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Business Case for Energy Efficiency in Support of Climate Change Mitigation, Economic and Societal Benefits in the United States

Michael A. McNeil, Nicholas Bojda, Jing Ke, Stephane de la Rue du Can, Virginie E. Letschert and James E. McMahon

Environmental Energy Technologies Division

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Disclaimer

EXECUTIVE SUMMARY

This study seeks to provide policymakers and other stakeholders with actionable information towards a road map for reducing energy consumption cost-effectively. We focus on individual end use equipment types (hereafter referred to as *appliance groups*) that might be the subject of policies - such as labels, energy performance standards, and incentives - to affect market transformation in the short term, and on high-efficiency technology options that are available today.

There is a strong, profit-based business case for investing in more energy-efficient products and designs. Energy efficiency, however, often is viewed as something that businesses and individuals "should" do as good citizens. The reality is that using energy inefficiently is like walking past money on the ground - money that could be put to far better use than paying electricity bills. Investing in energy efficiency therefore creates economic value.

As the study title suggests, the high efficiency or *Business Case* scenario is constructed around a model of cost-effective efficiency improvement. Our analysis demonstrates that a significant reduction in energy consumption and emissions is achievable at *net negative cost*, that is, as a profitable investment for consumers. Net savings are calculated assuming no additional costs to energy consumption such as carbon taxes. Savings calculated in this way relative to the base case are often referred to as "economic savings potential".

The United States energy demand picture is characterized by relatively high usage coupled with highly developed technology. Furthermore, the United States has a long history of appliance efficiency labels and standards. Therefore, efficiency improvement from U.S. appliances is characterized as successive stepwise improvement from an already efficient baseline. In spite of this already high baseline, the study finds significant opportunities for energy efficiency benefits at net negative cost. These include:

Final Energy savings:

- 230 billion kWh of electricity and 0.14 EJ of natural gas per year in 2020
- 430 billion kWh of electricity and 0.35 EJ of natural gas per year in 2030
- A total of 4900 billion kWh of electricity and 3.1 EJ natural gas cumulatively through 2030

The end uses studied in this report are concentrated in the buildings sector, and the bulk of the savings is to be found in electricity savings. The study finds that by 2030, cost-effective efficiency improvements could save 430 billion TWh, which represents about 12% of total buildings electricity consumption in that year, according to the International Energy Agency's World Energy Outlook[1]. This corresponds to 9.3% of electricity consumption in the U.S.

Primary Energy Savings

- 1.3 EJ of coal per year in 2020 and 0.58 EJ of natural gas per year in 2020

[1] World Energy Outlook 2010 Appendix A "Current Policies Scenario"

- 2.4 EJ of coal per year in 2030 and 1.2 EJ of natural gas per year in 2030
- A total of 27 EJ of coal and 13 EJ of natural gas cumulatively through 2030

This corresponds to 9.3% of electricity consumption in the U.S. or 3.7% of total energy consumption, in primary energy terms.

Cumulative emissions mitigation:

- 3000 million metric tons of CO_2 through 2030
- 12 million metric tons of SO_2 through 2030
- 3.5 million metric tons of NO through 2030
- 62 metric tons of mercury through 2030

The *Business Case* saves 265 mt CO_2 in 2030. According to WEO, with current policies in place, emissions in the United States will total 5310 mt CO_2 or 712 mt more than the Annex I target of 4598 mt (5.2% below the 1990 level of 4850 mt.) Implementation of the *Business Case* would close over a third of this gap.

Financial impacts to consumers through 2030:

- Equipment investment of 260 billion dollars (USD)
- Energy bill savings of 560 billion dollars (USD)
- Net savings of 300 billion dollars (USD)

In addition to the 300 billion dollars net savings provided to consumers through 2030, annual savings of 430 billion kWh would avoid capital investments of 32 billion dollars[2].

Job Creation

- Net creation of 85,000 to 200,000 jobs

The approach of the study is to assess the impact of short-term actions on long-term impacts. "Short-term" market transformation is assumed to occur by 2015, while "long-term" energy demand reduction impacts are assessed in 2030. In the intervening years, most but not all of the equipment studied will turn over completely. The 15-year time frame is significant for many products, in the sense that delay of implementation postpones economic benefits and mitigation of emissions of carbon dioxide. Such delays would result in putting in place energy-wasting technologies, postponing improvement until the end of their service life, or potentially resulting in expensive investment either in additional energy supplies or in early replacement to achieve future energy or emissions reduction targets.

The *Business Case* concentrates on technologies for which cost-effectiveness can be clearly demonstrated. The appliance groups studied are:

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[2] Levelized capital cost of $74.6/MWh for "Advanced Coal" plants according to Energy Information Administration, Annual Energy Outlook 2011.

Residential Equipment

Incandescent Lamps
Refrigerators
Room Air Conditioners
Water Heaters
Televisions
Standby Power
Electric Cooking Equipment
Central Air Conditioners and Heat Pumps
Gas Furnaces

Commercial Equipment

Air Conditioners and Heat Pumps
Commercial Linear Fluorescent Ballasts
High-Intensity Discharge Lamps
Distribution Transformers
Boilers

Energy savings and greenhouse gas emissions mitigation for these appliance groups are summarized in Table ES-1

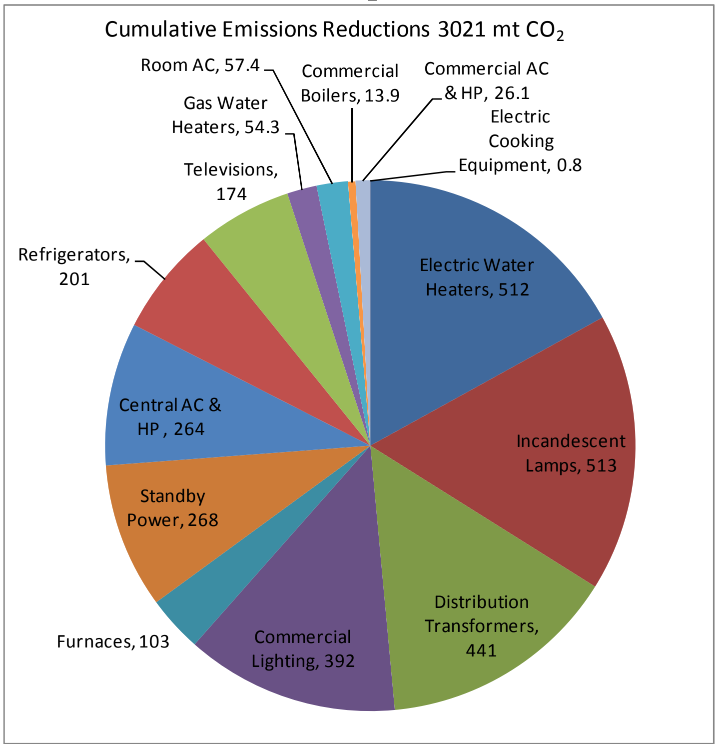
Table ES-1 – Energy Savings and Pollutant Mitigation by Appliance Group

Appliance Group	Final Energy Savings			Emissions Mitigation					
	In 2020	In 2030	Through 2030	In 2020	In 2030	Through 2030			
	TWh			mt CO_2		mt CO_2	mt SO_2	mt NO	t Hg
Electric Water Heaters	41.8	92.4	887	24.3	53.1	512	2.0	0.7	10.4
Incandescent Lamps	31.9	0.0	861	18.6	0.0	513	1.9	0.7	10.1
Distribution Transformers	33.3	89.8	764	19.4	51.6	441	1.7	0.6	9.0
Commercial Lighting	31.0	74.3	679	18.0	42.7	392	1.5	0.6	8.0
Furnaces	21.4	62.0	512	4.3	12.5	103	0.0	0.0	0.0
Standby Power	24.5	43.9	463	14.3	25.2	268	1.0	0.4	5.4
Central AC & HP	21.6	49.8	457	12.6	28.6	264	1.0	0.0	5.4
Refrigerators	15.7	39.3	348	9.1	22.6	201	0.8	0.1	4.1
Televisions	20.2	22.6	300	11.8	13.0	174	0.7	0.2	3.5
Gas Water Heaters	13.2	27.2	269	2.7	5.5	54.3	0.0	0.0	0.0
Room AC	5.5	9.2	99.2	3.2	5.3	57.4	0.2	0.1	1.2
Commercial Boilers	3.2	7.5	68.9	0.6	1.5	13.9	0.0	0.0	0.0
Commercial AC & HP	2.0	5.0	45.2	1.2	2.9	26.1	1.0	0.0	5.4
Electric Cooking Equipment	0.1	0.2	1.3	0.1	0.1	0.8	0.003	0.001	0.0
Total	**265**	**523**	**5754**	**140**	**265**	**3021**	**11.9**	**3.5**	**62**

Since the study includes only appliance groups for which cost-effectiveness can be clearly demonstrated, the benefits determined represent only a subset of the economy-wide potential. Specifically, transportation end uses and industrial processes technologies are not covered, because data sufficient to include them were not possible to collect within the scope of the research. Likewise, the study does not include system approaches such as smart grids. These approaches to efficiency may have important impacts but the calculation of costs and benefits is not as straightforward as for individual pieces of equipment. In addition, the technologies analyzed represent a snapshot of what is currently on the market. Technological innovations are certain to occur over the coming decades, and these will likely present new opportunities for efficiency improvement, and exert downward pressure on costs.

Efficiency measures are determined to be cost-effective if the cost of conserved energy associated with them is less than the consumer's energy price, that is, the amount saved in cumulative energy bills is greater than the initial investment. The *Business Case* scenario is generated by identifying the *maximum efficiency improvement for which cost of conserved energy is lower than utility energy prices* (projected to 2015). The relative contribution to cumulative emissions for each appliance group is shown in Figure ES-1.

Figure ES-1 – Contribution to Cumulative CO_2 Emissions Reductions 2010-2030



Several conclusions can be drawn from Table ES-1 and Figure ES-1. First, the largest accessible savings appears to be available in the residential sector. Notable among these are electric water heaters, for which heat pump technology was found to be cost-effective[3]. Incandescent lamps also show a large savings through a phase out and replacement with CFLs[4]. The Energy Independence and Security Act passed by Congress in 2007 includes a phase out of incandescent lamps starting in 2012 which will capture this savings when implemented. Large potential savings are also forecast for televisions, for which a minimum efficiency standard has never been set, but is under consideration. Similar potential is available for refrigerators, which have been regulated with several updates, but for which high-technology options such as vacuum insulation panels are just now becoming cost-effective. Finally, standby power reduction shows high potential savings. It is the policy of DOE to address standby power as part of future standards for electronics and other products with standby modes.

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[3] DOE has set a standard implying heat pump technology for only the largest capacity water heaters, citing market barriers for the bulk of the market. As this technology becomes more prevalent, wider penetration may become achievable.

[4] Incandescent lamps show no savings in year 2030 itself, because they are forecast to be phased out by that year in the base case scenario.

Savings are relatively low for commercial buildings' end uses, with the exception of lighting. While the dominant technology (fluorescent tube lamp ballasts) are already relatively efficient, much of the savings in this category comes from high intensity discharge lamps which, while constituting a much smaller fraction of the end use, permit large percentage savings, possibly as a result of not having been regulated in the past. Some of the limitation on savings is due to recent standards for HVAC equipment that restrict further cost-effective improvement given the available data[5]. Furthermore, an ever-growing fraction of commercial building energy is used in miscellaneous products for which efficiency improvement may be possible, but for which data are not yet available. Lastly, distribution transformers do show significant savings because of the scale of distribution losses at the national level, even though total efficiency improvement is small on a percentage basis, due in part to the recent standards rulemaking.

Table ES-2 – Cumulative Financial Impacts of Efficiency Improvement through 2030

Appliance Group	Cumulative Financial Impacts				
	Cost	Savings	**Net**	NPV @ 3% DR	NPV @ 7% DR
	$ Billions				
Incandescent Lamps	15.9	95.1	**79.2**	66.4	53.2
Commercial Lighting	9.4	65.3	**55.9**	36.2	21.2
Standby Power	9.3	51.2	**41.9**	27.5	16.3
Distribution Transformers	41.4	73.5	**32.0**	20.7	12.0
Televisions	6.0	33.1	**27.1**	18.4	11.3
Electric Water Heater	71.4	97.9	**26.5**	17.2	10.1
Central AC & HP	35.0	50.5	**15.4**	10.0	5.9
Refrigerator	31.3	38.4	**7.1**	4.6	2.7
Room AC	6.1	11.0	**4.9**	3.2	1.9
Gas Water Heaters	8.9	12.1	**3.2**	2.1	1.2
Furnaces	20.0	23.0	**3.0**	2.0	1.1
Commercial Boilers	1.0	2.7	**1.7**	1.1	0.6
Commercial AC & HP	3.5	4.3	**0.8**	0.5	0.3
Electric Cooking Equipment	0.1	0.1	**0.1**	0.04	0.02
Total	**259**	**558**	**299**	**210**	**138**

The analysis shows that cost-effective efficiency improvement could yield very significant financial benefits to U.S. consumers. Table ES-2 shows positive net savings for all appliance groups, which is not surprising, since the target efficiency levels were constructed to be cost-effective. The table shows that cost-effective efficiency improvements require an investment of 259 billion dollars over the next 20 years, but these investments will return over twice as much over the same period, for a net savings of 299 billion dollars, or of order of one thousand dollars per capita. The present value of net savings is 210 billion dollars assuming a discount rate of 3%, and 138 billion dollars with a 7% discount rate. Of the appliance groups studied, electric water heaters require the largest investment at $71.4 billion, but also have the highest payoff at

[5] It should be emphasized that efficiency technology costs are generally decreasing, especially after a standard creates a mass market for high-efficiency equipment. An update of the data may therefore reveal additional cost-effective improvement.

$97.9 billion. Phasing out incandescent lamps has a similar payoff of $95.1 billion, but requires an investment of only $15.9 billion. This technology has the highest net benefit, of $79.2 billion, with commercial lighting providing the second biggest, with $55.9 billion.

1. Introduction

This study seeks to provide policymakers and other stakeholders with actionable information towards a road map for reducing energy consumption in the most cost-effective way. A major difference between the current study and some others is that we focus on individual equipment types that might be the subject of policies - such as labels, energy performance standards, and incentives - to affect market transformation in the short term, and on high-efficiency technology options that are available today.

The approach of the study is to assess the impact of short-term actions on long-term impacts. "Short term" market transformation is assumed to occur by 2015, while "long-term" energy demand reduction impacts are assessed in 2030. In the intervening years, most but not all of the equipment studied will turn over completely. The 15-year time frame is significant for many products however, indicating that delay of implementation postpones impacts such as net economic savings and mitigation of emissions of carbon dioxide. Such delays would result in putting in place energy-wasting technologies, postponing improvement until the end of their service life, or potentially resulting in expensive investment either in additional energy supplies or in early replacement to achieve future energy or emissions reduction targets.

1.1. Description of Efficiency Measures to Date

The United States energy demand picture is characterized by relatively high usage coupled with highly developed technology. The commercial/service sector is very well-developed, and energy use in commercial buildings is correspondingly high, with total greenhouse gas emissions from this sector expected to overtake those of the residential sector within the next 20 years. Because of cold winters and warm summers in large regions, both space heating and space cooling are major end uses, and natural gas used in space and water heating constitutes a significant source of carbon dioxide emissions.

Ownership of major appliances (refrigerators, water heaters, televisions, washing machines and air conditioners) is nearly universal in U.S. households and while the capacity of some appliances continues to grow, energy consumption for the traditional major end uses is growing slowly. Most future growth in residential energy consumption is therefore expected to be due to consumer electronics, small appliances, standby power and other "plug loads".

Furthermore, the United States has a long history of appliance efficiency standards. Therefore, efficiency improvement from U.S. appliances is characterized as successive stepwise improvement from an already efficient baseline. While there remain opportunities for significant savings, some further major improvements may depend on innovative technologies which have not been commercialized and for which market prices are not yet known.

1.2. Policies and Programs to Encourage Efficiency

Regulatory measures such as the implementation of a minimum energy performance standard (MEPS) for new equipment coming on the market were first introduced in the U.S. after the first oil crisis of 1974. In addition, instruments such as labels, awards, and public information campaigns are used to increase consumers' knowledge and awareness of energy efficiency. Finally, financial incentives address the market barrier of high upfront costs of energy-efficient products.

In 1975 the Energy Policy and Conservation Act (EPCA) established the Energy Conservation Program for Consumer Products Other than Automobiles. This program started the first generation of appliance standards, focusing on residential end-uses. In 1978 the National Energy Conservation Policy Act amended the EPCA, changing the standards from voluntary to mandatory and requiring updates of the pre-existing standards. As DOE's Energy Efficiency and Renewable Energy Office reports, standards were not well developed until the 1980s[6]. The National Appliance Energy Conservation Policy Act (NAECA) of 1987 amended EPCA and established MEPS for household appliances, as well as revision schedules for DOE. The residential end-uses analyzed in this report had their first mandatory legislation start with NAECA.

Standards for commercial products were introduced with the Energy Policy Act of 1992 (EPAct 1992). A second Energy Policy Act was issued in 2005 (EPAct 2005), which introduced or renewed standards for over a dozen end-uses, covering commercial industrial and residential sectors. The EPAct of 1992 and 2005 together address most of the commercial end-uses covered in this study. The most recent major legislative action is the Energy Independence and Security Act of 2007 (EISA).

From 1987 to date, U.S. appliance standards have been implemented on 47 product types (ASAP, 2011). Today DOE is conducting more rulemakings than at any time in its history. Appendix 1 shows a list of equipment for which standards have been implemented at the federal level or state level. The list shows the date by which new standards were first implemented, the date they were issued by DOE or Congress, the date they became or will become effective and the date for scheduled updates. This information is collected by Appliance Standards Awareness Project (ASAP, 2011).

In parallel to MEPS, the U.S. Environmental Protection Agency (EPA) established an energy consumption labeling scheme starting in 1991 to promote energy-efficient product purchases and reduce greenhouse gas emissions. Computers and monitors were the first labeled products. Through 1995, EPA expanded the label to additional office and residential equipment. In 1996, the EPA partnered with the U.S. Department of Energy to expand significantly the range of equipment covered with the Energy Star label. Today, more than 40,000 individual product models, produced by nearly 3,000 manufacturers across more than 60 product categories.have earned the ENERGY STAR label. The ENERGY STAR program is estimated to have saved 204 billion kWh in 2009, about 5 percent of U.S. electricity demand (EPA, 2010). This amounts to nearly $17 billion from customer utility bills.

Other forms of energy efficiency programs include financial incentive measures that are implemented by utilities or independent state agencies. In the U.S., the power sector is decentralized and regulation is done at the state level. About half of the states have passed

[6] See http://www1.eere.energy.gov/buildings/appliance_standards/history.html

legislation to apply a small levy or public benefit charge as a fraction of a cent per kWh on electricity sales to finance a common public fund that is then used to support energy efficiency programs. The revenue from this charge is redistributed to consumers in the form of financial incentive programs.

Public benefits charges range from $0.00003 to $0.003 per kWh with a median value of about $0.0011 per kWh. Utility spending on energy efficiency represents between 0.7% and 3% of total utility retail revenue (Kushler, 2004). According to the last CEE report on the "State of the Efficiency Program Industry" (Caracino, 2010), this generates a total annual budget of $5.4 billion in 2010 for rate-funded electric efficiency programs across all States, an increase of 44% compared to 2009. Electric efficiency programs in the residential sector 31% of the budget in 2010. California, New York, Florida, and Massachusetts account for 50% (or $2.7 billion) of the total amount budgeted for electric energy efficiency for 2010. California alone accounts for 1.5 billion (or 28%) of which $436 million is directed to residential sector energy efficiency improvements. Electricity program budgets per capita vary widely across US states, ranging from 54.8 dollars in Vermont to 3 cents in Virginia (Caracino, 2010). In terms of energy savings, the CEE reports that combined U.S. electricity rate funded projects saved about 92,578 GWh in 2009, of which 26,876 GWh were in the residential sector (29%).

California has a long history in implementing utility demand-side management (DSM) programs and established itself as a leader in promoting energy efficiency in the U.S. Utilities started to implement utility DSM programs in the early 70's in California. A recent study conducted by the California Energy Commission (CEC, 2005) shows annual savings of 40,000 GWh and 12,000 megawatts of peak electricity, equivalent to 24 500-megawatt power plants (CEC, 2005).

2. Energy Demand Scenarios

As the study title suggests, the high efficiency or *Business Case* scenario is constructed around a model of cost-effective efficiency improvement. The point of the study is to demonstrate that a significant reduction in energy consumption and emissions is achievable at a net negative cost, that is, as a profitable investment for society. There are a variety of ways of assessing costs and benefits to society. We chose to focus on the end user's perspective: costs in terms of additional retail equipment prices (capital investments); savings from reduced energy bills (operating costs). Only direct energy savings are included, without valuing non-energy benefits that may also accrue (comfort, productivity, health). Finally, the cost-benefit analysis is made without the elevated effective energy prices that could be implied by carbon taxes, carbon trading schemes or other policies. Savings relative to the base case as calculated in this way is often referred to as "economic savings potential".

A national-level high-efficiency scenario is constructed by assuming that market transformation to high-efficiency technologies will occur by 2015, which is judged to constitute the "short term" by the study, because it considers that five years is sufficient time to achieve market transformation through aggressive policies and stakeholder actions. The study does not model specific actions, which could include mandatory standards, voluntary labeling programs, voluntary agreements by manufacturers, utility demand-side-management programs and others[7].

The target efficiency level chosen is that which *maximizes efficiency while providing a net benefit to consumers*. This is to be contrasted with scenarios which maximize consumer payoff but not necessarily efficiency improvement, or those that include the best available technology ("max tech") without consideration of cost-effectiveness. Consumer cost-benefit analysis is evaluated in terms of cost of conserved energy. Cost of conserved energy (CCE) is the amortized incremental cost of equipment divided by annual energy savings. In other words, it's the additional annual capital investment needed to purchase high-efficiency equipment instead of baseline equipment, divided by the energy savings provided by the investment. This quantity, which has units of dollar per unit energy, can be compared to prevailing energy prices to assess consumer cost-effectiveness. Technologies with a CCE less than forecast energy prices in 2015 are deemed cost-effective.

A few comments about whether this definition is optimistic or pessimistic are warranted. On one hand, high efficiency technologies are compared to the current baseline technology, even though there may already be a market for higher efficiency equipment, and the average efficiency of the market is constantly improving. This tends to underestimate the baseline forecast and overestimate savings. On the other hand, it likely underestimates the efficiency that will be achievable in a cost-effective way, first of all because technology costs are generally decreasing (according to technological learning rates) and the emergence of new technologies that may not be available for analysis. Therefore, there are two compensating effects not taken into account in the analysis. The results should therefore be taken as representative of the scale of potential improvement, not as a reliable prediction. The methodology is chosen to maximize concreteness and defensibility by relying on technologies that can be justified by actual cost data.

2.1. Literature Review

Some recent examples of studies that have identified potential energy savings from energy efficiency improvements include:

China

- China's appliance standards are estimated to have saved 1.08 EJ during 2006-2008, with refrigerators, air conditioners and televisions contributing the bulk of the savings. (Price, L, et al, Energy Policy (in press), 2011. http://china.lbl.gov/sites/china.lbl.gov/files/ACEStudy.2011.pdf
- (Fridley 2008) estimates potential savings of 1.2 TWh in 2012 and 16 TWh by 2020 for energy labels on refrigerators in China. Fridley, D., Zheng, N., Zhou, N., Aden, N., Lin, J., Chen, J., and Sakamoto, T. 2008. *China Refrigerator Information Label: Specification Development and Potential Impact.* LBNL-246E, LBNL, Berkeley, CA.

[7] For simplicity the high efficiency scenario assumes 100% of the market will reach the target level in 2015, a structure that closely resembles minimum efficiency performance standards. In the later years of the forecast, the scenario is not highly sensitive to the details of the market transformation.

http://china.lbl.gov/sites/china.lbl.gov/files/LBNL_246E._China_Refrigerator_Information_Label._Feb2008.pdf

- (Cheung 2008) describe the growth of China's energy efficiency industry, projecting spending of USD 300 billion over five years. Cheung, R., and Kang, A. 2008. *China's Booming Energy Efficiency Industry.* World Resources Institute (WRI). http://pdf.wri.org/chinas_booming_energy_efficiency_industry.pdf
- (Aden 2010) uses lifecycle assessment to show that for buildings in the Beijing area, 80% of energy use and related emissions is due to operations, and about 20% due to materials. Aden, N.,Qin, Y., and Fridley, D., 2010. *Lifecycle Assessment of Beijing-Area Building Energy Use and Emissions: Summary Findings and Policy Applications.* LBNL, Berkeley, CA. http://china.lbl.gov/sites/china.lbl.gov/files/LBNL-3939E.pdf
- (Zhou 2010) provides an overview of China's policies on energy efficiency. Zhou, N., Levine, M.D., and Price, L., 2010. "Overview of Current Energy Efficiency Policies in China," *Energy Policy.* http://china.lbl.gov/sites/china.lbl.gov/files/Overview.Energy_Policy_November2010.pdf

India

- (Delio 2009) estimates potential savings from energy efficiency across all sectors in India to be 183 TWh in five years. Delio, E.A., Lall, S., and Singh, C., 2009. *Powering Up: The Investment Potential of Energy Service Companies in India.* World Resources Institute. http://pdf.wri.org/powering_up_full_report.pdf
- (De la Rue du Can 2009) provides both retrospective and prospective views of energy use in the residential and transport sectors of India. de la Rue du Can, S., Letschert, V., McNeil, M., Zhou, N., and Sathaye, J., 2009. *Residential and Transport Energy Use in India: Past Trend and Future Outlook.* LBNL, Berkeley, CA. http://ies.lbl.gov/drupal.files/ies.lbl.gov.sandbox/LBNL-1753E.pdf

United States

- The National Research Council report, *America's Energy Future,* in 2009 estimated potential cost-effective energy savings in the U.S. of about 20% in 2020 and about 30% in 2030, with the greatest potential in the buildings sector (National Research Council, *Limiting the Magnitude of Future Climate Change*, 2010).
- The American Physical Society report, *Energy Future: Think Efficiency* (2008) estimated 572 TWh of electricity savings in the residential sector in 2030, and about 30% savings for the building sector as a whole, all below the retail price of electricity.
- The U.S. Department of Energy's Appliance Standards Programs has conducted extensive studies for regulated product types (http://www1.eere.energy.gov/buildings/appliance_standards/), identifying economically justified and technologically feasible energy efficiency improvements.
- The Energy Information Administration annually publishes additional efficiency scenarios, e.g., high technology cases, in conjunction with the *Annual Energy Outlook* (http://www.eia.doe.gov/oiaf/aeo/).

2.2. Construction of the Energy Demand Scenarios

Any study that aims to project energy efficiency improvements from specific technologies must make the link between unit-level improvements and national impacts. The current study achieves this using LBNL's Bottom-Up Energy Analysis System (BUENAS). As the name suggests, BUENAS is a bottom-up technology-oriented model, rather than a top-down macroeconomic model[8]. BUENAS combines unit-level efficiency scenarios with a forecast of stock size and turnover to calculate national energy savings impacts through 2030. Unit level energy demand by baseline and "target" technologies are collected in a database that the model takes as inputs, and which define the base case and high efficiency scenarios. Growth of the stock (number of units operating) by 2030 is a function of economic and population growth.

BUENAS uses minimum efficiency performance standards (MEPS) as a default policy, that is, it models a discrete change in the efficiency of equipment after a specific year. For the current study, we chose an implementation year of 2015, assuming that several years lead time are necessary between identification of efficiency targets, and making them mandatory.

Originally constructed as a global model, BUENAS covers a wide range of energy-consuming products, including most appliance groups generally covered by Energy Efficiency Standards and Labeling (EES&L) programs around the world. The global model covered the following appliance groups:

- *Residential Sector:* Lighting, Refrigerators, Air Conditioners, Fans, Washing Machines, Standby Power, Televisions, Electric Ovens, Space Heating and Water Heating.
- *Commercial Building Sector:* Lighting, Air Conditioning, Refrigeration, Ventilation, Office Products, Space Heating and Water Heating.
- *Industrial Sector:* Electric Motors.

For the purposes of the *U.S. Business Case for Energy Efficiency*, many of the end uses needed for the analysis were present in BUENAS. However, many modifications were made. First, the *Business Case* model is dependent on an evaluation of cost-effectiveness. Therefore, appliance groups for which data were insufficient to permit this calculation were not included. On the other hand, some equipment types for which data were available were not included in the original model. In that case, these end uses were added. Finally, the efficiency scenario originally constructed for the U.S. in BUENAS was updated in light of recent DOE rulemakings. In some cases, an updated standard meant that further improvement was not cost-effective (or data do not exist), so the end use was dropped. In other cases, the rulemaking resulted in data that were not available at the time the original model was built. In those cases, both the baseline and target level were updated. Several omissions are notable. First, commercial furnaces provide about half of the space heating in the commercial building sector, no data were available for this product. Furnaces were covered in (USDOE 2010c), but not analyzed for cost-effectiveness. Likewise, no data for commercial water heaters were provided, so this product was omitted.

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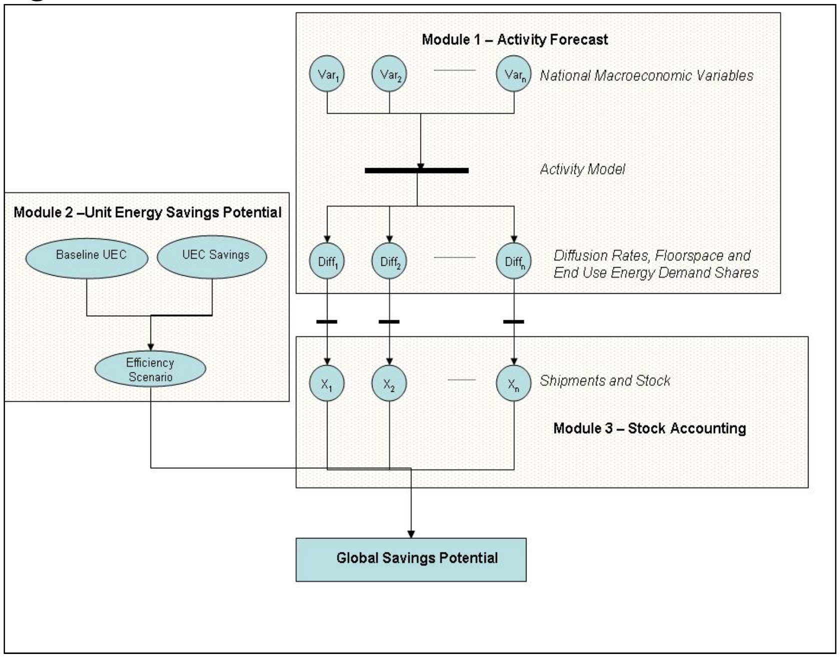
[8] BUENAS is described completely in McNeil, M.A., V.E. Letschert and S.A.De la Rue du Can (2008). *Global Potential of Energy Efficiency Standards and Labeling Programs*. LBNL 760E.

Finally, industrial motors are an important end use that are generally found to provide cost-effective improvement opportunities. The Energy Policy Act of 1992 (EPACT 1992) established nominal efficiency levels for electric motors. Most recently, this standard was updated in the Energy Independence and Security Act of 2007. This new standard, which makes mandatory a voluntary standard ("NEMA Premium"), covers electric motors from 1 to 500 hp, and came into effect in 2010. DOE is currently considering an update to the rulemaking set forth in the Energy Independence and Security Act of 2007. Technical studies supporting this rulemaking were not available at the time of the current study; therefore, motors were not included.

The BUENAS model uses the Long Range Energy Alternatives Planning (LEAP) platform[9] to forecast energy consumption by end use from 2005 (base year) to 2030. The strategy of the model is to first forecast end use *activity*, which is driven by increased ownership of household appliances and growth in the industrial sector. The total stock of appliances can be modeled either according to an econometric diffusion model or according to unit sales forecasts, if available. Electricity consumption or *intensity* of the appliance stock is then calculated according to estimates of the baseline intensity of the prevailing technology in the local market. Finally, the total final energy consumption of the stock is calculated by modeling the flow of products into the stock and the marginal intensity of purchased units, either as additions or as replacements of old units. The high efficiency or "policy" scenario is created by the assumption of increased unit efficiency relative to the baseline starting in a certain year. For example, if the average baseline unit energy consumption (UEC) of new refrigerators is 450 kWh/year, but a MEPS taking effect in 2012 requires a maximum UEC of 350 kWh/year, the stock energy in the policy scenario will gradually become lower than that of the base case scenario due to increasing penetration of high-efficiency units under the standard. By 2030, the entire stock will generally be impacted by the standard[10]. Figure 1 shows the analytical structure of BUENAS.

[9] More information about the LEAP platform may be found at http://www.energycommunity.org
[10] This depends somewhat on the lifetime of the product. For refrigerators we may assume a 15 -year lifetime, but some refrigerators may last 20 years, so the turnover of the stock may not be complete by 2030.

Figure 1 - Structure of BUENAS



The main outputs of BUENAS are base case energy consumption forecasts to 2030 by end use and energy, energy saving impacts of the modeled policy, and carbon dioxide emissions mitigation impacts. For this study, financial impacts were added to the model in a spreadsheet calculation.

For the residential sector, *activity* as modeled in Module 1 of the model is given by the stock of equipment, that is, the number of appliances installed and operating in U.S. households in a given year. Three different methods are used to estimate the total stock of a particular residential end use. For each region and end use, the method is chosen which is deemed to produce the most accurate result, and for which sufficient data are available. In order of priority, the methods are:

Method 1 - Stock based on historical and projected flows of products (unit sales).

Method 2 - Stock from historical and projected ownership rates – sales derived from stock increases and replacement rates.

Method 3 - Stock from econometric modeling driven by macroeconomic trends – sales derived from stock increases and replacement rates.

Sales forecasts are available as part of the U.S. rulemaking analysis for residential products. Therefore, the model was updated in most cases to model stock according to the first method listed above, which represents an improvement over the other methods in most cases.

Once the number of residential products in each appliance group in each year is established, this number is multiplied by the *annual unit energy consumption* (UEC) to yield energy demand for the appliance group. *UEC* is the subject of Module 2 of BUENAS, and determines the efficiency scenario modeled. Determination of the baseline and efficiency scenario UEC is discussed in Section 4 below.

Finally, Module 3 tracks the introduction of each year's cohort of appliances into the stock, taking account of growth in the market, equipment retirements, and replacements. Retirement and survival functions are derived from average lifetimes and assumed to have a distribution around the mean value. This shape of the retirement function is assumed to be that of a normal distribution centered around the mean lifetime by default, but takes the form of a more complicated function (Weibull distribution) if such a distribution is available. The survival function is given by:

$$Survival(age) = 1 - \int Retirement(age)$$

Using the retirement distribution, the model calculates the weighted average efficiency of the stock in each year. In the case of the high efficiency scenario, only a small fraction of the stock operates at high efficiency in the years immediately following the policy start date, but this fraction grows over time. The percentage of stock operating in 2030 that was installed after the policy start date is dependent on the assumed average lifetime of the product class.

Compared to the residential sector, energy demand in the commercial building sector is driven by a much wider variety of equipment types and follows distinct usage patterns depending on the type of building. For this reason, BUENAS models commercial buildings in an aggregate fashion, rather than at the level of individual appliances. The activity variable in this case is commercial building floor space. Commercial floor space projections for the United States are taken from DOE's Annual Energy Outlook 2010 (EIA 2010), which takes the place of Module 1 for the commercial sector. In Module 2, the commercial sector model uses aggregate energy intensity numbers for major appliance categories, such as lighting, space heating and air conditioning and refrigeration. Commercial clothes washers and distribution transformers were added to the model as individual appliances according to shipments forecasts. In order to model energy demand and savings from efficiency improvement, we estimate the fraction of energy covered by individual technologies for which data are available. Energy and demand are thereby calculated from base year values of energy intensity according to a scaling factor.

3. Efficiency Improvement Potential – Cost-Benefit Analysis

The primary sources for appliance group details in the United States are publicly available technical studies performed by the U.S. Department of Energy supporting its residential and commercial appliance standards program. These studies generally include forecasts of equipment stock and sales, baseline efficiency consumption, and use patterns. In addition, they provide an assessment of the price to consumers of equipment incorporating energy efficiency improvement measures and the resulting performance. These "cost efficiency curves" are the basis for determination of cost-effective efficiency targets incorporated in this study. Secondary sources are used for products not covered by DOE standards.

Because cost-efficiency data for the United States are generally taken from published results of appliance standards rulemakings either completed or in process, some interpretation of market baselines is needed. In the case where data are available but rulemakings are not finalized (preliminary analysis) we assume the same baseline as the DOE analysis (usually the previous standard). In cases where the available data corresponds to an already implemented standard, we adjust the baseline to the new standard.

Cost-effectiveness is defined in terms of cost of conserved energy, that is, how much the end user must pay in terms of annualized incremental equipment investment for each unit of energy saved by higher efficiency equipment. The formula for cost of conserved energy is

$$CCE = \frac{I \times q}{S} \qquad \textbf{Eq. 1}$$

In this equation, *I* is the total additional investment needed to purchase high efficiency equipment rather than the baseline technology, and *S* is the resulting annual energy savings. The capital recovery factor *q* is given in turn by:

$$q = \frac{d}{(1-(1+d)^{-L})} \qquad \textbf{Eq. 2}$$

In this equation, *d* is the end user discount rate and *L* is the average lifetime of the equipment, in years. Defined in this way, *I* times *q* is an annual payment for an amortized capital investment. Cost of conserved energy is a convenient metric for comparison of cost-effectiveness of measures[11].

3.1. Construction of Cost vs. Efficiency Curves

Over the past decade, technical parameters permitting efficiency cost-benefit analysis of a significant number of appliances[12] have become available as a result of analyses performed in support of the U.S. Department of Energy's Appliance Standards Program[13]. In fact, the appliances for which data are available now account for the majority of energy consumed in the U.S. residential sector. The data provided to support DOE rulemakings forms the basis of our cost-benefit calculation for many of the products analyzed. Obviously, using data supporting regulations in process brings up the question of additionality of savings capture, since much of the savings we will forecast is already the subject of DOEs program. Indeed, it is not our intention to suggest that the savings we present is being "left on the table", but only to say that the opportunities for cost-effective improvement are significant, and some of these opportunities will certainly be captured through aggressive policies like the DOE program. To be as precise as possible about what is considered still "on the table" and what is already part of the baseline, we followed the following guidelines:

[11] Other metrics such as life cycle cost and payback period establish cost effectiveness, but are not easily compared across disparate technologies and end uses.

[12] In this paper, 'appliances' refers to a broad category of energy-consuming equipment, including lighting and HVAC equipment. An 'appliance' is defined here as a category of equipment used for a general purpose, such as lighting, refrigeration or heating. We distinguish this from the term 'product class', which we take to be a subset of an appliance group. For example, a top-mounted refrigerator-freezer is a product class within an appliance group called 'refrigerators'.

[13] Data for commercial building equipment and equipment used in industrial facilities have also been published as a result of the DOE program, but are not presented here.

- Rulemakings for which a final rule has not been issued were not considered part of the *Base Case*. The baseline efficiency level used is the current baseline, as estimated by DOE.

- Rulemakings for which a final rule has been issued and for which standards come into effect before 2015 *are* considered as part of the *Base Case*. In this case, we adjusted the baseline to correspond to the new standard. Efficiency improvements in the *Business Case* are possible, if found to be cost-effective relative to the adjusted baseline.

- Rulemakings for which a final rule has been issued but comes into effect in 2015 or beyond *are* included in the *Business Case*. Because the *Business Case* considers energy efficiency policy taking effect in 2015, we include DOE standards set for that year or beyond as part of the *Business Case*, but adjust the target level according to the cost-effectiveness criterion. There is one appliance group that falls into this category (residential water heaters).

As a requirement of the DOE rulemaking process (NECPA, Pub.L. 95-619, 92 Stat. 3206, 42 U.S.C.), DOE must consider impacts on U.S. consumers and manufacturers. DOE typically analyzes costs and benefits likely to be result from any proposed efficiency rulemaking for appliances. The root of this assessment is an engineering analysis of possible efficiency improvements and their costs, and a national impact analysis which calculates the impacts of replacing commonly used equipment components with more efficient ones. The output of this analysis is a set of efficiency levels (called “design options” in the TSD), each of which is associated with reduction of energy consumption and increase in manufacturing cost. The relationship between design option costs and resulting energy consumption (or efficiency) is often referred to as a *cost-efficiency curve*. The cost-efficiency curve forms the basis of consumer cost-benefit analysis of efficiency improvement regulations. The parameters sourced from DOE Technical Support Documents (*TSDs*) needed to establish cost-efficiency curves are:

- *Baseline Unit Energy Consumption* – The annual electricity or gas energy consumption used by “standard efficiency” products. Energy consumption is generally estimated assuming typical use patterns. The standard efficiency product may represent the minimum efficiency required by the standard in force, or may be somewhat higher according to the market at the time of the analysis.

- *Design Option Unit Energy Consumption* – Annual electricity or gas consumption for each efficiency improvement technology, assuming no change in use patterns.

- *Baseline Equipment Price* – Estimated retail price of “standard efficiency” products. Baseline Equipment Prices are generally calibrated to actual prevailing retail prices. Equipment Prices may include the cost of installation, but do not include maintenance and repair costs[14]. Equipment prices given in DOE reports were inflation-adjusted using GDP deflators provided by (BEA, 2010).

[14] Maintenance and repair costs are included by DOE for products where these are significant. They are excluded

- *Design Option Equipment Price* – Projected price of equipment for each efficiency improvement technology. Design option equipment prices are generally calculated by adding estimated production costs, and then applying estimates of manufacturer and retail markups.

DOE categorizes covered products into separate product classes and formulates a separate energy conservation standard for each product class. The criteria for separation into different classes are type of energy used, capacity, and other performance-related features. Each product class has features that determine the above parameters in a distinct way. Therefore, cost-efficiency curves are determined at the product class level, and a cost-benefit calculation is performed on each individually. Efficiency and cost parameters are then calculated at the appliance class level by weighting according to market shares. For simplicity, we consider only those product classes that account for two percent of the market or more as estimated in the TSD. This selection generally covers the large majority of the market and we extend the results of these to the entire appliance group.

In order to demonstrate the construction of the cost-efficiency curve, we present the example of one product class. We chose refrigerator freezers with top mounted freezer compartments and auto-defrost features as a demonstrative example. This product class is the most common refrigerator on the U.S. market, representing 54.3% of refrigerator sales. Price and energy consumption are based on 18 ft^3 total volume. Baseline technology parameters, efficiency design options and resulting efficiency improvement are given in Table 1.

Table 1 – Efficiency Design Options for Top-Mount Refrigerator-Freezers

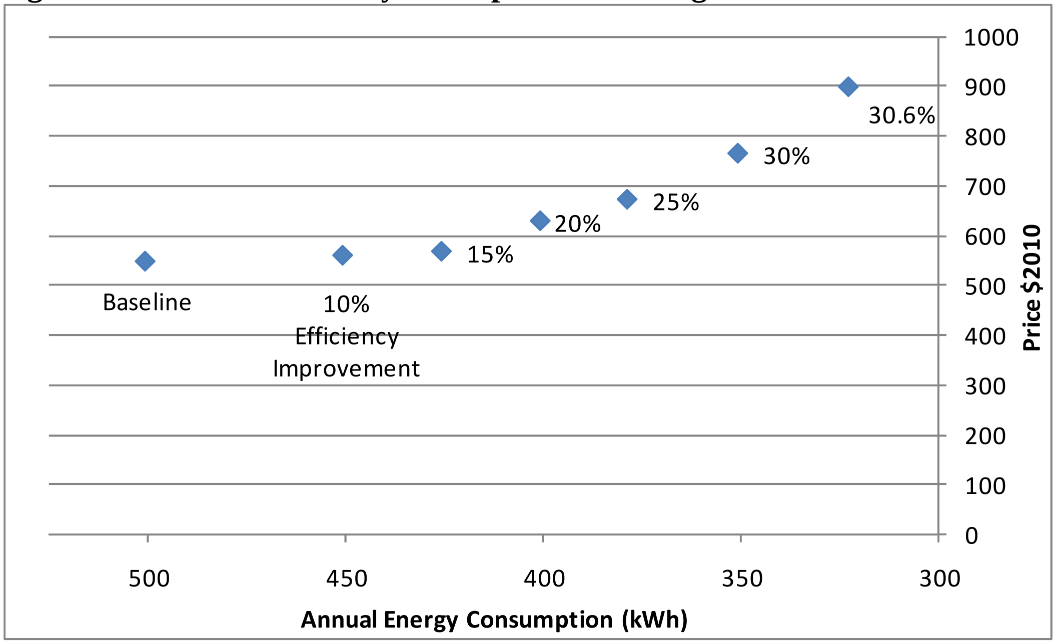
Efficiency Level	Design Option
Baseline	See Table 5-A.2.1 of 1
10%	Increase Condenser Size by 100% & Increase Compressor EER from 5.55 to 6.1
15%	Increase Compressor EER from 6.1 to 6.26 & Use Brushless DC Condenser Fan Motor
20%	Increase Evaporator Size by 14% & Use Adaptive Defrost & Use Variable Speed Compressor
25%	12.2 sqft VIP in FZR Cabinet
30%	2.9 sqft VIP in FZR Door & 7.1 sqft VIP in FF Door & 6.7 sqft VIP in FF Cabinet
30.60%	1.9 sqft more VIP in FF Cabinet

Source: Table 5-A.3.1 of USDOE (2010a)

Starting from the baseline configuration, alternate designs are constructed by replacing or adding components in turn, in order of cost-effectiveness. Each of these options is represented by a point in Figure 2. The resulting *cost-efficiency curve* has a typical shape with increasing costs per unit efficiency improvement.

here for simplicity and consistency.

Figure 2 – Cost vs. Efficiency for Top-Mount Refrigerator-Freezers



Source: Table A.2.1

The cost-benefit evaluation is a calculation that determines whether increases in first cost are justified by a return on investment in the form of reduced utility bills and accounting for discounting of delayed costs or savings. Using the cost of conserved energy metric, a cost-effective efficiency improvement costs less per unit energy saved than the energy tariff, with the initial investment amortized over the life of the appliance. Appliance groups and product classes are described in Section 3.2. The data used in this analysis are detailed in the tables in Appendix 2. Sources for these tables are summarized in the tables in Appendix 3. The following parameters are collected or calculated for each product class:

3.2. Equipment Data

Incandescent Lamps

Incandescent lamps constitute the bulk of residential lighting energy. According to the Building Energy Data Book (BEDB 2010)[15], lighting accounts for 14.2% of residential electricity or 10% of residential building energy, in primary energy terms. Replacement of incandescent lamps with compact fluorescent lamps (CFLs) or other technology such as LEDs is generally at the top of the list of attractive efficiency measures because of the large fractional savings (up to 60%) and the high degree of cost-effectiveness. Bans on incandescent lamps are also among the most popular efficiency policies globally. The United States has a planned phase-out of incandescent bulbs in 2012 as specified in the Energy Independence and Security Act of 2007. Although this regulation is currently "on the books", we chose to include its effects as part of the *Business Case* scenario, rather than in the Base Case. In this case, the high-efficiency scenario is

[15] U.S. Department of Energy office of Energy Efficiency and Renewable Energy – *Building Energy Data Book 2010*, available at http://buildingsdatabook.eren.doe.gov.

characterized by successful implementation and enforcement of the policy, rather than the establishment of it. Cost-effectiveness of incandescent lamp replacement is not highly controversial. For simplicity, we assume a retail cost of $5.00 for a 15 W CFL that lasts for 5 years versus $2.50 for five incandescent lamps, which we assume to last only a year each. Even with these conservative assumptions, incandescent lamp replacement is among the most cost-effective measures available.

Refrigerators

Taken together, refrigerators and freezers account for 8.9% of residential electricity or 6.3% of primary residential energy consumption in the United States (BEDB 2010), making them the highest consumption end use aside from lighting, water heating and HVAC (EIA 2010 Table 4). Efficiency improvement design options for refrigerators include added and/or improved insulation, increased compressor efficiency and increased evaporator and condenser area (see Table 1). As part of its upcoming final rule for updated refrigerator standard (USDOE 2010a) to take effect in 2014, DOE has released data showing equipment costs and energy consumption for the 7 product classes covered by the rulemaking. We analyzed the three product classes with more than 2% of the market. These three refrigerator–freezer classes; top mounted freezer, bottom-mounted freezer and side-by side, represent about 97% of the current market. Cost and energy consumption parameters for refrigerator products are given in Table A.2.1.

Room Air Conditioners

Space cooling accounts for 22.4% of residential electricity or 15.8% of U.S. residential energy use in primary terms (BEDB 2010). While the dominant technology for residential space cooling in the United States is central air conditioning, room air conditioners still play an important role, and as they have recently experienced a dramatic drop in price, the market for them has grown in residences that previously had no air conditioning, and in some small commercial buildings. Window units are still dominant in the United States, unlike much of the world, where the trend is toward split system RACs. Room air conditioner efficiency can be improved through a variety of design improvements (see USDOE 2010b). The analysis takes advantage of preliminary analysis supporting a rulemaking to be published in early 2011[16] with an implementation date of 2014. We consider four separate product classes, defined by cooling capacity and the presence of louvers. Cost and energy consumption parameters for refrigerator products are given in Table A.2.2.

Water Heaters

Electric and fuel-burning water heaters account for 8.9% of residential electricity and 27.4% of residential natural gas, or 13.2% of residential primary energy consumption (BEDB 2010). DOE passed new standards for residential water heaters in 2010. These standards will come into effect in 2015. Therefore, we consider the current baseline in construction of the *Base Case*, and construct the *Business Case* according to the cost-benefit criterion. The resulting target levels may or may not correspond to the standard set by DOE. Electric storage tank water heaters

[16] These data have since been updated, but were not publically available at the time of our analysis.

enjoy a sizeable market share in the United States. They have been subject to several standards updates by DOE and their efficiency is close to 100%. Since there is no virtually no waste heat from the electric heating element, remaining heating efficiency of conventional units is limited to reducing standby losses through improved insulation around the tank. However, over the past decade water heaters using heat pump technology have been introduced into the U.S. market[17]. These units can produce hot water with less than half of the energy required by traditional water heaters, and represent the next major leap in efficiency. Like electric water heaters, gas storage tank water heater efficiency can be improved by reducing standby losses through added tank insulation. In addition, efficiency can be improved by increasing heat transfer efficiency, usually by increasing the size of heat exchangers. Very high efficiency gas water heaters use *condensing* technology in which the flue gases are cooled to a degree to where they form a condensate. Cost and energy consumption parameters for water heaters are given in Table A.2.3.

Televisions

Televisions are estimated by the BUENAS model to consume 67 TWh of electricity which corresponds to 4.6% of residential electricity or 3.2% of total residential primary energy as estimated by BEDB 2010[18]. Televisions are a dynamic and rapidly evolving technology. Recent market trends include a massive shift to flat panel technology, with dramatic increases in screen size, along with market-driven efficiency improvements. Because of the dynamism in television technology, efficiency baselines and technology trends are difficult to forecast and historical cost data are not relevant. Recent history has shown, however, that efficiency targets such as Energy Star have been easily met, often capturing most of the market by the date they are implemented with virtually no increase in price. For this reason, we judged it a reasonable assumption that Energy Star 4.0 announced in 2010 will be the baseline by 2015, and that Energy Star 5.0 will be attainable through cost-effective technology[19]. We assume a cost of conserved energy of two cents per kWh for improvement from Energy Star 4.0 to 5.0 for televisions.

Standby Power

Standby power is estimated by the BUENAS model to consume 34 TWh of electricity which corresponds to 2.3% of residential electricity or 1.6% of total residential primary energy as estimated by BEDB 2010[20]. Standby power consumption is a feature of a wide range of products, including major appliances, consumer electronics and home entertainment equipment. This mode of power consumption is increasingly shown to be a major source of energy demand, and has become a prominent candidate for efficiency improvement (IEA, 2001). Reduction of standby power is typically very inexpensive to achieve through redesign of electronic components. DOE has decided not to consider standby power in a single rulemaking for all products, but will include the reduction of standby power as part of individual rulemakings

[17] Heat pump water heaters are already common in some other countries, notably Japan, China and Australia.
[18] 217 TWh of primary energy, using a site to source factor of 3.23 in 2010, compared to 14.4 quads total primary energy.
[19] The California Energy Commission recently found that television technology could be improved to meet its new minimum efficiency requirement at no additional cost (CEC 2009).
[20] 111 TWh of primary energy, using a site to source factor of 3.23 in 2010, compared to 14.4 quads total primary energy.

governing active mode use for each product type. For simplicity, we include standby power as an aggregate category, and assume an 80% reduction in standby power per product, from 5W to 1 W, at a cost of two cents per kWh.

Electric cooking appliances (Electric)

Electric cooking appliances account for 2.2% of residential electricity or 1.5% of residential primary energy consumption (BEDB 2010). Five electric cooking appliances were considered in DOE's recent rulemaking announced in 2009 (USDOE 2009). These are: coil cooktops, smooth cooktops, standard ovens, self-cleaning ovens and microwave ovens. Cost and energy consumption parameters for cooking appliances are given in Table A.2.4.

Central Air Conditioners and Heat Pumps

Space cooling accounts for 22.4% of residential electricity or 15.8% of U.S. residential energy use, in primary terms (BEDB 2010).Mechanical cooling is also the major contributor to peak electricity demand in the U.S.. Ducted central air conditioners, which are by far the most common means of cooling, were first regulated by NAECA in 1987. A major update of standards came into effect in 2006, with the next expected to come into effect in 2015. Space heating through electric heat pumps is also common in some regions of the United States. Due to the similarity of CAC and HP technologies, they are regulated together as product classes of the same appliance group. Cost and energy consumption parameters for central air conditioner and heat pump product classes are given in Table A.2.5

Gas Furnaces

Natural gas space heating contributes 67.1% of residential natural gas or 21.1% to residential primary energy demand (BEDB 2010). Natural gas warm-air furnaces are the most common form of space heating in U.S. homes. The main efficiency improvement options for furnaces are related to improvement of heat transfer, to minimize the amount of waste heat escaping through the flue. Like water heaters, high-efficiency gas furnaces use condensing technology. Residential furnace and boiler standards were updated in 2007 and are set to come into effect in 2015. We do not consider further improvement for boilers because furnaces are much more common. For furnaces, however, recent standards were set at the current market baseline. We therefore do consider cost-effective improvement options from this baseline. Cost and energy consumption parameters for gas furnace product classes are given in Table A.2.6.

Commercial Air Conditioners and Heat Pumps

Together with space heating and lighting, air conditioning is one of the most important commercial building end uses. Space cooling accounts for 12.6% of commercial sector electricity or 10.1% of total commercial building primary energy (BEDB 2010). New standards for commercial central air conditioning and heat pumps came into effect in 2010. We analyzed the potential for further cost-effective improvement from this new baseline. Cost and energy consumption parameters for commercial air conditioners and heat pumps are given in Table A.2.7.

Commercial Linear Fluorescent Ballasts

Lighting accounts for 22.2% of commercial sector electricity or 17.4% of total commercial building primary energy (BEDB 2010). According to DOE's *Commercial Building Energy Consumption Survey* (EIA, 2003), linear fluorescent lamps account for roughly 75% of lighting in commercial environments. While this type of lighting is already highly efficient, improvements are still possible, and even small percentage improvements can have a large effect on overall sector energy consumption. A standards rulemaking issued in 2000 taking effect in 2005 required electronic fluorescent lamp ballasts. The next rulemaking is expected in 2011 and will come into effect in 2014. Our analysis is based on data made available in the preliminary stage of the upcoming rulemaking. Cost and energy consumption parameters for commercial linear fluorescent lamp ballasts are given in Table A.2.8.

Commercial High Intensity Discharge Lamps

Lighting accounts for 22.2% of commercial sector electricity or 17.4% of total commercial building primary energy (BEDB 2010). HID lamps produce light by creating an electrical arc between electrodes in a tube that is filled with gas and metal salts. HID lamps are used in applications which include street lighting, security lighting, and lower wattage applications. To date, HID have never been regulated at the federal level. Recently, however, a DOE determination found significant saving potential for this class of lighting. Therefore, even though this lighting type accounts for only about 10% of commercial sector lighting, the potential for savings, in percentage terms, could be significant. Cost and energy consumption parameters for high intensity discharge lamps are given in Table A.2.9.

Distribution Transformers

Distribution Transformers are designed to reduce the voltage of the electricity coming from the electric grid, to a lower voltage which is applicable for appliances and other electricity-consuming systems. Losses in transformers account for an inefficiency in national electricity usage on the order of a percent. Distribution transformers efficiency is currently regulated by standards that came into effect in 2007 and 2010. New standards are due in 2012. We analyzed distribution transformers for cost-effective improvement using the data from the previous rulemaking and adjusted the baseline to account for the recent standards. Cost and energy consumption parameters for distribution transformers are given in Table A.2.10.

Commercial Boilers

Space heating accounts for 3.8% of commercial sector electricity and 51.9% of commercial sector natural gas, or 13.4% of total commercial building primary energy (BEDB 2010). Boilers provide roughly half of space heating in commercial buildings. Commercial boilers are regulated by a standard announced in 2009 that comes into effect in 2012. This standard covered efficiency requirements for several products included in voluntary standards issued by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE). DOE made the decision to make mandatory requirements of ASHRAE's ASHRAE 90.1 2007 standard. The analysis used data generated for that rulemaking. Data were not available for commercial furnaces. Cost and energy consumption parameters for high intensity discharge lamps are given in Table A.2.11.

3.3. Cost of Conserved Energy Calculation

As mentioned in the previous section, annual unit energy consumption (*UEC*) and equipment price (*Price*) are shown for all product classes considered in the analysis in Appendix 2, unless otherwise specified[21]. These parameters are used in the calculation of cost of conserved energy according to Equation 1 by comparing each design option to the baseline, according to:

$$I = Price_{DesignOption} - Price_{Baseline}$$

and

$$S = UEC_{Baseline} - UEC_{DesignOption}$$

The parameters used in calculation of q in Equation 2 are as follows:

Product Lifetime (*L*) – Average number of years that a product is used before failure and retirement. Lifetimes vary by product class and are estimated from manufacturer reports, or from survey data.

Discount Rate – Discount rates vary somewhat from product to product in DOE's analysis. For simplicity, we assume a consumer discount rate of 5% for residential products and 6% for commercial products, values that are similar to DOE estimates, which range from 4.0% to 6.2% for residential products and from 4.2% to 7.0% for commercial products. The consumer discount rate we use is a "real" discount rate, and represents the actual rate of interest on the financing of the equipment, the mortgage rate if new appliances are included in the home purchase.

Using these parameters, we calculate cost of conserved energy for each design option for each product class. The results of this calculation, shown in the Appendix 2 tables, are the basis of construction of the efficiency scenario.

As stated above, the target efficiency level chosen is that which *maximizes efficiency while providing a net benefit to consumers*. Following this definition, we identify the target UEC for each product class as the lowest UEC for which cost of conserved energy is below the utility price. In order to model efficiency improvements beginning in the year 2015, we use average national residential and commercial prices[22] provided by DOE's Annual Energy Outlook 2010

[21] Additional products were evaluated for cost-effectiveness with the result that no cost-effective improvements were possible beyond the current standard. These were removed from further consideration, and are not included in the Appendix.

[22] DOE appliance standards analyses typically use *marginal prices*, which represent the price of the last unit of energy paid, which can differ from average prices due to the structure of the tariff schedule. Strictly speaking, marginal prices are more appropriate than average prices when characterizing efficiency improvements. In addition, *regional prices* are also sometimes used for appliances with a large degree of regional variation in terms of product

(EIA 2010). The average residential electricity price is $0.11 per kilowatt-hour ($/kWh) and the average residential natural gas price is $13.17 per million British thermal units ($/MMBtu). The corresponding energy prices in the commercial sector are $0.10/kWh and $11.40/MMBtu, respectively.

To illustrate the construction of the efficiency scenario, we return to the refrigerator example. The top portion of Table 2 shows *UEC*, *Price* and *CCE* for each design option of the three major product classes. The lower portion of the table shows the target annual incremental cost and UEC for each class. For example, design options 1 through 4 can be implemented at a cost of $0.09/kWh or less, which is less than the electricity price of $0.10/kWh, while the cost of implementing design options 5 and 6 exceed the price of electricity. Therefore we determine design option 4 to be the maximum cost-effective technology. This design option costs $125 more to implement than the baseline, which gives an annual incremental cost of $11 when multiplied by *q*. The UEC for this design option is 379 kWh/yr, so the savings is 122 kWh with respect to the baseline.

Table 2 – Cost of Conserved Energy Calculation for Refrigerators

Class	Top Mount Auto Defrost Refrigerator-Freezer			Bottom-Mount Refrigerator-Freezer			Side-by-Side Refrigerator-Freezer		
Market share	54.3%			13.5%			28.9%		
Lifetime	17.1			17.1			17.1		
q	0.088			0.088			0.088		
Efficiency Level	UEC kWh/yr	Price $2010	CCE $2010	UEC kWh/yr	Price $2010	CCE $2010	UEC kWh/yr	Price $2010	CCE $2010
Baseline	501	547		613	953		768	1161	
1	451	559	0.021	551	955	0.003	691	1164	0.003
2	426	567	0.024	521	957	0.004	653	1169	0.006
3	401	629	0.072	490	963	0.007	614	1188	0.015
4	379	672	0.091	459	1028	0.043	576	1254	0.042
5	351	765	0.128	429	1136	0.087	538	1396	0.090
6	323	899	0.175	391	1286	0.132	515	1508	0.120

Target Annual Incremental Cost (I×q)	$11	$16	$21
Target UEC (kWh/yr)	379	429	538

Weighted Average Baseline UEC	588 kWh/yr	Weighted Average Incremental Cost	14.5 $2010
Weighted Average Target UEC	428 kWh/yr	Product CCE	0.090 $2010
Weighted Average Energy Savings	161 kWh/yr		

Following this pattern with the other product classes, we find a weighted average energy savings of 161 kWh per year and weighted average incremental cost of $14 per year, for a weighted average CCE of 14/161 or $0.09/kWh which is less than the utility price by construction[23]. Appendix 2 shows the calculation of CCE for each product class, and calculates weighted average target UEC and CCE for each appliance group. The cost of conserved energy for all appliance groups is compared to utility prices in Figure 3.

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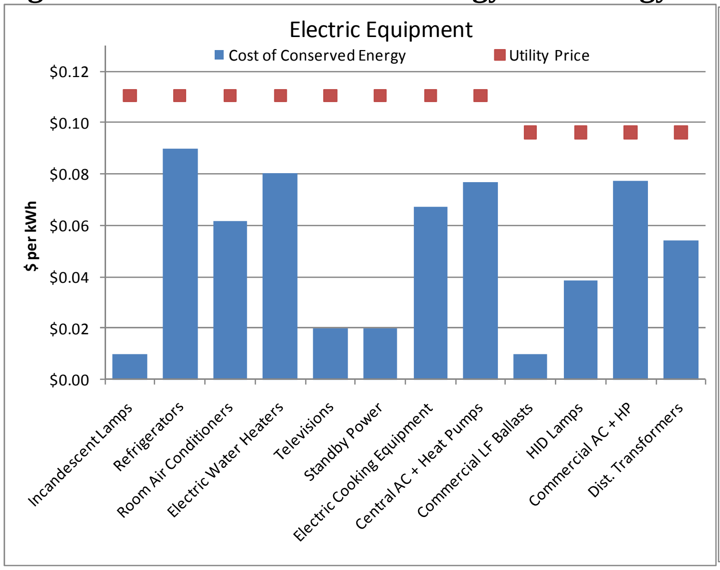
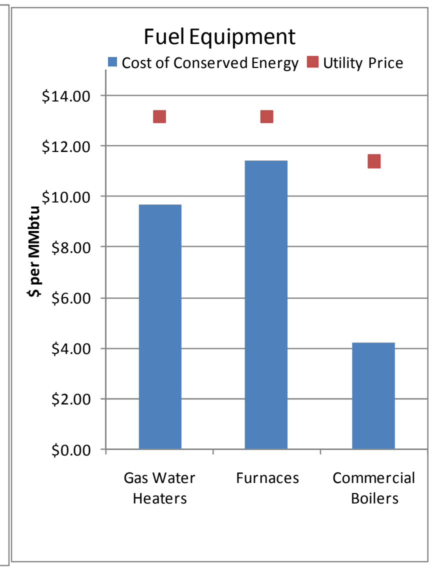
class share and energy consumption. For simplicity, neither of these refinements are considered here.

[23] It would be possible in principle to increase the efficiency savings potential by requiring only that the weighted average CCE be lower than the utility price. We chose the more stringent requirement that each product class be individually less than the utility price, since regulations generally apply at the product class level.

Figure 3 – Cost of Conserved Energy and Energy Prices





The main inputs to the construction of the two scenarios, the *Base Case* and the *Business Case* scenario are the baseline *UEC* and the UEC established by CCE in Figure 3. We call this the *Business Case UEC*. Baseline UEC, *Business Case* UEC, Percent Decrease and Cost of Conserved Energy are presented in Table 3.

Table 3 – Annual Energy Use Per Unit and Cost of Conserved Energy

Equipment	Baseline UEC	Business Case UEC	Percent Decrease	Cost of Conserved Energy
Electric Equipment	kWh/a	kWh/a	%	$/kWh
Commercial Linear Fluorescent Ballasts	306	285	7%	$0.010
Incandescent Lamps	46.5	15.1	67%	$0.018
Televisions*	200	141	30%	$0.020
Standby Power**	17.2	3.4	80%	$0.020
HID Lamps	729	335	54%	$0.038
Distribution Transformers (Losses Only)	5702	2720	52%	$0.054
Room Air Conditioners	700	581	17%	$0.062
Electric Cooking Equipment	153	152	1%	$0.067
Central AC + Heat Pumps	3285	2525	23%	$0.077
Commercial AC + HP	8901	8608	3%	$0.078
Electric Water Heaters	2604	1216	53%	$0.081
Refrigerator	588	428	27%	$0.090
Fuel Equipment	MMBtu/a	MMBtu/a	%	$/MMBtu
Commercial Boilers	2106	2042	3%	$4.241
Gas Water Heaters	16.6	14.7	11%	$9.68
Furnaces***	52.1	48.2	8%	$11.42

* Results shown for LCD display only
** Per product. Standby power is calibrated to total estimated household standby power

*** Residential boilers excluded due to recent rulemaking

Table 3 shows that energy efficiency improvements can be made to a wide variety of equipment that will provide not only energy savings, but financial benefits to consumers. It also demonstrates the importance of performing this type of analysis at the appliance group level, since the cost-effective potential varies widely between appliance groups.

We emphasize that the results may not match exactly with findings of the recent DOE rulemakings. There are several possible reasons for that:

1. The analysis presented here is highly simplified compared to the DOE analysis, which takes into account distributions of household characteristics, regional differences, marginal energy prices, etc.
2. The DOE analysis bases its evaluation of cost-effectiveness not only at the individual level (*Life-Cycle Cost Analysis*) but also from national financial impacts (*Net Present Value*).
3. The DOE analysis takes into consideration other factors, such as feasibility in ramping-up production of high efficiency technology to a mass scale.

Efficiency improvements found to be cost-effective for each appliance group are as follows:

Incandescent Lamps – Not surprisingly, switching from incandescent lamps to CFLs is found to be highly cost-effective. Switching to LEDs was not considered due to lack of data demonstrating significant cost reductions for LED technology.

Refrigerators – Despite dramatic improvements to this appliance in the past, the analysis finds that there are still affordable improvements to be made, notably through the use of vacuum insulated panels.

Room Air Conditioners – Design improvements to this appliance are also still available, but savings is not dramatic in the U.S. context.

Water Heaters – The analysis finds heat pump technology to be cost-effective, producing a large percentage savings for this high-intensity end use[24]. The analysis finds condensing technology for water heaters to be cost-effective.

Televisions – A 30% improvement is assumed based on Energy Star requirements, and assumed to be cost-effective.

Standby Power – A reduction in standby power from 5W to 1W per product is assumed to be cost-effective.

Electric Cooking Equipment – Savings from design options in this appliance group were found to be small, and often not cost-effective, so the weighted average improvement is very small.

[24] DOE also found heat pump water heaters to be an appropriate MEPS target, but only for large capacity units, which account for a small fraction (around 10%) of the residential market.

Central Air Conditioning and Heat Pumps – Like refrigerators, cooling is one of the most highly-regulated residential products. Additional cost-effective savings potential is likely the result of decreases in the cost of high-efficiency compressor technology in the last decade.

Residential Furnaces – A rulemaking in 2007 covered both residential furnaces and boilers, but an update is currently in progress for furnaces only. Our analysis finds that a shift to condensing gas furnaces would be cost-effective to consumers on an average basis.

Commercial Linear Fluorescent Ballasts – Due to the high intensity of this technology in commercial buildings, additional cost-effective savings potential are available. Improvement of this technology was found not to be cost-effective in the residential sector.

High Intensity Discharge Lamps – High intensity discharge lamps have not yet been regulated by the DOE standards program, but a recent DOE determination found significant energy savings potential for this product, which triggers a future rulemaking proceeding. Our analysis also finds significant cost-effective efficiency improvement potential across all product classes considered in this category.

Distribution Transformers – Revised standards for distribution transformers came into effect in 2010. Our readjustment of the baseline to the new standard results in the finding that additional cost-effective savings is possible, given our assumptions.

Commercial Boilers – DOE issued a rulemaking in 2009 covering commercial boilers along with other equipment covered by the ASHRAE 90.1 2007 voluntary standard. DOE subsequently decided to set standards for boilers at the ASHRAE level, to come into effect in 2012. Although these standard levels are included in our Base Case, we find significant (7%) additional cost-effective improvement.

Commercial Air Conditioners and Heat Pumps – The most recent standards for these product classes came into effect in 2010. Using the data supporting the previous rulemaking, we readjusted the baseline to correspond to the current standard. Using this method, we find that additional cost-effective potential is possible but, not surprisingly, the magnitude is small compared to savings from the pre-standard baseline.

4. National Level Energy Savings Opportunities

Because of the modular structure of the BUENAS model (see Figure 1), once the inputs are established it is a relatively straightforward process to construct the two energy demand scenarios and compare them to calculate savings potential. The full details of the calculation of energy demand are provided in (McNeil 2008) and are omitted here. Instead, we present a summary of inputs modified and added to the model for the present study.

Activity was largely modeled through Method 1 described in Section 2.2. Sales forecasts for most products were taken directly from the TSD documents or accompanying analysis tools downloaded from the DOE website without modification. These forecasts are generally highly detailed and complex, and are based on relevant drivers, including housing construction, normal replacements, early replacements and fuel switching. The exceptions to this method of activity forecasting are as follows:

Incandescent Lamps – Incandescent lamps are considered in the residential sector only. Total points of light in 2002 are based on a recent study (IEA 2006) and grown according to the relationship between number of light fixtures and household income as determined by (McNeil 2008). In the *Base Case*, incandescent are assumed to be completely phased out in favor of CFLs by 2020. The *Business Case* is based on the scenario set forth in EISA, which phases out incandescent in the two years following 2012.

Televisions – Television ownership is calibrated to data provided by DOE's *Residential Energy Consumption Survey 2005* (EIA 2005). Since U.S. television ownership rates are already the highest in the world, we assume no further increase in the number of televisions per household. The stock of TVs therefore grows only with the number of U.S. households. Market shares of CRT, LCD and Plasma display technologies and average screen size are taken from (Display Search 2010).

Standby Power – BUENAS models the total wattage of standby power per household according to a model determined in (McNeil 2008). This model was calibrated to a recent report (IEA 2001) which found an average of 67 W per U.S. household in 2005.

Commercial Lighting – Commercial lighting intensity in the United States in terms of kWh/m^2 is modeled in (McNeil 2008). In order to calculate energy demand and savings in the *Business Case*, we consider the percentage savings found to be cost-effective for linear fluorescent ballasts and high-intensity discharge lamps shown in Table 3 and consider their estimated contribution to commercial building lighting energy according to DOE's *Commercial Building Energy Consumption Survey* (EIA 2003) to derive a weighted average percentage improvement, which is applied to the *Business Case* lighting intensity.

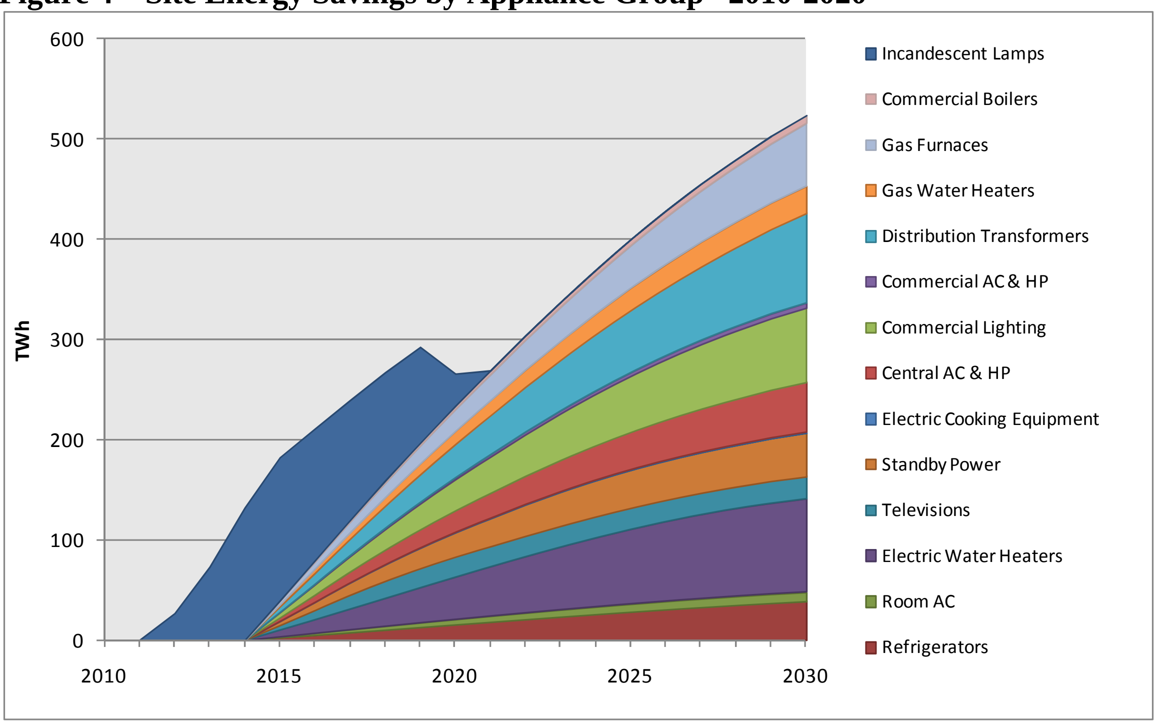
Commercial Heating and Air Conditioning Equipment – Commercial air-source air conditioners and heat pump savings was applied to overall cooling intensity according to market shares in a similar way to commercial lighting. Commercial boiler savings was also applied to heating in this way. Since only about 40% of heating is accomplished with boilers, overall heating savings is relatively small.

4.1. Energy Savings and Emissions Reductions

Site energy savings is the basis for all national impacts calculations. Site energy demand refers to electricity and natural gas consumed in a home or business, and does not include fuel inputs in generation of electricity, or losses in transmission or distribution. Site energy is the energy affected most immediately by efficiency improvement. It is also the energy consumption that appears on consumer utility bills, and forms the basis for the cost-benefit analysis detailed above.

Site energy consumption is calculated by BUENAS for both the *Base Case* and *Business Case* scenarios. Energy *activity* is the same in both cases[25], so the difference between them is driven by the trend in *marginal intensity*, that is, the UEC of products sold in each year. The UEC for the two scenarios are identical until the policy implementation date of 2015[26]. After that date, the efficiency target in the *Business Case* is the high efficiency level determined by cost-benefit analysis, while it remains at the baseline efficiency level in the *Base Case*. The difference in UEC in the two scenarios applies only to new products – in this way, the policy modeled has the structure of a minimum efficiency performance standard, and does not imply retrofits of existing equipment. By 2016 overall energy demand of stock in the *Business Case* is only slightly lower than the *Base Case*, because only one year's sales are affected by the policy. Moving through the forecast, LEAP tracks the gradual flow of high efficiency products into the stock and the retirement of less efficient ones, so that the average stock UEC gets closer to the target level. Depending on the lifetime of the product, the entire stock may not be converted by 2030, since some low-efficiency products installed before 2015 will survive. Figure 4 shows the evolution of site energy savings by appliance group. From 2012-2015, all of the savings is due to the accelerated phase-out of incandescent lamps in the *Business Case*. This savings goes to zero by 2020 however, as incandescent lamps are eliminated by this date in both scenarios. From 2015 onward, energy savings is growing for all other products as high efficiency products begin to penetrate the stock in the *Business Case*.

Figure 4 – Site Energy Savings by Appliance Group– 2010-2020



Site energy savings results are summarized in Table 4. Total savings for all appliance groups totals 523 TWh in the year 2030. Cumulative savings through 2030 total 5754 TWh.

[25] It is possible to model, for example, the reduction of sales or fuel switching resulting from price increases associated with efficiency regulations. This effect is not captured in BUENAS.

[26] The exception is the phase-out of incandescent lamps, which begins in 2012 in the *Business Case*.

Emissions reductions are calculated directly from energy savings according to a carbon factor. The carbon factor for electricity includes fuel inputs to generation, and accounts for transmission and distributions losses. The carbon factor is taken from (EIA 2010) and is 0.594 kg CO_2/kWh in 2015 decreasing to 0.574 kg CO_2/kWh in 2030. Carbon factors for natural gas and fuel oil are assumed to remain constant at 0.202 and 0.264 kg/CO_2, respectively. Emissions reductions from energy savings determined by multiplying energy savings by carbon factors are shown in Table 4. Total mitigation in the *Business Case* is found to be 265 mt CO_2 in 2030 and 3021 mt CO_2 over the entire forecast. Figure 5 shows the contribution to cumulative CO_2 mitigation from all appliance groups. In addition, we also evaluate the amount of other pollutants avoided by energy savings, including SO_2, NO and mercury (Hg). Avoided pollutants are estimated according to emissions factors available in (EIA 2010)

Table 4 – Energy Savings and Pollutant Mitigation by Appliance Group

Appliance Group	Final Energy Savings			Emissions Mitigation					
	In 2020	In 2030	Through 2030	In 2020	In 2030	Through 2030			
	TWh			mt CO_2		mt CO_2	mt SO_2	mt NO	t Hg
Electric Water Heaters	41.8	92.4	887	24.3	53.1	512	2.0	0.7	10.4
Incandescent Lamps	31.9	0.0	861	18.6	0.0	513	1.9	0.7	10.1
Distribution Transformers	33.3	89.8	764	19.4	51.6	441	1.7	0.6	9.0
Commercial Lighting	31.0	74.3	679	18.0	42.7	392	1.5	0.6	8.0
Furnaces	21.4	62.0	512	4.3	12.5	103	0.0	0.0	0.0
Standby Power	24.5	43.9	463	14.3	25.2	268	1.0	0.4	5.4
Central AC & HP	21.6	49.8	457	12.6	28.6	264	1.0	0.0	5.4
Refrigerators	15.7	39.3	348	9.1	22.6	201	0.8	0.1	4.1
Televisions	20.2	22.6	300	11.8	13.0	174	0.7	0.2	3.5
Gas Water Heaters	13.2	27.2	269	2.7	5.5	54.3	0.0	0.0	0.0
Room AC	5.5	9.2	99.2	3.2	5.3	57.4	0.2	0.1	1.2
Commercial Boilers	3.2	7.5	68.9	0.6	1.5	13.9	0.0	0.0	0.0
Commercial AC & HP	2.0	5.0	45.2	1.2	2.9	26.1	1.0	0.0	5.4
Electric Cooking Equipment	0.1	0.2	1.3	0.1	0.1	0.8	0.003	0.001	0.0
Total	**265**	**523**	**5754**	**140**	**265**	**3021**	**11.9**	**3.5**	**62**

Several conclusions can be drawn from Table 4 and Figure 5. First, the largest accessible savings appears to be available in the residential sector. Notable among these are electric water heaters, for which heat pump technology was found to be cost-effective[27]. Incandescent lamps also show a large savings through a phase-out and replacement with CFLs[28]. The Energy Independence and Security Act passed by Congress in 2007 includes a phase out of incandescent lamps starting in 2012 which will capture this savings when implemented. Large potential savings is also forecast for televisions, for which a minimum efficiency standard has never been set, but is in process. Similar potential is available for refrigerators, which have been regulated

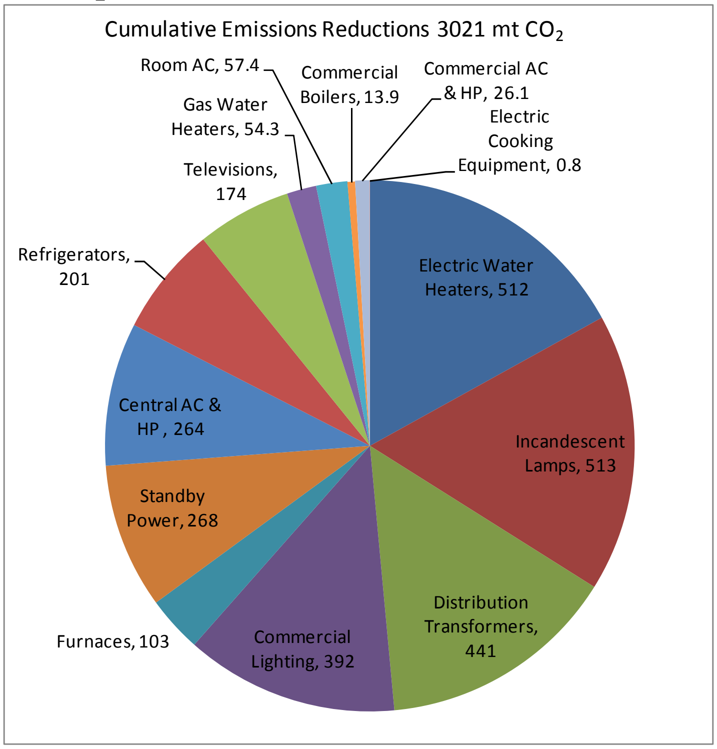
[27] DOE has set a standard implying heat pump technology for only the largest capacity water heaters, citing market barriers for the bulk of the market. As this technology becomes more prevalent, wider penetration may become achievable.

[28] Incandescent lamps show no savings in year 2030 itself, because they are forecast to be phased out by that year in the base case scenario.

with several updates, but for which high-technology options such as vacuum insulation panels are just now becoming cost-effective. Finally, standby power reduction shows high potential savings. It is the policy of DOE to address standby power as part of future standards for electronics and other products with standby modes.

Savings are relatively low for commercial buildings end uses, with the exception of lighting. While the dominant technology (fluorescent tube lamp ballasts) are already relatively efficient, much of the savings in this category comes from high intensity discharge lamps which, while constituting a much smaller fraction of the end use, permit large percentage savings, possibly as a result of not having been regulated in the past. Some of this is due to recent standards for HVAC equipment that restrict further cost-effective improvement given the available data[29]. Furthermore, an ever-growing fraction of commercial building energy is used in miscellaneous products for which efficiency improvement may be possible, but for which data are not yet available.   Lastly, distribution transformers do show significant savings because of the scale of distribution losses at the national level, even though total efficiency improvement is small on a percentage basis, due in part to the recent standards rulemaking.

Figure 5 – Cumulative CO_2 Emissions Reductions 2010-2030



4.2. Consumer Financial Impacts

By construction, the *Business Case* implements energy efficiency in a way that is cost-effective to consumers. Because this study insisted on quantifying investments needed to improve

[29] It should be emphasized that efficiency technology costs are generally decreasing, especially after a standard creates a mass market for high-efficiency equipment. An update of the data may therefore reveal additional cost-effective improvement.

efficiency relative to the base case technology, the necessary information to evaluate these investments and financial benefits of energy savings, and therefore net financial impacts to consumers, is available for all appliance groups considered.

Recalling the definition of cost of conserved energy from Equation 1:

$$CCE = \frac{I \times q}{S}$$

The denominator of this equation $I \times q$ is the annualized equipment investment necessary to yield an annual energy savings S. BUENAS calculates the total savings $S_T(y)$ in each year, given by:

$$S_T(y) = S \times Stock'(y)$$

In this equation, $Stock'(y)$ is the affected stock, that is, the number of units operating in the stock that were installed after the policy implementation date, and are each providing a savings S relative to the *Base Case*. Likewise, the total annualized investment in each year $I_T(y) \times q$ is given by:

$$I_T(y) \times q = I \times q \times Stock'(y)$$

Substituting Equation 1, and cancelling terms, yields:

$$I_T(y) \times q = S_T(y) \times CCE$$

In other words, total annualized investment can be calculated for each appliance group by multiplying its total energy savings by the cost of conserved energy shown in Table 5.

Financial savings from energy savings is given simply by the utility price in each year multiplied by the total energy savings $S_T(y)$. Net financial impacts are then given by:

$$N(y) = S_T(y) \times (Utility\ Price - CCE)$$

Costs, Savings and Net Impacts calculated in this way are shown in Table 5. In evaluating the financial value of efficiency or other government programs, it is customary to take account of deferred benefits through a discount rate calculation. The resulting *Net Present Value* (NPV) of benefits is given by:

$$NPV = \sum_{y=2010}^{2030} \frac{N(y)}{(1 + DR)^{y-2010}}$$

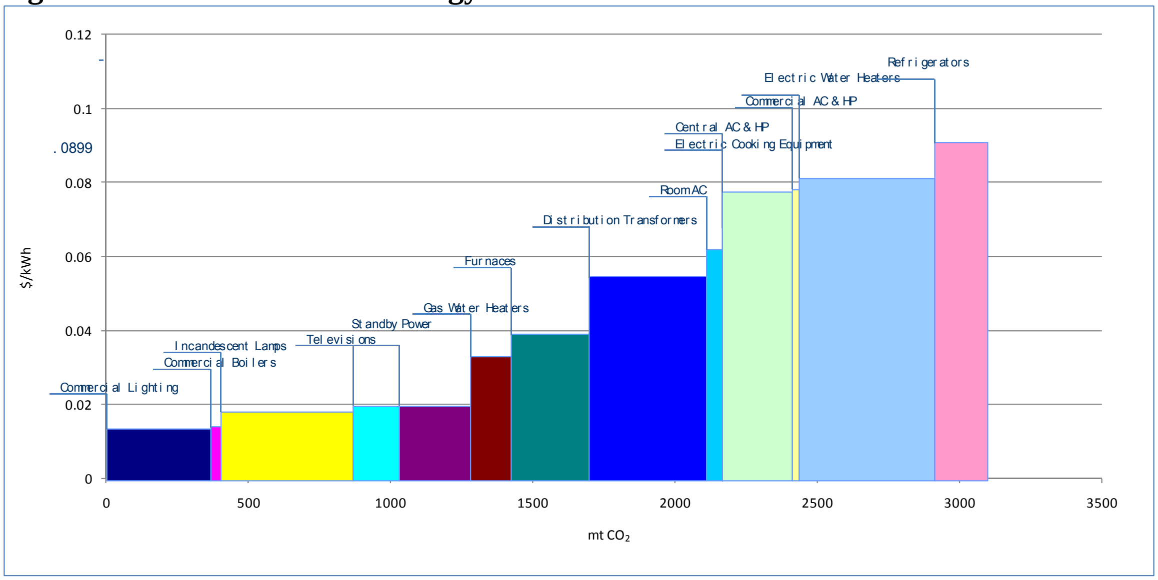
In this equation, DR is a "societal" discount rate that parameterizes the preference for immediate returns on public investments. We consider two scenarios in which the societal discount rate is taken to be 3% or 7%. Cumulative equipment costs, energy bill savings, net savings and *NPV* are shown in Table 5. The table shows positive net savings for all appliance groups, which is not surprising, since the target efficiency levels were constructed to be cost-effective. The table shows that cost-effective efficiency improvements require an investment of 259 billion dollars over the next 20 years, but these investments will return over twice as much over the same period, for a net savings of 304 billion dollars, or of order of a thousand dollars per capita. The net present value is 214 billion dollars assuming a discount rate of 3%, and 140 billion with a 7% discount rate. Of the appliance groups studied, electric water heaters require the largest investment at $71.4 billion, but also have the highest payoff at $97.9 billion. Phasing out incandescent lamps has a similar payoff of $95.1 billion, but requires an investment of only $15.9 billion. This technology has the highest net benefit, of $79.2 billion, with commercial lighting providing the second highest, with $55.9 billion.

Table 5 – Cumulative Financial Impacts of Efficiency Improvement through 2030

Appliance Group	Cumulative Financial Impacts				
	Cost	Savings	Net	NPV @ 3% DR	NPV @ 7% DR
	$ Billions				
Incandescent Lamps	15.9	95.1	79.2	66.4	53.2
Commercial Lighting	9.4	67.9	58.4	37.9	22.1
Standby Power	9.3	51.2	41.9	27.5	16.3
Distribution Transformers	41.4	76.4	34.9	22.6	13.1
Televisions	6.0	33.1	27.1	18.4	11.3
Electric Water Heater	71.4	97.9	26.5	17.2	10.1
Central AC & HP	35.0	50.5	15.4	10.0	5.9
Refrigerators	31.3	38.4	7.1	4.6	2.7
Room AC	6.1	11.0	4.9	3.2	1.9
Gas Water Heaters	8.9	12.1	3.2	2.1	1.2
Furnaces	20.0	23.0	3.0	2.0	1.1
Commercial Boilers	1.0	2.7	1.7	1.1	0.6
Commercial AC & HP	3.5	4.5	1.0	0.7	0.4
Electric Cooking Equipment	0.1	0.1	0.1	0.04	0.02
Total	**259**	**564**	**304**	**214**	**140**

Finally, financial impacts, emissions savings and their relationship can be shown using a "conservation supply curve". This unique way of expressing the cost and benefits of carbon mitigation measures has become very widespread in the literature because of the key information it conveys. A conservation supply curve for the *Business Case* is presented in Figure 6. The x-axis shows cumulative carbon mitigation and expresses the relative importance of each appliance group. The total extent of the curve is 3021 mt CO_2, as shown in Table 4. The y-axis displays relative affordability according to cost of conserved energy. The blocks corresponding to each measure are ordered with increasing cost of conserved energy, from left to right. For comparability, cost of conserved energy for all end uses is expressed as dollars per kWh. The conversion factor for natural gas is 3412 Btu per kWh.

Figure 6 Cost of Conserved Energy for All End Uses 2010-2030



Finally, we note that there are other benefits to the energy savings achieved in the *Business Case* besides the direct energy and financial benefits. The effect of reduction of greenhouse gas emissions and resulting avoided costs are difficult to quantify, but could be very large. One metric to consider the order of magnitude of the value of these types of impacts is the assumption of a carbon price. The assumption of a price of 25 dollars per ton of carbon dioxide yields an additional $76 billion dollars of savings, while a 100 dollar per ton price yields $302 billion additional dollars, doubling the total.

The negative impacts of emissions of SO_2 and NO from power plants are well-known (see, for example, EPA 2011), including acid rain, acidification of watersheds and lakes, and respiratory illness from inhaling particulates. Likewise, the reduction of mercury emissions from coal-burning power plants reduces fish contamination, which is now recognized as a major health risk. We do not try to quantify the health impacts of reduction of these emissions, only point out the obvious – that savings due to efficiency is equivalent to installation of clean electricity generation. In the *Business Case*, this reduction provides a large net financial benefit to consumers, which may not be true with alternatives.

Lastly, we consider the impacts of efficiency-related financial savings on the U.S. economy, and particularly in terms of job creation. In general, it is often stated that consumer spending generates growth and creates jobs at a higher rate than other types of expenditures. When efficiency improvements are implemented at the level of equipment purchased by residences and businesses, the result is a net savings distributed over a very large number of consumers. Presumably, much of this savings, which comes in the form of lowered utility bills, will be injected back into the economy in the form of purchased consumer goods. A recent study found that:

> *"The principle energy-related sectors of the U.S. economy are not especially job-intensive in comparison to the rest of the economy. They support only 7.4 total jobs for every one million dollars of revenue received in utility bill payments in comparison with the rest of the economy, which supports between 13 and 21 direct jobs per million dollars of receipts". (Gold 2011 p.8)*

Using this result as a guide, we deduce that energy savings can be translated into job creation at the rate of 5.6-13.6 jobs per million dollars. A net savings of 304 billion dollars over 20 years corresponds to 15.2 billion dollars per year which supports 85,000 to 207,000 jobs for the entire period.

5. Conclusions

The *Business Case* analysis found additional potential for cost-effective efficiency improvement in the United States for fourteen appliance groups in the residential and commercial building sectors. Efficiency improvement for these technologies could deliver twice as much financial benefit to U.S. households and business than the investment needed to implement them. In addition to direct financial benefits, impacts on greenhouse gas emissions and job creation are significant. Total net impacts from additional deployment of high efficiency technology include:

Final Energy savings:

- 230 billion kWh of electricity and 0.14 EJ of natural gas per year in 2020
- 430 billion kWh of electricity and 0.35 EJ of natural gas per year in 2030
- A total of 4900 billion kWh of electricity and 3.1 EJ natural gas cumulatively through 2030

Primary Energy Savings

- 1.3 EJ of coal per year in 2020 and 0.58 EJ of natural gas per year in 2020
- 2.4 EJ of coal per year in 2030 and 1.2 EJ of natural gas per year in 2030
- A total of 27 EJ of coal and 13 EJ of natural gas cumulatively through 2030

Cumulative greenhouse gas emissions mitigation:

- 3000 million metric tons of CO_2 through 2030
- 12 million metric tons of SO_2 through 2030
- 3.5 million metric tons of NO through 2030
- 62 metric tons of mercury through 2030

Financial impacts to consumers through 2030:

- Equipment investment of 260 billion dollars
- Energy bill savings of 560 billion dollars
- Net savings of 300 billion dollars

Job Creation

- Net creation of 85,000 to 200,000 jobs

The end uses studied in this report are concentrated in the buildings sector, and the bulk of the savings is to be found in electricity savings. The study finds that by 2030, cost-effective efficiency improvements could save 430 billion TWh, which represents about 12% of total buildings electricity consumption in that year, according to the International Energy Agency's

World Energy Outlook[30]. This corresponds to 9.3% of electricity consumption in the U.S. or 3.7% of total energy consumption, in primary energy terms. In the same year, the *Business Case* saves 265 mt CO_2 in 2030. According to WEO, with current policies in place, emissions in the United States will total 5310 mt CO_2 or 712 mt more than the Annex I target of 4598 mt (5.2% below the 1990 level of 4850 mt. Implementation of the *Business Case* would close over a third of this gap. In addition to the 300 billion dollars net savings provided to consumers through 2030, annual savings of 430 billion kWh would avoid capital investments of 32 billion dollars[31].

Since most of the equipment studied has been the subject of at least one efficiency standard, this finding supports the notion of efficiency improvement as an ongoing process. For example, although residential refrigerators have improved dramatically in efficiency over the last 30 years, there is room for improvement.

It should also be noted that many of the technologies included in the *Business Case* scenario were not available ten to twenty years ago, or at least weren't shown to be cost-effective. These technologies have become available and cost-effective through research, new materials and components, improvements in production processes, or changes in design of systems. We expect that a similar analysis performed 10 years from now will show improvements not accessible to the current study due either to lack of data or prohibitively high cost of "prototype" technologies.

Two main caveats must be made in the interpretation of these results. First, because the rigor of the methodology used to evaluate cost-effectiveness requires a significant amount of technical data, we only cover a subset of equipment types for which significant savings potential might be available. In particular, the appliance groups covered are limited to buildings applications. For this sector, however, we believe a large fraction of energy demand is accounted for. For this reason, while the overall savings potential is large, it cannot be interpreted as "comprehensive". Second, most of the data used are sourced from DOE rulemakings to set mandatory energy performance standards. As a consequence, only those product types already subject to standards are covered, introducing a bias towards equipment with a relatively high efficiency baseline. Furthermore, much of the data are for products with a recent standard, or one that is expected in the near future, limiting the amount of savings that can be considered additional. In some cases, the cost-effective efficiency level may exceed the standards set by DOE. We emphasize that this is not to be taken as a claim that DOE standards are less stringent than what is economically justified, rather that the simplified analysis performed in the current study is representative of the potential additional savings, but cannot be precisely compared. In some cases, technologies found by DOE to be attractive for standards on a purely cost-benefit basis were not adopted as standards due to other barriers, such as the absence of wide-scale production capability by manufacturers. The current analysis does not investigate these, but implicitly assumes that many of these barriers are removed by 2015.

Finally, we believe this study to be among the few to attempt to evaluate the "economic" potential of efficiency improvement on a national scale and in a transparent way. In addition to demonstrating significant savings potential, we hope that it demonstrates a clear and consistent

[30] World Energy Outlook 2010 Appendix A "Current Policies Scenario"

[31] Levelized capital cost of $74.6/MWh for "Advanced Coal" plants according to Energy Information Administration, Annual Energy Outlook 2011.

methodology for creation and expansion of alternative energy scenarios in the U.S. and beyond. Additional scenarios that could be explored include the potential impact of carbon taxes, cap-and-trade, R&D investments and other policy- or market-based drivers. The ability of the research community to utilize this type of analysis to inform government and private sector decision makers will depend largely on investments made in development of the type of data used here, both more widely and with greater frequency.

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APPENDIX 1 – U.S. Department of Energy Appliance Standards Schedule

Product Covered	Initial Legislation	Last MEPS issued	Effective Date	Update Expected	Potential Effective Date
Residential Products					
Battery Chargers	EPACT 2005	None	None	2011	2013
Boilers	NAECA 1987	2007	2012	2015	2020
Central AC and Heat Pumps	NAECA 1987	2001	2006	2011	2015
Clothes Dryers	NAECA 1987	1991	1994	2011	2014
Clothes Washers	NAECA 1987 EPACT 2005	2007	2011	2011	2015
Compact Audio Equipment	None				
Dehumidifiers	EPACT 2005	2007	2012	2015	2018
Direct Heating Equipment	NAECA 1987	2010	2013	2018	2023
Dishwashers	NAECA 1987	2007	2010	2015	2018
DVD Players and Recorders	None				
External Power Supplies	EPACT 2005	2007	2008	2011	2013
Furnaces	NAECA 1987	2007	2015	2011	2013
Furnace Fans	EPACT 2005	None	None	2013	2016
Microwave Ovens	NAECA 1987	None	None	2011	2014
Plumbing Products	EPACT 1992	1992	1994		
Pool Heaters	NAECA 1987	2010	2013	2018	2021
Pool Pumps	None				
Portable Electric Spas (Hot Tubs)	None				
Ranges and Ovens (electric)	NAECA 1987	None	None	2017	2020
Ranges and Ovens (gas)	NAECA 1987	2009	2012	2014	2017
Refrigerators & Freezers	NAECA 1987	1997	2001	2010	2014
Room AC	NAECA 1987	1997	2000	2011	2014
Televisions	None			2013	2016
Water Heaters	NAECA 1987	2010	2015	2018	2023
Commercial Products					
Automatic Commercial Ice Makers	EPACT 2005	2005	2010	2010	2015
Commercial 3-Phase Central AC	EPACT 1992	2007	2008	2015	2018
Commercial AC & Heating Equipment (Air-cooled)	EPACT 1992	2005	2010	2013	2016
Commercial AC & Heating Equipment (Water- and evaporatively-cooled)	EPACT 1992	2009	2011	2017	2020
Commercial Boilers	EPACT 1992	2009	2012	2017	2020
Commercial Clothes Washers	EPACT 2005	2010	2013	2015	2018
Commercial Warm Air Furnaces	EPACT 1992	2001	2003	2009	2012
Commercial Refrigeration					
Supermarket (built-up) Refrigerators & Freezers	EPACT 2005	2009	2012	2013	2016
Refrigerator and Freezer Cases without Doors	EPACT 2005	2009	2012	2013	2016
Reach-In Refrigerators & Freezers	EPACT 2005	2005	2010	2013	2016
Walk-In Refrigerators Freezers	EISA 2007	2007	2009	2012	2015
Commercial Water Heaters	EPACT 1992	2001	2003	2009	2012
Distribution Transformers					
Low-V, Dry-Type	EPACT 2005	2005	2007	2013	2016
Medium-V, Dry-type	EPACT 1992	2007	2010	2012	2015
Liquid Immersed	EPACT 1992	2007	2010	2012	2015
Electric Motors (> 1 hp)	EPACT 1992	2007	2010	2012	2015
Electric Motors, small (<= 1 hp)	EPACT 1992	2010	2015	2018	2021
Hot Food Holding Cabinets	None				

Packaged Terminal AC and Heat Pumps	EPACT 1992	2008	2010/2012	2016	2019
Pre-Rinse Spray Valves	EPACT 2005	2005	2006	2013	2016
Unit Heaters	EPACT 2005	2005	2008	2013	2016
Vending Machines	EPACT 2005	2009	2012	2017	2020
Water Dispensers	None				
Lighting Products					
65 watt BR and ER IRL's and IRL's < 50 watts	None	None	None	2010	2013
Ceiling Fans and Ceiling Fan Light Kits	EPACT 2005	2005	2007	2013	2016
Compact Fluorescent Lamps	EPACT 2005	2005	2006	2013	2016
Fluorescent Lamp Ballasts	NAECA 1987 EPACT 2005	2000	2005	2011	2014
General Service Incandescent Lamps plus CFL, GSLED, GSOLED	EPACT 1992	2007	2012	2017	2020
HID Lamps	EPACT 1992	None	None	2014	2017
Illuminated Exit Signs	EPACT 2005	2005	2006	2013	2016
Incandescent Reflector Lamps (IRL)	EPACT 1992	2009	2012	2014	2017
Linear Fluorescent Lamps	EPACT 1992	2009	2012	2014	2017
Mercury Vapor Lamp Ballasts	EPACT 2005	2005	2008 (ban)	N/A	N/A
Metal Halide Lamp Fixtures	EISA 2007	2007	2009	2012	2015
Torchiere Lamps	EPACT 2005	2005	2006	2013	2016
Traffic Signals	EPACT 2005	2005	2006	2013	2016

Source: ASAP (2011)

APPENDIX 2 – Efficiency-Cost Relationship and Cost of Conserved Energy Calculation for Appliance Groups

Parameters used in Calculation of Cost of Conserved Energy:

Residential Consumer Discount Rate = 5%
Commercial Consumer Discount Rate = 6%
Residential Electricity Price (2015) = $0.11 $/kWh
Commercial Electricity Price (2015) = $0.10 $/kWh
Residential Natural Gas Price (2015) $13.17 $/MMBtu
Commercial Natural Gas Price (2015) $11.40 $/MMBtu

Table A.2.1 – Efficiency-Cost Relationship for Residential Refrigerators

Class	Top Mount Auto Defrost Refrigerator-Freezer			Bottom-Mount Refrigerator-Freezer			Side-by-Side Refrigerator-Freezer		
Market share	54.3%			13.5%			28.9%		
Lifetime	17.1			17.1			17.1		
q	0.088			0.088			0.088		
Efficiency Level	UEC kWh/yr	Price $2010	CCE $2010	UEC kWh/yr	Price $2010	CCE $2010	UEC kWh/yr	Price $2010	CCE $2010
Baseline	501	547		613	953		768	1161	
1	451	559	0.021	551	955	0.003	691	1164	0.003
2	426	567	0.024	521	957	0.004	653	1169	0.006
3	401	629	0.072	490	963	0.007	614	1188	0.015
4	379	672	0.091	459	1028	0.043	576	1254	0.042
5	351	765	0.128	429	1136	0.087	538	1396	0.090
6	323	899	0.175	391	1286	0.132	515	1508	0.120

Target Annual Incremental Cost (I×q)	$11	$16	$21
Target UEC (kWh/yr)	379	429	538

Weighted Average Baseline UEC	588 kWh/yr	Weighted Average Incremental Cost	14.5 $2010
Weighted Average Target UEC	428 kWh/yr	Product CCE	0.090 $2010
Weighted Average Energy Savings	161 kWh/yr		

Table A.2.2 – Efficiency-Cost Relationship for Residential Room Air Conditioners

Class	< 6000 Btu/Hr with Louvered sides			8000-13999 Btu/Hr with Louvered sides			≥20,000 Btu/Hr, with Louvered sides			8000-13999 Btu/Hr without Louvered sides		
Market share	41.0%			44.6%			3.8%			10.6%		
Lifetime	10.5			10.5			10.5			10.5		
q	0.125			0.125			0.125			0.125		
Efficiency Level	UEC kWh/yr	Price $2010	CCE $2010	UEC kWh/yr	Price $2010	CCE $2010	UEC kWh/yr	Price $2010	CCE $2010	UEC kWh/yr	Price $2010	CCE $2010
Baseline	688	335		672	497		1118	875		712	567	
1	648	343	0.025	632	512	0.044	1052	899	0.046	673	572	0.016
2	618	353	0.033	602	526	0.051	1007	929	0.061	644	579	0.022
3	590	368	0.043	576	552	0.071	966	967	0.076	611	600	0.041
4	565	386	0.052	566	612	0.135	947	1013	0.101			
5	546	396	0.054									

Target Annual Incremental Cost (I×q)	$8	$7	$17	$4
Target UEC (kWh/yr)	546	576	947	611

Weighted Average Baseline UEC	700 kWh/yr	Weighted Average Incremental Cost	7.27	$2010
Weighted Average Target UEC	581 kWh/yr	Product CCE	0.062	$2010
Weighted Average Energy Savings	118 kWh/yr			

Table A.2.3 – Efficiency-Cost Relationship for Residential Water Heaters

Class	Electric Water Heater		
Market share	100.0%		
Lifetime	13		
q	0.106		
Efficiency Level	UEC kWh/yr	Price $2010	CCE $2010
Baseline	2604	666	
1	2569	677	0.033
2	2535	688	0.034
3	2515	695	0.035
4	2467	730	0.049
5	2431	763	0.060
6	1399	1589	0.081
7	1216	1717	0.081
8	2356	813	0.063

Target Annual Incremental Cost (I×q)	$112
Target UEC (kWh/yr)	1216

Weighted Average Baseline UEC 2604 kWh/yr
Weighted Average Target UEC 1216 kWh/yr
Weighted Average Energy Savings 1388 kWh/yr
Weighted Average Incremental Cost 112 $2010
Product CCE 0.081 $2010

Class	Gas Water Heater			Gas-Fired Instantaneous Water Heater		
Market share	90.2%			9.1%		
Lifetime	13			13		
q	0.106			0.106		
Efficiency Level	UEC MMBtu	Price $2010	CCE $2010	UEC MMBtu	Price $2010	CCE $2010
Baseline	16.5	1185		16.7	2605	
1	15.8	1245	8.69	14.8	2605	0.00
2	15.3	1302	10.55	11.5	2616	0.23
3	14.9	1580	25.54	11.2	2626	0.41
4	14.5	1612	22.11	10.9	2633	0.52
5	13.9	1672	20.15	10.7	2986	6.70
6	12.4	1908	18.53	10.6	3050	7.67
7	15.7	1263	9.73	9.8	2943	5.16
8	15.2	1320	11.18	9.4	3122	7.55

Target Annual Incremental Cost (I×q)	$14	$55
Target UEC (MMBtu/yr)	15	9

Weighted Average Baseline UEC 16.6 MMBtu/yr
Weighted Average Target UEC 14.7 MMBtu/yr
Weighted Average Energy Savings 1.87 MMBtu/yr
Weighted Average Incremental Cost 18.1 $2010
Product CCE 9.68 $2010

Table A.2.4 – Efficiency-Cost Relationship for Residential Electric Cooking Equipment

Class	Electric Coil Cooktops			Electric Smooth Cooktops			Electric Standard Ovens			Electric Self-Cleaning Ovens			Microwave Ovens		
Market share	9.7%			11.4%			5.6%			17.3%			56.0%		
Lifetime	19			19			19			19			9		
q	0.083			0.083			0.083			0.083			0.141		
Efficiency Level	UEC kWh/yr	Price $2010	CCE $2010	UEC kWh/yr	Price $2010	CCE $2010	UEC kWh/yr	Price $2010	CCE $2010	UEC kWh/yr	Price $2010	CCE $2010	UEC kWh/yr	Price $2010	CCE $2010
Baseline	128	292		128	331		167	443		171	362		156	235	
1	123	295	0.055	126	589	11.225	160	445	0.033	171	369	1.403	149	249	0.293
2							154	450	0.049	168	431	1.822	149	263	0.569
3							152	456	0.075				147	286	0.811
4							149	517	0.354				146	315	1.142
5							149	523	0.371						

	Electric Coil Cooktops	Electric Smooth Cooktops	Electric Standard Ovens	Electric Self-Cleaning Ovens	Microwave Ovens
Target Annual Incremental Cost (I×q)	$0.29	$0.00	$1.10	$0.00	$0.00
Target UEC (kWh/yr)	123	No option with CCE below utility price	152	No option with CCE below utility price	No option with CCE below utility price

Weighted Average Baseline UEC 153 kWh/yr
Weighted Average Target UEC 152 kWh/yr
Weighted Average Energy Savings 1.33 kWh/yr
Weighted Average Incremental Cost 0.090 $2010
Product CCE 0.067 $2010

Table A.2.5 – Efficiency-Cost Relationship for Residential Central Air Conditioners and Heat Pumps

Class	Split System AC (Coil Only)			Split System AC (Blower-Coil)			Single Package AC			Split System HP			Single Package HP		
Market share	56.7%			6.3%			5.9%			27.6%			3.5%		
Lifetime	19.01			19.01			19.01			19.01			19.01		
q	0.083			0.083			0.083			0.083			0.083		
Efficiency Level	UEC kWh/yr	Price $2010	CCE $2010	UEC kWh/yr	Price $2010	CCE $2010	UEC kWh/yr	Price $2010	CCE $2010	UEC kWh/yr	Price $2010	CCE $2010	UEC kWh/yr	Price $2010	CCE $2010
Baseline	2407	2799		2433	4126		2376	2649		5236	3296		5184	3009	
1	2322	2873	0.071	2347	4201	0.072	2292	2710	0.060	5079	3381	0.045	5029	3090	0.043
2	2243	2949	0.075	2267	4276	0.075	2214	2774	0.064	4933	3471	0.048	4884	3195	0.051
3	2168	3038	0.083	2190	4357	0.079	2139	2859	0.073	4792	3540	0.045	4774	3345	0.068
4	2097	3139	0.091	2119	4416	0.076	2070	2983	0.090	4660	3606	0.045	4672	3477	0.076
5	2031	3262	0.102	2052	4477	0.076	2004	3085	0.097	4536	3678	0.045	4481	3630	0.073
6	1968	3419	0.117	1988	4541	0.077	1942	3212	0.107	4418	3772	0.048	4305	3811	0.076
7	1912	3599	0.134	1932	4606	0.079	1876	3362	0.118	4173	3930	0.049	4239	3993	0.086
8				1878	4673	0.082				3954	4100	0.052			
9				1780	4816	0.087				3758	4282	0.055			
10				1692	4969	0.094				3673	4381	0.057			
11				1613	5133	0.102									
12				1541	5309	0.110									
13				1476	5498	0.119									

Target Annual Incremental Cost (I×q)	$38	$98	$47	$90	$81
Target UEC (kWh/yr)	2031	1541	1942	3673	4239

Weighted Average Baseline UEC	3285 kWh/yr	Weighted Average Incremental Cost	58.2	$2010
Weighted Average Target UEC	2525 kWh/yr	Product CCE	0.077	$2010
Weighted Average Energy Savings	759 kWh/yr			

Table A.2.6 – Efficiency-Cost Relationship for Residential Gas Furnaces

Class	Non-Weatherized Gas Furnace			Weatherized Gas Furnace			Mobile home Gas Furnace			Oil-fired Furnace		
Market share	84.0%			9.5%			3.6%			3.0%		
Lifetime	20			18			19			15		
q	0.080			0.086			0.083			0.096		
Efficiency Level	UEC MMBtu	Price $2010	CCE $2010	UEC MMBtu	Price $2010	CCE $2010	UEC MMBtu	Price $2010	CCE $2010	UEC MMBtu	Price $2010	CCE $2010
Baseline	53.9	2530		33.7	4169		40.9	1010		73.2	3439	
1	53.9	2530	0.72	33.5	4170	0.98	40.1	1025	1.57	73.1	3439	0.26
2	53.9	2735	-233.41	33.2	4180	1.89	40.2	1405	46.57	72.6	3444	0.88
3	53.5	2581	10.21	32.8	4301	12.49	39.6	1119	7.16	72.7	3462	4.41
4	53.6	2788	65.40	32.4	4342	11.52	39.7	1505	35.23	72.8	3681	59.45
5	50.4	3003	10.84				39.2	1150	6.80	72.0	3447	0.69
6	49.7	3141	11.65				39.3	1535	26.91	72.1	3477	3.37
7	49.7	3416	17.07				36.0	1397	6.56	72.2	3710	26.53
8	49.6	3462	17.66							71.3	3595	8.17
9	47.7	4167	21.37							71.4	3628	10.44
10										71.5	3883	26.26
11										70.6	3756	12.04
12										70.7	3791	13.94
13										70.8	4069	26.16
14										69.9	3939	14.72
15										70.0	3977	16.35
16										70.1	4277	26.40

Target Annual Incremental Cost (I×q)	$49	$15	$32	$31
Target UEC (MMBtu/yr)	49.7	32.4	36.0	70.6

Weighted Average Baseline UEC	52.1 MMBtu/yr	Weighted Average Incremental Cost	44.6	$2010
Weighted Average Target UEC	48.2 MMBtu/yr	Product CCE	11.42	$2010
Weighted Average Energy Savings	3.91 MMBtu/yr			

Table A.2.7 – Efficiency-Cost Relationship for Commercial Building Air Conditioners and Heat Pumps

Class	≥65,000 and <135,000 Btu/Hr Unitary Air Conditioners			≥135,000 and <240,000 Btu/Hr Unitary Air Conditioners			Packaged Terminal Air Conditioners Standard, 9 kBtu/Hr			Packaged Terminal Air Conditioners Standard, 12 kBtu/Hr		
Market share	30.5%			13.3%			13.8%			20.3%		
Lifetime	15.4			15.4			10			10		
q	0.101			0.101			0.136			0.136		
Efficiency Level	UEC kWh/yr	Price $2010	CCE $2010	UEC kWh/yr	Price $2010	CCE $2010	UEC kWh/yr	Price $2010	CCE $2010	UEC kWh/yr	Price $2010	CCE $2010
Baseline	13857	9046		29854	14774		1013	1235		1294	1476	
1				28733	15426	0.016	1001	1244	0.097	1279	1488	0.113
2				27714	16420	0.020	990	1256	0.102	1264	1501	0.104
3										1251	1515	0.125

Target Annual Incremental Cost (I×q)	$0	$167	$1.84	$2.26
Target UEC (kWh/yr)	No option with CCE below utility price	27714	No option with CCE below utility price	No option with CCE below utility price

Class	Packaged Terminal Air Conditioners Non-standard, 11 kBtu/Hr			Packaged Terminal Heat Pumps Standard, 9 kBtu/Hr		
Market share	2.1%			10.8%		
Lifetime	10			10		
q	0.136			0.136		
Efficiency Level	UEC kWh/yr	Price $2010	CCE $2010	UEC kWh/yr	Price $2010	CCE $2010
Baseline	1658	1575		1984	1358	
1	1584	1599	0.044	1957	1367	0.047
2	1559	1611	0.050	1945	1377	0.069
3	1536	1626	0.057			

Target Annual Incremental Cost (I×q)	$6.92	$2.68
Target UEC (kWh/yr)	1536	1945

Weighted Average Baseline UEC	8901 kWh/yr	Weighted Average Incremental Cost	22.7	$2010
Weighted Average Target UEC	8608 kWh/yr	Product CCE	0.078	$2010
Weighted Average Energy Savings	293 kWh/yr			

Table A.2.8 – Efficiency-Cost Relationship for Commercial Building Fluorescent Lamp Ballasts

Class	Two-Lamp RS and IS Ballasts Operating 4-Foot MBP and 2-Foot U-Shaped Lamps in the Commercial Sector (F32T8 Baseline)			Two-Lamp PS Ballasts Operating 4-Foot MBP and 2-Foot U-Shaped Lamps in the Commercial Sector			Four-Lamp RS and IS Ballasts Operating 4-Foot MBP and 2-Foot U-Shaped Lamps in the Commercial Sector			Four-Lamp PS Ballasts Operating 4-Foot MBP and 2-Foot U-Shaped Lamps in the Commercial Sector		
Market share	54.3%			6.4%			24.0%			3.5%		
Lifetime	15			15			15			15		
q	0.103			0.103			0.103			0.103		
Efficiency Level	UEC kWh/yr	Price $2010	CCE $2010	UEC kWh/yr	Price $2010	CCE $2010	UEC kWh/yr	Price $2010	CCE $2010	UEC kWh/yr	Price $2010	CCE $2010
Baseline	208	57		153	60		383	103		289	107	
1	196	62	0.048	142	63	0.027	380	109	0.205	275	109	0.019
2	194	60	0.025									

Target Annual Incremental Cost (I×q)	$0.34	$0.28	-$1.74	$0.28
Target UEC (kWh/yr)	194	142	No option with CCE below utility price	275

Class	Two-Lamp PS Ballasts Operating 4-Foot T5 MiniBP SO Lamps in the Commercial Sector			Two-Lamp PS Ballasts Operating 4-Foot T5 MiniBP HO Lamps in the Industrial Sector			Four-Lamp RS and IS Ballasts Operating 8-Foot RDC HO Lamps (Cold Temperature/Sign Ballasts) in the Commercial Sector		
Market share	3.3%			3.3%			2.9%		
Lifetime	15			10			0.15		
q	0.103			0.136			0.103		
Efficiency Level	UEC kWh/yr	Price $2010	CCE $2010	UEC kWh/yr	Price $2010	CCE $2010	UEC kWh/yr	Price $2010	CCE $2010
Baseline	267	68		688	71		1352	228	
1	223	71	0.005	598	73	0.004	1113	218	-0.005
2	215	82	0.027	571	81	0.012			

Target Annual Incremental Cost (I×q)	$0.28	$0.42	-$1.08
Target UEC (kWh/yr)	215	571	1113

Weighted Average Baseline UEC	306 kWh/yr	Weighted Average Incremental Cost	0.212	$2010
Weighted Average Target UEC	285 kWh/yr	Product CCE	0.010	$2010
Weighted Average Energy Savings	21.2 kWh/yr			

Table A.2.9 – Efficiency-Cost Relationship for High-Intensity Discharge Lamps

Class	Low Wattage 1			Low Wattage 2			Low Wattage 3			Small Area			Roadway Arch		
Market share	3.7%			3.0%			2.9%			5.9%			6.1%		
Lifetime	13.6			9.8			12.1			12.1			12.1		
q	0.110			0.138			0.119			0.119			0.119		
Efficiency Level	UEC kWh/yr	Price $2010	CCE $2010	UEC MMbtu	Price $2010	CCE $2010	UEC MMbtu	Price $2010	CCE $2010	UEC MMbtu	Price $2010	CCE $2010	UEC MMbtu	Price $2010	CCE $2010
Baseline	1672	25		768	16		1875	25		861	16		861	16	
1	1413	66	0.017	749	88	0.537	1586	66	0.017	840	88	0.412	840	88	0.412
2	1672	76	0.000	694	28	0.024	1875	76		778	28	0.018	778	28	0.018
3	1303	133	0.032	461	39	0.011	1461	133	0.031	518	39	0.008	518	39	0.008
4	1542	84	0.049	697	23	0.015	1731	84	0.048	782	23	0.011	782	23	0.011
5	1524	36	0.008	461	39	0.011	1710	36	0.008	518	39	0.008	518	39	0.008
6	1354	43	0.006	343	20	0.001	1519	43	0.006	385	20	0.001	385	20	0.001
7	1092	20	-0.001	413	35	0.007	1225	20	-0.001						
8	1081	21	-0.001	321	9	-0.002	1213	21	-0.001						
9	1063	41	0.003				1192	41	0.003						
10	886	19	-0.001				994	19	-0.001						
11	1007	69	0.007												
12	878	40	0.002												

	Low Wattage 1	Low Wattage 2	Low Wattage 3	Small Area	Roadway Arch
Target Annual Incremental Cost (I×q)	$1.64	-$0.95	-$0.71	$0.55	$0.55
Target UEC (kWh/yr)	878	321	994	385	385

Class	Street			Security			Security - Res			Landscape		
Market share	17.5%			16.6%			15.5%			7.0%		
Lifetime	12.1			12.1			12.1			12.1		
q	0.119			0.119			0.119			0.119		
Efficiency Level	UEC MMbtu	Price $2010	CCE $2010	UEC MMbtu	Price $2010	CCE $2010	UEC MMbtu	Price $2010	CCE $2010	UEC MMbtu	Price $2010	CCE $2010
Baseline	861	14		861	14		861.12	16.00		861.12	13.55	
1	840	78	0.367	840	76	0.357	385.02	20.25	0.001	840.42	75.83	0.357
2	778	25	0.016	778	25	0.016				778.32	24.58	0.016
3	518	35	0.007	518	34	0.007				517.50	34.16	0.007
4	782	21	0.010	782	20	0.010				782.46	20.14	0.010
5	385	18	0.001	385	18	0.001				517.50	34.16	0.007
6										385.02	17.55	0.001
7												
8												
9												
10												
11												
12												

	Street	Security	Security - Res	Landscape
Target Annual Incremental Cost (I×q)	$0.49	$0.47	$0.50	$0.47
Target UEC (kWh/yr)	385	385	385	No option with CCE below utility price

Weighted Average Baseline UEC	729 kWh/yr	Weighted Average Incremental Cost	0.242	$2010
Weighted Average Target UEC	335 kWh/yr	Product CCE	0.038	$2010
Weighted Average Energy Savings	394 kWh/yr			

Table A.2.10 – Efficiency-Cost Relationship for Distribution Transformers

Class	Design Line 1 (Liquidimmersed, 50kVA, singlephase, rectangular tank)			Design Line 2 (Liquidimmersed, 25kVA, singlephase, round tank)			Design Line 4 (Liquidimmersed, 150kVA, threephase)		
Market share	35.9%			59.3%			3.0%		
Lifetime	32			32			32		
q	0.071			0.071			0.071		
Efficiency Level	UEC kWh/yr	Price $2010	CCE $2010	UEC kWh/yr	Price $2010	CCE $2010	UEC kWh/yr	Price $2010	CCE $2010
Baseline	5691	3301	0.012	1407	2143	0.007	9306	7411	0.037
1	4829	3639	0.020	884	2359	0.017	8856	8117	0.054
2	2231	5394	0.037	817	3916	0.104	8398	8117	0.044
3	4583	3301	0.005	1407	2143	0.007	5520	10972	0.058
4	5403	3348	0.012	1548	2285	0.028	5520	12013	0.072
5	5403	3348	0.012	1656	2285	0.035	8363	7411	0.023
6	5691	3639	0.039	1691	2511	0.081	8398	7411	0.023
7							8856	7411.02	0.029
8							8398	7411	0.023

Target Annual Incremental Cost (I×q)	$149	$126	$253
Target UEC (kWh/yr)	2231	817	5520

Weighted Average Baseline UEC	5702 kWh/yr	Weighted Average Incremental Cost	162	$2010
Weighted Average Target UEC	2720 kWh/yr	Product CCE	0.054	$2010
Weighted Average Energy Savings	2982 kWh/yr			

Table A.2.11 – Efficiency-Cost Relationship for Commercial Building Boilers

Class	Packaged Boilers, Gas-Fired, HW 400-1500 kBtu/Hr			Packaged Boilers, Gas-Fired, HW 3000 kBtu/Hr			Packaged Boilers, Gas-Fired, Steam (no natural draft) 400-1500 kBtu/Hr			Packaged Boilers, Gas-Fired, Steam (no natural draft) 3000 kBtu/Hr			Packaged Boilers, Gas-Fired, Steam (natural draft) 400-1500 kBtu/Hr		
Market share	24.2%			3.9%			8.2%			7.1%			12.6%		
Lifetime	30			30			30			30			30		
q	0.073			0.073			0.073			0.073			0.073		
Efficiency Level	UEC MMbtu	Price $2010	CCE $2010	UEC MMbtu	Price $2010	CCE $2010	UEC MMbtu	Price $2010	CCE $2010	UEC MMbtu	Price $2010	CCE $2010	UEC MMbtu	Price $2010	CCE $2010
Baseline	1035	23513		3958	44665		1077	27564		4025	67175		1111	26303	
1	1029	24471	11.60	3934	47147	7.51	1072	28973	20.47	4005	69057	6.84	1101	28686	17.31
2	1016	25939	9.28	3897	47147	2.96	1061	30799	14.69	3968	70655	4.44	1090	29742	11.90
3	998	29344	11.45	3858	57049	9.00	1050	33976	17.25	3931	72411	4.05	1077	31798	11.74
4	979	34966	14.86	3671	86005	10.46	1038	36557	16.75	3893	74500	4.03			

Target Annual Incremental Cost (I×q)	$176	$3,003	$0	$532	$0
Target UEC (MMBtu/yr)	1016	3671	No option with CCE below utility price	3893	No option with CCE below utility price

Class	Packaged Boilers, Gas-Fired, Steam (natural draft) 3000 kBtu/Hr			Packaged Boilers, Oil-Fired, HW 400-1500 kBtu/Hr			Packaged Boilers, Oil-Fired, Steam 400-1500 kBtu/Hr			Packaged Boilers, Oil-Fired, Steam 3000 kBtu/Hr		
Market share	9.1%			6.8%			11.4%			15.0%		
Lifetime	30			30			30			30		
q	0.073			0.073			0.073			0.073		
Efficiency Level	UEC MMbtu	Price $2010	CCE $2010	UEC MMbtu	Price $2010	CCE $2010	UEC MMbtu	Price $2010	CCE $2010	UEC MMbtu	Price $2010	CCE $2010
Baseline	4111	69953		1022	25278		1052.00	24373.30		3920.00	67593.40	
1	4104	70451	5.26	1007	27898	12.69	1046.00	25964.21	19.26	3904.00	69226.02	7.41
2	4074	71974	4.04	990	30165	11.10	1037.00	27540.88	15.34	3875.00	71596.11	6.46
3	4035	75037	4.94	968	34793	12.80	1014.00	31800.94	14.20	3836.00	76772.68	7.94
4	3989	80239	6.23							3757.00	86603.98	8.47

Target Annual Incremental Cost (I×q)	$760	$355	$0	$1,381
Target UEC (MMBtu/yr)	3989	990	No option with CCE below utility price	3757

Weighted Average Baseline UEC	2106 MMBtu/yr	Weighted Average Incremental Cost	296	$2010
Weighted Average Target UEC	2042 MMBtu/yr	Product CCE	4.24	$2010
Weighted Average Energy Savings	64.0 MMBtu/yr			

APPENDIX 3 – Data Sources for Cost of Conserved Energy Calculations

Table A.3.1 – Data Sources for Residential Appliance Groups

Reference Title and Reference	Source Location By Category*			
	UEC	**Price**	**Shipments**	**Lifetime**
Refrigeration Equipment				
Refrigerator, Refrigerator-Freezer and Freezers Rulemaking Technical Support Document, USDOE (2010h)	Table 7.6.x**	Table 8.4.x		9.3.1.1 & 9.3.2.1
Refrigerator, Refrigerator-Freezer and Freezers NOPR National Impact Analysis Spreadsheet, USDOE (2010g)			'Historical Shipment & Market Share'	
Compact Refrigerator, Refrigerator-Freezer and Freezers NOPR National Impact Analysis Spreadsheet, USDOE (2010d)			'Historical Shipment'	
Room Air Conditioners				
Residential Clothes Dryers and Room Air Conditioners Preliminary Technical Support Document, USDOE (2010l)	7.3.x	8.2.x		8.1.1
Residential Clothes Dryers and Room Air Conditioners Preliminary NIA for Room Air Conditioners, USDOE (2010k)			'Shipments Forecast'	
Water Heaters				
Residential Water Heater National Impacts Analysis Spreadsheet, USDOE (2010m)	'LCC Inputs'	<- Same	'Base Case Shipments'	'Retirement Function'
Furnaces & Boilers				
Residential Furnaces and Boilers NIA Main, USDOE (2008c)	'LCC Inputs'	<- Same	'Base Case Shipments'	'Retirement function'
Cooking Products				
Residential Cooking Products Final Rule National Impact Analysis Spreadsheet, USDOE (2009c)	'Efficiency and Price'	<- Same	'Base Case Shipment Elec Cooking'	'Lifetime'
Residential Cooking Products Final Rule National Impact Analysis Spreadsheet: Including Microwave Ovens, USDOE (2009b)	'Input and Summary'	<- Same	'Base Case'	'Lifetime'
Residential Cooking Products Technical Support Document, USDOE (2009d)		Table 8.2.x		
Central Air Conditioning & Heat Pumps				
Residential Central Air Conditioners and Heat Pumps Preliminary Technical Support Document, USDOE (2010j)	Table 7.11.x	Table 8.2.x		Table 8.1.1
Residential Central AC/HP National Impact Analysis Spreadsheet, USDOE (2010i)			'Historical Shipments'	
Fluorescent Lamp Ballasts				
Fluorescent Lamp Ballasts Preliminary Technical Support Document, USDOE (2010f)	Table 6.3.x	Table 8.5.x		
Fluorescent Lamp Ballasts Preliminary National Impact Analysis, USDOE (2010e)			'Assumptions'	<- Same

* All single-quoted titles are the worksheet in the given analysis spreadsheet
**The 'x' at the end of a table location indicates a range of tables all or most of which contain the desired values

Table A.3.2 – Data Sources for Commercial Building Appliance Groups

Reference Title and Reference	Source Location By Category*			
	UEC	Price	Shipments	Lifetimes
Distribution Transformers				
Distribution Transformer Final Rule National Impact Analysis Spreadsheet, USDOE (2007a)	LCC Data By Product Class' combining Load & No-Load Losses		'Market Share'	'Lifetime'
Distribution Transformer Final Rule Technical Support Document, USDOE (2007b)		Table 8.7.3		
Commercial Unitary Air Conditioners and Heat Pumps				
Commercial Unitary Air Conditioners and Heat Pumps ANOPR Technical Support Documents, USDOE (2003c)	Table 10.2.x**	Table 8.2.x		
Commercial Unitary Air Conditioners and Heat Pumps ANOPR Life Cycle Cost Analysis Spreadsheet (Tariff), USDOE (2003a)				'Lifetime'
Commercial Unitary Air Conditioners and Heat Pumps ANOPR National Energy Savings Spreadsheet, USDOE (2003b)			'65-135 Stock' & '135 -240 Stock'	
Packaged Terminal Air Conditioners and Heat Pumps				
Packaged Terminal Air Conditioners and Heat Pumps Final Rule Life-Cycle Cost Spreadsheet, USDOE (2008a)				'Lifetime'
Packaged Terminal Air Conditioners and Heat Pumps Final Rule National Impact Analysis Spreadsheet, USDOE (2008b)	'Equipment Parameters'	<- Same	'Shipments'	
High-Intensity Discharge Lamps				
High-Intensity Discharge Lamps Proposed Determination National Energy Savings Spreadsheet, USDOE (2004b)			'MV Lamp Shipments by Wattage' & '175W MV Applications' & '400W MV Applications'	
High-Intensity Discharge Lamps Proposed Determination Life-Cycle Cost Spreadsheet, USDOE (2004a)	Each product class has a worksheet which includes the UEC, price	<- Same		<- Same
Boilers				
ASHRAE Equipment (Boilers) Final Rule Technical Support Documents, USDOE (2010c)	Table 7.3.5	Table 7.3.4	Table 6.4.1	Section 5.6.2.4
Fluorescent Lamp Ballasts				
Fluorescent Lamp Ballasts Preliminary Technical Support Document, USDOE (2010f)	Table 6.3.x	Table 8.5.x		
Fluorescent Lamp Ballasts Preliminary National Impact Analysis, USDOE (2010e)			'Summary Shipments'	'Assumptions'

* All single-quoted titles are the worksheet in the given analysis spreadsheet
**The 'x' at the end indicates a range of tables all or most of which contain the desired values
***The prices were calculated using the tables for base prices, incremental costs, markup, and installation cost for specifically 800 or 3000 kBtu/h boilers