save hot water (clothes washers, faucets, and showerheads) assume current water heater efficiency levels. However, in calculating total potential savings, we account for the interaction effects among residential water heaters, clothes washers, faucets, and showerheads. If the standards for water heaters evaluated in this analysis were adopted, the energy savings from adopting standards for faucets, showerheads, and clothes washers would be lower due to improved water heater efficiency.

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[8] We assume declining shipments over time for incandescent reflector lamps and metal halide lamp fixtures.

Similarly, if the standards for products that use hot water were adopted, the savings from water heaters would be lower due to reduced household hot water consumption.

For water-using products in this analysis, we have included only the direct energy savings from reduced hot water use. There is also significant embedded energy in water due to pumping and treatment. Energy embedded in water may account for as much as 3.5% of national energy use (Griffiths-Sattenspiel and Wilson 2009). We have not attempted to estimate those additional energy savings for this report.

Like any study that looks at many technologies over a relatively long period, this analysis is subject to many sources of uncertainty. Energy prices may be higher or lower than estimated. Innovation will undoubtedly lead to new energy-saving technologies and approaches not evaluated here. Other policies and programs such as ratepayer-funded efficiency programs and ENERGY STAR and WaterSense may capture a larger portion of potential savings than we assume; conversely, those programs may drive more cost-effective innovation enabling stronger standards than modeled. DOE may choose to accelerate the adoption of standards, completing updates in advance of legal deadlines. In addition, policy approaches such as those described in Part II of this report will likely open up new savings opportunities for standards. Taking into account these various sources of uncertainty, we believe the overall savings potential estimates in this report are likely to be conservative. Details of our methodology and assumptions for each product can be found in Appendix A.

FINDINGS

We found that the potential savings from updated standards are enormous. As shown in figure 2, potential primary energy savings grow to an annual rate of 2.6 quads of energy in 2035, increasing to 4.0 quads per annum in 2050. Annual savings rates grow over time as more standards come into force and as those already in place affect a greater portion of products in use; standards affect only new product sales, and it can take many years for the in-use stock of products to turn over. Potential annual energy savings in 2035 equal current annual energy consumption of all the homes in Texas and Ohio combined. Potential savings in 2050 would grow to cover the current consumption of homes in those states plus New York and South Carolina (EIA 2015b).

As the figure shows, electricity accounts for most of the energy savings, reaching an annual rate of 215 billion kilowatt hours (kWh) by 2035 and 335 billion kWh by 2050 (see table 4). For comparison, it would take about 60,000 new wind turbines to generate 335 billion kWh per year (EPA 2016a). The potential annual rate of CO_2 reductions from all fuels rises to 130 million metric tons in 2035, further increasing to an annual rate of 200 million metric tons in 2050, an amount about equal to the emissions of 60 coal-fired power plants (EPA 2016a).

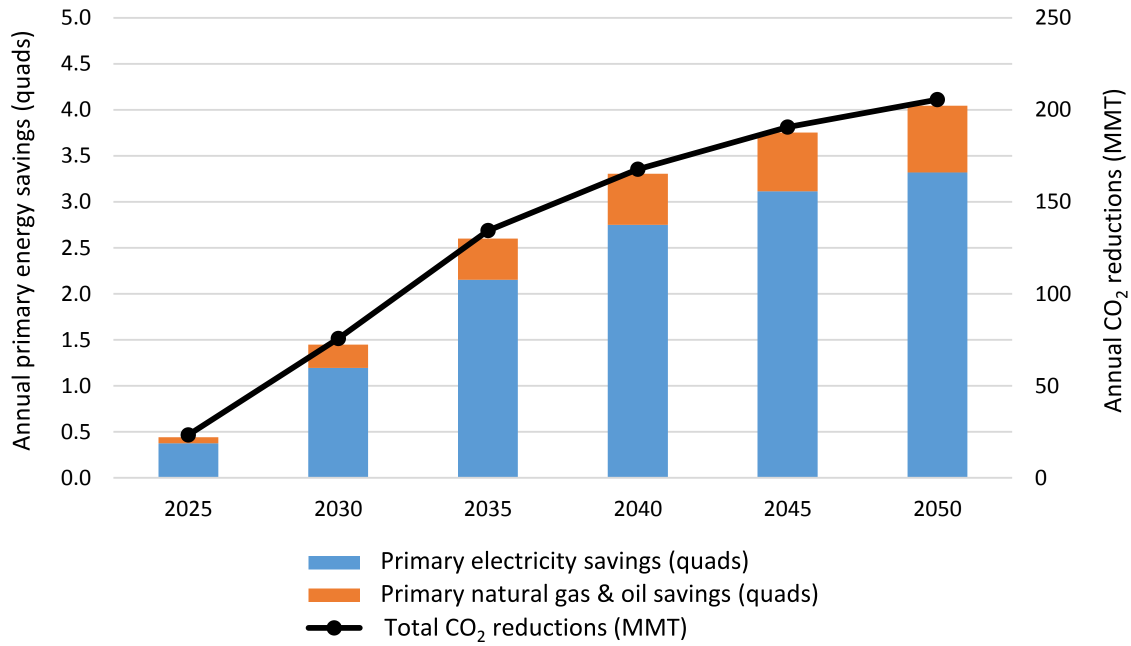

Figure 2. Potential annual primary energy savings and CO_2 reductions from post-2016 standards

Several standards address water-using products such as showerheads and faucets. Updates to these standards have the potential to save 770 billion gallons of water annually by 2035, increasing to an annual rate of 850 billion gallons by 2050, an amount greater than all the water used each year by the nine million-plus households in Texas (Maupin et al. 2014).

These energy and water savings translate into very large utility bill reductions for consumers and businesses. As shown in figure 3, the potential annual bill savings for electricity, gas, oil, and water reach nearly $43 billion by 2035 and grow to $65 billion in 2050, with electricity accounting for the majority of the bill savings.[9]

[9] Water bill savings include both water and wastewater costs.

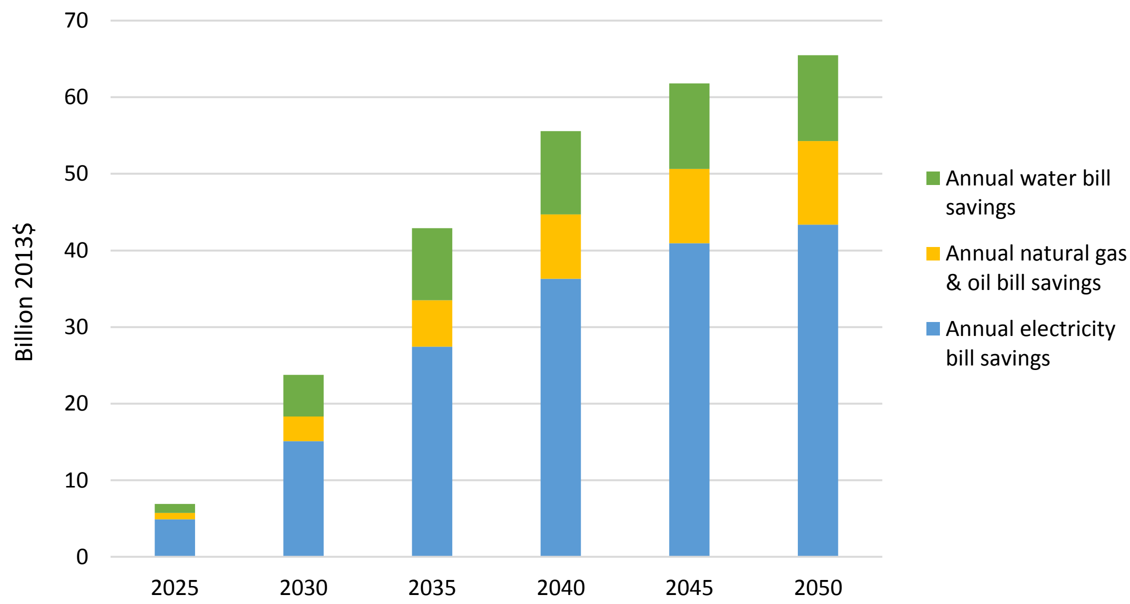

Figure 3. Potential annual utility bill savings from post-2016 standards

Tables 2 and 3 show the annual savings estimates for residential and commercial/industrial products, respectively. Table 4 shows the total annual savings estimates.

Table 2. Potential annual energy and water savings, CO_2 reductions, and utility bill savings from post-2016 standards for residential products

	Annual savings in 2035					Annual savings in 2050				
Product	Electricity (TWh)	Natural gas (TBtu)	Water (billion gallons)	CO_2 (MMT)	Utility bills (million 2013$)	Electricity (TWh)	Natural gas (TBtu)	Water (billion gallons)	CO_2 (MMT)	Utility bills (million 2013$)
Battery chargers	1.7	--	--	0.9	233	1.7	–	–	0.8	242
Boilers	(0.2)	18.5	--	1.0	288	(0.6)	61.3	–	3.4	1,078
Ceiling fans	2.5	--	--	1.3	342	4.0	–	–	2.0	577
Central air conditioners and heat pumps	18.8	--	--	9.7	2,621	49.7	–	–	24.8	7,199
Clothes dryers	17.7	16.3	--	9.9	2,684	20.9	19.3	–	11.5	3,329
Clothes washers	2.6	21.7	126.5	2.5	2,213	3.2	26.8	156.2	3.0	2,945
Dehumidifiers	1.1	--	--	0.5	148	1.4	–	–	0.7	201
Direct heating equipment	--	4.2	--	0.2	58	–	5.1	–	0.3	78
External power supplies	1.6	--	--	0.8	228	1.6	–	–	0.8	237
Faucets	9.4	70.8	280.6	8.6	5,727	9.4	70.8	280.6	8.5	6,167
Furnaces	--	42.7	--	2.3	588	–	141.4	–	7.5	2,187
Furnace fans	2.3	--	--	1.2	324	5.8	–	–	2.9	839
General service lamps	0.5	--	--	0.3	72	0.9	–	–	0.4	128
Incandescent reflector lamps	6.6	--	--	3.4	923	3.8	–	–	1.9	552
Microwave ovens	1.4	--	--	0.7	189	1.4	–	–	0.7	196
Pool heaters	--	7.4	--	0.4	102	–	7.4	–	0.4	114
Portable air conditioners	2.2	--	--	1.1	309	2.7	–	–	1.4	397
Ranges and ovens	1.0	0.6	--	0.5	147	2.0	1.3	–	1.1	310
Refrigerators and freezers	17.1	--	--	8.8	2,378	19.7	–	–	9.8	2,860
Room air conditioners	2.3	--	--	1.2	319	2.3	–	–	1.1	331
Showerheads	13.6	102.6	278.1	12.4	6,721	13.6	102.6	278.1	12.3	7,236
Toilets	--	--	52.3	–	641	–	–	101.3	–	1,338
Water heaters	55.2	169.7	--	37.4	10,037	57.4	188.7	–	38.7	11,247
Wine chillers	1.3	--	--	0.7	181	1.6	–	–	0.8	235

Table 3. Potential annual energy and water savings, CO_2 reductions, and utility bill savings from post-2016 standards for commercial and industrial products

	Annual savings in 2035					Annual savings in 2050				
Product	Electricity (TWh)	Natural gas (TBtu)	Water (billion gallons)	CO_2 (MMT)	Utility bills (million 2013$)	Electricity (TWh)	Natural gas (TBtu)	Water (billion gallons)	CO_2 (MMT)	Utility bills (million 2013$)
Automatic ice makers	0.5	--	--	0.2	53	0.5	--	--	0.2	55
Beverage vending machines	0.4	--	--	0.2	40	0.6	--	--	0.3	66
Commercial boilers	(0.03)	22.5	--	1.2	264	(0.1)	62.1	--	3.4	829
Commercial clothes washers	0.1	0.2	4.7	0.1	77	0.2	0.2	5.3	0.1	92
Commercial furnaces	(0.3)	27.2	--	1.3	271	(1.1)	90.0	--	4.3	1,029
Commercial packaged air conditioners and heat pumps	7.3	--	--	3.7	821	24.0	--	--	12.0	2,829
Commercial refrigeration equipment	4.0	--	--	2.0	449	4.0	--	--	2.0	468
Commercial three-phase air conditioners and heat pumps	1.0	--	--	0.5	113	2.0	--	--	1.0	230
Commercial water heaters	--	5.9	--	0.3	65	--	9.0	--	0.5	113
Compressors	14.3	--	--	7.3	1,477	18.5	--	--	9.2	2,005
Computer room air conditioners	2.3	--	--	1.2	263	2.8	--	--	1.4	328
Distribution transformers	10.9	--	--	5.6	1,231	25.1	--	--	12.5	2,956
Electric motors	15.8	--	--	8.1	1,566	23.6	--	--	11.8	2,443
Fans	11.6	--	--	5.9	1,211	38.3	--	--	19.1	4,186
Metal halide lamp fixtures	0.9	--	--	0.5	107	1.6	--	--	0.8	184
Packaged terminal air conditioners and heat pumps	0.6	--	--	0.3	64	0.6	--	--	0.3	67
Pumps	2.6	--	--	1.4	246	4.0	--	--	2.0	393
Single-package vertical air conditioners and heat pumps	0.3	--	--	0.1	31	0.4	--	--	0.2	51
Small motors	1.5	--	--	0.8	143	1.5	--	--	0.8	150
Urinals	--	--	25.3	--	310	--	--	26.4	--	349
Water-source heat pumps	3.3	--	--	1.7	375	6.6	--	--	3.3	782

Table 4. Potential annual energy and water savings, CO_2 reductions, and utility bill savings from post-2016 standards

	Annual savings in 2035					Annual savings in 2050				
	Electricity (TWh)	Natural gas (TBtu)	Water (billion gallons)	CO_2 (MMT)	Utility bills (million 2013$)	Electricity (TWh)	Natural gas (TBtu)	Water (billion gallons)	CO_2 (MMT)	Utility bills (million 2013$)
Residential total	138	388	737	92	33,732	182	554	816	121	45,888
Commercial/industrial total	77	56	30	43	9,178	153	161	32	85	19,604
Total	215	444	768	134	42,910	335	715	848	206	65,493

The total savings for residential products are not equivalent to the sum of the savings for the individual residential products due to the interaction effects among residential water heaters, clothes washers, faucets, and showerheads. In addition, totals may not sum due to rounding.

Cumulatively, we estimate that updates for the evaluated products have the potential to reduce US energy use by 70 quads by 2050 while cutting consumer and business utility bills by $1.1 trillion. Potential cumulative CO_2 emissions reductions are 3.5 billion metric tons by 2050. For comparison, total US CO_2 emissions in 2014 were about 5.6 billion metric tons (EPA 2016b). Tables 5 and 6 show the cumulative savings estimates for residential and commercial/industrial products, respectively. Table 7 shows the total cumulative savings estimates.

Table 5. Potential cumulative primary energy and water savings, CO_2 reductions, and utility bill savings from post-2016 standards for residential products

	Cumulative savings through 2050			
Product	Primary energy (quads)	Water (billion gallons)	CO_2 (MMT)	Utility bills (billion 2013$)
Battery chargers	0.4	--	19.7	5.5
Boilers	0.7	--	38.7	11.8
Ceiling fans	0.7	--	34.3	9.7
Central air conditioners and heat pumps	6.6	--	333.5	95.4
Clothes dryers	4.8	--	244.4	68.3
Clothes washers	1.2	3,109	60.8	56.5
Dehumidifiers	0.3	--	12.9	3.7
Direct heating equipment	0.1	--	5.5	1.5
External power supplies	0.4	--	21.5	5.9
Faucets	3.6	6,174	187.8	129.9
Furnaces	1.6	--	84.5	24.0
Furnace fans	0.8	--	39.0	11.1
General service lamps	0.1	--	7.6	2.1
Incandescent reflector lamps	1.6	--	84.5	23.0
Microwave ovens	0.3	--	14.8	4.1
Pool heaters	0.2	--	9.0	2.5
Portable air conditioners	0.5	--	25.9	7.3
Ranges and ovens	0.3	--	16.6	4.7
Refrigerators and freezers	4.2	--	212.3	59.4
Room air conditioners	0.5	--	27.8	7.7
Showerheads	5.3	6,117	272.1	152.5
Toilets	--	1,606	--	20.6
Water heaters	16.2	--	835.4	232.9
Wine chillers	0.3	--	15.3	4.3

Table 6. Potential cumulative primary energy and water savings, CO_2 reductions, and utility bill savings from post-2016 standards for commercial and industrial products

	Cumulative savings through 2050			
Product	Primary energy (quads)	Water (billion gallons)	CO_2 (MMT)	Utility bills (billion 2013$)
Automatic ice makers	0.1	--	4.9	1.1
Beverage vending machines	0.1	--	4.9	1.1
Commercial boilers	0.8	--	41.4	9.8
Commercial clothes washers	0.04	105	1.8	1.8
Commercial furnaces	0.9	--	48.2	11.3
Commercial packaged air conditioners and heat pumps	2.7	--	135.6	31.6
Commercial refrigeration equipment	0.8	--	42.3	9.6
Commercial three-phase air conditioners and heat pumps	0.3	--	15.5	3.6
Commercial water heaters	0.2	--	8.3	1.9
Compressors	3.3	--	169.4	35.8
Computer room air conditioners	0.6	--	28.9	6.6
Distribution transformers	3.4	--	174.0	40.1
Electric motors	4.3	--	216.5	43.7
Fans	4.3	--	216.1	46.7
Metal halide lamp fixtures	0.3	--	13.6	3.1
Packaged terminal air conditioners and heat pumps	0.1	--	6.0	1.4
Pumps	0.7	--	35.5	6.8
Single-package vertical air conditioners and heat pumps	0.1	--	3.8	0.9
Small motors	0.4	--	18.7	3.6
Urinals	--	555	--	7.0
Water-source heat pumps	1.0	--	51.8	12.0

Table 7. Potential cumulative primary energy and water savings, CO_2 reductions, and utility bill savings from post-2016 standards

	Cumulative savings through 2050			
	Primary energy (quads)	Water (billion gallons)	CO_2 (MMT)	Utility bills (billion 2013$)
Residential total	45	17,006	2,319	865
Commercial/industrial total	24	659	1,237	279
Total	70	17,665	3,556	1,144

The total savings for residential products are not equivalent to the sum of the savings for the individual residential products due to the interaction effects among residential water heaters, clothes washers, faucets, and showerheads. In addition, totals may not sum due to rounding.

A disproportionate share of the potential savings derives from the top 10 standards, which account for more than 70% of cumulative energy and utility bill savings potential. Figure 4 shows the cumulative primary energy savings and utility bill savings from the top 10 standards. For products that save both electricity and natural gas or oil, the share of energy savings for each energy source is shown.

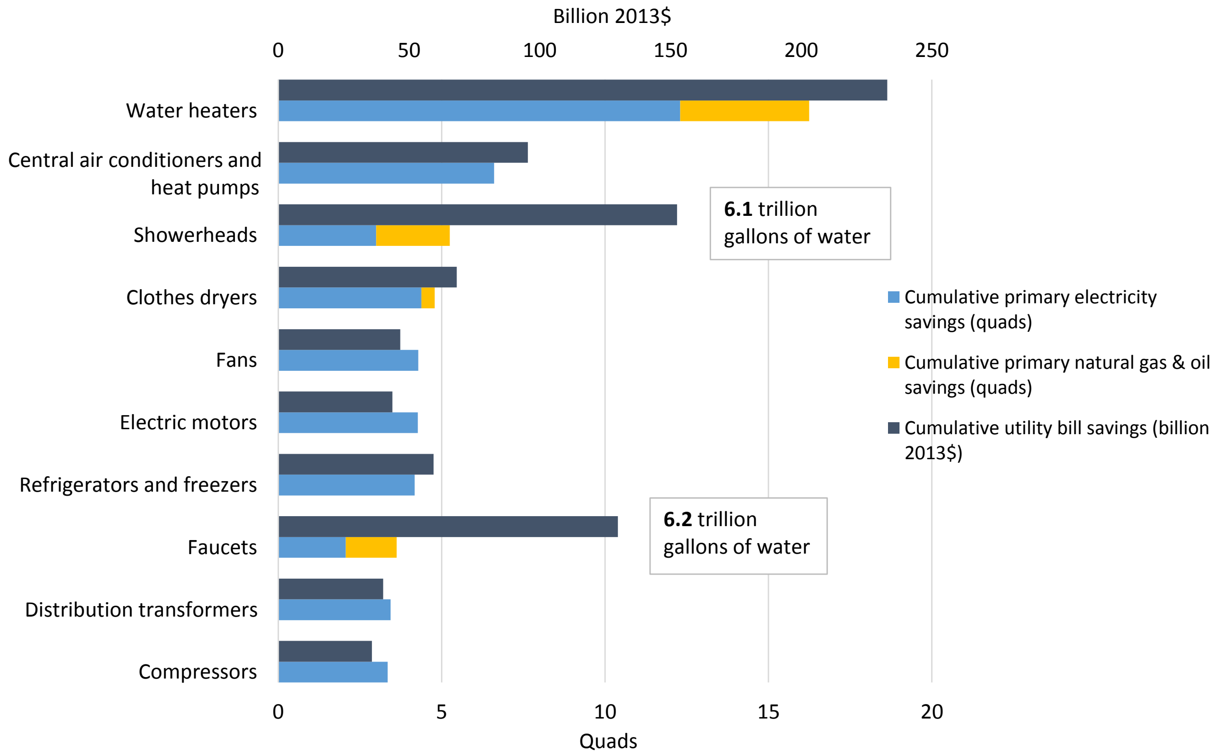

Figure 4. Cumulative primary energy savings and utility bill savings through 2050 for top 10 standards

Notably, six of the products with the greatest savings potential have already had multiple rounds of updated standards. The next refrigerator and central air conditioner standards updates will be the fifth national standards for these products, dating back to the originals enacted in 1987. For water heaters the next update will be the fourth, and for others it will be the third. For four of the products on the list—showerheads, commercial and industrial fans, faucets, and compressors—the next new standard completed after January 2017 will be only the second.[10]

For products that have already been subject to multiple standards to rank among those with the top savings potential may be surprising. However several factors explain these products' large remaining potential. First, even though they have become more efficient over the past 30 years, each continues to account for a significant percentage of energy use in homes or businesses. Second, each has large annual sales volumes. Third, in part due to the size of their energy use and their sales volume, these products get the attention of

[10] DOE is scheduled to complete the first standards for commercial and industrial fans and compressors by the end of 2016.

innovators and companies looking to improve efficiency. As a result, technological progress has continued to open pathways to higher efficiency levels.

Top 10 Savings Opportunities

The paragraphs below describe in more detail the potential opportunity for each of the top 10 products. Each heading includes the potential cumulative primary energy savings and utility bill savings through 2050.

Water Heaters: 16.2 Quads and $233 Billion

Water heating represents about 13% of residential energy consumption (EIA 2015a). The efficiency of water heaters is described by a metric called energy factor (EF).[11] The current standards are 0.95 EF for the most common electric storage water heaters and 0.62 EF for the most common gas storage water heaters. Heat pump technology can reduce electric water heater energy consumption by 50% or more in appropriate applications, while condensing technology can reduce gas water heater energy consumption by about 25%. We analyzed standard levels for water heaters based on heat pump technology for electric water heaters (2.35 EF) and condensing technology for gas water heaters (0.77 EF).[12] The current standards effectively require heat pump and condensing technology for water heaters with storage volumes larger than 55 gallons. However these large water heaters represent only a very small portion of the market.

Central Air Conditioners and Heat Pumps: 6.6 Quads and $95 Billion

Space cooling represents about 11% of residential energy consumption, and about two-thirds of homes have central air conditioning (EIA 2015a, EIA 2011). The cooling efficiency of central air conditioners and heat pumps is described by a metric called SEER (seasonal energy efficiency ratio). The current standards are SEER 14 for all heat pumps and for most air conditioners installed in states in the South, and SEER 13 for most air conditioners installed in the North. A negotiated rulemaking working group reached an agreement in early 2016 that would raise the standards to SEER 15 for heat pumps and for most air conditioners in the South, and SEER 14 for air conditioners in the North as of 2023 (DOE 2016a). We analyzed standard levels of 17 SEER and 21.8 SEER for the most common air conditioners and heat pumps, respectively.[13] These standard levels would reduce air conditioner energy consumption by 10–15% and heat pump energy consumption by about 25% relative to the expected 2023 standards. These higher efficiency levels could be met

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[11] An ongoing DOE rulemaking will shift the water heater standard to a new metric called "uniform energy factor," or UEF.

[12] Excluding small water heaters (e.g., those under 30 gallons) would slightly reduce savings and may improve cost effectiveness.

[13] Most central air conditioners and heat pumps are split-system equipment, where the compressor and condenser are located outdoors and the evaporator is indoors. The other type of equipment is single-package equipment, where the compressor, condenser, and evaporator are located in a single package outdoors. For split-system air conditioners, we analyzed the max-tech level for coil-only units, which are sold without a supply fan (and typically are installed in homes with a furnace that already has a supply fan), since these represent the most common configuration sold. The max-tech levels for heat pumps are higher than those for air conditioners since heat pumps are typically sold with a supply fan and therefore can incorporate additional efficiency improvements.

using variable-speed compressors, improved heat exchangers, and more-efficient fan motors.

Showerheads: 5.3 Quads and $153 Billion

The standards for showerheads have not been updated since 1992. The current standards require that showerheads use no more than 2.5 gallons per minute (gpm). California recently adopted standards for showerheads that set the maximum flow rate at 1.8 gpm as of 2018. We analyzed standards for showerheads that are equivalent to the California standards. In addition to saving water, more-efficient showerheads save a significant amount of energy by reducing hot water consumption.

Clothes Dryers: 4.8 Quads and $68 Billion

Electric clothes dryers consume about as much energy as a typical refrigerator, clothes washer, and dishwasher combined (Horowitz et al. 2014). However until recently there had been very little change in clothes dryer technology. Clothes dryer energy consumption is now receiving attention from both policymakers and manufacturers. The first ENERGY STAR specification for clothes dryers took effect on January 1, 2015, and requires a 20% reduction in energy use compared with conventional models (EPA 2015b). ENERGY STAR also offered an Emerging Technology Award in 2014 for clothes dryers that provide savings of about 40% in their most efficient setting (EPA 2014). LG and Whirlpool both introduced heat pump clothes dryers in 2014 that meet the Emerging Technology Award specification. We analyzed standard levels for both electric and gas clothes dryers that represent savings of 30% relative to the current standards.[14]

Fans: 4.3 Quads and $47 Billion

Commercial and industrial fans are used in a wide variety of applications such as commercial building HVAC systems, commercial kitchen exhaust systems, and agricultural ventilation. DOE is currently conducting a rulemaking, scheduled for completion in 2016, that would establish the first national efficiency standards for fans and would apply to fans ranging from roughly 1 to 200 horsepower. For the base case in the analysis for this paper, we assumed efficiency levels equivalent to levels jointly recommended by efficiency advocates and fan manufacturers in the currently open rulemaking. We analyzed standard levels for fans that reflect the most-efficient fan designs available today and would achieve weighted-average savings of 8% relative to the assumed base case efficiency levels.

Electric Motors: 4.3 Quads and $44 Billion

Almost 70% of the electricity consumed in the industrial sector is used to power systems driven by electric motors (Scheihing 1998). Electric motors are commonly used to drive pumps, fans, compressors, mechanical processes, and material-handling equipment. New standards taking effect in 2016 apply to three-phase induction electric motors from 1 to 500 horsepower and are equivalent to the NEMA[15] Premium (or IE3) efficiency levels. We analyzed standard levels for electric motors that are roughly equivalent to the Super

[14] We assume that clothes dryers meeting the 2014 Emerging Technology Award specification would achieve savings of 30% on average in the field.

[15] National Electrical Manufacturers Association

Premium (or IE4) levels. These efficiency levels, which would reduce energy losses by about 15%, can be met by more-efficient conventional induction motors as well as by advanced motor technologies including permanent magnet, switched reluctance, and synchronous reluctance motors.[16]

Refrigerators and Freezers: 4.2 Quads and $59 Billion

Refrigerator energy use has declined substantially over the past 25 years as a series of updated efficiency standards have taken effect. Between 1987 and 2010, average refrigerator energy use decreased by more than 50% (Mauer et al. 2013). However there are still significant potential energy savings from refrigerators. We analyzed standard levels that would reduce the energy consumption of standard-size refrigerators and freezers by about 10–20% relative to the current standards, which took effect in 2014. For compact products (those with a refrigerated volume less than 7.75 cubic feet), larger savings are possible, and we analyzed standard levels that would reduce energy consumption by 45% and 35% for compact refrigerators and freezers, respectively. Refrigerator efficiency can be improved beyond the current standards using technologies such as variable-speed compressors and vacuum insulated panels.

Faucets: 3.6 Quads and $130 Billion

As with showerheads, the standards for faucets have not been updated since 1992. The current standards require that faucets use no more than 2.2 gallons per minute (gpm). California recently adopted standards for faucets that set the maximum flow rate at 1.2 gpm for lavatory faucets and 1.8 gpm for kitchen faucets. We analyzed standards for faucets that are equivalent to the California standards. Like showerheads, in addition to saving water, more-efficient faucets save a significant amount of energy by reducing hot water consumption.

Distribution Transformers: 3.4 Quads and $40 Billion

Distribution transformers reduce electricity voltage from the high voltage used in electricity distribution lines to the lower voltages used by equipment in homes, businesses, and factories. Since virtually all of the electricity consumed in the United States passes through distribution transformers, even small improvements in transformer efficiency can yield significant energy savings. Energy losses in transformers can be significantly reduced by using amorphous metal for the transformer steel core. We analyzed standards for distribution transformers based on the use of amorphous metal that would reduce energy losses by 40–70% relative to the current standards.

Compressors: 3.3 Quads and $36 Billion

Air compressors are used in industrial facilities to provide compressed air for a wide variety of applications such as powering pneumatic tools and automation equipment. DOE estimates that air compressors consume about 91 billion kWh annually, or about 2.5% of total US electricity consumption (DOE 2012). DOE is currently conducting a rulemaking that

[16] The current test procedure for electric motors is not applicable to advanced motor technologies. The test procedure would need to be amended in order to consider these advanced motors within the scope of a future standards rulemaking.

would establish the first national efficiency standards for compressors. We assumed base case efficiency levels equivalent to the levels put forth in DOE's May 2016 proposed rule (DOE 2016d). We analyzed standard levels for compressors that reflect the most-efficient compressors available today, which would achieve weighted-average savings of 36% relative to the assumed base case efficiency levels.

Part II. Recommendations for Increasing Savings

Part I of this report shows that the next generation of minimum efficiency standards have enormous savings potential. Simply by updating existing and pending standards using current product scopes, metrics, and test methods and known technological improvements, potential savings would substantially add to the progress achieved by standards to date.

Over the past few years, DOE has employed several approaches that have helped achieve successful outcomes for various standards rulemakings. These approaches, some of them entirely new or underutilized in the past, have included:

- Using a formal negotiated rulemaking process to develop standards for 10 products, helping to resolve standards that might otherwise have been controversial.
- Using modeling to assess efficiency levels that are technologically feasible but beyond those in the market today.
- Exercising agency authority to cover new products and to complete updates in advance of legal deadlines, going beyond the bare minimum number of standards required by Congress.[17]
- Designing standards to take advantage of potential savings from controls. For example, the latest commercial refrigerator display case test method captures savings from sensors that turn off lighting when people are not around, and the latest beverage vending machine test method captures savings from lighting and refrigeration system controls that reduce energy use during extended periods of inactivity.
- Updating test methods to better reflect field performance, in some cases fixing long-standing problems. For example, the dehumidifier test now includes a more accurate ambient temperature, the clothes dryer test captures the effectiveness of automatic termination controls, the water heater test includes a more accurate draw pattern, and the latest revised central air conditioner test uses a more realistic external static pressure (a measure of resistance in air distribution systems).
- Improving the accuracy of product price estimates by incorporating price projections (e.g., for LEDs) and learning into rulemaking analyses.
- Adopting metrics that facilitate product differentiation. For example, the pumps metric allows better ratings for a pump sold as part of a high-efficiency pump/motor/drive package rather than simply as a bare pump, although either can comply with the minimum standard.

[17] DOE did fall behind on a number of legal deadlines in 2012–2014 but has generally caught up again and, in some cases, gotten ahead.

For this part of the report, we explored potential strategies for further increasing savings or otherwise improving national standards, building on some of the approaches identified above. Drawing on two expert panels, individual expert interviews, and our own knowledge, we considered a wide range of ideas. We applied two criteria: Actions had to be indisputably within DOE's control (i.e., they could not require new legislation), and they had to offer potentially very large savings benefits. We distilled these ideas into five actionable recommendations:

- Invest in improved test methods, including expedited updates for top priorities.
- Systematically assess opportunities to expand scope and conduct rulemakings for the biggest new opportunities.
- Continue to improve analysis methods and data sources.
- Consider how DOE test methods, ratings, and standards can realize or facilitate systems savings opportunities.
- Develop a strategic approach to address connected products.

Each of these five recommendations is described and discussed below. Appendix C of the report lists and briefly describes changes to the underlying legislation that could strengthen the national standards program.

Certification, Compliance, and Enforcement

A robust certification, compliance, and enforcement system undergirds the national appliance standards program. Manufacturers and importers must certify compliance with national standards by, among other things, submitting efficiency performance data as specified in DOE regulations. After review by DOE, these certified data are published in DOE's Compliance Certification Database. In response to complaints and on the agency's own initiative, DOE performs spot testing to check that products perform according to manufacturer submittals. If manufacturers fail to submit data, submit data that are incomplete or erroneous, or market products that do not meet standards, DOE can bring enforcement action. In recent years, DOE has brought numerous enforcement actions resulting in fines. Maintaining a strong, fully funded certification, compliance, and enforcement program is fundamental to sustaining the benefits of the national standards program.

DOE's compliance, certification, and enforcement programs are described fully at energy.gov/eere/buildings/implementation-certification-and-enforcement. Recent enforcement actions are described at energy.gov/gc/enforcement-news.

RECOMMENDATION 1. INVEST IN IMPROVED TEST METHODS, INCLUDING EXPEDITED UPDATES FOR TOP PRIORITIES

The adage "What you don't measure, you can't manage" sums up why test procedures are fundamental to efficiency progress. Underlying virtually every national standard is a test procedure used for determining a product's efficiency (or energy or water use) and thus its compliance with national standards. These test procedures are also used for other programs (e.g., ENERGY STAR, EnergyGuide labels, and utility program eligibility).

A few historic examples help show how test procedure revisions can open up new pathways for efficiency progress. Until the clothes washer test procedure took into account how well a washer spun out moisture (which reduces dryer time and energy use), manufacturers had no incentive to design and market products with higher spin speeds. A revised test procedure, completed in the 1990s, provided credit for moisture removal. As a result, new standards could take this technological advancement into account. The shipment-weighted average remaining moisture content for washers dropped by 13% over eight years (DOE 2010), reducing the energy used to dry clothes. Clothes dryers provide a second example. Dryers marketed prior to about 2013 showed little efficiency performance difference. But a revised test method that took into account the effectiveness of automatic termination controls revealed that the best dryers were about 30% more efficient than the worst ones (DOE 2013), and this enabled EPA to launch an ENERGY STAR specification for dryers. Finally, under the current test method for commercial rooftop air conditioners, the most-efficient products are about 25% more efficient than the least-efficient units. But with the test method revised to better reflect annual energy consumption with a focus on part-load performance (most equipment operates a large portion of the year at part load), products using technologies such as variable-speed fans and compressor staging can demonstrate in their ratings the benefits they provide. The best equipment as measured under the new test method now outdistances the least efficient by about 90% (AHRI 2014).

Over the past few years, DOE has significantly ramped up test method work, developing major revisions to test methods for several products, including the commercial rooftop air conditioner and clothes dryer examples above. A major revision for residential central air conditioners and heat pumps is also under development, and many other test methods have been reviewed and improved, including those for refrigerators and dehumidifiers. DOE should continue to expand this work. We recommend a two-pronged approach: (1) DOE should identify and prioritize test methods most in need of revision and expedite updates for these products, and (2) DOE's reviews of all test methods should systematically take into account specific recent developments and trends.

Identify Top-Priority Test Methods and Expedite Their Updates

Top-priority test method revisions should address those products that have the largest energy savings potential and whose test method shortcomings are already fairly well understood. We recommend that DOE prioritize updates for the following test procedures: clothes dryers, commercial rooftop air conditioners, walk-in coolers, and water heaters. Additional priorities include televisions, computers, central air conditioners and heat pumps, and commercial boilers. In some instances, DOE test methods are based on industry-developed methods; by initiating its own work, DOE can help motivate and accelerate industry processes. The paragraphs below describe the test methods that should be given top priority for review and updates.

CLOTHES DRYERS

As shown in Part I of this report, we found that clothes dryers represent the fourth-largest opportunity for energy savings. A test procedure that better represents clothes dryer energy use in the field will be critical for ensuring that the potential energy savings are realized. The current test procedure uses test cloths that are not representative of real clothing, a single load size, and testing only on the "normal" cycle. Testing conducted by the

Northwest Energy Efficiency Alliance (NEEA) and the California Investor-Owned Utilities found that when tested with real clothing and varying load sizes, the relative ranking of clothes dryers in terms of efficiency changes significantly (DOE 2014a). NEEA also found that more than one-third of all loads dried in the field are significantly smaller than the current load size used in the test procedure (Hannas and Gilman 2014). Testing with a single load size fails to encourage technologies that could improve the efficiency of drying small loads. Finally, manufacturers are offering more cycle settings, which presents a risk of potential gaming of the test procedure. For example, a dryer could be designed with a "normal" setting at which it performs very efficiently but with a very long cycle time. This could cause many consumers to immediately select a faster cycle and never revert to the "normal" cycle, in which case the dryer's tested rating would be entirely unrepresentative of its performance in the field.

We recommend that DOE consider three changes to the test procedure for clothes dryers: (1) include a more realistic test load; (2) add a test with a smaller load size; and (3) include testing using multiple cycle settings.

COMMERCIAL PACKAGED AIR CONDITIONERS AND HEAT PUMPS

As shown in Part I, commercial packaged air conditioners and heat pumps represent a significant potential savings opportunity (11th-largest savings potential among evaluated products). However amending the test procedure to better reflect total annual energy consumption would enable even greater savings. Specifically, the current test procedure for commercial air conditioners captures energy use only in cooling mode. In the field, there are a large number of hours during the year when cooling is not required but the supply fan on the air conditioning unit is running to provide ventilation to the building. In addition, the test procedure uses a value for external static pressure (which reflects the resistance in the duct system that the fan has to overcome) that is unrealistically low. The combination of these two factors means that the test procedure does not sufficiently incentivize high-efficiency fans. Fan energy represents roughly half of the total energy consumption of a commercial air conditioner, which means that improved fan efficiency could yield significant savings.

The June 2015 term sheet from the negotiated rulemaking working group for commercial air conditioners and heat pumps included a recommendation that DOE complete a test procedure rulemaking by January 1, 2019, to better incorporate total fan energy use, including capturing fan energy in ventilation mode and changing the values for external static pressure (DOE 2015a). DOE should implement the recommendations outlined in the term sheet for amending the test procedure for commercial air conditioners and heat pumps.

WALK-IN COOLERS AND FREEZERS

Walk-in coolers and freezers were not included in the products analyzed in Part I of this report since the 2014 final rule adopted the max-tech levels for walk-in refrigeration systems. However there are three test procedure changes that would allow the unlocking of additional potential savings from walk-in coolers and freezers. First, the current test procedure measures energy consumption only when the compressor is running. Power consumption during times when the compressor is not running can be significant since many walk-in refrigeration systems use crankcase heaters to keep the compressor warm. In many cases these heaters are powered continuously, even during times when they are not needed. Including a measurement of power consumption when the compressor is off would encourage control strategies to reduce crankcase heater power consumption. Second, the current test procedure does not include a method for measuring defrost energy consumption, even though electric defrost control strategies and alternative methods of defrost (e.g., hot gas defrost) have the potential to significantly reduce defrost energy use. Third, the current test procedure does not allow separately rating variable-capacity condensing units (while it does allow separately rating fixed-capacity condensing units). Since condensing units and unit coolers (the two major components of walk-in refrigeration systems) are generally sold separately, the current test procedure discourages the introduction of variable-capacity condensing units, which can be more efficient than fixed-capacity units.

The December 2015 term sheet from the negotiated rulemaking working group for walk-in coolers and freezers included a recommendation that DOE initiate a test procedure rulemaking to address these three issues: (1) incorporating off-cycle power consumption; (2) including a method for measuring defrost energy consumption; and (3) including a method to separately rate variable-capacity condensing units (DOE 2015b). DOE should implement the recommendations outlined in the term sheet for amending the test procedure for walk-in coolers and freezers.

WATER HEATERS

We found that water heaters represent the largest opportunity for energy savings. A change to the test procedure will be important for realizing these enormous potential savings, most of which come from electric water heaters. As described in Part I, we analyzed standard levels based on heat pump technology for electric water heaters. However the efficiency of heat pump water heaters is affected significantly by the conditions under which they operate (particularly ambient temperature and inlet water temperature), and not all heat pump water heaters are created equal. For example, many units are designed to switch to electric resistance heating when ambient temperatures drop below around 45°F, at which point their efficiency plummets by 50% or more; other units continue to utilize the heat pump in colder temperatures and thus generate savings well below 45°F.

The current test procedure requires testing at only one inlet water temperature (58°) and one ambient temperature range (65–70°, though most manufacturers probably test closer to 70° to maximize their ratings). An ambient temperature specification of 70° is not representative of many installations—water heaters are often installed in basements or garages where temperatures drop well below 70°, even in warm climates—and does not encourage the development of products that perform well even at very low temperatures. We recommend that DOE revise the test procedure to incorporate testing at multiple ambient temperatures and inlet water temperatures, similar to the test procedure for NEEA's Northern Climate Specification for Heat Pump Water Heaters (NEEA 2014). A revised test procedure should also incorporate a method for testing split-system heat pump water heaters.

OTHER PRIORITY TEST METHODS: TELEVISIONS, COMPUTERS, CENTRAL AIR CONDITIONERS AND HEAT PUMPS, AND COMMERCIAL BOILERS

In addition to the test methods above, other revisions should be initiated relatively soon. These include revised television and computer test methods and further updates to the central air conditioner and heat pump and the commercial boiler test methods. The Natural

Resources Defense Council (NRDC) conducted an extensive study on televisions in November 2015, which found that the energy consumption of some new features are not well represented in the current television test procedure (NRDC 2015). Some needed updates include testing with ultra-high-definition and high-dynamic-range content, testing in active and standby mode while the television is connected to the Internet, and measurement of power in quick-start mode.

For computers, the current test method used for ENERGY STAR relies largely on idle mode. This test procedure is being used for state-level standards under development in California and a concurrent DOE proceeding. However new computer technology is resulting in an increasingly large difference between idle mode power, as measured by the current test, and real-world power draw in both idle and active modes. The solutions that can save energy in active and real-world idle modes are not necessarily captured in the current test. For example, power supplies can be optimized for idle mode but not for active mode, and graphics can be made to switch off in idle but not in active mode. A revised test that better captures energy savings in real-world use will help provide a basis for future improvements beyond current ENERGY STAR or any proposed standards levels.

For central air conditioners and heat pumps, current test methods do not represent variable-speed operation accurately because variable-speed equipment is tested at fixed compressor speeds. Because high-efficiency equipment relies on variable-speed compressors, an accurate variable-speed test should be adopted by DOE. Similarly, heat pumps are more and more commonly installed in colder climates, and current methods may not accurately reflect their performance in those climates. For commercial boilers, capturing part-load efficiency should be the focus of a future test method revision.

The above list of test method needs is far from exhaustive. New data from field measurements and new technologies can both necessitate test method revisions. For example, new standards issued in 2016 for battery chargers do not cover wireless chargers, yet those chargers may grow in popularity in the years ahead. A revised test method will be needed to address these products.

Systematically Take into Account Specific Recent Developments and Trends in All Test Method Reviews

Reviewing and updating test procedures is one of DOE's major responsibilities under existing law, which requires the agency to review all test procedures at least once every seven years. As DOE undertakes these regular reviews, it should take into account a number of crosscutting developments that will affect many products. These include:

- New modes of operation, such as network standby
- Expanded user-selectable options or modes
- Controls, which may help save energy
- Software or firmware updates post installation

None of these topics is altogether new; all have come up in at least one test procedure revision process. However, by systematically considering each of these topics during all test procedure reviews, DOE will be able to improve many procedures. The paragraphs below examine each type of development further.

New modes of operation, such as network standby. Current law requires DOE to address standby and off mode energy use for consumer products, and DOE has been updating test methods accordingly. However more and more products, including items as mundane as lightbulbs, are incorporating a "network standby" mode, wherein the product is connected and able to receive or provide a signal through a network. Revised test methods need to accurately represent energy use resulting from network connectedness.

Expanded user-selectable options or modes. Test procedures for some products (e.g., clothes washers and dryers and dishwashers) measure performance in a "normal" cycle. But modern products often include many additional cycle options, which may be selected as often as, or more often than, the cycle specified in the test. In actual use, if product performance suffers in the cycle specified in the test procedure, then the alternate cycles will be more commonly selected by users. Updated test procedures need to take into account the full range of cycle options offered by products. Data from field studies can help determine the range of cycles selected by users, but such data may remain insufficient given the large number of new cycle options and the rapidity with which new cycles are offered. One approach would be to weight all cycles, but this approach would increase testing costs, perhaps prohibitively. Another would be to require at least some testing in the most consumptive settings.

Controls, which may help save energy. Many products are available with built-in controls that can reduce energy consumption. For example, vending machines can dim or turn off lights when no one is around, and dishwashers can automatically adjust their water use and cycle time depending on what is needed to clean a given load. Test procedures can capture savings from controls by either providing a fixed credit toward meeting the required standard for any product that has a given built-in control or measuring the performance of the product with the control in the test method.[18]

Fixed credits can be a relatively simple way to encourage controls, since a fixed credit does not require additional testing. But they do not necessarily encourage controls that work well, nor do they foster the development of even better controls. For example, in the clothes dryers test method used for standards compliance purposes today, any unit employing some sort of automatic termination control is awarded a credit of about 12% to its efficiency rating. However testing revealed that many clothes dryers with automatic termination controls significantly over-dried clothes, thereby wasting energy, yet they still received the credit (DOE 2013). DOE recently completed an update to the clothes dryer test method that now measures the effectiveness of the automatic termination control. The new test procedure requires the measurement of energy consumption until the machine shuts itself off. (If the clothes are not yet dry, the test run is invalid and a new run is conducted using

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[18] Another approach is to require a specific control as part of a product's regulation. While some standards established by Congress require specific controls (e.g., outdoor re-set control for residential boilers), for most products, DOE has interpreted its authority to preclude control requirements (or any other prescriptive requirements) on top of performance requirements.

the machine's highest dryness level setting.) Controls that work well at sensing when clothes are just dry will yield better efficiency ratings than those that shut off too soon (leaving the clothes wet) or those that run too long (over-drying). This revised test method is now used for the ENERGY STAR program, and it (or a further revision) will be used for the next DOE standard.

Therefore, the best approach, when possible, is to devise a test procedure that measures performance of a product and its controls under real-world conditions; this way, units with more-effective controls will get credit for their improved design. If capturing the effectiveness of the control in the test method is prohibitively costly or complicated, then using a credit may be a useful alternative.

Software or firmware updates post installation. More and more products are Internet connected and capable of receiving software upgrades that impact energy use, either positively or negatively. These manufacturer-provided upgrades may introduce new product capabilities, new schedules or cycle options, new sleep mode settings, or other features. DOE recently moved to address this issue in an update to the clothes washer test procedure (DOE 2015d). Under DOE's approach for clothes washers, every time manufacturers send out a new software/hardware setting that changes the operation of a unit, they have to confirm that the unit with the new settings will still meet the standard. DOE should consider this approach for other products and perhaps apply it generally. In addition, DOE should monitor the market for connected appliances and use field data to stay abreast of how real-world consumption may diverge from the levels expected under a given standard.

RECOMMENDATION 2. SYSTEMATICALLY ASSESS OPPORTUNITIES TO EXPAND SCOPE AND CONDUCT RULEMAKINGS FOR THE BIGGEST NEW OPPORTUNITIES

A systematic assessment of new standards opportunities within DOE's existing authority will enable the agency to identify new standards work that can deliver increased savings. DOE can expand the scope of the national standards program in two ways. First, subject to statutory limitations, the agency can develop standards for categories of products not previously subject to national standards. Second, DOE can, in some cases, expand the types of a given product category that are subject to standards. During the Obama administration, DOE has exercised its authority in both of these areas, developing standards for products such as pumps and fans and expanding coverage to new types of already-regulated products such as motors and refrigerators.

There are constraints on DOE's authority. For DOE to establish standards, consumer products must meet energy use thresholds (annual per-household consumption of 150 kWh and annual national consumption of 4.2 TWh), and only a specified list of commercial and industrial products can be covered. For products already subject to standards, there may be particular limitations or opportunities to expand coverage depending on existing law.

Televisions are one product currently not subject to national standards that DOE should consider, although only in coordination with California state standards work. Computers are another category for which California has taken the lead, with standards under development in 2016.

Examples of where DOE could extend coverage of existing standards to types of products previously excluded include additional types of small motors, additional integral horsepower motors (including advanced motor technologies), high color rendering index (CRI) linear fluorescent lamps, two-foot linear fluorescent lamps, and additional pumps such as wastewater pumps. Also, some of the categories of commercial and industrial products for which DOE is permitted to develop standards are very broad (e.g., "electric lights" and "refrigeration equipment"). This authority may be a mechanism for DOE to extend standards to technologies left out of current regulation or to consolidate existing standards into technology-neutral categories. For example, reflector lamps using incandescent and LED technologies are both electric lights, but they are not subject to the same standards.

Figures 5 and 6 show projections for changes in energy consumption through 2040 for residential and commercial end uses, respectively. Notably, many products subject to existing standards observe a projected decline in energy use over this period. These declines will be even greater with additional standards updates. Air conditioners are an exception: Residential space cooling is expected to increase dramatically, mainly due to population growth in hot climates and warming weather trends. Several categories subject to only modest current standards (e.g., televisions, dryers, cooking products) see a projected increase.

Most notably, the category with by far the largest absolute increase in projected energy use in both sectors is the loosely defined "other uses." "Other uses" now account for 21% of residential and 38% of commercial energy consumption (EIA 2015a). The growth of "other uses" suggests that there may be some hidden opportunities for new standards among these end uses. DOE should mine this category for additional opportunities for standards.[19]

[19] Many of these growing uses are electronic products. Energy waste from low power factor in electronics and inductive loads represents a potential energy-saving opportunity on both the customer and the utility sides of the meter. Future analysis should explore potential savings from higher power factor requirements for electronics and inductive loads.

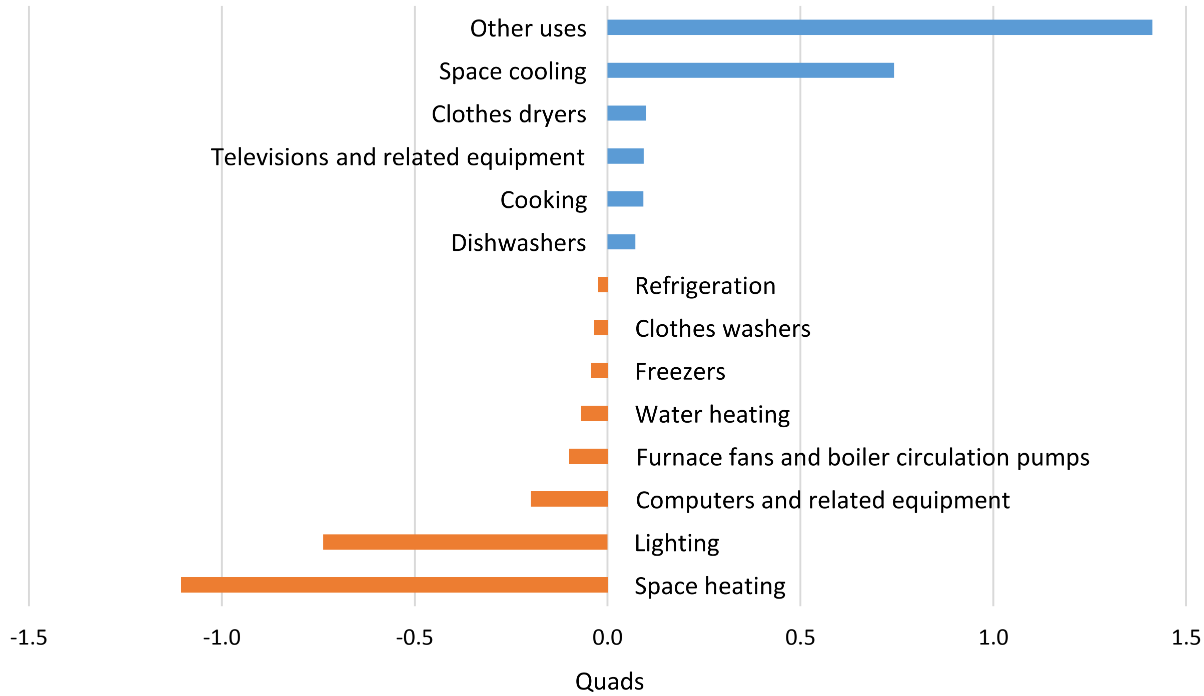

Figure 5. Projected change in energy consumption (quads) for residential energy uses from 2015–2040. ***Source:*** **EIA 2015a.**

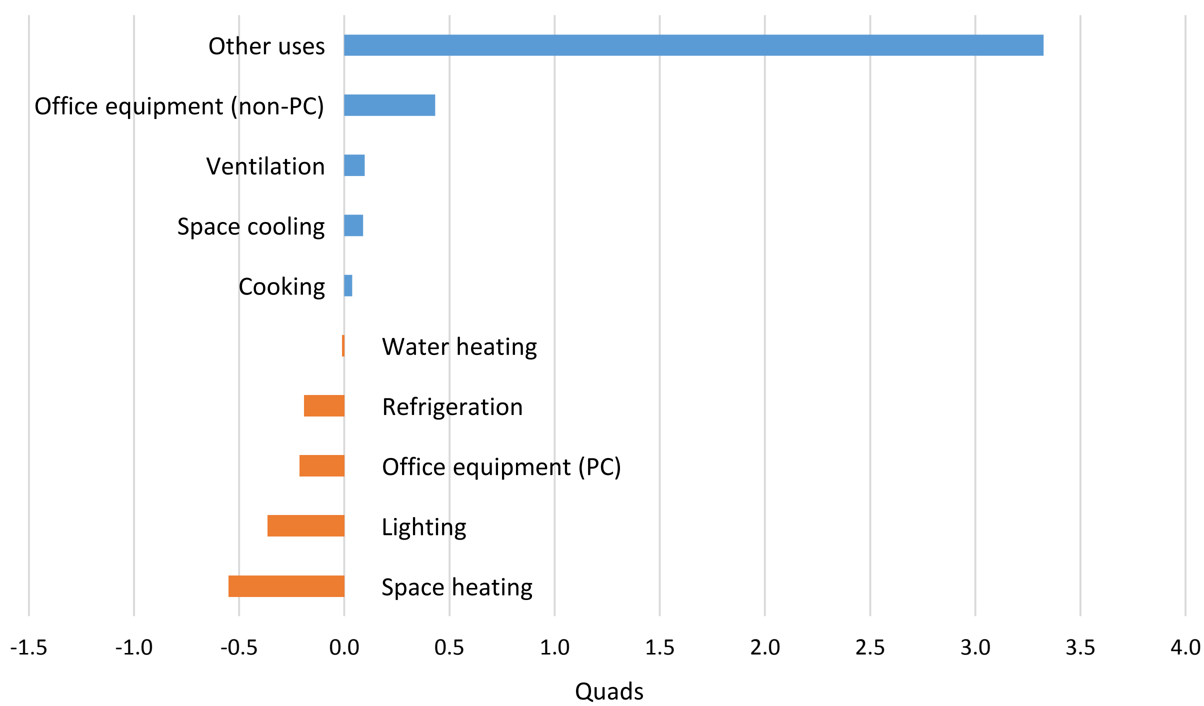

Figure 6. Projected change in energy consumption (quads) for commercial energy uses from 2015–2040. ***Source:*** **EIA 2015a.**

The paragraphs below describe rationales for why DOE should consider standards for several products currently outside the scope of existing national standards.

TELEVISIONS

In 2009, the California Energy Commission (CEC) adopted mandatory efficiency standards for televisions, the first such standards in the nation. The standards apply only to televisions 55 inches or smaller and are two-tiered; the first tier went into effect in 2011 and the second, more stringent tier took effect in 2013. These state-level standards have been effective at reducing the energy consumption of televisions nationwide, since manufacturers have been implementing efficiency strategies on all televisions sold in the United States to meet California's standards. However, according to DOE, televisions still consume 4–5% of the electricity used by all households in the nation, with each household having on average 2.8 televisions. The features most in demand by consumers include larger screen sizes, higher resolution (such as ultra-high definition), and Internet-enabled capabilities. All these features significantly increase energy consumption. For instance, recent research found that ultra-high-definition televisions use on average 30% more energy than regular high-definition units (NRDC 2015).

Given the expected growth of energy-intensive features, standards for televisions should be updated to ensure efficient designs. Since the California regulations have been effective up to this point as de facto national standards, we recommend that DOE coordinate with CEC to ensure there is a plan in California to revise the current standards. If CEC is unable to move forward with updating its standards, DOE should consider opening a rulemaking to address the current and future features in television technology.

ADDITIONAL SMALL ELECTRIC MOTORS

The current standards for small motors apply only to open motors and to specific motor technologies: capacitor-start capacitor-run, capacitor-start induction-run, and polyphase motors. Notably, the current standards do not cover enclosed motors or several motor types that are generally less efficient than the covered motors, including shaded pole, split phase, and permanent split capacitor motors. The current standards also do not cover advanced motor technologies such as brushless permanent magnet motors.

ADDITIONAL ELECTRIC MOTORS

The current standards for electric motors apply only to three-phase conventional induction motors. The standards do not cover advanced motor technologies including permanent magnet, switched reluctance, and synchronous reluctance motors. Expanding the scope of the current standards to include all motor technologies would both allow advanced motor technologies to be included in the consideration of future standard levels and provide information to purchasers enabling them to compare efficiency across motor technologies.

ADDITIONAL FLUORESCENT LAMPS

The current standards for general service fluorescent lamps (GSFL) apply to several categories of 4-foot lamps, 8-foot lamps, and U-bend lamps. A significant opportunity exists to broaden coverage to 2-foot lamps, which are currently available in a range of efficiencies. These lamps are the second-most common lamp type (after 4-foot lamps) and have been increasing in market share as a common replacement for U-bend lamps in 2x2 fixtures. Additionally, the current definition of general service fluorescent lamp excludes lamps with a color rendering index (CRI) above 87. Historically, high-CRI fluorescent lamps were a niche product type with very little market share. However, after the adoption of DOE's standards that were intended to shift the market to high-efficiency T8 or T5 lamps, low-efficacy, low-cost T12 lamps were introduced to the market with CRIs of 87 or greater. These products have seen a dramatic increase in market share and represent a way to skirt the general service fluorescent lamp standards, eroding the anticipated savings. DOE should initiate a rulemaking to cover these lamps, perhaps under the agency's broad authority to cover "electric lights."

ADDITIONAL PUMPS SUCH AS WASTEWATER PUMPS

The current standards for pumps apply only to clean water pumps from 1 to 200 hp. Ongoing rulemakings are considering standards for specific additional types of clean water pumps: circulator pumps and pool pumps. Greater savings could be achieved by expanding the pump standards to apply to additional pump types. For example, pumps designed to pump water with a higher solid content (e.g., some wastewater pumps) may represent a significant savings opportunity. The EU is currently developing standards for wastewater pumps (EC 2015).

ELECTRIC LIGHTS

Most DOE standards are technology neutral, meaning DOE can set improved standards levels without regard to the particular technology or design approach enabling that higher level. However some of the current lighting product categories are not technology neutral, which greatly limits DOE's ability to achieve savings for these products. For example, current standards cover "incandescent reflector lamps" (IRLs). LED reflector lamps provide the same service while drawing 80% less electricity, yet the limited technological scope of the IRL standard has prevented DOE from considering LED efficiency levels when developing revised standards.

DOE's existing broad authority to develop standards for "electric lights," a term not defined in statute, may provide a pathway to overcome this barrier to improved standards. Alternatively, DOE could encompass reflector lamps within a future general service lamp standard, similar to DOE's current proposal to supersede existing compact fluorescent lamp and general service incandescent lamp standards with more broadly applied standards. Other lighting products for which DOE should consider moving to broader, technology neutral standards include general service fluorescent lamps, high-intensity discharge lamps, and metal halide lamp fixtures.

RECOMMENDATION 3. CONTINUE TO IMPROVE ANALYSIS METHODS AND DATA SOURCES

DOE's analysis methods have improved significantly over the more than 30 years that the agency has conducted rulemakings. Analyses that once relied on averages now incorporate statistical techniques that reflect variability across many inputs. In general, DOE has moved to reflect marginal effects in its analyses. For example, product prices now reflect incremental markups on efficiency improvements rather than average markups. Nevertheless, DOE's analyses can be further improved. This recommendation includes three components: further improving DOE's use of learning curves to model product prices, conducting retrospective analyses, and enhancing data gathering.

Improve Product Price Estimates

Research has shown that historical price predictions made by DOE in standards rulemaking analyses, which assumed constant prices over time, have consistently overestimated the actual cost to improve efficiency (Desroches et al. 2011; Dale et al. 2009; Nadel and deLaski 2013). Overestimating costs has the effect of undervaluing the economic benefits of higher standard levels. Starting in 2010, DOE began to incorporate learning rates (or experience curves) in estimating future prices for products where data show that real prices have declined over time. While incorporating price trends is a significant improvement to the rulemaking analyses, analyzing price trends of whole categories of equipment fails to capture the price trends of the actual technologies that are employed to improve efficiency. In many cases, the prices of technologies used in high-efficiency equipment will decline much faster than the total price of the equipment. For example, the prices of high-efficiency compressors and vacuum insulation panels, which can be used to improve refrigerator efficiency, are likely to decline much faster than the total price of refrigerators. Similarly, the price of heat pump water heaters is likely to decline much faster than the price of all water heaters.

In a current rulemaking for ceiling fans, DOE for the first time applied a learning rate to a specific technology that can significantly improve efficiency—DC motors and their associated electronics and controls (DOE 2016c). While we recognize the challenge of obtaining sufficient data, we recommend that, where possible, DOE attempt to incorporate learning rates for the actual technologies assumed to be employed to improve efficiency.

Undertake Retrospective Analysis

We recommend that DOE undertake a retrospective analysis of standards that have taken effect within the past few years. This analysis could be used to assess whether the standards have had the energy savings and economic and manufacturer impacts anticipated. To the extent that actual events have diverged from estimates, DOE can use this information to help inform how analyses for future standards can be improved. DOE should periodically (approximately every five years) conduct such retrospective analyses.

Enhance Data Gathering

We recommend that DOE undertake a major data gathering effort aimed at better characterizing the energy usage of products subject to standards. This effort should focus on products with the largest energy savings potential. In each rulemaking process, DOE solicits data early and repeatedly. But often, data available on actual energy use in the field and other critical inputs (e.g., duty cycles, load profiles, etc.) are regional and sometimes rejected by DOE as not representative of national conditions. DOE should work in partnership with regional energy efficiency organizations, utilities, and states to develop a research and data gathering project aimed at better characterizing the consumption of the highest-priority products that will be subject to standards revisions in the years ahead. This data collection effort could assist standards development for years to come, helping to improve both test procedures and analysis of economic and energy savings impacts.

RECOMMENDATION 4. CONSIDER HOW DOE TEST METHODS, RATINGS, AND STANDARDS CAN REALIZE OR FACILITATE SYSTEMS SAVINGS OPPORTUNITIES

Multiple studies have documented large savings available from improving system efficiency, where building systems are defined as "a combination of equipment, operations, controls, accessories, and means of interconnection that use energy to perform a specific function. Building systems may be mechanical, such as climate control systems (heating, ventilating, and air conditioning, or HVAC), or non-mechanical, such as lighting systems or office electronics (Alliance to Save Energy 2016)."

Improved test methods can be a critical step toward improved system efficiency. By capturing more modes of operation or features of a product as shipped by a manufacturer, an improved test method is also likely to capture a larger portion of the system opportunity. Recommendation 1 above addresses test methods. Examples discussed that relate to system efficiency include fan-only operation of commercial air conditioners and occupancy controls for lighting included with refrigeration products.

Because DOE standards apply to the manufacturer or importer of a product and not to the installer, operator, or owner, there are limits to how far standards can go in addressing systems opportunities. How a product is operated, what aftermarket controls are installed, and how a product interacts with other, separately installed products and other building systems are generally outside the reach of product standards.

However there have been some notable exceptions, and these exceptions have sometimes opened the door to significant energy savings. Below we describe some examples of where standards have been able to achieve system-level efficiency improvement and some possibilities for where they might be applied in the future.

Include Energy Use from Related Products

If a product's function directly affects the energy use of another product, this impact can be taken into account in the ratings and standards for the regulated product. DOE's current standard for clothes washers includes the impact of clothes washer operation on water heater and dryer energy use (i.e., the household laundry "system"), which encourages clothes washer designs that reduce hot water use and spin more moisture out of clothes. Pool heaters may be a future candidate for this sort of approach, as good hydraulic efficiency in the heater will reduce energy use by the pool pump.

Provide Higher Ratings for Efficient Packaged Systems

DOE rating methods can encourage system efficiency by allowing higher efficiency ratings for products sold by the manufacturer as a packaged system of components than for components sold separately. DOE's recent pump standards are an example: a pump sold with a variable-speed drive gets a higher efficiency rating than the same pump sold without a drive. This approach encourages pumps sold with drives and may facilitate programs designed to provide rebates or other incentives for efficient pump/drive combinations, but it does not require that all pumps be sold with a drive. DOE refers to the pump standards as an "extended product approach." A similar approach could be used with fans, where fans sold with a variable-speed drive could get a higher efficiency rating than fans sold without a drive.

Use Defaults to Encourage Higher-Efficiency Systems

DOE used another approach with recent standards for walk-in cooler refrigeration systems. If the refrigeration system components (unit coolers and condensing units) are sold separately, they must be rated based on nominal default values for the other major components. These default values are set such that significant performance gains must be achieved by the system component a given manufacturer makes. Since manufacturers of all components must meet performance requirements designed to improve each component, the overall system efficiency improves. Manufacturers that sell both refrigeration system components together have more flexibility in how they comply since they do not have to use these nominal default values and can trade off efficiency between their components to improve the overall system efficiency at least cost.

Each of these examples demonstrates how standards that apply to manufacturers can enhance system-level efficiency, even though the entire system is not subject to DOE standards. We recommend that for products for which system efficiency opportunities appear significant, DOE should consider options for encouraging or requiring system efficiency improvement as part of rulemakings to update test methods, ratings, and standards. By making consideration of system efficiency opportunities a normal part of relevant DOE rulemakings, DOE may be able to uncover new savings opportunities that have previously been ignored by the national standards program.

RECOMMENDATION 5. DEVELOP A STRATEGIC APPROACH TO ADDRESS CONNECTED PRODUCTS

An increasing array of products will be connected to the Internet and internal building networks in the coming years, including products subject to DOE standards. The International Energy Agency (IEA) estimates that 14 billion devices were network connected globally in 2013, and the total will grow to 50 billion by 2020. IEA warns, "In their current state, network-enabled devices carry an inherent paradox. They have enormous potential to deliver diverse efficiencies across many sectors and services, yet they fall far short of their own potential to be energy efficient" (IEA 2014). Other researchers are concerned that a focus on the efficiency of connected devices could hamper broader systems efficiency (Laitner, McDonnell, and Keller 2015). Some utilities and equipment and controls manufacturers envision connected appliances as a tool for ramping up load shifting to times when energy is cheaper, cleaner, or more abundant and for providing grid services (Hledik, Chang, and Leuken 2016).[20]

Some of the largest opportunities for savings from updated standards identified in Part I (e.g., water heaters and air conditioners) reside with products that manufacturers and others are targeting to include connected functionality. Manufacturers of other products are also interested in enhancing them by making them connected. While connected functionality continues to evolve and potential energy efficiency benefits remain largely unquantified, the

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[20] For more information on the evolving opportunities for energy efficiency made possible through information and communications technology, see ACEEE's work on intelligent efficiency: aceee.org/topics/intelligent-efficiency.

growth in connected devices and interest in potential energy savings strongly suggest the need to direct attention to these topics in future test methods and standards.

Connected devices may have additional characteristics with implications for standards. These include:

- a tendency to continuously consume some amount of power to remain connected;
- the potential to be readily controlled in a way that reduces energy use;
- the opportunity for manufacturers or third parties to easily modify function and settings after installation (i.e., remotely); and
- the ability to provide a stream of data on their energy consumption and behavior.

Efforts already exist to develop common communications protocols for products (Thomas 2014), and some manufacturers have a strong commercial interest in offering products that provide enhanced services through connectedness. In 2014–2015, DOE convened a public stakeholder process to better define and characterize connected equipment and the benefits it can provide (DOE 2015e). In February 2016, DOE prepared a white paper on behalf of the Appliance Standards and Rulemaking Federal Advisory Committee (ASRAC), which outlined work to date on connected appliances (DOE 2016b).

For purposes of the national appliance standards program, we recommend that DOE develop a strategic approach that accounts for the potential benefits and energy use of connectedness. A strategic approach consistently applied across relevant dockets will enable DOE to systematically address the intersection between connected devices and national appliance standards. More thinking and research are needed to better define such a strategic approach. However some elements of a strategic approach would be as follows:

- Include energy use due to connectedness in product ratings and standards. If including this energy use in the main metric is unlikely to limit energy waste, then DOE should consider separate standby requirements.
- Allow for innovation, especially in the use of connectedness for energy efficiency purposes. Limits on energy allowed for connectedness should not be so restrictive as to inhibit innovation. In addition, products that have the potential to deliver real-world energy savings due to connected features may merit a higher efficiency rating. However DOE should not trade off relatively certain savings achieved by meeting a given efficiency performance standard against benefits that depend on connected features that may or may not be used in the field.
- Ensure that connected devices do not circumvent standards. Any product that is systematically altered by a manufacturer post-sale or post-installation in such a way that its consumption under the DOE test method would exceed minimum standards should be deemed noncompliant.
- Leverage information potentially available from connected devices to better understand real-world energy consumption and usage patterns. Connected devices may dramatically lower the cost of data gathering, leading to a better understanding of how products are used in the field and how much energy they

consume. This information can inform test method revisions and future standards revisions, making them more representative of real-world usage.

Additional Topics: New Legislation and Certification, Compliance, and Enforcement

The five recommendations above represent near-term, actionable items that DOE can implement to enhance savings from appliance standards. However this list is by no means comprehensive. As mentioned above, potential changes to the law could also open the door to greater savings; Appendix C lists some ideas for potential changes. Another area within DOE's current control is certification, compliance, and enforcement. The Obama administration has prioritized this work, completing and updating certification requirements, including moving to web-based certifications and actively enforcing standards (see text box on page 21). These efforts should be maintained and enhanced. In 2016, DOE proposed regulations to tighten reporting requirements for covered products imported into the United States (DOE 2015d), largely in response to concerns expressed by some manufacturers that importers have sometimes skirted standards. This problem may be most serious for products that are embedded in or are a component of another product (e.g., electric motors, external power supplies, and battery chargers). DOE efforts to ensure high compliance rates with existing standards are essential.

Conclusion

Efficiency standards have resulted in very large energy and economic savings for the nation, and enormous opportunity remains with future standards. In this paper we have estimated the potential savings from the next round of standards after January 2017 and outlined potential strategies to further increase savings. Potential savings from updating existing and pending standards using current product scopes, metrics, test methods, and known technology improvements reach an annual rate of 2.6 quads of energy, 770 billion gallons of water, and $43 billion in utility bill savings in 2035. Annual savings rates grow to 4 quads, 850 billion gallons, and $65 billion in 2050. Cumulative savings by 2050 will reach 70 quads of energy, 3.5 billion metric tons of CO_2, and 17.5 trillion gallons of water, lowering consumer and business utility bills by $1.1 trillion. Deploying additional strategies could boost savings. DOE can achieve additional savings by investing in improved test procedures, systematically assessing opportunities for expanding the scope of national standards, improving analysis techniques and data sources, assessing opportunities for standards to contribute to systems-level savings, and taking into account network connectedness.

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Appendix A. Methodology and Assumptions

We estimate annual electricity, natural gas, oil, and water savings based on estimates of annual shipments of products, per-unit energy and/or water savings, and average product lifetime. For annual shipments, we use estimates of shipments in the year the standard is assumed to take effect. We take into account that some portion of sales will likely meet the assumed standard level even in the absence of a new standard. In general, for products that do not have an ENERGY STAR specification, we assume that 10% of the shipments will meet the assumed standard level in the base case. For products that do have an ENERGY STAR specification, we assume that 25% of shipments will meet the next standard level. In a few cases where available data indicate that the portion of sales meeting the assumed standard level in the base case will be higher than 25% (e.g., faucets, showerheads, and general service lamps), we account for this higher base case.

We assume that both annual shipments and the portion of shipments meeting the assumed standard level in the base case remain constant over time.[21] In reality, both shipments and base case efficiency tend to increase over time. Thus, we implicitly assume that these two factors cancel each other out.

We use the equation below to calculate savings in each year through 2050:

Annual savings = Number of installed units meeting new standard * Per-unit savings * (1 – % of shipments meeting new standard)

where the number of installed units meeting new standard is:

- Before stock turnover: Annual shipments * (Number of years after compliance date + 0.5)
- After stock turnover: Annual shipments * Average product lifetime

In calculating the number of installed units meeting the new standard before stock turnover (in the equation above), we account for products being purchased throughout the year. Thus, in any given year we count only one-half year of savings from products purchased in that year.

Tables A1 and A2 below show our assumptions for compliance date, annual shipments, average lifetime, and per-unit savings for residential products and commercial and industrial products, respectively. For residential products that are also used in the commercial/industrial sector and vice versa (e.g., incandescent reflector lamps and toilets), the assumptions for annual shipments, average lifetime, and per-unit savings correspond to the product and not to the specific sector.

[21] We assume declining shipments over time for incandescent reflector lamps and metal halide lamp fixtures.

Table A1. Assumptions for compliance date, annual shipments, average lifetime, and per-unit savings for residential products

Product	Compliance date	Annual shipments (million)	Average lifetime (years)	Per-unit savings	Units	% savings
Battery chargers	2026	555.7	3.7	0.8	kWh	58%
Boilers*	2029	0.4	–	–	–	–
Gas	–	0.3	26.2	12	MMBtu	14%
Electricity	–	–	–	(108)	kWh	–59%
Oil	–	0.1	24.4	4.7	MMBtu	6%
Electricity	–	–	–	(31)	kWh	–14%
Ceiling fans	2027	22.0	13.8	17	kWh	24%
Central air conditioners and heat pumps	2029	8.7	–	–	–	–
Air conditioners	–	5.2	19.2	205	kWh	12%
Heat pumps	–	3.4	16.4	811	kWh	24%
Clothes dryers	2022	8.6	–	–	–	–
Electric	–	6.8	16.0	257	kWh	30%
Gas	–	1.8	16.0	0.9	MMBtu	30%
Clothes washers	2024	10.5	14.2	–	–	–
Electricity	–	–	–	29	kWh	7%
Gas	–	–	–	0.2	MMBtu	30%
Water	–	–	–	1,392	gallons	24%
Dehumidifiers	2027	2.2	11.1	76	kWh	14%
Direct heating equipment	2023	0.1	15.0	2.8	MMBtu	10%
External power supplies	2023	288.9	4.6	1.4	kWh	32%
Faucets	2024	47.2	–	–	–	–
Residential lavatory	–	31.3	10.0	–	–	–
Electricity	–	–	–	13	kWh	45%
Gas	–	–	–	0.1	MMBtu	45%
Water	–	–	–	394	gallons	45%
Kitchen	–	16.0	10.0	–	–	–
Electricity	–	–	–	33	kWh	18%
Gas	–	–	–	0.2	MMBtu	18%
Water	–	–	–	986	gallons	18%
Furnaces	2029	3.5	21.5	2.5	MMBtu	7%
Furnace fans	2027	4.3	21.2	86	kWh	16%
General service lamps	2025	236.6	18.1	0.5	kWh	6%
Incandescent reflector lamps	2024	118.0	2.0	36	kWh	34%
Microwave ovens	2024	16.0	10.9	9	kWh	98%
Pool heaters	2023	0.2	10.0	5	MMBtu	14%
Portable air conditioners	2027	1.4	10.5	202	kWh	29%
Ranges and ovens	2028	8.8	–	–	–	–
Electric	–	6.0	15.0	25	kWh	16%
Gas	–	2.8	17.0	0.03	MMBtu	4%
Refrigerators and freezers	2022	20.7	15.6	81	kWh	18%
Room air conditioners	2022	8.8	10.3	34	kWh	7%
Showerheads	2024	16.6	10.0	–	–	–
Electricity	–	–	–	82	kWh	28%
Gas	–	–	–	0.6	MMBtu	28%
Water	–	–	–	1,672	gallons	28%
Toilets	2024	16.9	22.3	269	gallons	20%
Water heaters	2023	11.4	–	–	–	–
Gas-fired storage	–	4.4	13.0	3.6	MMBtu	23%
Electric storage	–	5.4	13.0	1,090	kWh	47%
Oil-fired storage	–	0.0	13.0	1.7	MMBtu	10%
Gas-fired instantaneous	–	1.5	20.0	1.5	MMBtu	14%
Wine chillers	2027	1.7	10.6	99	kWh	54%

*Boilers have negative electricity savings due to additional electricity consumption of pumps and heat tape at the evaluated standard level.

Table A2. Assumptions for compliance date, annual shipments, average lifetime, and per-unit savings for commercial and industrial products

Product	Compliance date	Annual shipments (million)	Average lifetime (years)	Per-unit savings	Units	% savings
Automatic ice makers	2026	0.2	8.5	324	kWh	8%
Beverage vending machines	2027	0.1	13.4	503	kWh	38%
Commercial boilers*	2027	0.03	–	–	–	–
Gas-fired	–	0.02	24.8	112	MMBtu	9%
Electricity	–	–	–	(141)	kWh	-30%
Oil-fired	–	0.00	24.8	48	MMBtu	5%
Electricity	–	–	–	(145)	kWh	-23%
Commercial clothes washers	2026	0.2	10.7	–	–	–
Electricity	–	–	–	99	kWh	12%
Gas	–	–	–	0.1	MMBtu	2%
Water	–	–	–	3,286	gallons	13%
Commercial furnaces*	2029	0.3	–	–	–	–
Gas-fired	–	0.3	23.0	19	MMBtu	12%
Electricity	–	–	–	(217)	kWh	-26%
Oil-fired	–	0.003	23.0	10	MMBtu	9%
Electricity	–	–	–	(239)	kWh	-35%
Commercial packaged air conditioners and heat pumps	2029	0.3	22.5	4,658	kWh	26%
Commercial refrigeration equipment	2025	1.6	10.0	330	kWh	8%
Commercial three-phase air conditioners and heat pumps	2026	0.3	18.5	516	kWh	19%
Commercial water heaters	2027	0.2	12.9	6	MMBtu	4%
Compressors	2028	1.6	9.7	1,204	kWh	36%
Computer room air conditioners	2023	0.02	15.0	8,824	kWh	27%
Distribution transformers**	2024	0.1	32.0	11,910	kWh	40-72%
Electric motors	2025	8.7	15.6	193	kWh	1%
Fans***	2029	0.5	28.3	3,463	kWh	8%
Metal halide lamp fixtures	2025	1.9	23.6	58	kWh	5%
Packaged terminal air conditioners and heat pumps	2026	0.6	8.0	137	kWh	9%
Pumps***	2027	0.5	13.0	668	kWh	3%
Single-package vertical air conditioners and heat pumps	2026	0.1	15.0	503	kWh	5%
Small motors	2023	5.0	7.4	45	kWh	7%
Urinals	2024	0.9	12.0	2,504	gallons	88%
Water-source heat pumps	2026	0.2	19.0	1,591	kWh	36%

*Commercial boilers and furnaces have negative electricity savings due to additional electricity consumption of pumps, fans, and heat tape at the evaluated standard levels. ** For distribution transformers, shipments and per-unit savings are in terms of MVA, and the % savings represent the reduction in losses. *** The % savings for fans and pumps are relative to the base case efficiency distribution.

We calculate total primary energy savings (quads) by summing primary electricity, natural gas, and oil savings. We use average heat rates to convert site electricity savings to primary energy savings. Table A3 shows the heat rates used over the analysis period (EIA 2015a).[22]

Table A3. Assumptions for heat rates

	2025	2030	2035	2040	2045	2050
Heat rate (Btu/kWh)	10,174	10,072	10,000	9,923	9,923	9,923

We calculate utility bill savings by multiplying annual electricity, natural gas, oil, and water savings by respective average prices. For energy bill savings, we use residential energy prices for residential products and commercial energy prices for commercial and industrial products, with the exception of compressors, electric motors, fans, pumps, and small motors, where we use a weighted average of commercial and industrial electricity prices. Table A4 shows the energy and water prices used over the analysis period (EIA 2015a; DOE 2014b).

Table A4. Assumptions for electricity, natural gas, fuel oil, and water and wastewater prices

	2025	2030	2035	2040	2045	2050
Electricity price (2013$/kWh)						
Residential	0.135	0.136	0.139	0.145	0.145	0.145
Commercial	0.111	0.111	0.113	0.118	0.118	0.118
Industrial	0.076	0.077	0.079	0.084	0.084	0.084
Natural gas price (2013$/MMBtu)						
Residential	12.71	12.79	13.75	15.47	15.47	15.47
Commercial	10.54	10.40	11.12	12.62	12.62	12.62
Fuel oil price (2013$/MMBtu)						
Residential	23.67	26.35	29.39	32.90	32.90	32.90
Commercial	23.22	25.84	28.91	32.45	32.45	32.45
Water and wastewater price (2013$/thous. gal.)	10.36	11.31	12.26	13.21	13.21	13.21

Finally, we calculate CO_2 emissions by multiplying annual electricity, natural gas, and oil savings by respective average CO_2 emissions factors. Table A5 shows the CO_2 emissions factors used over the analysis period (EIA 2015a).

Table A5. Assumptions for CO_2 emissions factors

	2025	2030	2035	2040	2045	2050
Electricity (MMT/TWh)	0.536	0.525	0.513	0.499	0.499	0.499
Natural gas (MMT/quad)	53.1	53.1	53.1	53.1	53.1	53.1
Fuel oil (MMT/quad)	73.2	73.2	73.2	73.2	73.2	73.2

[22] We use projections for 2040 from AEO for 2041–2050.

Appendix B. Sources for Product Assumptions

Table B1. Sources for product assumptions for residential products

Product	Sources
Battery chargers	DOE, *Technical Support Document: Energy Efficiency Program for Consumer Products and Commercial and Industrial Equipment: Battery Chargers* (Washington, DC: DOE, 2015). www.regulations.gov/#!documentDetail;D=EERE-2008-BT-STD-0005-0230. DOE, *Analytical Spreadsheets: BC SNOPR National Impact Analysis (NIA)* (Washington, DC: DOE, 2015). www.regulations.gov/#!documentDetail;D=EERE-2008-BT-STD-0005-0227.
Boilers	DOE, *Technical Support Document: Energy Efficiency Program for Consumer Products and Commercial and Industrial Equipment: Residential Boilers* (Washington, DC: DOE, 2015). www.regulations.gov/#!documentDetail;D=EERE-2012-BT-STD-0047-0070.
Ceiling fans	DOE, Technical Support Document: Energy Efficiency Program for Consumer Products and Commercial and Industrial Equipment: Ceiling Fans (Washington, DC: DOE, 2015). www.regulations.gov/#!documentDetail;D=EERE-2012-BT-STD-0045-0125.
Central air conditioners and heat pumps	DOE, *Technical Support Document: Energy Efficiency Program for Consumer Products: Residential Central Air Conditioners and Heat Pumps* (Washington, DC: DOE, 2015). www.regulations.gov/#!documentDetail;D=EERE-2014-BT-STD-0048-0029. DOE, *2015-08 NODA Spreadsheet: National Impact Analysis (NIA)* (Washington, DC: DOE, 2015). www.regulations.gov/#!documentDetail;D=EERE-2014-BT-STD-0048-0031 DOE, *Working Group Meeting Presentation: CAC and HP ASRAC Working Group Fifth and Sixth Meetings* (Washington, DC: DOE, 2015). www.regulations.gov/#!documentDetail;D=EERE-2014-BT-STD-0048-0052.
Clothes dryers	DOE, *Technical Support Document: Energy Efficiency Program for Consumer Products and Commercial and Industrial Equipment: Residential Clothes Dryers and Room Air Conditioners* (Washington, DC: DOE, 2011). www.regulations.gov/#!documentDetail;D=EERE-2007-BT-STD-0010-0053. DOE, *Energy Conservation Program: Test Procedures for Residential Clothes Dryers: Proposed Rule* (Washington, DC: DOE, 2013). www.regulations.gov/#!documentDetail;D=EERE-2011-BT-TP-0054-0006 www.energystar.gov/products/appliances/clothes_dryers www.energystar.gov/about/awards/energy-star-emerging-technology-award/2014-emerging-technology-award-advanced-clothes-dryers.
Clothes washers	DOE, *Technical Support Document: Energy Efficiency Program for Consumer Products and Commercial and Industrial Equipment: Residential Clothes Washers* (Washington, DC: DOE, 2012). www.regulations.gov/#!documentDetail;D=EERE-2008-BT-STD-0019-0047; DOE, *2012-05 National Impact Analysis* (Washington, DC: DOE, 2012). www.regulations.gov/#!documentDetail;D=EERE-2008-BT-STD-0019-0046.
Dehumidifiers	DOE, *Technical Support Document: Energy Efficiency Program for Consumer Products and Commercial and Industrial Equipment: Residential Dehumidifiers* (Washington, DC: DOE, 2015). www.regulations.gov/#!documentDetail;D=EERE-2012-BT-STD-0027-0030.

Product	Sources
Direct heating equipment	DOE, *Technical Support Document: Energy Efficiency Program for Consumer Products and Commercial and Industrial Equipment: Residential Water Heaters, Direct Heating Equipment, and Pool Heaters (*Washington, DC: DOE, 2010). www.regulations.gov/#!documentDetail;D=EERE-2006-STD-0129-0149.
External power supplies	DOE, *Technical Support Document: Energy Efficiency Program for Consumer Products and Commercial and Industrial Equipment: External Power Supplies (*Washington, DC: DOE, 2014). www.regulations.gov/#!documentDetail;D=EERE-2008-BT-STD-0005-0217.
Faucets	California Investor-Owned Utilities. *Faucets: Codes and Standards Enhancement (CASE) Initiative for PY 2013: Title 20 Standards Development: Analysis of Standards Proposal for Residential Faucets and Faucet Accessories*, 2013. www.energy.ca.gov/appliances/2013rulemaking/documents/proposals/12-AAER-2C_Water_Appliances/California_IOUs_and_Natural_Resources_defense_Councils_Response_to_the_Invitation_for_Standards_Proposals_for_Faucets_-_Updated_2013-08-05_TN-71810.pdf. CEC. *Staff Analysis of Water Efficiency Standards for Toilets, Urinals, and Faucets*, 2015. docketpublic.energy.ca.gov/PublicDocuments/15-AAER-01/TN203718_20150220T141432_Staff_Analysis_of_Water_Efficiency_Standards_for_Toilets_Urinal.pdf. DOE, *Compliance Certification Database,* accessed October 18, 2015. www.regulations.doe.gov/certification-data/#q=Product_Group_s%3A*.
Furnaces	DOE, *Technical Support Document: Energy Efficiency Program for Consumer Products and Commercial and Industrial Equipment: Residential Furnaces (*Washington, DC: DOE, 2015). www.regulations.gov/#!documentDetail;D=EERE-2014-BT-STD-0031-0027. DOE, *NOPR Spreadsheets: Residential Furnace National Impact Analysis (NIA) (*Washington, DC: DOE, 2015). www.regulations.gov/#!documentDetail;D=EERE-2014-BT-STD-0031-0022.
Furnace fans	DOE, *Technical Support Document: Energy Efficiency Program for Consumer Products and Commercial and Industrial Equipment: Residential Furnace Fans (*Washington, DC: DOE, 2014). www.regulations.gov/#!documentDetail;D=EERE-2010-BT-STD-0011-0111. DOE, *Final Rule National Impact Analysis Spreadsheet (*Washington, DC: DOE, 2014). www.regulations.gov/#!documentDetail;D=EERE-2010-BT-STD-0011-0116.
General service lamps	DOE, *Technical Support Document: Energy Efficiency Program for Consumer Products and Commercial and Industrial Equipment: General Service Lamps (*Washington, DC: DOE, 2016). www.regulations.gov/#!documentDetail;D=EERE-2013-BT-STD-0051-0042. DOE, *NOPR Analytical Spreadsheet: National Impact Analysis and Shipments Analysis (*Washington, DC: DOE, 2016). www.regulations.gov/#!documentDetail;D=EERE-2013-BT-STD-0051-0040.

Product	Sources
Incandescent reflector lamps	DOE, *Final Rule Technical Support Document (TSD): Energy Conservation Standards for General Service Fluorescent Lamps and Incandescent Reflector Lamps* (Washington, DC: DOE, 2009). www.regulations.gov/#!documentDetail;D=EERE-2006-STD-0131-0147. DOE, *Final Rule Technical Support Document: Energy Efficiency Program for Consumer Products and Commercial and Industrial Equipment: General Service Fluorescent Lamps and Incandescent Reflector Lamps* (Washington, DC: DOE, 2014). www.regulations.gov/#!documentDetail;D=EERE-2011-BT-STD-0006-0066. DOE, *2014 National Impacts Analysis and Shipments Analysis for DOE's Final Rule Analysis for GSFL and IRL (Final Rule)* (Washington, DC: DOE, 2014). www.regulations.gov/#!documentDetail;D=EERE-2011-BT-STD-0006-0062. DOE, 2010-05-26 Presentation Slides (Washington, DC: DOE, 2010). www.regulations.gov/#!documentDetail;D=EERE-2010-BT-STD-0005-0007.
Microwave ovens	DOE, *Technical Support Document: Energy Efficiency Program for Consumer Products and Commercial and Industrial Equipment: Residential Microwave Ovens: Stand-By Power* (Washington, DC: DOE, 2013). www.regulations.gov/#!documentDetail;D=EERE-2011-BT-STD-0048-0021. DOE, *National Impact Analysis for Microwave Ovens* (Washington, DC: DOE, 2013). www.regulations.gov/#!documentDetail;D=EERE-2011-BT-STD-0048-0024.
Pool heaters	DOE, *Technical Support Document: Energy Efficiency Program for Consumer Products and Commercial and Industrial Equipment: Residential Water Heaters, Direct Heating Equipment, and Pool Heaters* (Washington, DC: DOE, 2010). www.regulations.gov/#!documentDetail;D=EERE-2006-STD-0129-0149.
Portable air conditioners	DOE, *Technical Support Document: Energy Efficiency Program for Consumer Products and Commercial and Industrial Equipment: Portable Air Conditioners* (Washington, DC: DOE, 2016). www.regulations.gov/?#!documentDetail;D=EERE-2013-BT-STD-0033-0018.
Ranges and ovens	DOE, *Technical Support Document: Energy Efficiency Program for Consumer Products and Commercial and Industrial Equipment: Residential Conventional Ovens* (Washington, DC: DOE, 2015). www.regulations.gov/#!documentDetail;D=EERE-2014-BT-STD-0005-0018.
Refrigerators and freezers	DOE, *Technical Support Document: Energy Efficiency Program for Consumer Products and Commercial and Industrial Equipment: Residential Refrigerators, Refrigerator-Freezers, and Freezers* (Washington, DC: DOE, 2011). www.regulations.gov/#!documentDetail;D=EERE-2008-BT-STD-0012-0128. DOE, *2011-08-30 Analytical Tools: National Impact Analysis for Residential Refrigerators, Refrigerator-Freezers, and Freezers Final Rule* (Washington, DC: DOE, 2011). www.regulations.gov/#!documentDetail;D=EERE-2008-BT-STD-0012-0130.
Room air conditioners	DOE, *Technical Support Document: Energy Efficiency Program for Consumer Products and Commercial and Industrial Equipment: Residential Clothes Dryers and Room Air Conditioners* (Washington, DC: DOE, 2011). www.regulations.gov/#!documentDetail;D=EERE-2007-BT-STD-0010-0053.

Product	Sources
Showerheads	California Investor-Owned Utilities, *Showerheads: Codes and Standards Enhancement (CASE) Initiative for PY 2015: Title 20 Standards Development: Analysis of Standards Proposal for Showerheads*, 2015. docketpublic.energy.ca.gov/PublicDocuments/15-AAER-05/TN205606_20150731T141501_Sarah_Schneider_Energy_Solutions_on_behalf_of_California_IOUs_C.pdf. CEC, *Staff Analysis of Water Efficiency Standards for Showerheads*, 2015. www.energy.ca.gov/business_meetings/2015_packets/2015-08-12/Item_06/Item_6_Showerhead_Staff_Report_8-6-15.pdf. DOE, *Compliance Certification Database,* Accessed October 18, 2015. www.regulations.doe.gov/certification-data/#q=Product_Group_s%3A*.
Toilets	California Investor-Owned Utilities, *Toilets and Urinals Water Efficiency: Codes and Standards Enhancement (CASE) Initiative for PY 2013: Title 20 Standards Development: Analysis of Standards Proposal for Toilets and Urinals Water Efficiency*, 2013. www.energy.ca.gov/appliances/2013rulemaking/documents/proposals/12-AAER-2C_Water_Appliances/California_IOUs__and__Natural_Resources_defense_Councils_Responses_to_the_Invitation_for_Standards_Proposals_for_Toilets__and__Urinals_2013-07-29_TN-71765.pdf. CEC. *Staff Analysis of Water Efficiency Standards for Toilets, Urinals, and Faucets*, 2015. docketpublic.energy.ca.gov/PublicDocuments/15-AAER-01/TN203718_20150220T141432_Staff_Analysis_of_Water_Efficiency_Standards_for_Toilets_Urinal.pdf. DOE, *Compliance Certification Database,* Accessed October 18, 2015. www.regulations.doe.gov/certification-data/#q=Product_Group_s%3A*.
Water heaters	DOE, *Technical Support Document: Energy Efficiency Program for Consumer Products and Commercial and Industrial Equipment: Residential Water Heaters, Direct Heating Equipment, and Pool Heaters* (Washington, DC: DOE, 2010). www.regulations.gov/#!documentDetail;D=EERE-2006-STD-0129-0149. DOE, *2010-03-23 National Impact Analysis Water Heaters* (Washington, DC: DOE, 2010). www.regulations.gov/#!documentDetail;D=EERE-2006-STD-0129-0148.
Wine chillers	DOE, *2015-08-30 Working Group Materials: DRAFT National Impact Analysis Model Spreadsheet (NIA model with original cost curve 2015-08-30)* (Washington, DC: DOE, 2015). www.regulations.gov/#!documentDetail;D=EERE-2011-BT-STD-0043-0073. DOE, *2015-08-31 Working Group Materials: DRAFT Consumer Economic Results Spreadsheet (Consumer economic results 2015-08-31)* (Washington, DC: DOE, 2015). www.regulations.gov/#!documentDetail;D=EERE-2011-BT-STD-0043-0074. DOE, *2015-08-30 Working Group Materials: DRAFT Life Cycle Cost Model Spreadsheet (LCC model with original cost curve 2015-08-30)* (Washington, DC: DOE, 2015). www.regulations.gov/#!documentDetail;D=EERE-2011-BT-STD-0043-0072.

Table B2. Sources for product assumptions for commercial and industrial products

Product	Sources
Automatic ice makers	DOE, *Technical Support Document: Energy Efficiency Program for Consumer Products and Commercial and Industrial Equipment: Automatic Commercial Ice Makers* (Washington, DC: DOE, 2014). www.regulations.gov/#!documentDetail;D=EERE-2010-BT-STD-0037-0136.
Beverage vending machines	DOE, *Technical Support Document: Energy Efficiency Program for Consumer Products and Commercial and Industrial Equipment: Refrigerated Bottled or Canned Beverage Vending Machines* (Washington, DC: DOE, 2015). www.regulations.gov/#!documentDetail;D=EERE-2013-BT-STD-0022-0067. DOE, *Final Rule Beverage Vending Machine Spreadsheet: National Impact Analysis (NIA)* (Washington, DC: DOE, 2015). www.regulations.gov/#!documentDetail;D=EERE-2013-BT-STD-0022-0069.
Commercial boilers	DOE, *Technical Support Document: Energy Efficiency Program for Consumer Products and Commercial and Industrial Equipment: Commercial Packaged Boilers* (Washington, DC: DOE, 2016). www.regulations.gov/#!documentDetail;D=EERE-2013-BT-STD-0030-0044. DOE, *2016-03-15 NOPR Analysis Spreadsheet: Commercial Packaged Boiler National Impact Analysis (NIA)* (Washington, DC: DOE, 2016). www.regulations.gov/#!documentDetail;D=EERE-2013-BT-STD-0030-0047.
Commercial clothes washers	DOE, *Technical Support Document: Energy Efficiency Program for Consumer Products and Commercial and Industrial Equipment: Commercial Clothes Washers* (Washington, DC: DOE, 2014). www.regulations.gov/#!documentDetail;D=EERE-2012-BT-STD-0020-0036. DOE, *Final Rule National Impact Analysis Spreadsheet (FR_CCW__NIA_2014_09)* (Washington, DC: DOE, 2014). www.regulations.gov/#!documentDetail;D=EERE-2012-BT-STD-0020-0034.
Commercial furnaces	DOE, *Technical Support Document: Energy Efficiency Program for Consumer Products and Commercial and Industrial Equipment: Commercial Warm Air Furnaces* (Washington, DC: DOE, 2015). www.regulations.gov/#!documentDetail;D=EERE-2013-BT-STD-0021-0050.
Commercial packaged air conditioners and heat pumps	DOE, *Technical Support Document: Energy Efficiency Program for Consumer Products and Commercial and Industrial Equipment: Small, Large, and Very Large Commercial Package Air Conditioning and Heating Equipment* (Washington, DC: DOE, 2015). www.regulations.gov/#!documentDetail;D=EERE-2013-BT-STD-0007-0105. DOE, *Direct Final Rule National Impact Analysis Spreadsheet* (Washington, DC: DOE, 2015). www.regulations.gov/#!documentDetail;D=EERE-2013-BT-STD-0007-0107.
Commercial refrigeration equipment	DOE, *Technical Support Document: Energy Efficiency Program for Consumer Products and Commercial and Industrial Equipment: Commercial Refrigeration Equipment* (Washington, DC: DOE, 2014). www.regulations.gov/#!documentDetail;D=EERE-2010-BT-STD-0003-0102.
Commercial three-phase air conditioners and heat pumps	DOE, *Technical Support Document: Energy Efficiency Program for Consumer Products and Commercial and Industrial Equipment: ASHRAE Equipment* (Washington, DC: DOE, 2015). www.regulations.gov/#!documentDetail;D=EERE-2014-BT-STD-0015-0043.

Product	Sources
Commercial water heaters	DOE, *Technical Support Document: Energy Efficiency Program for Consumer Products and Commercial and Industrial Equipment: Commercial Water Heating Equipment* (Washington, DC: DOE, 2016). www.regulations.gov/#!documentDetail;D=EERE-2014-BT-STD-0042-0016.
Compressors	DOE, *Technical Support Document: Energy Efficiency Program for Consumer Products and Commercial and Industrial Equipment: Air Compressors* (Washington, DC: DOE, 2016). www.regulations.gov/#!documentDetail;D=EERE-2013-BT-STD-0040-0037. DOE, *2016-02-12 NOPR Analytical Spreadsheet: National Impact Analysis (NIA) Spreadsheet* (Washington, DC: DOE, 2016). www.regulations.gov/#!documentDetail;D=EERE-2013-BT-STD-0040-0034.
Computer room air conditioners	DOE, *Technical Support Document: Energy Efficiency Program for Consumer Products and Commercial and Industrial Equipment: ASHRAE Equipment* (Washington, DC: DOE, 2012). www.regulations.gov/#!documentDetail;D=EERE-2011-BT-STD-0029-0021.
Distribution transformers	DOE, *Technical Support Document: Energy Efficiency Program for Consumer Products and Commercial and Industrial Equipment: Distribution Transformers* (Washington, DC: DOE, 2013). www.regulations.gov/#!documentDetail;D=EERE-2010-BT-STD-0048-0760. DOE, *Final Rule: National Impacts Analysis Spreadsheet* (Washington, DC: DOE, 2013). www.regulations.gov/#!documentDetail;D=EERE-2010-BT-STD-0048-0765.
Electric motors	DOE, *Technical Support Document: Energy Efficiency Program for Consumer Products and Commercial and Industrial Equipment: Electric Motors* (Washington, DC: DOE, 2014). www.regulations.gov/#!documentDetail;D=EERE-2010-BT-STD-0027-0108. DOE, *Final Rule. National Impact Analysis Design AB Spreadsheet* (Washington, DC: DOE, 2014). www.regulations.gov/#!documentDetail;D=EERE-2010-BT-STD-0027-0112. DOE, *Final Rule. National Impact Analysis Design C* (Washington, DC: DOE, 2014). www.regulations.gov/#!documentDetail;D=EERE-2010-BT-STD-0027-0113. DOE, *Final Rule. National Impact Analysis Fire Pump Spreadsheet* (Washington, DC: DOE, 2014). www.regulations.gov/#!documentDetail;D=EERE-2010-BT-STD-0027-0114. DOE, *Final Rule. National Impact Analysis Brake Spreadsheet* (Washington, DC: DOE, 2014). www.regulations.gov/#!documentDetail;D=EERE-2010-BT-STD-0027-0111.
Fans	DOE, *Working Group Materials: ASRAC Fan Working Group Analytical Results Presentation—corrected version (DOE NODA with static results)* (Washington, DC: DOE, 2015). www.regulations.gov/#!documentDetail;D=EERE-2013-BT-STD-0006-0141. DOE, *2015 NODA (2) National Impact Analysis (NIA) Spreadsheet* (Washington, DC: DOE, 2015). www.regulations.gov/#!documentDetail;D=EERE-2013-BT-STD-0006-0061.
Metal halide lamp fixtures	DOE, *Technical Support Document: Energy Efficiency Program for Consumer Products and Commercial and Industrial Equipment: Metal Halide Lamp Fixtures* (Washington, DC: DOE, 2014). *www.regulations.gov/#!documentDetail;D=EERE-2009-BT-STD-0018-0069.* DOE, *Final Rule. National Impact Analysis Spreadsheet* (Washington, DC: DOE, 2014). www.regulations.gov/#!documentDetail;D=EERE-2009-BT-STD-0018-0067.

Product	Sources
Packaged terminal air conditioners and heat pumps	DOE, *Technical Support Document: Energy Efficiency Program for Consumer Products and Commercial and Industrial Equipment: Packaged Terminal Air Conditioners and Heat Pumps* (Washington, DC: DOE, 2015). www.regulations.gov/#!documentDetail;D=EERE-2012-BT-STD-0029-0040. DOE, *Final Rule Spreadsheet: National Impact Analysis (NIA)* (Washington, DC: DOE, 2015). www.regulations.gov/#!documentDetail;D=EERE-2012-BT-STD-0029-0043.
Pumps	DOE, *Technical Support Document: Energy Efficiency Program for Consumer Products and Commercial and Industrial Equipment: Pumps* (Washington, DC: DOE, 2015). www.regulations.gov/#!documentDetail;D=EERE-2011-BT-STD-0031-0056.
Single-package vertical air conditioners and heat pumps	DOE, *Technical Support Document: Energy Efficiency Program for Consumer Products and Commercial and Industrial Equipment: Single Package Vertical Units* (Washington, DC: DOE, 2015). www.regulations.gov/#!documentDetail;D=EERE-2012-BT-STD-0041-0027.
Small motors	DOE, *Energy Conservation Program: Energy Conservation Standards for Small Electric Motors: Final Rule* (Washington, DC: DOE, 2010). www.regulations.gov/#!documentDetail;D=EERE-2007-BT-STD-0007-0004. DOE, *Small Electric Motors Final Rule Analytical Spreadsheets: Small Polyphase Electric Motors National Impact Analysis Spreadsheet* (Washington, DC: DOE, 2010). www.regulations.gov/#!documentDetail;D=EERE-2007-BT-STD-0007-0055. DOE, *Small Electric Motors Final Rule Analytical Spreadsheets: Small Capacitor-Start Electric Motors National Impact Analysis Spreadsheet* (Washington, DC: DOE, 2010). www.regulations.gov/#!documentDetail;D=EERE-2007-BT-STD-0007-0055.
Urinals	California Investor-Owned Utilities, *Toilets and Urinals Water Efficiency: Codes and Standards Enhancement (CASE) Initiative for PY 2013: Title 20 Standards Development: Analysis of Standards Proposal for Toilets and Urinals Water Efficiency*, 2013. www.energy.ca.gov/appliances/2013rulemaking/documents/proposals/12-AAER-2C_Water_Appliances/California_IOUs__and__Natural_Resources_defense_Councils_Responses_to_the_Invitation_for_Standards_Proposals_for_Toilets__and__Urinals_2013-07-29_TN-71765.pdf. CEC. *Staff Analysis of Water Efficiency Standards for Toilets, Urinals, and Faucets*, 2015. docketpublic.energy.ca.gov/PublicDocuments/15-AAER-01/TN203718_20150220T141432_Staff_Analysis_of_Water_Efficiency_Standards_for_Toilets_Urinal.pdf. DOE, *Compliance Certification Database,* Accessed October 18, 2015. www.regulations.doe.gov/certification-data/#q=Product_Group_s%3A*.
Water-source heat pumps	DOE, *Technical Support Document: Energy Efficiency Program for Consumer Products and Commercial and Industrial Equipment: ASHRAE Equipment* (Washington, DC: DOE, 2015). www.regulations.gov/#!documentDetail;D=EERE-2014-BT-STD-0015-0043.

Appendix C. Potential Legislative Reforms

Expand DOE's authority to cover new products by lowering the energy use threshold for consumer products. The current threshold for newly covered products (150 kWh per household per year) precludes DOE from establishing standards for many miscellaneous electrical loads, whose share of consumption is growing.

Reduce lead times for newly covered products. Standards for newly covered consumer products cannot take effect sooner than five years after a final rule publication date. This period should be reduced to the more common three-year period used in the statute. For products with shorter design cycles, like many consumer electronics, one to two years of lead time may be more appropriate.

Authorize standards for additional commercial and industrial products. Currently, only a specific list of commercial and industrial products may be covered by DOE. The agency should be able to address products more broadly.

Explicitly authorize multiple metrics. In some cases, measuring a product's performance with a single energy or water efficiency or use metric fails to effectively capture its efficiency performance. For example, standards enacted by Congress for residential boilers in 2007 included both an efficiency metric and two prescriptive requirements. However with the exception of a couple of cases where DOE has used a separate metric to capture standby energy use, DOE has generally interpreted its authority to forbid more than one metric. Examples of additional metrics important to efficiency that are not reflected in the main metric include power factor requirements, water use of ice-making equipment, and peak efficiency for air conditioners.

Shift lighting standards from technology focused to application focused. Definitions determining the scope of standards for lighting products are often limited to specific lighting technologies (e.g., general service fluorescent lamps and incandescent reflector lamps). As a result, current standards for those products are not technology neutral, effectively preventing DOE from considering new technologies as the basis for improved standards.

Relax preemption, especially for products whose energy use varies substantially with climate. States that wish to lead or face special challenges (e.g., long-term drought or particular energy supply constraints) face a very difficult process for setting standards stricter than the federal levels. One approach would mimic the system for automobiles under which California can adopt higher levels and other states can opt in to that level but not set their own.

Authorize non-preemptive standards for building components. Windows, doors, and other building components are generally designed to meet regional climate needs. However national minimum standards for building components may be useful for assuring a basic level of performance. But, such national minimums should not prevent states from establishing their own stronger product standards or building codes suited to their climate and/or to particular applications.

Authorize DOE to establish product performance metrics. As efficiency improves, manufacturers may sometimes compromise performance to keep first cost down, yet compromised performance can undermine energy savings. In some cases (e.g., color rendering for lightbulbs, dishwashing), product performance standards may make sense.

Authorize development of "horizontal standards," which cut across multiple product types, such as a network standby requirement. The European Union's standards for network standby are among the largest-saving standards adopted there. Similar standards exist in Korea and elsewhere. Granting DOE authority to develop such standards for the United States could open the door to large additional savings.

Provide for civil penalties commensurate with product value. Currently, when DOE uncovers a violation of efficiency standards, the department is limited to imposing a maximum penalty of $200 per incident whether the noncompliant product is a $2 lightbulb or a $10,000 electric utility transformer. To effectively deter violations among high-value products, DOE needs the option of assessing a maximum penalty that reflects at least the full value of the noncompliant product.