Potential Impact of Adopting Maximum Technologies as Minimum Efficiency Performance Standards in the U.S. Residential Sector

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ABSTRACT

The US Department of Energy (US DOE) has placed lighting and appliance standards at a very high priority of the U.S. energy policy. However, the maximum energy savings and CO_2 emissions reduction achievable via minimum efficiency performance standards (MEPS) has not yet been fully characterized.

The Bottom Up Energy Analysis System (BUENAS), first developed in 2007, is a global, generic, and modular tool designed to provide policy makers with estimates of potential impacts resulting from MEPS for a variety of products, at the international and/or regional level.

Using the BUENAS framework, we estimated potential national energy savings and CO_2 emissions mitigation in the US residential sector that would result from the most aggressive policy foreseeable: standards effective in 2014 set at the current maximum technology (Max Tech) available on the market. This represents the most likely characterization of what can be maximally achieved through MEPS in the US.

The authors rely on the latest Technical Support Documents and Analytical Tools published by the U.S. Department of Energy as a source to determine appliance stock turnover and projected efficiency scenarios of what would occur in the absence of policy.

In our analysis, national impacts are determined for the following end uses: lighting, television, refrigerator-freezers, central air conditioning, room air conditioning, residential furnaces, and water heating. The analyzed end uses cover approximately 65% of site energy consumption in the residential sector (50% of the electricity consumption and 80% of the natural gas and LPG consumption).

This paper uses this BUENAS methodology to calculate that energy savings from Max Tech for the U.S. residential sector products covered in this paper will reach an 18% reduction in electricity demand compared to the base case and 11% in Natural Gas and LPG consumption by 2030 The methodology results in reductions in CO_2 emissions of a similar magnitude.

Introduction

The U.S. Department of Energy (U.S. DOE) has placed lighting and appliance standards at a very high priority of the U.S. energy policy. However, the maximum energy savings and CO_2 emissions reduction achievable via minimum efficiency performance standards (MEPS) has not yet been fully characterized.

In the trail of the recent “Ka-BOOM” report (ACEEE-ASAP, 2009), which evaluated most likely impacts from all upcoming DOE standards, we investigated an alternative efficiency scenario to estimate CO_2 potential savings from standards set at the maximum technology level. Ka-BOOM estimates a 4% reduction in electricity consumption and a 5% reduction in natural gas consumption by 2030 resulting from upcoming appliance standards established at likely efficiency levels, scheduled to be completed by 2016.

In this paper, maximum technology (Max Tech) also referred to as Best Available Technology (BAT) is considered to be the most effective product on the market for each end use that allows for a large scale production by the time of the standard, which we assume to take effect in 2014. A similar study (Rosenquist et al., 2006) estimated potential CO_2 savings from additional cost-effective energy efficiency standards in 2010 and 2020 based on data available at that time. In our analysis, CO_2 savings potential for unregulated products such as televisions and general lighting incandescent services (GLIS) are estimated using the BUENAS[1] model.

This paper presents the methodology used to build the BUENAS framework scenarios for unregulated products (Lighting and TVs). Estimated savings for products covered by DOE's regulations (refrigerators, room and central air conditioners, water heaters and furnaces) are modeled under a BAT scenario and the BAT saving potential is provided. Finally, the paper compares the BAT scenario to the Ka-BOOM scenario and draws conclusions about additional energy and CO_2 savings potential from more stringent DOE standards.

Main Assumptions

In this section, we present the assumptions considered in our analysis first for the unregulated products (Lighting and TVs) followed by the assumptions considered for products covered by DOE's regulations (refrigerators, room and central air conditioners, water heaters and furnaces)

Unregulated Products

Lighting. Phase out of incandescent lighting has been passed by Congress in 2007 as part of the Energy Independence and Security Act (EISA, 2007). EISA specifies a progressive phase out of general service incandescent lamps (GSIL) which don't meet a certain efficacy level (W/lm), see Table 1.

This study considers two different base cases; one based on the EISA regulation and an alternative scenario based on the absence of the regulation.

In determining the impact of the phase out regulation, the penetration of Compact Fluorescent Lamps (CFLs) in the base case scenario is a major determinant of the achievable savings through energy efficiency policy. As reported by IEA (IEA, 2006), Navigant found out that by 2002 households had on average 1 CFL and 36 Incandescent bulbs. In 2007, a large survey (34,750 households) found an average of 3.37 CFL per household (Reid, 2008). Using these two data points, we estimate the past trend of CFLs penetration. Assuming that the total number of bulbs per household remains constant, we can keep track of the remaining

[1] BUENAS (Bottom Up Energy Analysis System) is a Bottom Up model developed by LBNL for the Collaborative Labeling and Appliance Standards Program (CLASP) to forecast energy savings and CO_2 emission reduction under given policy scenarios at the regional/country level covering the whole world and for a variety of end use in the residential, commercial and industrial sectors. BUENAS relies on macroeconomic drivers to predict future penetration of efficient appliances. Originally BUENAS has been developed to estimate the global potential of Standards and Labeling programs (McNeil and A. 2007). But, recently, in collaboration with CLASP and with Climate Works Funding, BUENAS was improved to better reflect regional requirements for Standard and Labeling programs such as Ecodesign requirements in Europe and CNIS projections for China

incandescent lamps to be replaced in every year of the forecast. The forecast of the number of households is taken from the annual energy outlook (AEO) 2010 (DOE/EIA-0383, 2010).

In order to model the Energy Independence and Security Act (EISA) of 2007, the following market shares from the lamp industry in 2007 were used (Lamp Industry Representatives, 2007)

Table 1: EISA Schedule for Phase Out of General Service Incandescent Lamps

Rated Lumen Ranges	Maximum Wattage	Effective Date
1490-2600	72	1/1/2012
1050-1489	53	1/1/2013
750-1049	43	1/1/2014
310-749	29	1/1/2014

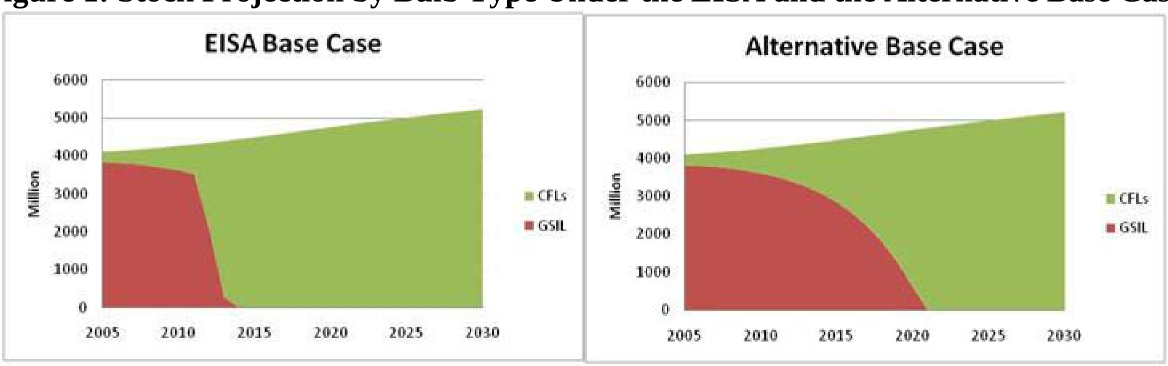
Source: EISA

Table 2: Market Shares by Wattage

Wattage	>100W	100W	75W	60W	40W	25W
% of Market	1%	21%	19%	46%	12%	1%

Assuming a one year lifetime for incandescent lamps, the resulting stock for both base case (EISA and the alternative one) are as follows:

Figure 1: Stock Projection by Bulb Type Under the EISA and the Alternative Base Case



In the EISA scenario, as specified in Table 1, part of the market of incandescent lights are phased out each year between 2012 and 2014, until their complete ban in 2014. While, in the alternative base case scenario based on the 2002-2007 trends, incandescent lamps will disappear by 2020 through other mechanisms than an energy efficiency standard.

The average wattage has been found to be 67W for GSIL and 18W for CFLs and the average usage to be 1.9 hrs per day for GSIL and 2.3 hrs per day for CFLs by Navigant (IEA, 2006). The resulting annual consumption is 46.5 kWh/year for GSIL versus 15.1kWh/year for CFLs.

In our analysis, we considered Light Emitting Diodes LEDs as the best available technology for lighting. Typical LEDs are designed to operate with low currents in order to provide efficient, low-level illumination. They are thus ideal for applications such as small flashlights and headlamps. White LEDs for general purpose lighting are more problematic, however. LEDs typically suffer severe drops in efficiency at high currents and high temperatures. Powerful LEDs therefore require extensive heat sinks to provide optimum illumination. This is an important factor (in addition to the cost) that has prevented widespread proliferation of LEDs for general lighting applications.

Standard incandescent lamps operate at roughly 15 lumens per watt (Lm/W) efficacy. Compact fluorescent light bulbs (CFLs) achieve on average 60 Lm/W, especially when replacing 60W or 100W incandescent light bulbs. Although white LEDs can achieve greater efficiencies under controlled testing conditions, in practice they are generally not better than CFLs at approximately 60 Lm/W (ECOS, 2009). This is primarily due to the difficulty of heat dissipation. Ideal field conditions using top-of-the-line commercial LEDs could reasonably achieve 100 Lm/W. The most advanced, state-of-the-art; white LEDs currently achieve approximately 160 Lm/W in controlled laboratory conditions, although commercialization is likely several years away.

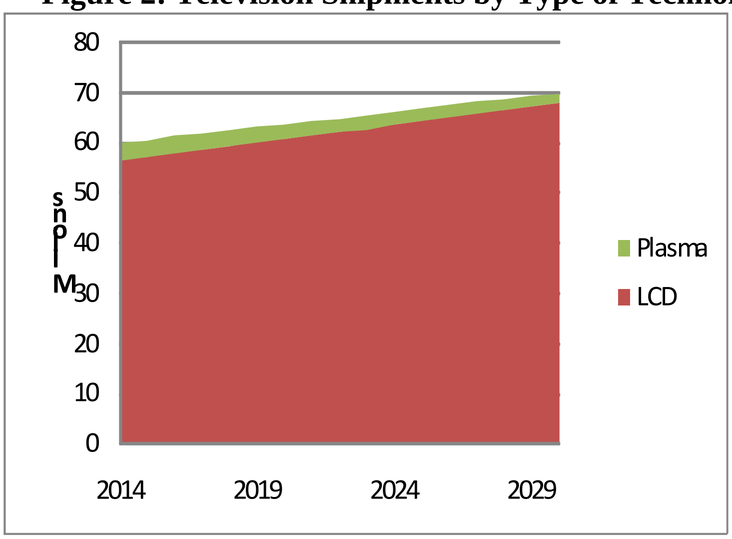
For the purpose of our analysis we will assume that most of these obstacles will be resolved by 2014 and that an efficiency of 100 Lm/W is achievable at a reasonable cost for consumers.

Televisions. Televisions have never been regulated by any federal rulemaking while the market of televisions is moving very fast with the emergence of flat screen televisions. With reported shipments of 91 million LCD televisions in 2008 by appliance magazine (Appliance Magazine, 2009), it appears that shipments are boosted by early replacements of CRTs.

To develop the stock turnover model, the total stock has been derived from the Residential Energy Consumption Survey (RECS) 2005 (EIA, 2009), which found that households have 2.5 television sets on average. This value is kept constant throughout the forecast period, which implies that LCDs and Plasma sales replace CRTs that get discarded. Historical and future market shares sales of CRT, LCD and Plasma are given by DisplaySearch (DisplaySearch, 2010) between 2003 and 2013. We extrapolate the 2008-2013 trend to 2030.

Based on these assumptions, the resulting shipments are as shown in Figure 2.

Figure 2: Television Shipments by Type of Technology

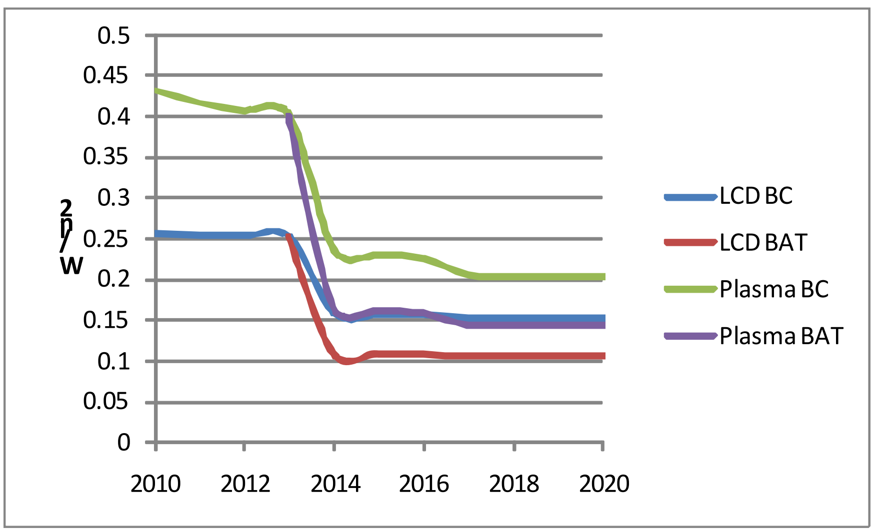


Technology for televisions has been evolving very rapidly during the past years and we can assume that trend will keep going in the future. Given the success of the Energy Star program (Energy Star, 2009), we assume that when a version enters into effect the market has already reached the preceding criteria. For example, when energy star version 4.0 entered into effect in 2010, we assume the market is at the 3.0 level. Our UEC also takes into account average screen size projections from DisplaySearch (DisplaySearch, 2010), with a cap at 42". Hours of usage have been found to be equal to 1882 hours per year in a PGE study (PGE,2007). Figure 3 shows the resulting specific consumption (W/in^2) in the base case (BC).

OLEDs are similar to a standard semi-conductor LEDs, but use a plastic polymer as the substrate instead of usual semi-conductors. These plastics can be deposited in very thin and flexible films. OLEDs are small enough to eliminate backlighting entirely – the OLEDs themselves serve as light-producing pixels. The end result is a display panel that is remarkably thin compared to current models, flexible, and consumes far less power than any current technology. Current applications are limited to small sizes (i.e. cell phone and PDA screens), though prototype panels already exist at roughly 12". OLED TVs at 50" and beyond are likely technically achievable in a few years. Some concerns subsist over lifetime issues of these prototypes and prohibitive costs associated with their production. As a consequence we don't use OLED as BAT in 2014. Instead we use a more conservative assumption using the next Energy Star next criteria entering into effect in 2012 (Energy Star, 2009).

For the average size of screen considered in 2014 (39" for LCD and 50" for plasma screen), this is equivalent to 89W for a LCD and 108W for plasma. Above 50", all screens are required to consume less than 108W[2]. Figure 3 shows the average specific consumption in the base case and the BAT scenario.

Figure 3: Average Specific Consumption in the Base Case and BAT scenarios for Televisions



DOE Regulated Appliances

For the products under DOE's regulation we compiled information from the DOE Technical Support Documents[3] (TSD) along with the BAT associated for each end use. In its

[2] ENERGY STAR Program Requirements for TVs: Versions 4.0 and 5.0 available at http://www.energystar.gov/ia/partners/prod_development/revisions/downloads/television/Final_Version%204_5_TV_Program_Requirements.pdf

[3] All documents are available on http://www1.eere.energy.gov/buildings/appliance_standards

rulemaking, DOE defines a Maximum Technology (Max Tech) level by incorporating all the design options in its engineering analysis. We use this engineering approach in this analysis for most of the appliances, but explore further combinations when data are available.

For each product, energy savings under the BAT scenario are calculated considering the:

- Estimation of the average unit energy use (UEC) in every year *y* in the base case *BC* and *BAT* (TSD, chapter 7) : $UEC_{y,BC}$ *and* $UEC_{y,BAT}$
- Lifetime distribution (TSD, chapter 8): fraction of surviving appliances in each year *y*: $Surv_y$
- Shipments forecast to 2030 (TSD, chapter 9): $Ship_y$
- National impact analysis (TSD, chapter 10): Heat Rates.

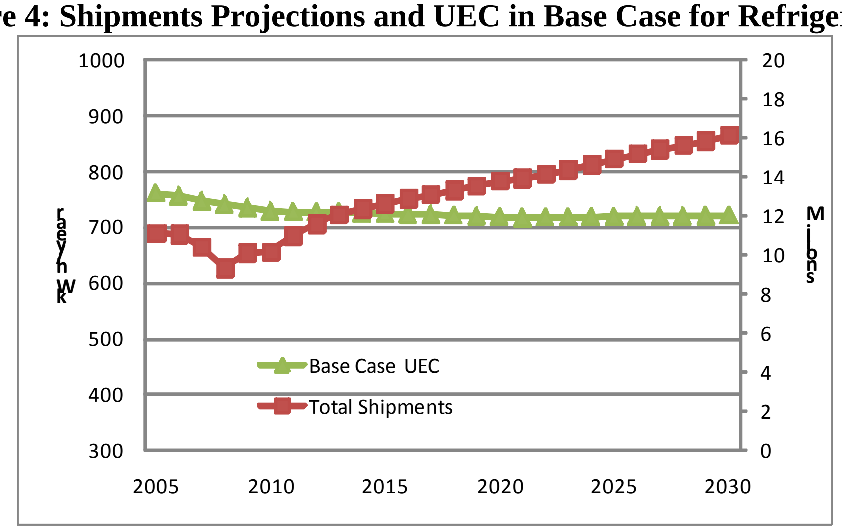
Refrigerators-freezers. DOE will issue a new rule for refrigerators-freezers in December 2010. The shipments and energy use estimates have been gathered from the preliminary Technical Support Document (USDOE, 2009).

For standard size refrigerator-freezers, three major product classes have been considered by DOE; bottom mount refrigerator-freezers, top mount refrigerator-freezers and side by side refrigerator-freezers. To aggregate energy use into a weighted average value, market shares are used.

In the absence of a standard, DOE assumes that Energy Star would strengthen its criteria by another 5% in 2014, and that the program would achieve the same market transformation as what was found in the 2007 market share data by 2021.The resulting average UEC and cumulative shipments are shown in Figure 4.

Based on DOE analysis, top-mount refrigerators with a combination of larger heat exchange area, compressor efficiency, adaptive defrost, vacuum insulated panels (VIP) and variable speed compressor (VS compressor) can yield up to a 55% increase in overall efficiency (USDOE, Public Meeting presentation). In our analysis, we consider this assumption valid for all product classes.

Figure 4: Shipments Projections and UEC in Base Case for Refrigerators



Water heaters. DOE has issued a final rule for water heaters in March 2010. The shipments and energy use estimated have been gathered from the Final Rule Technical Support Document (USDOE, 2010). We consider only the BAT for storage water heaters.

Shipments for gas storage water heaters are projected to remain flat around 4.2 million units sold per year while electric storage water heaters are projected to go from 4.2 million in 2008 to 5.9 million in 2030. DOE includes penetration of Energy Star in its base case scenario with 5% penetration by 2015.

For its rulemaking DOE considers a heat pump water heater of 2.2 EER as the BAT option for electric water heater and condensing water heating at 90% efficiency for gas water heaters.

Room air conditioners (RAC). DOE is currently working on a new rulemaking for RAC that will be finalized by mid-2011.

The current average energy efficiency ratio EER is 9.47 across all capacities studied in details in the TSD and a maximum of 11.48 EER is found on the market (USDOE, 2010 and CEC database). Shipments are forecasted to stay pretty flat around 10 million units per year. DOE estimated that a residential RAC consumed 680 kWh/year on average, while the max tech level would lead to a 580 kWh/year UEC.

Central air conditioners (CAC). The latest standard has been enacted in 2006 and sets a minimum seasonal energy efficiency ratio (SEER) standard of 13. From the latest technical support document (USDOE, 2010) it has been found that shipments to the residential sector are forecasted to go from 4 million in 2008 to 5.5 million by 2030. The average UEC of a unit sold in 2014 has been found to be 2280 kWh/year and the most efficient CAC can achieve an annual consumption of 1842 kWh.

Furnaces. The standard passed for furnaces in 2007 mandates minimum annual fuel-utilization efficiency (AFUE) of 80% in 2015 but DOE will revise this level by May 2011.

For the purpose of this paper we consider only one product class represented by non-weatherized furnaces, which represent roughly 85% of shipments.

The average consumption in the base case is then 55.5 MMBtu/year and 453 kWh/year. In its last rulemaking (2007), DOE considered a condensing furnace with a 96% AFUE as its best available technology option, this yields an average annual consumption of 46.4 MMBtu/year and 400 kWh/year (USDOE, 2008).

Summary of Characteristics of Selected Technologies

For both base case (BC) and BAT scenarios, characteristics of selected technologies for each product included in the analysis are summarized in the table below.

Table 4: Summary of Selected Technology

End use/product	Baseline technology	UEC BC (2014)	BAT	UEC BAT (2014)
Lighting	Incandescent	46 kWh	LEDs (110 Lm/W)	9 kWh
	CFLs (60 Lm/W)	15 kWh	LEDs (110 Lm/W)	9 kWh
Televisions	Energy Star v4.0	200 kWh	Energy Star v5.0	171 kWh
Refrigerator-Freezers*	DOE Standard	726 kWh	VIP, VS compressor	367 kWh
Water Heater Elec	90 EF	2518 kWh	Heat Pump 2.2 EF	1283 kWh
Water Heater Gas	59 EF	16 MMBtu	Condensing 0.8 EF	11 MMBtu
RAC*	9.44 EER	683 kWh	11.47 EER	576 kWh
CAC	13 SEER	2282 kWh	16.5 SEER	1843 kWh
Furnace	78 AFUE	52 MMBtu	Condensing 96% AFUE	46 MMBtu

*Average over different product classes

Potential Savings Calculation Method

For each appliance or lighting product, National Energy Savings (NES) are calculated as follows by keeping track of the stock's consumption in every year after the standard is enacted using the average unit energy consumption in both cases (BC & BAT).

$$NES(y) = AffStock(y) \times \left(UEC(y)_{Base} - UEC(y)_{BAT}\right)$$

Where:

$AffStock(y)$ = the stock of equipment sold after the year of the standard that is still in operation in year y (affected stock),
$UEC(y)_{base}$ = the unit energy consumption sold in the base case in year y,
$UEC(y)_{BAT}$ = the unit energy consumption sold in the standard case in year y.
The affected stock in year y is given by:

$$AffStock(y) = \sum_{i=stdyr}^{y} S(i) \times Surv(y-i)$$

The quantity of stock in year y is dependent on the number of shipments $S(y)$ sold in years after the standard is passed (*stdyr*), multiplied by the survival function $Surv(v)$, which is the fraction of shipments that survive until age v (vintage). Survival functions are derived from average lifetime with a Weibull function (USDOE, TSD).

For televisions, the retirement function is defined with a triangular distribution centered on the average lifetime and spanning the published min/max lifetimes (Appliance Magazine, 2009).

The lifetime for CFLs is assumed to be 6000 hours (which is the current Energy Star minimum requirement) with 2.3 hrs per day usage.

The average lifetime considered in the model for each product is shown in the Table 5.

Table 5: Average Lifetime

Product	Years
Refrigerators	17
RAC	12
WH	14
GLIS	1
CFL	7
TV	5
CAC	18
Furnaces	20

Cumulative energy savings are the sum of annual NES during the defined period (2014-2030).

Site energy savings are converted to primary energy savings using heat rates factors developed by the National Energy Modeling System (NEMS) based on the load shape of the appliance for furnaces, air conditioning and refrigerators both for electricity and natural gas (AEO 2010).

Lighting and TV are assumed to follow the refrigerator load shape.

Potential Savings

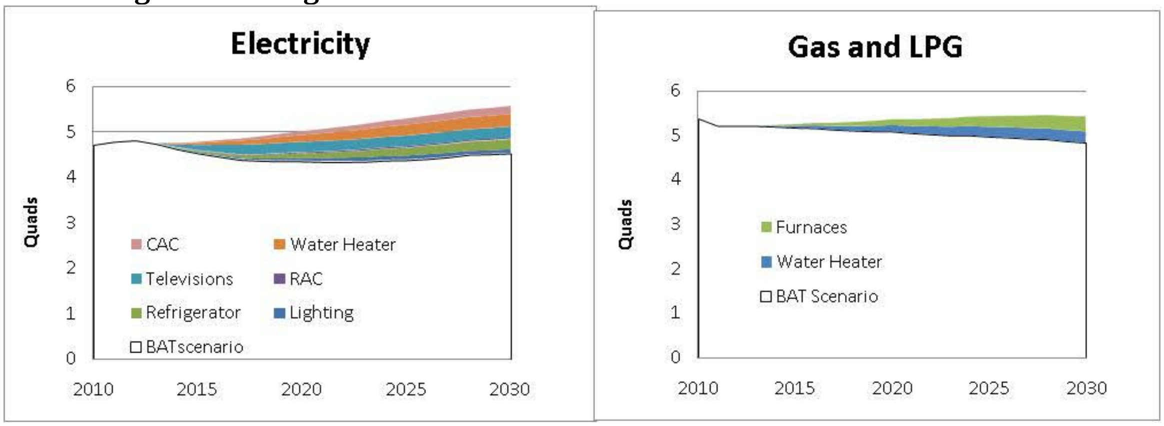
Considering the calculation method and the assumptions described above for both regulated and unregulated products, the estimated energy savings by 2030 using the BAT for the residential sector are summarized in Table 6.

Also the comparison of savings potential for BAT to the projections of AEO2010 (base case) for both electricity and natural gas/LPG shows that considering BAT for the products covered in our study will allow the US to achieve 18% reduction in its electricity demand compared to the base case by 2030 and 11% reduction in natural gas and LPG consumption; see Figure 3.

Table 6: Energy Savings from BAT Standard

	Site Energy Savings				Source Energy Savings	
	in 2030		through 2030		in 2030	through 2030
Product	Elec (TWh)	Gas (Quads)	Elec (TWh)	Gas (Quads)	Quads	Quads
LEDs compared to EISA BC	0		306		0.2	2.9
LEDs compared to alt. BC	0		971		0.2	10.5
Refrigerator	65		645		0.5	6.0
Televisions	19		268		0.1	2.2
WH	83	0.2	895	2.4	0.9	10.9
RAC	9		100		0.1	1.0
CAC	18		223		0.2	2.2
Furnaces	3	0.4	26	3.0	0.4	3.4
TOTAL EISA BC	197	1	2463	5	2	29
TOTAL Alt. BC	197	1	3129	5	2	36

Figure 3: Wedges for the Residential Sector Relative to AEO Forecast



Energy savings are converted into CO_2 emissions savings using the Carbon Factor from AEO 2010. Transmission and distribution losses are estimated to be around 5% from the same source.

Table 7 summarizes the results in terms of CO_2 emissions reduction potential and compares them to the ones reported in the "Ka-BOOM report" (ACEEE-ASAP, 2009) as a reference point (Ka-BOOM reports impact from expected standards from DOE)

Table 7 shows the full potential of CO_2 emissions reduction by implementing standards based on BAT given reasonable assumptions for technical opportunities in the next 5 years. It also shows a comparison between Ka-Boom and BAT CO_2 reduction potential. The differences between Ka-BOOM and BAT scenarios represent the remaining savings to be captured by energy efficiency standards in the US, above and beyond what is likely to be enacted in future standards.

Table 7: Comparison of CO2 Emissions reduction between Ka-BOOM and BAT Scenarios

	Assumption	**KABOOM**	Assumptions	**BAT Scenario**
Product		Mt CO_2 through 2030		Mt CO_2 through 2030
LEDs compared to EISA			LEDs (110 Lm/W)	197
LEDs compared to alternative BC			LEDs (110 Lm/W)	641
Refrigerators	25% improvement	13.3	VIP, VS compressor	40.7
Televisions			Energy Star 2012 Criteria	11.0
Gas WH	0.63 AFUE	4.1	Heat Pump 2.2 EF	11.2
Elec WH	95% Eff	11.4	Condensing 0.8 EF	49.4
RAC	Energy Star	2.6	11.47 EER	5.4
CAC	Regional Standard 15 SEER	13.6	16.5 SEER	11.6
Furnaces	90 AFUE	10.1	Condensing 96 AFUE	20.4
TOTAL EISA BC		55.1		326.2
TOTAL Alt. BC				790.8

Conclusion

This paper provides stakeholders with a methodology for assessing the full scale of the potential energy saving and CO_2 emission reduction that is technically achievable in the U.S. residential sector. The paper demonstrates that methodology and calculates that energy savings from BAT for the products covered in our study will allow the US to achieve 18% reduction in its electricity demand compared to the base case by 2030 and 11% in Natural Gas and LPG consumption. The methodology results in reductions in CO_2 emissions of a similar magnitude. Additional potential savings from the use of these products would have to come from either technology innovation, or changes in behavior.

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